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An Extensional Fracture Acting as Hot Water Source for Travertine Deposition on the North Anatolian Fault Zone, Turkey: the Reşadiye Fissure-Ridge

Kuzey Anadolu Fay Zonu'nda Traverten Çökeliminde Sıcak Su Kaynağı Olarak Görev Yapan Bir Açılma Çatlağı: Reşadiye Çatlak Sırtı

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Abstract: The Reşadiye (Tokat) geothermal field is located in the northern part of the right-lateral North Anatolian Fault Zone. Geothermal waters at temperatures between 48-52°C from this geothermal field are currently used mostly in hotels, pools and bathrooms and provide significant tourism potential for the region. The area where the geothermal sites are located includes a ~NW-SE trending fissure-ridge type travertine with a length of about 600 meters. Approximately 500 meters south of the geothermal field and parallel to the Kelkit River, the active segment of the North Anatolian Fault Zone comprises the Kelkit Valley fault segment extending N72°W. The average strike direction of Reşadiye fissure-ridge type travertine is around N33°W. There is an angle of 39° between the master trend of NAFZ and the direction of the Reşadiye fissure-ridge travertine. This 39° angle between the extensional cracks in the fissure-ridge travertine and the NAFZ is compatible with extensional fractures developing in well-formed strike-slip faults at an angle of ~45° with the master fault. U/Th determination of two samples from banded travertines from the travertine deposits yielded ages of 7,563 and 12,529 years. Combined with other evidence, the samples indicate an opening rate of 0.093 mm/year for the Reşadiye geothermal travertine field.

Keywords: Active tectonics, North Anatolian Fault Zone, Reşadiye, Travertine tectonics, Travitonics, U/Th age dating

Öz: *Reşadiye (Tokat) jeotermal sahası, doğrultu atımlı sağ yanal Kuzey Anadolu Fay Zonunun kuzeyinde yer almaktadır. Bu jeotermal alanda çıkan 48-52° C sıcaklıktaki jeotermal su çoğunlukla otellerde, havuzlarda ve banyolarda kullanılmakta ve bölge için önemli turizm potansiyeli sağlamaktadır. Jeotermal sahanın bulunduğu alanda yaklaşık 600 metre uzunluğunda ~KB-GD gidişe sahip bir çatlak sırtı tipi traverten bulunmaktadır. Jeotermal alanın yaklaşık 500 metre güneyinde ve Kelkit Nehri'ne paralel olarak K72°B doğrultuda, Kuzey Anadolu Fay Zonu'nun aktif, Kelkit Vadisi segmenti yer almaktadır. Reşadiye çatlak sırtlı traverteninin ortalama doğrultusu K33°B'dir. Kuzey Anadolu Fayı Zonu'nun ana gidişi ile Reşadiye çatlak sırt tipi travertenin ortalama doğrultusu arasında yaklaşık 39°'lik bir açı bulunmaktadır. Çatlak sırtlı traverten ve KAFZ arasındaki bu 39°'lik açı, iyi gelişmiş doğrultu atımlı faylarda ana fay ile ~45°'lik açı yapan açılma çatlaklarınn açısıyla uyumludur. Reşadiye çatlak sırtı tipi travertende bulunan bantlı travertenlerden alınan iki örneğin U/Th yaş analizleri 7.563 ve 12.529 yıllarını vermiştir. Bu sonuçlar bölgesel anlamda olmasa da Reşadiye jeotermal traverten alanı için 0,093 mm/yıl açılma hızı vermektedir.*

Anahtar Kelimeler: *Aktif tektonik, Kuzey Anadolu Fay Zonu, Reşadiye, Traverten tektoniği, Travitonik, U/Th yaş analizi*

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INTRODUCTION

Travertines are typically sediments rich in calcium bicarbonate precipitated around hot and cold-water springs reaching the surface along discontinuity surfaces, usually faults or well-developed joint systems. As in the classic Pamukkale (Denizli) example, in addition to their unique natural beauty and use as an attractive construction material, they make an important contribution to several branches of earth sciences including hydrogeology, sedimentology and tectonics. They create unique morphologic landforms (Altunel, 1996) and are usually found where hot and cold springs reach the surface, usually along normal or strike-slip fault systems with an extensional component. Within the classification scheme of Altunel (1996), the travertines developed as fissure-ridge types comprising fault front, channel and cone shapes reflecting a tectonic signature. Where they continue to grow in the present, they can be used to determine the contemporary regional stress field and thus are related to active regional tectonics (Altunel, 1996; Mesci et al., 2008; De Filippis et al., 2012; Brogi et al., 2009; Mesci, 2012; Brogi et al., 2016; Mesci et al., 2018).

The Reşadiye geothermal and travertine area is located ~90 km east-northeast of Tokat and occurs on the most important active dextral lineament of the North Anatolian Fault Zone (NAFZ) in Turkey (Figure 1). The NAFZ has a complex surface expression with morphologic and structural elements including splay faults, pull-apart basins, sag ponds, extended ridges, offset streams and hot spring sites. The Reşadiye area is located in the Kelkit valley where the local geomorphology has been shaped by a combination of the lithological characteristics of the rock units outcropping in the region, the NAFZ master fracture and the Kelkit River drainage system (Figure 2). The present study was undertaken to determine the relationship between the Reşadiye fissure-ridge travertine formation and the North Anatolian Fault Zone; it further aimed to reveal the age range embraced by the travertine formation and hence to resolve the rate at which the extensional fissure has opened.

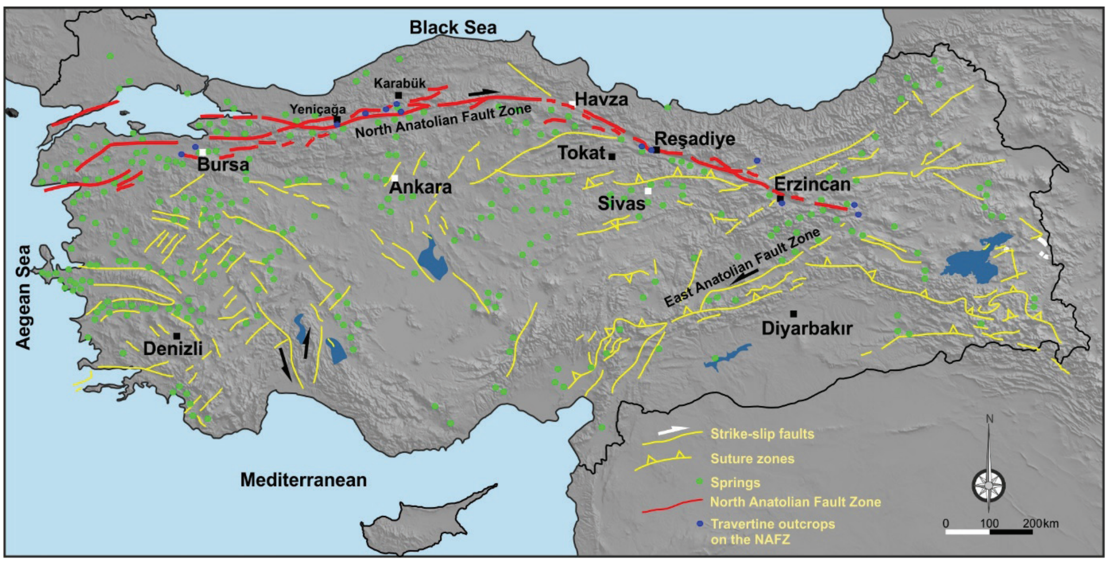

Figure 1. Distribution of hot water springs and active tectonic features in Turkey showing travertine occurrences along North Anatolian Fault Zone (simplified from Şimşek, 2003 and Polat, 2011).

***Şekil 1.** Türkiye'deki aktif tektonik hatların, sıcak su kaynaklarının ve Kuzey Anadolu Fay Zonu boyunca gözlenen traverten oluşumlarının dağılımı (Şimşek, 2003 ve Polat, 2011'den basitleştirilmiştir).*

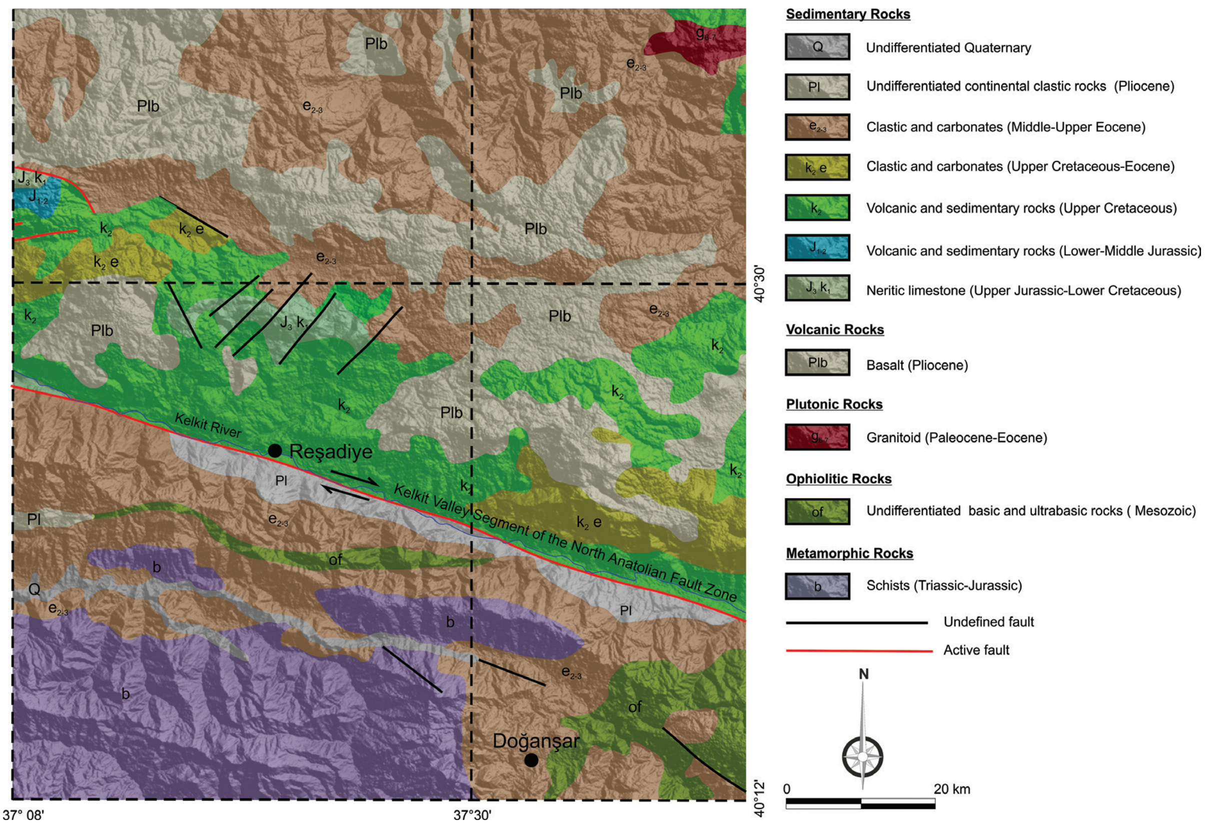

Figure 2. Geological map of Reşadiye and its vicinity (modified from Hakyemez and Papak, 2002).
Şekil 2. *Reşadiye ve çevresinin jeolojik haritası (Hakyemez ve Papak'tan değiştirilmiş, 2002).*

HISTORICAL BACKGROUND AND TECTONIC IMPLICATIONS OF TRAVERTINES

Travertines were first classified by Russel (1882) and subsequent classifications have been based on a multiplicity of features including plant content, precipitation environment, porosity and morphology (see Mesci, 2004 and references therein). However, more recent studies have focused on their tectonic signature and primarily link their morphologic features to the regional stress fields (Heimann, 1989; Chafetz and Folk, 1984; Altunel and Hancock, 1993a; Mesci et al. 2008).

The geothermal fields found extensively across Turkey and related travertine deposits are the prime markers of active tectonics in the present and also the geological past. Predictably, there is a very close relationship between travertine morphology and regional stress fields deduced from other methods. Hot water springs tend to be located mostly near the three most important structural elements in Turkey, namely, the NAFZ, the East Anatolian Fault Zone (EAFZ) and the Aegean Extensional Region; while travertine outcrops are generally found near the NAFZ, confirming the correlation between contemporary tectonics and hydrothermal activity (Figure 1).

Travertine research in Turkey began to gain more serious attention from the beginning of the 1990s, when it was identified as an important tool for identifying the age and character of deformation associated with fault activity. It was also recognized as a potential tool for measuring the rate of dislocation along fissures. Initial investigation of travertines in relation to active tectonic studies in Turkey was first performed on the Pamukkale (Denizli) travertines by Altunel and Hancock (1993a, b, 1996) and Altunel (1994). They studied the relationship between travertine formation and active tectonics and how to use travertines in active tectonic studies by measuring the opening direction of fissure-ridge travertines in order to determine the deformation rate in Western Anatolia.

Altunel and Hancock (1993a) classified travertines in terms of morphology and introduced the term *travitonics* to represent the close correlation between travertines and neotectonics. Çakır (1998) found that carbonate-rich hot waters reached the surface either near the tips of fault segments or in extensional regions at fault offsets. From studies in Italy, Brogi et al. (2009) and Brogi et al. (2014) identified travertines deposited along normal faults, and at points where strike-slip and normal faults intersected. In recent years, many studies have been performed to investigate the correlation between active hot springs and travertine occurrences in both recent and extinct travertine outcrops in the central and western sections of Anatolia (Altunel and Karabacak, 2005; Mesci et al., 2008 and 2012; Temiz and Eikenberg, 2011; Noten et al., 2019), whilst comparable studies have been performed in east and SE Anatolia by Çolak et al. (2015).

GEOLOGICAL SETTING OF REŞADİYE TRAVERTINE FIELD

Two contrasting rock assemblages, which crop out on the northern and southern blocks of the main branch of the North Anatolian Fault Zone, are seen along the Kelkit River valley covering the Reşadiye travertine field (Seymen, 1975). The northern section where the travertines are concentrated comprises Cretaceous limestones, volcanics and sedimentary rocks with flysch facies as well as Eocene limestone, marl, volcanic flysch, basaltic lava and tuffs. The Eocene sediments, comprising a range of different facies, are located on both sides of the NAFZ in this sector (Seymen, 1975) (Figure 2).

The right-lateral strike-slip character of the NAFZ is initiated in the north of the Aegean Sea and extends nearly 1600 km east to Karlıova in a deformation zone up to 100 km wide, occasionally illustrating an anastomosing structure (Figures 1 and 3). During the last century, dozens of earthquakes with a magnitude above 6 occurred on the NAFZ and their consequences in the light of local and regional scale studies have aided in understanding the age, total offset and formation mechanism of the master fault (e.g. Herece and Akay, 2003; Şengör et al., 2005). Several basins associated with strike-slip faulting along the North Anatolian Fault Zone have been formed. Young volcanic outputs have also developed in some basins, such as the Erzincan and Niksar basins (Akpınar et al., 2016).

Since the 1990s, GPS measurements of the NAFZ and bordering regions have provided important information on fault slip rates (Oral, 1994; McClusky et al., 2000; Reilinger et al., 2006; Tatar et al., 2012), while paleoseismologic studies have yielded data on the timing and recurrence of large earthquakes. Further, geoarcheological research of cultural artifacts with historical and archeological value has been used to provide information on historic seismic activity on the NAFZ (Benjelloun et al., 2018), whilst historical documents from the 16th century onwards have revealed details about historical seismic activity on the NAFZ, as well as elsewhere in Turkey and surrounding regions (Ambraseys and Finkel, 1995).

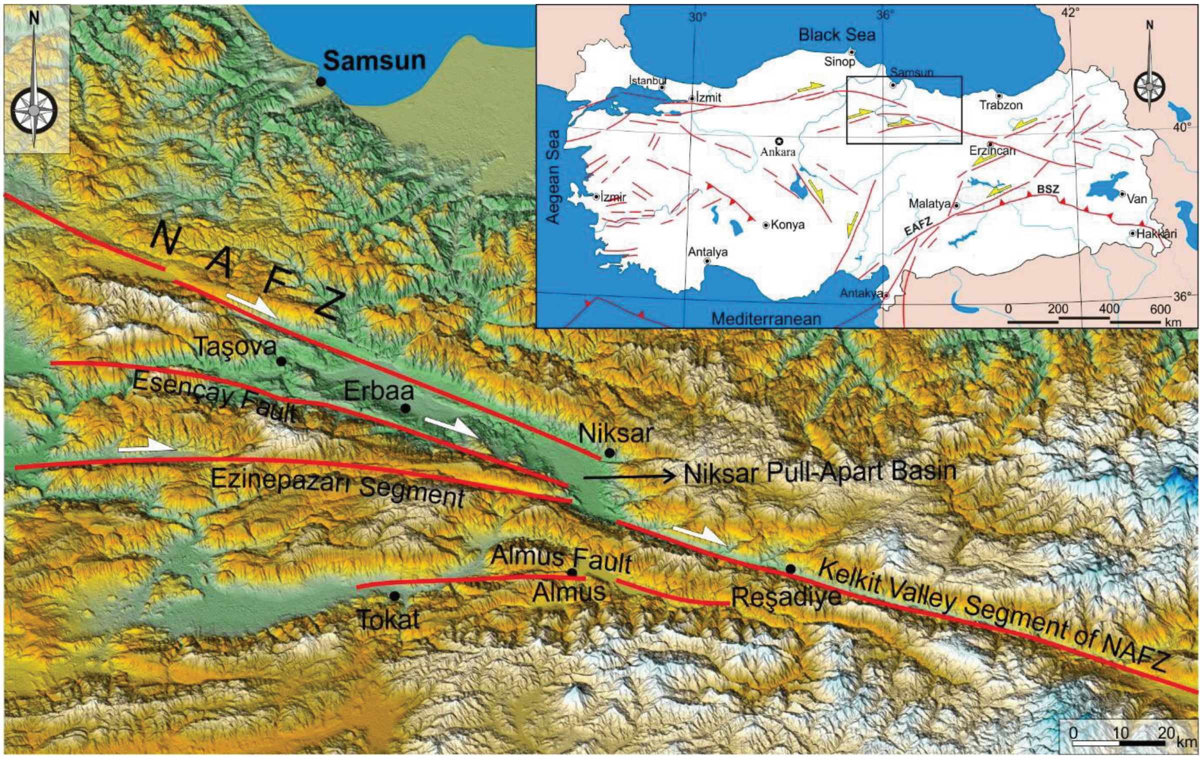

Figure 3. Distribution of active faults around Reşadiye on SRTM image.
Şekil 3. *SRTM görüntüsünde Reşadiye çevresindeki aktif fayların dağılımı.*

During the periods covered by historical and instrumental evidence, noteworthy earthquakes on the NAFZ include the M=7.8 Erzincan earthquake on 29 December 1939 responsible for a ~360 km surface rupture extending through Reşadiye. Barka (1996) identified 5 separate segments on the 360 km long surface rupture formed by this earthquake and a segment with a length of nearly 70 km following the Kelkit River and embracing Reşadiye; he defined this as the Kelkit Valley segment. Offsets developed on the surface rupture of this segment have been measured and reported by Barka (1996) and Gürsoy et al. (2013). In the natural depression at Reşadiye (Location 6 in Figure 5 of Gürsoy et al., 2013) and immediately east in trenches opened on a segment for paleoseismologic purposes (Zabcı et al., 2011), both the 1939 Erzincan earthquake surface rupture and previous historical earthquake traces were identified. Also, during excavations of the foundations of a water collection pool for the Reşadiye regulator, set up with the aim of producing energy, a wide fracture zone was revealed which showed a negative flower structure created by earthquake ruptures from the 1939 and previous historical earthquakes (Gürsoy et al., 2013). Field evidence observed around the travertine area for previous large earthquakes suggests that the area has been actively deforming due to the activity of the NAFZ. Secondary fractures of the NAFZ also contribute to the deformation of the upper crust in the area, which keeps the fissures open at all times so that water can reach the surface.

MORPHOLOGICAL CHARACTERISTICS OF REŞADIYE FISSURE-RIDGE TRAVERTINE

The result of a 30-month periodic measurement investigation in the Reşadiye (Tokat) geothermal and travertine area determined a mean temperature of 50.59°C, an electrical conductivity of 5631 µS/cm, and a pH of 6. These measurements were taken from 29.04.2007 to 08.10.2019 within the scope of a multi-disciplinary project funded by the DPT (State Planning Agency) looking into the long-term viability of the region for tourist development.

In the area of geothermal facilities, there is a single fissure-ridge travertine about 600 m in length trending approximately NW-SE (Figure 4-A). The wells and catchment where water is obtained for geothermal pools and baths are located twenty five meters away, SE of the fissure axis and the initial NW point of the ridge. At the NW part of the spa facilities, the ridge extends toward the SE with offsets or branching of the fissure axis occurring at several points along the ridge (Figures 4-A and 5-B). The total length of the fissure axis on the ridge is 863 meters and the total surface area formed by the layered travertine forming the ridge has been calculated at 17,507 m^2. The width of the fissure-thickness of the banded travertines measured on the fissure axis reaches a maximum of 158 cm. The strike of the layered travertines is entirely parallel to the ridge axis, with dips varying from horizontal to vertical (Figure 4-A). That the slope of the layered travertines developed perpendicular to the fissure axis shows that deposition has been mainly asymmetric, a feature attributable to the paleo-topography on which the ridge developed. The fissure axis begins at the NW point with an elevation of 558 m, continues for 230 meters in a direction S 45°-50° E, gains a slightly convex structure at this point extending S 30° E to 357 meters, and then ends at an elevation of 503 meters. As in many fissure-ridge travertine examples (Sivas-Sıcak Çermik, Denizli-Pamukkale and Ağrı-Diyadin, etc.), the whole ridge displays a convex geometry linked to the rheology of the unit beneath the travertine deposition.

In the southeast section of the ridge, a fissure axis separates from the main fissure and extends towards the SE; this is considered to be very young due to the appearance of the travertine and the narrow width of the fissure axis. A significant portion of the geothermal water emerging from this fissure drains down the SW slope of the ridge and has deposited layered travertines on this slope with dips close to vertical, giving the formation a waterfall-like character. The travertines on the southwest-facing slope in this section of the ridge reach heights of up to 12 meters (Figure 5-C).

U/TH AGE RESULTS AND OPENING RATE OF FISSURE

The majority of studies carried out on travertines have used the U/Th method for dating the deposition (Sturchio, 1994; Eikenberg et al., 2001; Semghouli et al., 2001; Mallick and Frank, 2002; Soligo et al., 2002; Altunel, 1994; Çakır, 1998, Altunel and Hancock 1993a, b, 1996; Altunel, 1996; Hancock et al., 1999; Mesci et al., 2008; Brogi et al., 2009; Temiz et al., 2011; Mesci, 2012; Çolak et al., 2015; Brogi et al., 2014; Brogi et al., 2016; Mesci et al., 2018). However, the electron spin resonance (ESR) method has also been applied (Grün, 1989; Rink et al., 1997; Engin et al., 1999a), and a few studies have used the thermoluminescence (TL) method for dating (Engin et al., 1999b).

The U/Th method was applied for age dating in this study by taking two samples in each fissure-ridge travertine - one from the youngest band of fissure fill and one from the oldest - with the aim of resolving the opening rate of the fissure-ridge. Ages obtained from these samples can potentially identify the annual opening rate in proportion to the width of the banded travertine (Figures 6 and 7) and hence solve the mean opening rate. Previous examples of this application were reported by Altunel (1994) and (Mesci, 2008). Two travertine samples were taken for this study area due to the presence of a single fissure-ridge; one sample from the fissure axis and the other from outside the fissure (Figures 4-B, 6 and 7).

Hitherto the alpha spectrometer used in U/Th analysis for travertine dating was unable to resolve the age of samples younger than ~5000 years. However, due to improvements in mass spectrometric methods (TIMS and MC-ICP-MS), it has become possible to measure older carbonate samples with an accuracy of 100 to 200 years (Pons et al., 2005). Additionally, Shen et al. (2013) were able to measure very young stalagmites with annual sensitivity by this method. The age analysis in the present study used the MC-ICP-MS method carried out in the GEOTOP Radiochronology laboratory (Canada).

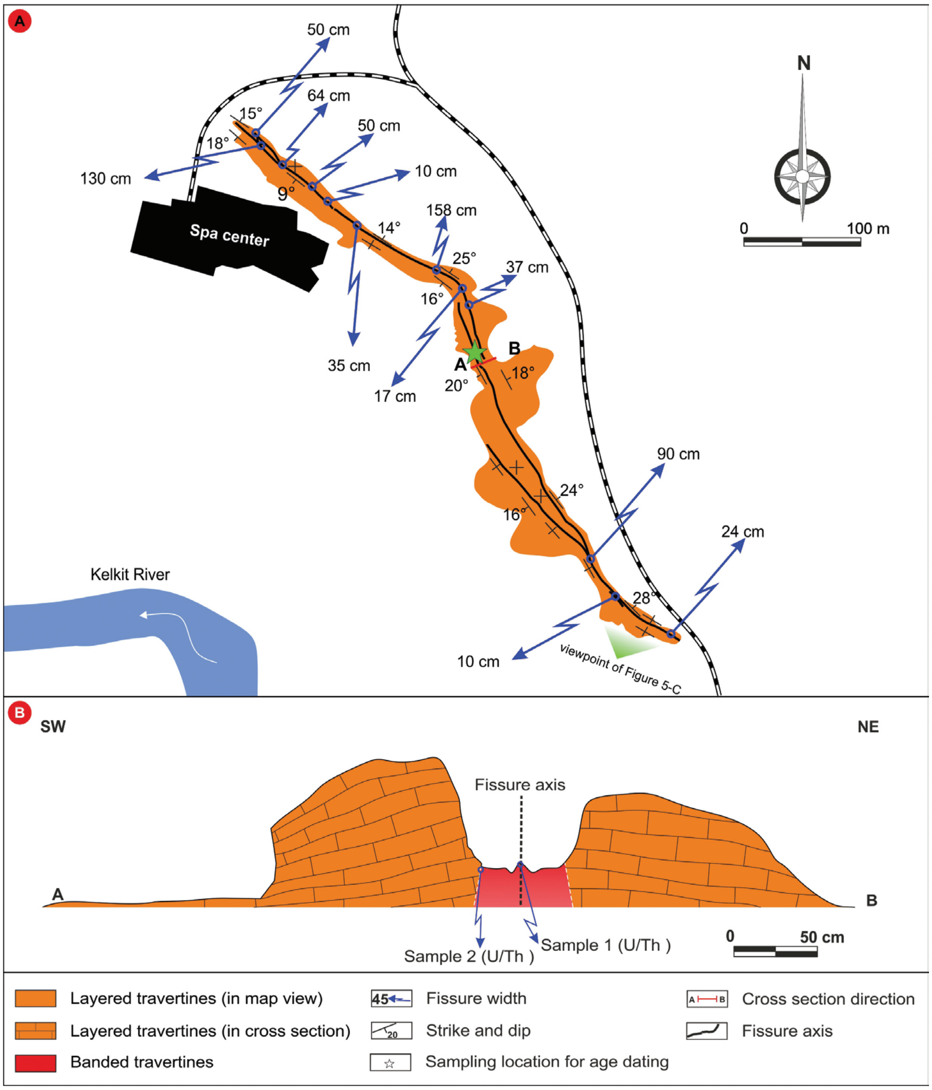

Figure 4. Map of the Reşadiye fissure-ridge (A) and its geological cross-section (B).
Şekil 4. *Reşadiye çatlak sırtlı travertenin haritası (A) ve jeolojik kesiti (B).*

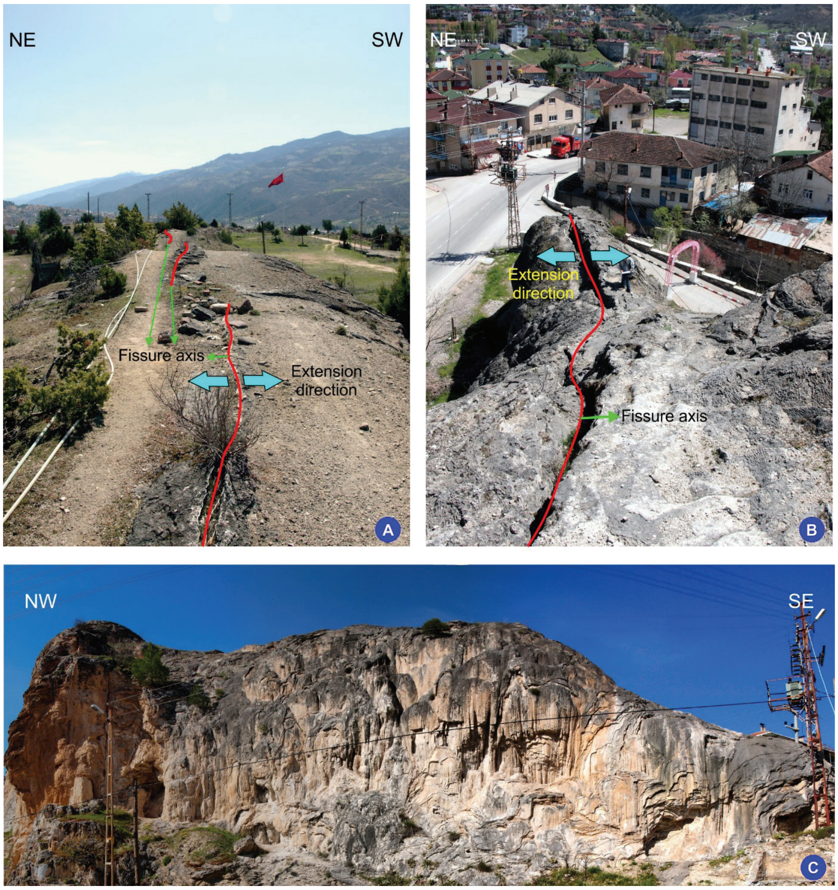

Figure 5. Views of fissure axis (A, B) and panoramic view of SE slope of Reşadiye fissure-ridge travertine from SW to NE (C).

Şekil 5. *Çatlak ekseninin görünümü (A ve B) ve Reşadiye çatlak sırtı travertenlerin GD yamacının panoramik görüntüsü (C; GB'dan KD'ya bakış).*

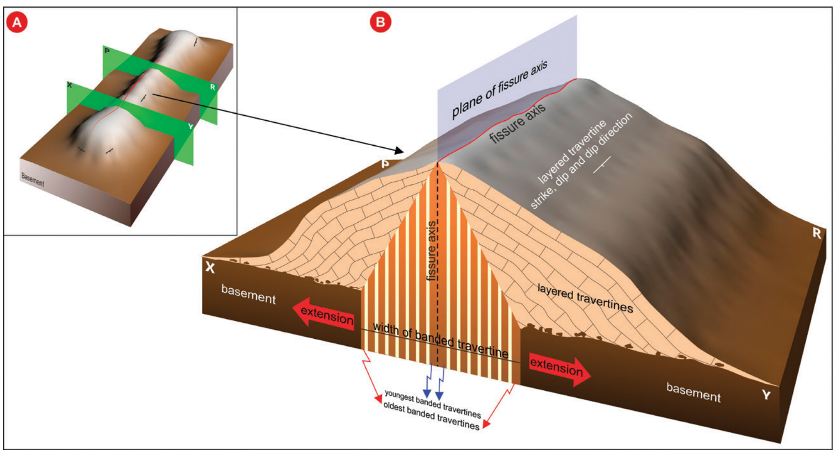

Figure 6. Three-dimensional appearance of fissure-ridge travertine (A) and appearance of basic components in block model taken between planes X-Y and P-R (B).

Şekil 6. *Bir çatlak sırtı travertenin üç boyutlu görünümü (A), ve X-Y ve P-R düzlemleri arasından alınan blok modelde temel bileşenlerin görünümü (B).*

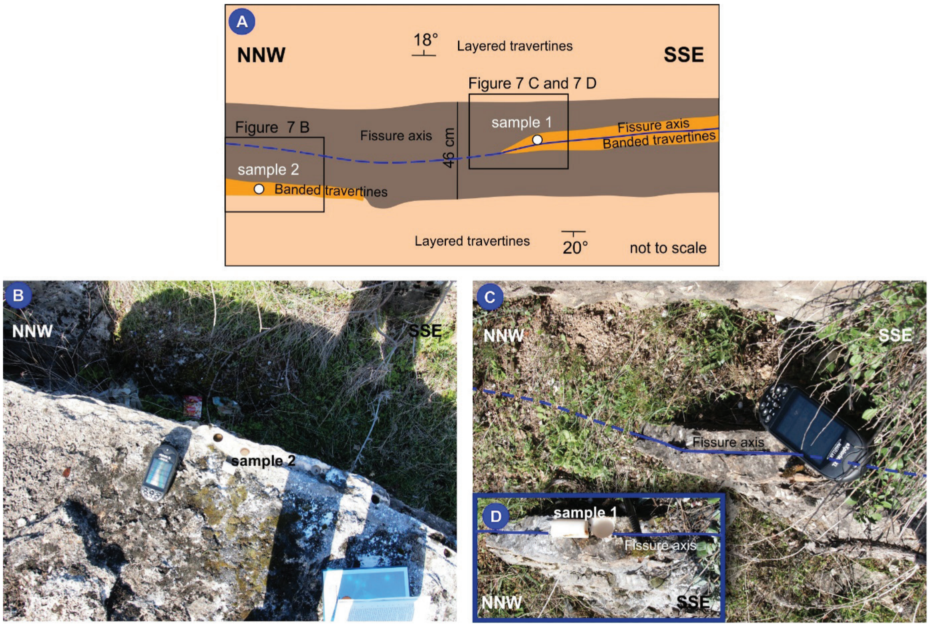

Figure 7. Plan of samples' location (A), and close up views of where sample 2 (B) and sample 1 (C, D) were taken.

Şekil 7. *Reşadiye çatlak sırtı traverteninde yaş analizi örnekleme konumunun plan görünümü (A), 2 numaralı örneğin yakın görünümü (B), numaralı örneğin yakın görünümleri (C ve D).*

The results of this analysis determined an age for the banded travertine taken from the fissure axis (sample 1) of 11,251 years (uncorrected) and 7,563 years (corrected). The age of the banded travertine from outside the axis (sample 2) was dated to 15,519 years (uncorrected) and 12,529 years (corrected). The results are summarized in Table 1. The ages obtained in this study are older than those obtained by Karabacak et al. (2019).

The two samples show non-negligible amounts of detrital thorium, indicated by the low activity ratios of $^{230}Th/^{232}Th$ (Table 1). To correct for the detrital thorium derived from silt and clay incorporated in the travertine, we used the average crustal model of Ludwig and Paces (2002) where ^{232}Th is used as the index, and the detrital isotopic activity ratios are according to: $^{232}Th/^{238}U = 1.21 \pm 50\%$, $^{230}Th/^{238}U = 1 \pm 10\%$, and $^{234}U/^{238}U = 1 \pm 10\%$. Due to the large errors involved in this assumption regarding the detrital component of the corrected ^{230}Th, the ages have large uncertainties (Table. 1).

Table 1. Location and age of samples from Reşadiye fissure-ridge travertine.

Çizelge 1. *Reşadiye çatlak sırtı traverteninden alınan örneklerin konumları ve yaşları.*

Location	**Sample No.**	**^{238}U ppb**	**^{232}Th ppb**	**$^{234}U/^{238}U$**	**$^{230}Th/^{234}U$**	**$^{230}Th/^{238}U$**	**$^{230}Th/^{232}Th$**	**Age (ka)**	**Corrected age (ka)**
37 3581070 E 4473270 N	Sample 1	7.386 ±0.052	0.924 ±0.009	1.015 ±0.014	0.098 ±0.003	0.100 ±0.003	2.436 ±0.082	11.251 ±0.422	7.563 ±2.092
	Sample 2	5.384 ±0.030	0.552 ±0.006	1.022 ±0.013	0.133 ±0.007	0.136 ±0.007	4.052 ±0.224	15.519 ±0.928	12.529 ±1.898

RESULTS

Age data obtained from different tectonic settings in Turkey have enhanced the importance of travertine investigation on the NAFZ and contributed to understanding the active tectonics of travertines. The best-known examples of travertine formations directly on the NAFZ are observed in Akkaya (Bolu) (Demirtaş, 2000), Reşadiye (Tokat) (Seymen, 1975) and west of Reşadiye (Gürsoy et al., 2013). Residents of this region also noted that hot water and steam gushed out during the 1939 Erzincan earthquake (M=7.9) where travertines are exposed in the Katmerkaya area to the west of Reşadiye (Gürsoy et al., 2013). Studies conducted in Bolu (Demirtaş, 2000; Temiz et al., 2013) and Reşadiye (Tokat) (Karabacak et al., 2019) on the NAFZ have contributed new ages using the U/Th method. However, defining the general geometry and understanding the mechanisms responsible for structures formed during travertine deposition is required for wider interpretation of the stress fields around the NAFZ. The geometry and faulting-mechanism of the Reşadiye fissure-ridge travertine is a local contribution to this objective.

Experimental clay studies by Riedel (1929) and Wilcox et al. (1973) showed that in a well-developed strike-slip fault, extensional fractures develop at a ~45° angle to the main fault (Figure 8-A). Nearly 500 meters south of the Reşadiye geothermal facility, an active branch of the North Anatolian Fault Zone, the Kelkit Valley segment, extends parallel to the Kelkit River with a strike of N72°W (Figures 2 and 3). This segment also records the surface rupture of the 1939 Erzincan earthquake. The average strike direction of the Reşadiye fissure-ridge type travertine is N33°W (Figure 4-B), producing an angular difference of about 39° between the NAFZ Kelkit Valley segment and the strike of the fissure axis in the Reşadiye travertine (Figure 8-B). This 39° angle between the extensional fracture in the Reşadiye travertine and the Kelkit Valley segment closely accords with the 45° angle between the main fault and extensional fractures in well-developed strike-slip faults. The theoretical models do not always overlap one-on-one with the structures formed in nature. Considering that experimental-theoretical models are completed using homogeneous material in laboratory environments, the 6° angular difference is likely due to the heterogeneous nature of rocks found in the crust.

In this study area with ongoing hydrothermal activity and travertine formation, the width of the banded travertine in the fissure axis and age of the fissure-ridge type travertine have been assessed and the opening rate of the fissure during periods of hydrothermal activity calculated. A similar study was first applied to the Pamukkale (Denizli) ridge type travertine by Altunel (1996), where age analysis of samples taken from the fissure center and fissure walls resolved a regional opening rate during the last 200,000 years of 0.23 to 0.6 mm/year in a NW-SE direction.

In this study, using the same method, the opening rate for the Reşadiye geothermal and travertine formation area was calculated as a slower 0.093 mm/year rate in a NE-SW direction (Table 2). This opening rate for Reşadiye fissure-ridge travertine does not represent regional extension but is nevertheless important in terms of understanding extensional structures developing on strike-slip fault zones, especially where the formation mechanisms have produced fissure-ridge travertines.

Within the scope of this study, the age obtained from the Reşadiye fissure-ridge travertine is not the age when the ridge began to form. Ridge formation began earlier. The age obtained in this study shows that water sources have reached the surface along this ridge over the last 12,000 years without interruption. Field observations reveal that there is a close correlation between ridge formation and NAFZ activity. As a result, this ridge has the potential to contain a record of large earthquakes that occurred on the NAFZ in the past. Determining and dating this data will make a significant contribution to understanding previous earthquake activity on the NAFZ.

Table 2. Opening rates obtained from age results and banded travertine widths.

Çizelge 2. *Yaş sonuçları ve bantlı travertenlerin genişliğinden elde edilen açılma oranı.*

Sample No.	Corrected Age (ka)	Occurrence Interval (ka)	Maximum Width of Banded Travertines (mm)	Opening Rate (mm.y^{-1})
Sample-1	7.563±2.092	4.268	460	0.093 ($-0.004/^{+0.003}$)
Sample-2	12.529 ±1.898			

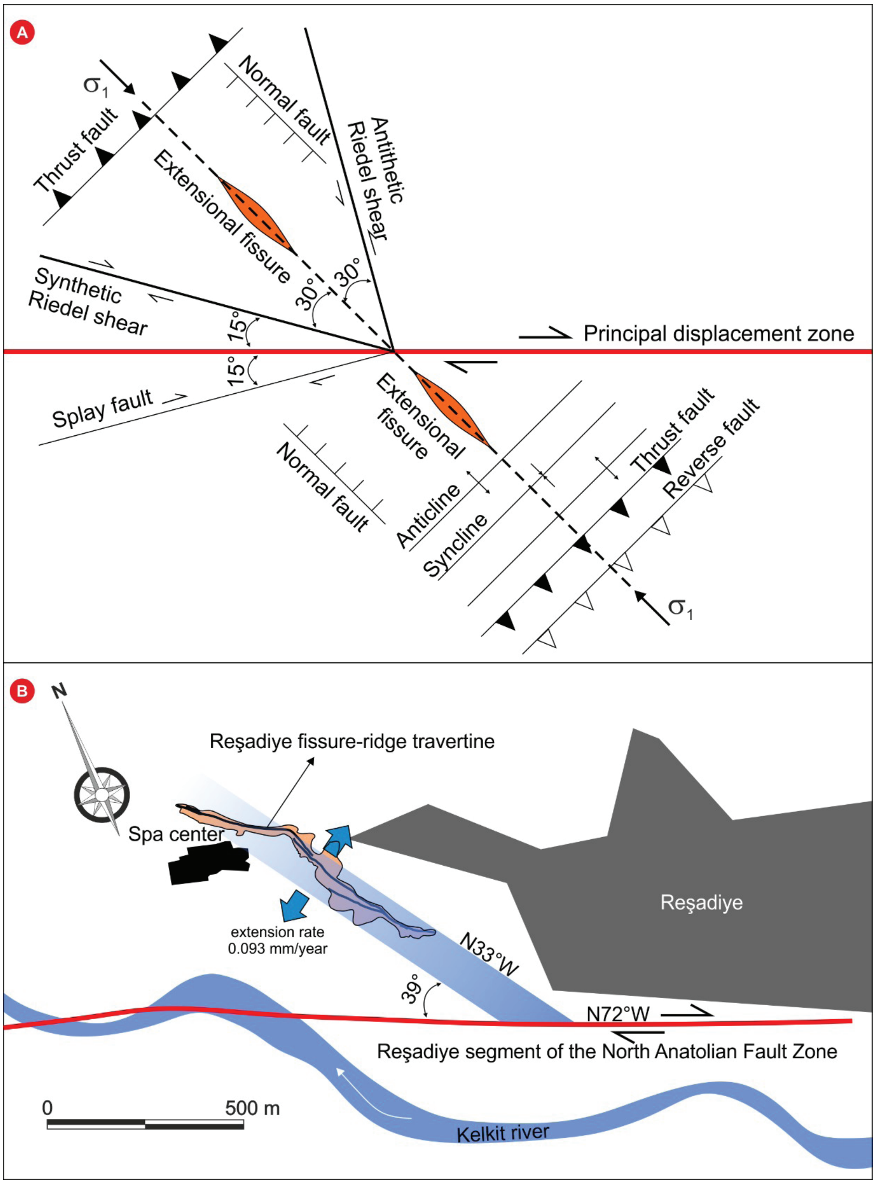

Figure 8. Appearance and similarity of extensional fractures on well-developed strike-slip faults (A) and extensional fissure in Reşadiye fissure-ridge travertine (B).

Şekil 8. *İyi gelişmiş doğrultu atımlı faylardaki açılma çatlaklarının (A) ve Reşadiye sırt tipi travertenindeki açılma çatlağının (B) görünümü ve benzerliği.*

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GENİŞLETİLMİŞ ÖZET

Aktif tektonik özelliklere sahip bölgelerle jeotermal etkinlik arasında önemli bir ilişki bulunmaktadır. Özellikle sıcak suların yüzeye ulaşmasında çatlak-fay sistemlerinin oynadığı rol göz ardı edilemez niteliktedir. Faylar ve çatlaklar, hidrotermal akışkanın yüzeye taşınmasında önemli rol oynar. Türkiye'nin birçok bölgesinde yaygın jeotermal sahaların ve bunların çevresinde birçok traverten yüzleklerinin varlığı, aktif tektonik etkinliğin jeolojik geçmişte ve günümüzde de devam ettiğinin bir göstergesidir. Bu nedenle, tektonik açıdan aktif zonlar ile traverten oluşumu arasında çok yakın bir ilişki vardır (Mesci, 2004). Özellikle çatlak sırtı tipi travertenler tektonik açıdan önemli veriler barındırmaktadır.

Reşadiye jeotermal ve traverten alanı, Tokat ilinin yaklaşık 90 km doğu-kuzeydoğusunda ve Türkiye'deki doğrultu atımlı sağ yanal özellikli en önemli aktif fay zonu olan Kuzey Anadolu Fay Zonu üzerinde yer almaktadır. Reşadiye'nin de üzerinde bulunduğu Kelkit Vadisi, bölgede yüzeyleyen kaya birimlerinin litolojik özellikleri, KAFZ ve Kelkit çayı tarafından şekillendirilmiştir. Kuzey Anadolu Fay Zonu; ayrılma fayları, çek-ayır havzalar, çöküntü gölleri, uzamış sırtlar, ötelenmiş dereler gibi üzerinde yer alan birçok morfolojik ve yapısal unsur ile de dikkat çekmektedir.

Bu çalışma, Reşadiye sırt tipi traverten oluşumunun Kuzey Anadolu fay zonu ile olan ilişkisini anlamak, sırt tipi travertenin morfolojik özellikleri yanı sıra oluşum yaşı ve buna bağlı olarak bölgesel bir sonuç olmamakla birlikte açılma oranının saptanması amacıyla gerçekleştirilmiştir.

Reşadiye (Tokat) jeotermal ve traverten alanı önemli turizm potansiyeline sahip bir bölgedir. Jeotermal tesislerin kurulu olduğu alanda KB-GD doğrultuda uzanan 600 metre uzunluğa sahip bir adet sırt tipi traverten bulunmaktadır.

KB'da kaplıca tesislerinden başlayarak GD'ya doğru uzanan sırt üzerinde yer alan çatlak ekseni birkaç noktada atlama yapmakta ya da dallanmaktadır. Sırt üzerinde bulunan çatlak eksenlerinin toplam uzunluğu 863 metredir. Sırtı oluşturan tabakalı travertenlerin toplam yüzey alanı ise 17.507 m^2 olarak hesaplanmıştır. Çatlak ekseni üzerinde ölçülen çatlak genişliği-bantlı traverten kalınlıkları en çok 158 cm'ye kadar ulaşmaktadır. Tabakalı travertenlerin doğrultuları tamamen çatlak eksenlerine paraleldir ve eğim miktarları yatay konumdan dik konuma kadar değişebilmektedir. Tabakalı travertenlerin eğimleri çatlak ekseninin iki tarafında çoğunlukla asimetrik bir çökelimi yansıtmaktadır. Bu asimetrik çökelimin sırtın üzerinde geliştiği paleotopoğrafya ile ilişkili olduğu düşünülmektedir.

Çatlak ekseni KB uçta 558 m kotunda başlayarak K45°-50°B doğrultuda GD yönünde 230 metre uzanmakta, bu noktada hafif bir konveks yapı kazanarak K30°B doğrultuda güneydoğuya doğru 357 metre kadar devem ederek 503 metre kotuna ulaşarak sonlanmaktadır. Birçok sırt tipi traverten örneğinde olduğu gibi (Sivas Sıcak Çermik, Denizli Pamukkale ve Ağrı Diyadin vb.) çatlak ekseni dolayısıyla da tüm sırt, travertenlerin altında yer alan birimin reholojisine bağlı olarak konveks bir geometri sergileyebilmektedirler.

Sırtın güneydoğu bölümünde ana çatlaktan ayrılarak KB'ya doğru uzanan, gerek çökelen travertenlerin görünümleri gerekse çatlak ekseninin genişliğinin az olması bakımından çok genç olduğu düşünülen bir çatlak ekseni bulunmaktadır. Bu çatlaktan yüzeye çıkan

jeotermal suyun önemli bölümünün sırtın GB yamacından boşaldığı ve tabakalı travertenleri bu GB yamaçta çökelttiği düşünülmektedir. Bu yamaç boyunca tabakalı travertenler dike yakın eğim değerleri göstermekte ve şelale tipi travertenlere benzer bir oluşum göze çarpmaktadır. Sırtın bu bölümünün güneybatıya bakan yamacında travertenlerin 12 metreye ulaşan yüksekliğe sahip olduğu gözlenmiştir.

Reşadiye jeotermal ve traverten alanı doğrultu atımlı sağ yanal Kuzey Anadolu Fay Zonu üzerinde yer almaktadır. Reşadiye jeotermal tesislerinin yaklaşık 500 metre güneyinden Kelkit nehrine paralel olarak Kuzey Anadolu Fayı Zonu'nun aktif bir kolu olan K75°B doğrultulu ve Kelkit vadisi segmenti olarak adlandırılmış fay uzanmaktadır. Riedel (1929), Wilcox vd., (1973) tarafından deneysel kil çalışmaları iyi gelişmiş bir doğrultu atımlı fayda ana fay ile açılma çatlakları arasında 45° açı bulunduğu ortaya konulmuştur. KAFZ bu bölgede K72°B doğrultuya sahipken, Reşadiye sırt tipi traverteni ortalama K33°B doğrultudadır. Kelkit vadisi segmenti ile Reşadiye sırt tipi travertenininin çatlak eksenlerinin gidişleri arasında 39°'lik bir açı bulunmaktadır. Reşadiye sırt tipi travertenlerindeki açılma çatlakları ile KAFZ Kelkit vadisi segmenti arasındaki bu 39° açı, iyi gelişmiş doğrultu atımlı faylarda gelişen ve ana fay ile 45° açı yapan açılma çatlakları ile uyumluluk göstermektedir.

Reşadiye jeotermal ve traverten alanından birisi çatlak ekseninden diğeri ise çatlağın en dışından olmak üzere iki adet traverten örneği alınmıştır. Bu örneklerin yaşları MC-ICP-MS yöntemi ile saptanmıştır. Bu analizler sonucunda çatlak ekseninden alınan bantlı traverten örneğinin düzeltilmiş yaşı 7.563 yıl, çatlak ekseninin en dışındaki bantlı travertenden alınan örneğin düzeltilmiş yaşı ise 12.529 yıl olarak belirlenmiştir. Elde edilen bu yaşlar örneklerin alındığı konumdaki bantlı traverten kalınlığına oranlandığında bölgesel olmamakla birlikte KD-GB yönünde 0,093 mm/yıllık açılma hızı hesaplanmıştır.

Bu çalışma kapsamında Reşadiye sırt-tipi travertenden elde edilen yaş elbette ki bu sırtın oluşmaya başladığı yaş değildir. Sırtın oluşumu daha önce başlamıştır. Bu çalışmada elde edilen yaş su kaynaklarının bu sırt boyunca yaklaşık son 12.000 yıl içinde kesintisiz yüzeye çıktığını göstermektedir. Bu çalışma kapsamında yapılan gözlemler, sırtın oluşumu ile KAFZ'ın aktivitesi arasında yakın bir ilişki olduğunu somut olarak ortaya koymaktadır. Bu nedenle bu sırt, KAFZ üzerinde geçmiş dönemlerde meydana gelen büyük depremlerin kayıtlarını saklama potansiyeline sahiptir. Bu verilerin belirlenmesi ve yaşlandırılması KAFZ'ın geçmiş dönemlerdeki deprem aktivitesini anlamaya yönelik çalışmalara önemli katkılar sağlayabilir.

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