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Geographic Distribution of Rock Glaciers in Turkey: The Case Study of Erciyes Rock Glacier

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This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Arts.

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ABSTRACT

Ayşe ÜNAL **June 2013**

Geographic Distributions of Rock Glacier in Turkey: The Case Study of Erciyes Rock Glacier

Rock glaciers are one of the specific determiners of periglacial and permafrost formation process. They are usually located in continental climate regions. They are encountered on the high parts of the mountains where cold and arid climates dominate. Rock glaciers are formed on talus compromised by frozen rocks and ice. There is little information about the rock glaciers in Turkey. They are usually located in (1) southeast Taurus Mountains, (2) mountains near the coast of Eastern Black Sea and (3) other independent mountains scattered in Anatolia. The main purpose of this study is to examine the distributions of rock glaciers in Turkey by remote sensing techniques and field observations. As a case study, the present form and formation process of the rock glacier on Erciyes (38.53°N, 35.45°E, and 3917 m) were studied. The Erciyes rock glacier is situated on the eastern side of the mountain. In this study, 15 m resolution ASTER (Advanced Spaceborne and Thermal Emission and Reflection Radiometer) satellite images between 2001 and 2012 were used. The data obtained from satellite images were controlled during the fieldwork performed in August 2012. As a result, the Erciyes rock glacier covers an area of about 0.84 km² in elevations in between 2900 m and 3200 m. In 2001, it was covering an area of about 0.88 km². In 11 years, it retreated about 0.04 km² (~4 hectare).

Key words: Erciyes, Glacier, Rock glaciers, Permafrost, Geographic Information System.

KISA ÖZET

Ayşe ÜNAL **Haziran 2013**

TÜRKİYE'DE KAYA BUZULLARININ COĞRAFİ DAĞILIMI: ERCİYES KAYA BUZULU ÖRNEĞİ

Kaya buzulu, periglasiyel ve permafrost oluşum süreçlerinin en önemli göstergelerinden biridir. Genellikle kıtasal iklim bölgelerinde bulunur. Özellikle soğuk ve kurak iklimin hâkim olduğu dağların yüksek kesimlerinde görülür. Kaya buzulları, donmuş kaya ve buzun karışımıyla talus üzerinde oluşur. Maalesef şimdiye kadar Türkiye'de bu konu hakkında yeterli derecede çalışma yapılmamıştır. Bu eksikliği gidermek için Türkiye'deki kaya buzullarının coğrafi dağılımı incelenmiş, Erciyes'de bulunan güncel kaya buzulu ise uzaktan algılama ve arazi gözlemleri ile detaylı bir şekilde araştırılmıştır. Türkiye' de kaya buzulları genel olarak (1) güneydoğu Toroslar, (2) Doğu Karadeniz kıyısındaki dağlar ve (3) Anadolu'ya dağılmış diğer bağımsız dağlarda yer almaktadır. Bu amaçla; Kayseri ili sınırları içerisinde bulunan Erciyes Dağı'nın (38.53°N, 35.45°E, 3917 m) doğu yamacında, 2900 m ile 3200 m arasında yeralan kaya buzulunun 2001-2012 yılları arasındaki değişim süreci ve günümüz karakteri, 15 m çözünürlüklü ASTER (Advanced Spaceborne and Thermal Emission and Reflection Radiometer) uydu görüntüleri kullanılarak incelenmiştir. Ayrıca, uzaktan algılama teknikleri ile elde edilen veriler 2012 yaz aylarında yapılan saha çalışmaları ile kontrol edilmiştir. Bu gözlemler neticesinde, Erciyes Kaya Buzulu'nun 2012 verilerine göre yaklaşık 0.84 km²'lik bir alan kapladığı, 2001'de ise 0.88 km²'lik bir alana sahip olduğu tespit edilmiştir. Bu 11 yıl içerisinde, kaya buzulunun yaklaşık 0.04 km² (~4 hektar)'lık bir alan gerilemesine sahip olduğu belirlenmiştir.

Anahtar Kelimeler: Erciyes, Buzul, Kaya Buzulu, Permafrost, Coğrafi Bilgi Sistemleri.

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LIST OF ABBREVIATIONS

ASTER: Advanced Spaceborne Thermal Emissions and Reflections

EOSDIS: Earth Observing System Data and Information System

GIS: Geographic Information Systems

GPS: Global Position System

L1A: Level-1 data

NDVI: Normalized Difference Vegetation Index

RGB: Red, Green, Blue

SILCAST: Sensor Information Laboratory Corporations

UTM: Universal Transverse Mercator

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CHAPTER I: INTRODUCTION

1.1. Goals

Rock glaciers of Turkey have not been studied in detail, yet. In previous studies, largely, rock glaciers are examined within the field of glacial geomorphology. This study is based on two objectives. The primary principal of the study is distribution and monitoring of permafrost rock glaciers in Turkey. The second principal is to determine activity of the rock glaciers of Mount Erciyes at specific duration and evaluate using quantitative analysis of the rock glaciers as a case study. Also, monitoring Erciyes rock glacier is accomplished through field observations and remote sensing techniques.

1.2. Physical Setting

Turkey is situated between latitudes 36° and 42° N , longitudes 26° and 45° E, which displays different topographic and climatic characteristics from the west to the east likewise from coastal to interior regions (Şensoy, 2004). Therefore, these irregular topography or diverse regions bring about different climates. Even though Turkey is located in extensive geographical location where climatic conditions are quite temperate, diverse nature of the landscape, and the existence particular mountains that run parallel to the coasts, result in significant differences in climatic conditions from one region to the other. While the coastal areas enjoy milder climates, the inland Anatolian plateau experiences extremes of hot summers and cold winters with limited rainfall (Şensoy, 2004). Most of the rainfall is received within the winter season. In this season, mean temperature constantly is below 5°C and evaporation is not seen adequately. According to Şensoy (2004) summer rainfall is restricted. Increasing temperature and evaporation is not sufficient to take off water deficit. The Aegean and Mediterranean coasts have cool, rainy winters and hot, moderately dry summers. Annual precipitation in those areas varies from 580 to 1,300 millimeters, depending on location. (Şensoy, 2004). The greatest amount of rainfall is received in the Black Sea coast regions, the eastern part of which is the

only region in Turkey that receive 2,200 millimeters annually. Despite the fact that Turkey's interior regions have significant portions of highest terrain; the most remarkable terrains are situated in central and eastern parts of Turkey. Particularly, many dormant or inactive volcanoes are located in Turkey. In addition, distinctive glacial landforms or many fluctuations process have been occurring afterward the end the Pleistocene Epoch. Particularly, rock glaciers which emerged during Holocene are distributed to three regions. These are: the Taurus Mountains along the Mediterranean coast and south-eastern Turkey, the mountain ranges along the Eastern Black Sea Region and the volcanoes and independent mountain chains scattered on the Anatolian Plateau (Kurter and Sungur, 1980; Çiner, 2003).

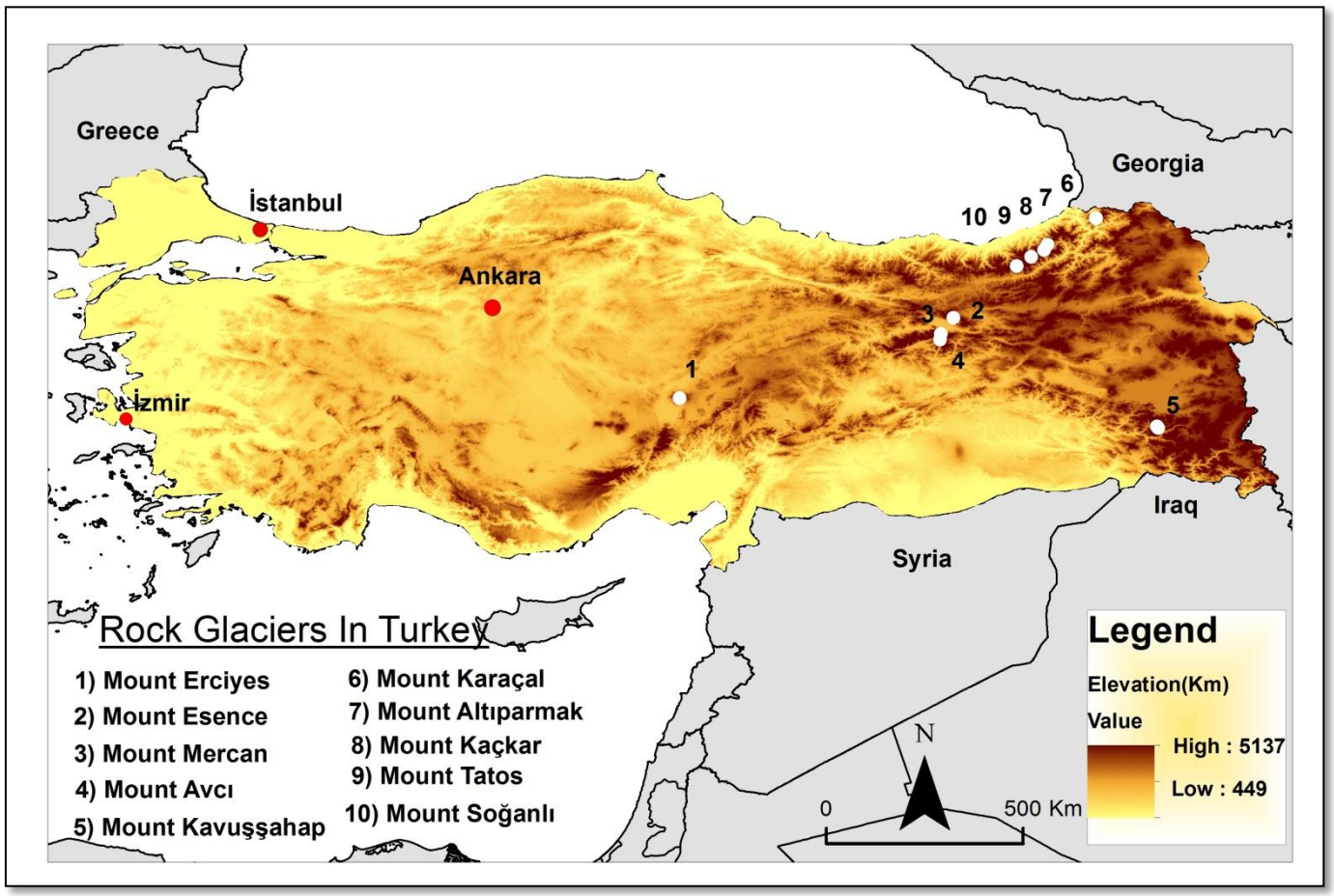

Figure 1: Distributions of Rock glaciers in Turkey

1.3. Study Area

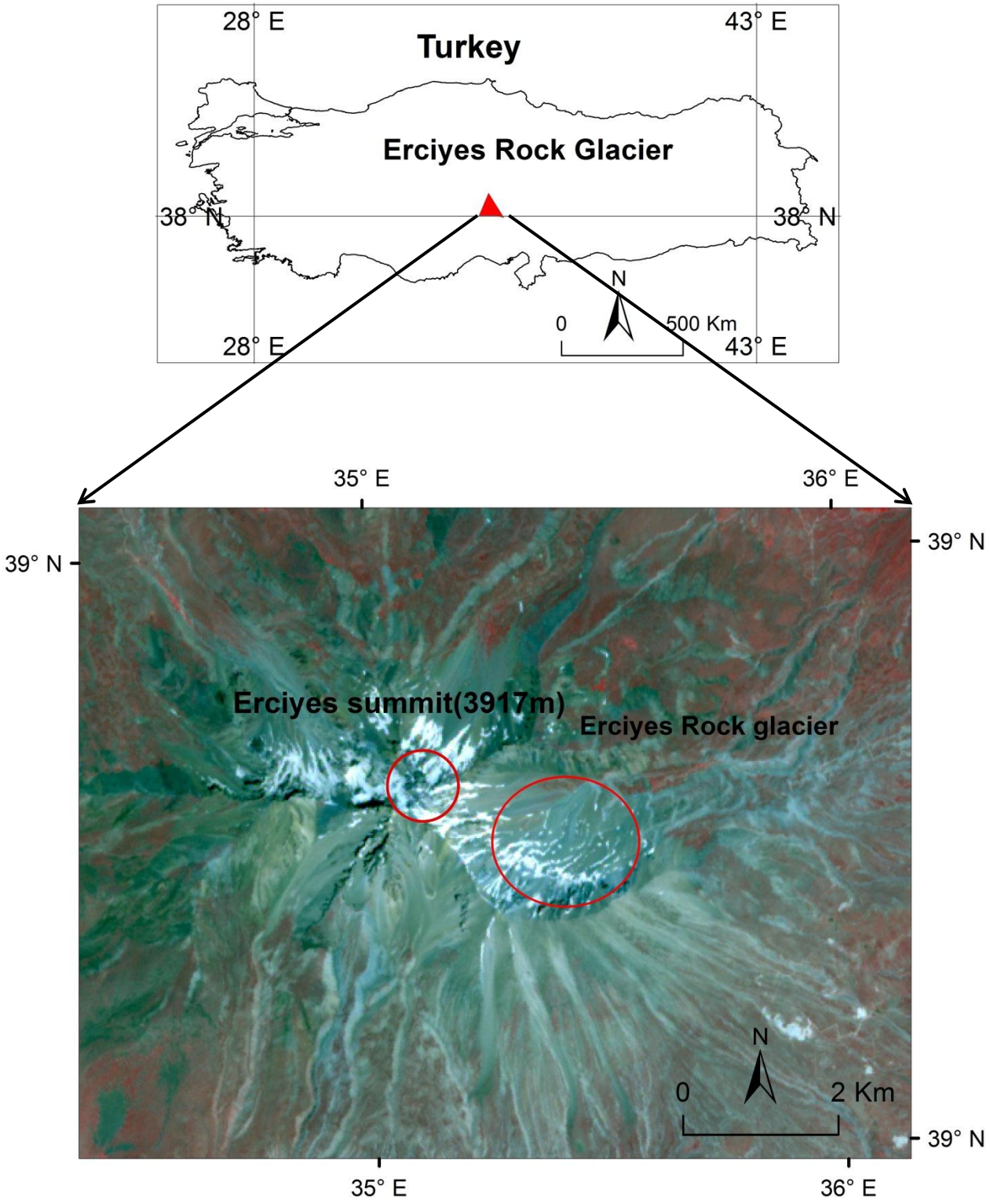

Figure 2. Map of the study Area

1.3. Literature Review and Previous Study

Krainer and Mostler (2000) described and analyzed the thermal and dynamic aspects of the Reichenkar rock glacier problems. Within this context, they have shown movements of rock glaciers with aerial photographs. Also, geological setting of rock glaciers is analyzed. As a result, morphology and ground temperatures of rock glaciers are identified. Velocity measurements of rock glaciers have been extracted within 25 years.

Another study is of Isaksen et al. (2000), in which two tongue-shaped rock glaciers are examined on Svalbard via to gain a better understanding of the Climate and Permafrost Conditions. Moreover, geomorphologies of rock glaciers are determined. In this article, data has mainly been obtained from air photo and ground penetrating radar. Also, surface velocity measurements of rock glaciers are useful in this study.

Humlum (2000) studied regional climate of rock glacier and its growth. Rock glacier is analyzed in selected regions of central west Greenland and north-east Greenland, and Antarctica. Glaciers and rock glaciers are close to each other. After analysis of the climate data, the typical rock glacier climate is not exactly continental climate which is dry and moderate humid with cool summers. On the contrary, the data shows that the topographic position of rock glaciers probably contain unique climatic information. As a result, relict rock glaciers represent a potentially important source of palaeoclimatic information.

Humlum (1996) worked surface and interior characteristics of a tongue-shaped rock glacier in Mellemfjord on Disko Island. The implications shows that rock glacier has origins of ice and its surface of debris layer shows that the rock glacier's age is determined as about 550 years; it is formed during the initial period of the Little Ice Age. In addition, the geomorphological feature is described.

Humlum (1998) studied regional climate of rock glacier with presenting geomorphological and meteorological observations. He examined active rock glaciers in Greenland and Antarctica. As a result, rock glaciers were compared with other glacial and high-relief landscape of periglacial phenomena.

Kääb et al, (1997) have monitored on Gruben rock glacier over 1970 to 1995. Elevation and surface velocities of rock glaciers were measured consecutive five-year periods using an advanced photogrammetric monoplotting technique of multi-temporal stereo models. Eventually, flow directions estimates the age of rock glacier.

Kaufmann and Ladstädter (2002) studied on quantitative analysis of rock glacier creep using multi-temporal aerial photographs in the Austrian Alps. Investigations show where rock glaciers are located in numerically and graphically.

Kaufmann and Ladstädter's (2003) study measured rock glaciers by surface velocity fields using terrestrial, air and space-borne. They compared surface velocity fields and developments of rock glaciers surface. Consequently, this monitoring series are identified for a major requirement of future research.

CHEAPTER 2: ROCK GLACIERS

2.1. Definition of Rock Glaciers

The geomorphological form of rock glaciers is still a problem to define in detail. The first study was introduced by in the Wrangle Mountains in Alaska (Cross and Howe 1905). The first information was water infiltrated into the debris layer which was frozen to generate ice cored. The term, rock glaciers, is formed in 1959, when Wahrhaftig and Cox prepared the report which includes their climate, distribution, motions. In recent years, researchers greatly studied in a variety of ways to classify it. Definition of rock glaciers is advanced by Potter in 1972.

Rock Glaciers are large tongue shaped or lobate generally composed of angular boulders. Their overall appearance resembles that of glaciers in that they occur high mainly in Alpine valleys and have surface micro topography, including ridges and furrows, and a steep snout (Potter, 1972).

In other words, rock glaciers are slowing mixtures of rock and ice common to many alpine and arctic regions (Whalley and Martin, 1992) Nevertheless, rock glacier characteristics is not supplied for terminological meaning.

The term “rock glacier” was defined in morphological ways:

Haeberli (1995) states that non-consolidated debris from talus or moraines is often supersaturated in ice and undergo downstream creep with characteristic velocities of a few decimeters per year.

In recent years, the rock glaciers are offering flowing permafrost definitions.

Rock glaciers are lobate or tongue-shaped creeping permafrost body’s flowing due to deformation of the ice. (Barsch 1992; Barsch 1996; Haeberli 2000).

Figure3. Mount Sneffels rock glaciers in the Colorado (2008).

(*http://xpda.com/mountains/sneffels/*)

2.2. Morphology of Rock Glaciers

Rock Glaciers are formed by periglacial or glacial forms. Potter (1972) considered that they may have an ice core of glacial origins. Many researchers agree that some rock glaciers come from glacial landforms. Periglacial landforms contain interstitial ice. Shape and topography of rock glaciers display significant geomorphological features; therefore they need to be explained in detail.

Rock glaciers can be described as lob-like or tongue-like permafrost features consisting of two layers: an upper blocky (active) layer, normally 1-5 thick and a lower layer/ core often 20-50 m thick consisting of a mixture of ice and debris. Active rock glaciers are in motion because of the inner deformation of ice (Barsch, 1996).

Rock glaciers are divided into three categories morphologically.

Talus-derived rock glaciers frost-shattered clasts from the talus slopes commonly fed by rock walls of glacial cirques and valleys. (Serrat, 1979; Gutierrez andPena, 1981).

Harris considers that tongue-shaped rock glaciers are not found in alpine environments in maritime climates. At the same time, they are formed below ice glaciers. Lobate types are found on talus slope in cold regions with permafrost environments.

Other categorizations are made through move of rock glaciers which are active or inactive. Active rock glaciers are featured by the absence of vegetation, by unstable surfaces and steep front with slope angle often higher than 40° to devoid of ground of ice. (Paepe et all.2001: 260) Active rock glaciers have been advancing continental and semi-arid climates (Barsch, 1988).

Inactive rock glaciers have flat regions. They are not moving unless they have bedrock sliding. It contains ground ice at depths more than 10 m. (Paepe et all.2001: 260).

2.3. Characteristics of Rock Glaciers

Rock glaciers characteristics are cold climates and moderately humid climates on the mountain regions. (Figure 4). They are extended in the Alps, Caucasus, Pamirs, Hindu Kush, Tien Shan, Karakoram, Rock and Andes Mountains, and in Greenland, Spitsbergen, New Zealand, and coastal areas of Antartica. (Gorbunov et al. 2008). Small rock glaciers in the Central America and Africa in general are seen at high mountainous areas. (Govorushko, S.M., 2012:196). The remarkable example comes upon Disko Island of Rock Glaciers, of the western coast of Greenland. Its area is 8,575 km² and their maximum height reaches 1.904 m. There are about 1.700 Rock Glaciers (Gorbunov et al. 2008). Rock Glaciers sizes are varying from 1km to 3km length. Also, width has a few hundred meters.

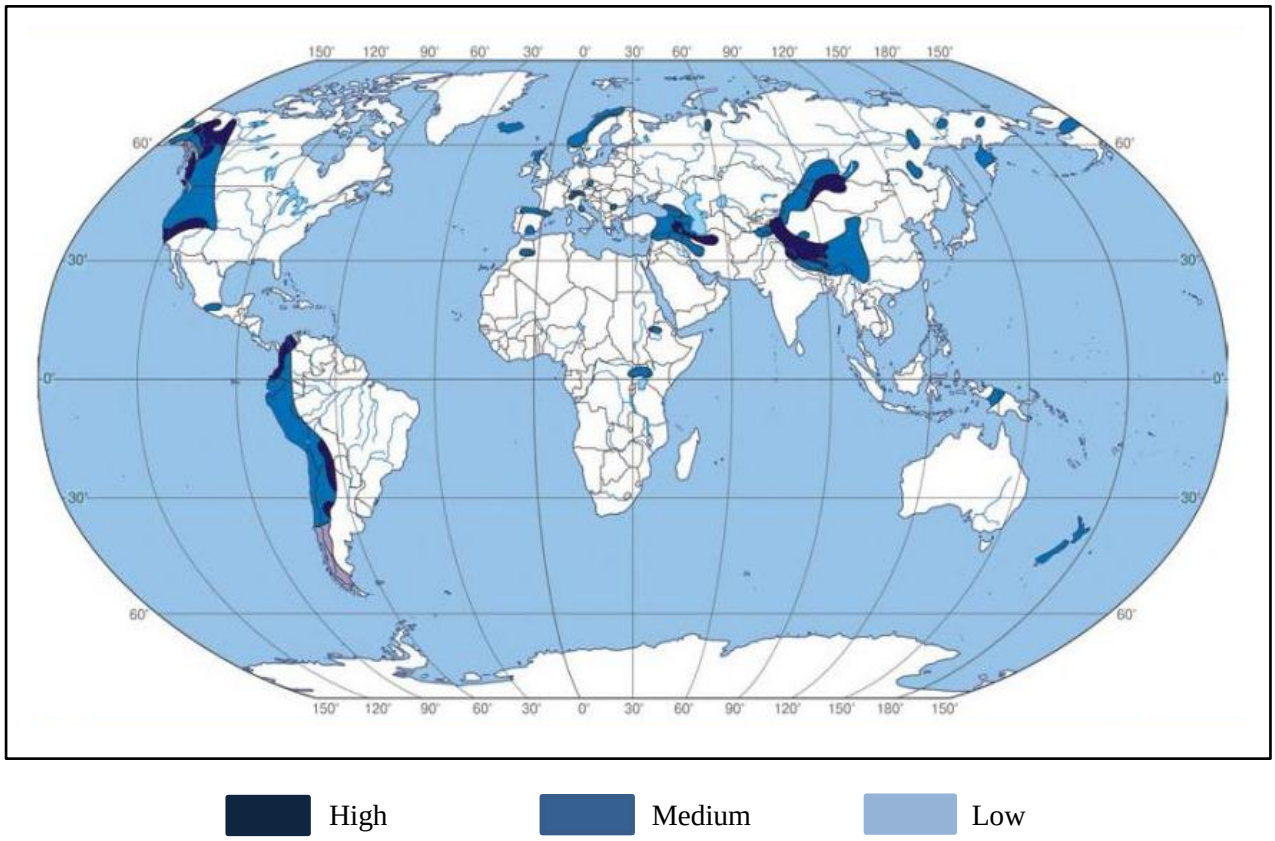

Figure 4. The favorable conditions for the formations of Rock Glaciers (Barsch 1996).

2.4. Composition and Inner Structure of Rock Glaciers

Rock Glaciers occur where rock debris and ice have been mixed together. In this context, it can be divided into two categories. Firstly, Ice-Cemented Rock glaciers, they are not connected with historico-genetic glaciers. (Govorushko, S.M., 2012:196) Secondly, Ice cored Rock Glaciers are formed of glaciers in the course of their reductions and burial under layers of detritus.

2.5. Distributions of Rock Glaciers

Rock Glacier identifies regional characteristics. These characteristics are controlled by climatic feature, topography and lithology or other climatic variables. According to Brazier et al. (2004) if weather data is not found in the region, distributions of rock glaciers gives information about the present regional climates. In addition, there are some criteria for advanced rock glaciers. Microclimates are effective for distributions of rock glaciers. For example, in an interior of British Columbia climatic feature is heavy snowfall. Also, many glaciers are stated on this region. It means that rock glaciers are advanced within light snowfall or moderate climate not heavy fall. Rock glaciers have specific altitude which is influenced by mean annual temperature. Nevertheless, rock glaciers disappear on more maritime climates in the Central and western Cascades. As a consequence, rock glaciers have been advancing within less snowfall and less maritime climate on the mountain regions. When climate data in the ben Oahu range (New Zealand) analyzed, active rock glaciers are above the lowest estimated altitude of the –2°C isotherm. However, at the other extreme, only four active talus rock glaciers lie at or above the highest estimated altitude of this isotherm. (Brazier et al. 2004). Another microscale factor is topography which is effective on widely-distributed rock glaciers. Usually, they are found in the steep wall-cliffs or cirques. The total elevation range of rock glaciers is 1710–2670 meters. Optimal rock glacier sites are below north- or northeast-facing quartzite cliffs in cirques or on valley walls. Due to, topographic features is one of the spectacular factors in existing lots of the rock glaciers. Usually, there is no visible ice and also surface has flat.

2.6 Rock Glaciers and Climate

Ice-cored rock glaciers have the advantage of number. At first sight, rock glaciers or glaciers are distinguished too difficult. For example, glaciers are examined according to structure, dynamics. There are determined rock glaciers on the Alps (Krainer et al. 2000).

Rock glaciers are spectacular indicator in glacial geomorphology. (Turoğlu, H. 2011) In recent years, rock glacier identifies climate features. Rock glaciers are present in many cold-climates, mountain regions and are often seen as characteristic features for continental mountain areas such as Rocky Mountains, Alaska Range, Alpes, Pyrenees, Sierra Nevada, Scandinavian ranges, Andes, Antarctica, Himalayas or Tien Shan. (Blasco et al.2009). (King, 1986; Barsch, 1992). Nevertheless, some rock glaciers are identified in maritime regions. (Eyles, 1978; Birnie and Thom, 1982; Humlum, 1982; 1988a; Martin and Walley, 1987). Other studies have recently suggested rock glaciers have been seen in middle latitude and high mountain ranges, not tropical mountains. They are hardly seen in middle-latitude Mountain with maritime climates. Rock glaciers are best seen in continental climate where it exhibits frost activity and they have little snow with low temperature. For example, Pacific side of the Sierra Nevada has not rock glaciers or Coast Ranges of Alaska. Rock glaciers find leeward side of the mountains. (Larry W.P, 1986:208)

According to Barsch (1988) even though rock glaciers have been formed as continental and semi-arid climates, they can occur between glacial and periglacial belt in humid climates. Additionally, they advance on the permafrost environment within mountain ranges.

Temperature and precipitation are determiner factors about rock glacier formations. This determiner factor is identified by a curve (Figure 5). The upper limits of annual precipitation for rock glacier formation are 2500 mm a^{-1} at -2°C, and 400 mm a^{-1} at -15°C. The lowest altitude of rock glacier snouts is normally well above the limit of continuous permafrost (Corte 1987; Wahrhaftig 1987). If mean

annual temperature is below -2C°, that forms mixture of ice and debris. If mean annual temperature is above -15C°, that is for ice deform. (Payne, D. 1998)

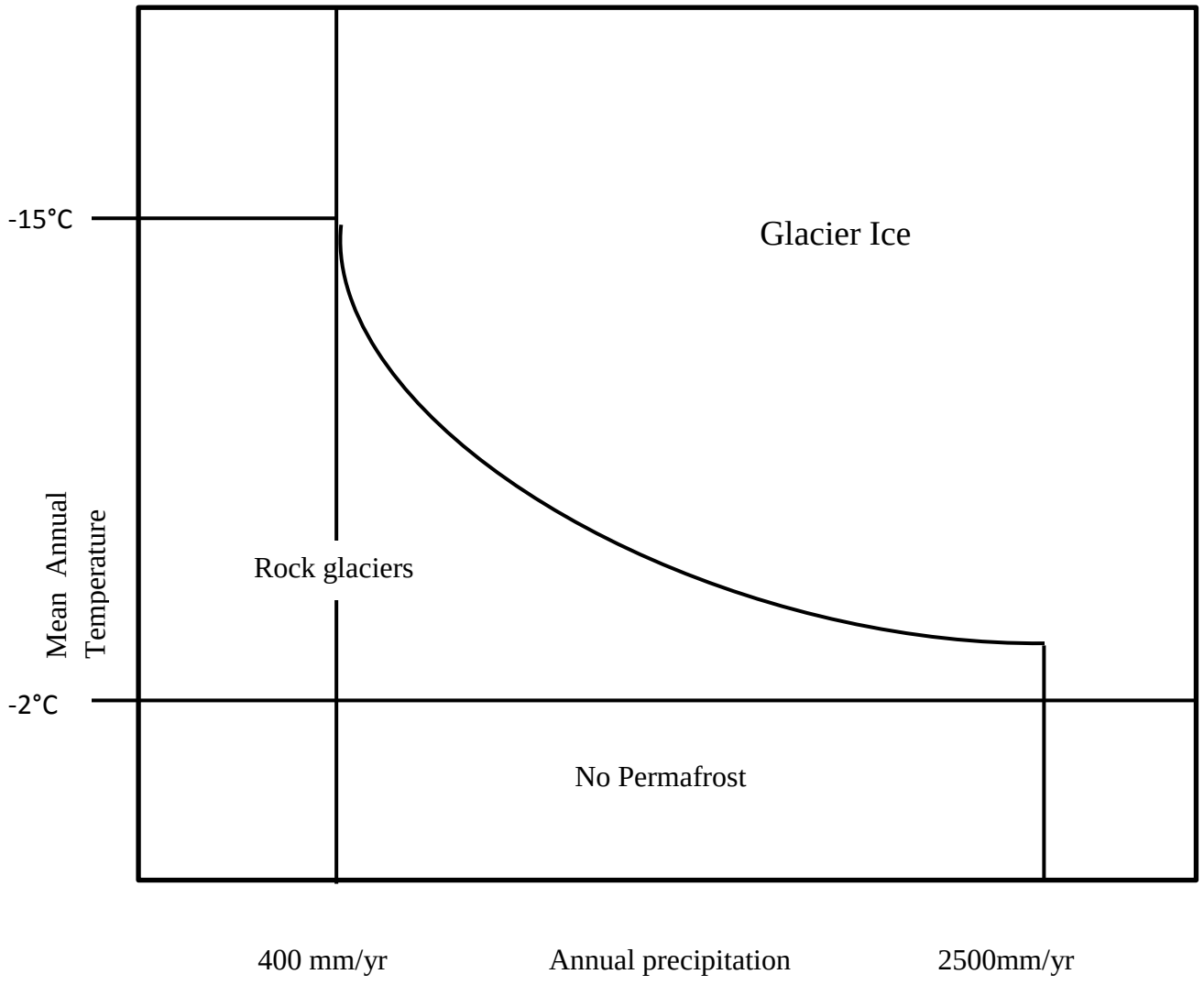

Figure 5. Climatic constraints on the formation of rock glaciers. (Payne, D. 1998)

CHAPTER 3: MATERIAL AND METHOD

The goal of the study is organized in two basic concepts. These concepts are to demonstrate regional distributions of rock glaciers in Turkey, to determine characteristics of rock glaciers, in Erciyes mountain, to digitize and visualize rock glaciers into GIS (Geographic Informations Systems) environments. In this study, data of the years 2001 and 2012 has been acquired via EOSDIS (http://reverb.echo.nasa.gov). The extent of this study is supplied by fieldwork in 2012. As a conclusion, the study is analyzed by ArcGIS 10.1 software.

3.1. Regional Distributions of Rock Glaciers

In this section, the goals are to visualize and demonstrate regional distributions of rock glaciers in each part of Turkey.

3.1.1. Data Collection

At the beginning of the study, ASTER (Advanced Space Borne Thermal Emissions) was acquired from EOSDIS (http://reverb.echo.nasa.gov). Data of Eastern Black sea Mountains, southeastern Anatolian mountains and individual mountains belonging to the years between 2001 and 2009 were collected. On the other hand, minimum of snow and cloud cover images which are taken in the summer are particularly preferred. Also, best resolutions images were preferred as 15 m resolutions.

3.1.2. Data Process

These images were automatically orthorectified with silcast 1.08 software. Thus, distortions of images became smoother. After that, images of silcast were transferred to ArcGIS 10.1. Rock glaciers were determined according to regional distributions in Turkey. Each of Rock glaciers was hand-digitized.

3.2. Morphological Features and Character of Rock Glaciers

Figure 6.Image of Erciyes Mountain (looking west).

3.2.1. Data Collection

3.2.1.1. Field Work

The objectives of field work the goals are to determine morphological features and character of rock glaciers with internal structure.

3.2.1.1.2. Fieldwork Equipment

- Aerial Photo
- GPS
- Cameras

Prior to field work, Erciyes Rock glacier was investigated on the aerial photos Different aspect of aerial photos was gathered. Minimum cloud cover of aerial photos was preferred.

3.2.2. Data Process

Erciyes rock glacier was worked in August in 2012 and it is located in Kayseri. Kayseri-Develi road was chosen to go study area. A GPS (Global Position system) was used for measurements accurate locations (Figures 7, 8). Rock glacier was defined according to Potter (1972) definition. In Parallel with, it were analyzed morphological features as talus-derived, tongue-shaped features belonging to climatic features. The other analyze is made by moving to rock glacier. Such as active or inactive rock glaciers and their surface feature was extracted.

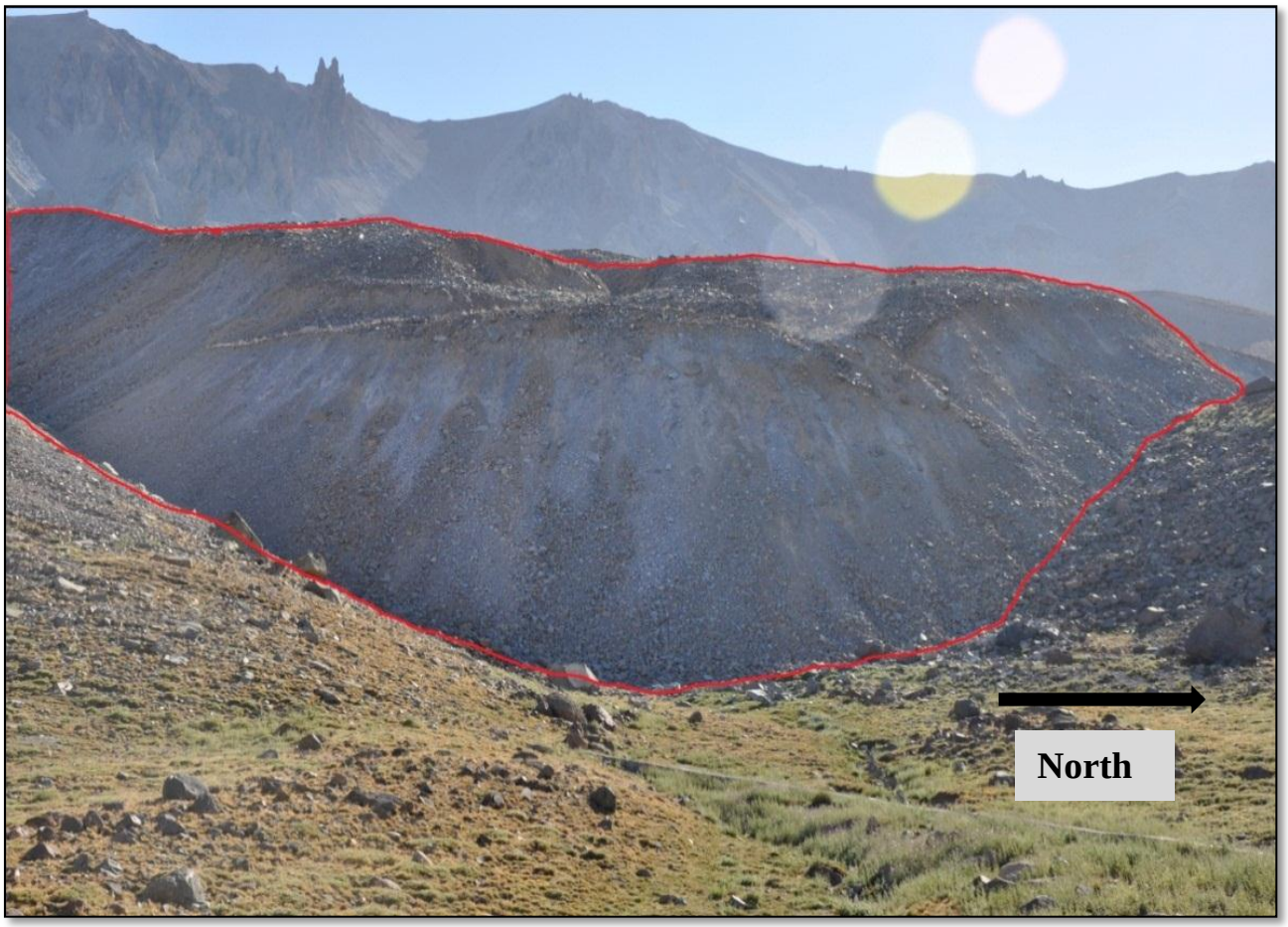

Figure 7. Erciyes Rock glacier in Üçker Valley (looking west).

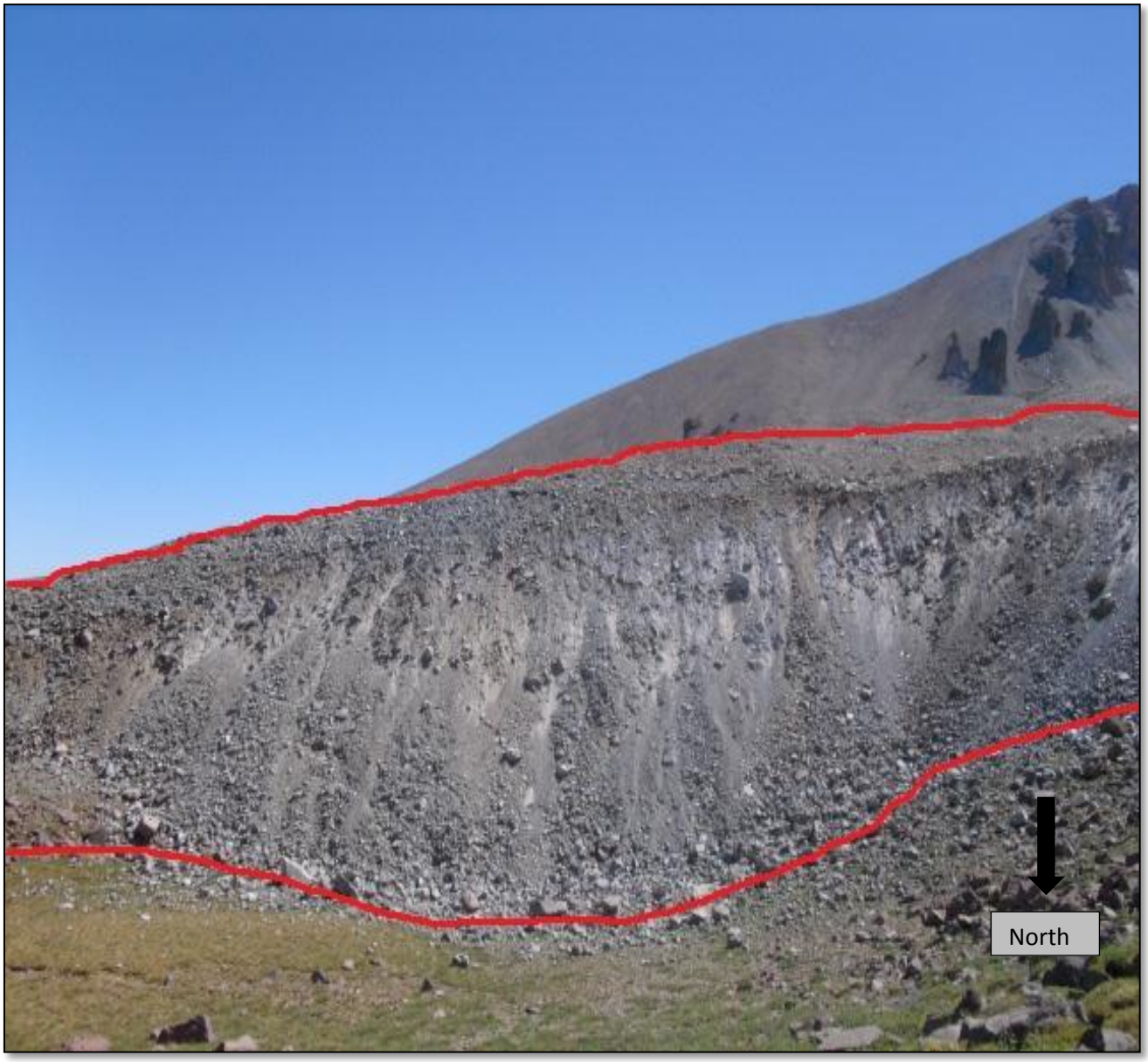

Figure 8. Erciyes Rock glacier (looking south)

3.3. GIS (Geographic Information Systems)

GIS method is being used in land cover or geological applications which explain change detections. Thus, rock glaciers were monitored in a specific time.

3.3.1. Data Collection

In this section, The Erciyes rock glacier was examined specifically which was quantified. So that the Erciyes Rock glacier was mapped and interpreted according to morhological features. ASTER was downloaded from EOSDIS which belongs to 2001 and 2012. (Table 1).In this process, ArcGIS 10.1 was used to visualize and analyse of satellite images.

3.3.2.Data Process

In this section, On the ASTER Band, Orthorectify operations was used for an accurate specter. ASTER L1A data was converted to orthorectified images. Within this transition, Silcast 1.08 Software was used. In this study, Natural composite images, false colours and composite colours were used enrichment process of images. Band Arithmetical Process and Normal differance Vegetation index (NDVI) were used in land cover and change detections.

3.2.3. Silcast Analysis

AST_L1A_07022001084052.hdf and AST_L1A_07232012083844_hdf bands are analyzed for Erciyes Rock glaciers. These two data base are used for orthorectification process. Of those two were preferred on June 02, 2001 and June 23, 2012.Because of free cloud images. Some downloaded images were ignored because of cloudy images. These two bands are converted into digital elevation models by Sensor Information Laboratory Corp (SILC) Silcast Software 1.08 version. (Developed for ASTER main functions dem and ortho rectify).

On June 02, 2001 belonging to all of ASTER L1A bands had Granule was applied three processes. Coordinate system of Study area is UTM, Zone 36, and WGS 84. Non silcastted images and silcastted images were compared for accuracy. (Figures 8a, 8b). Dam on the east of Erciyes Mountain was preferred. ASTER L1A has been containing distortions so that silcast is used on this image. On this ID 07022001084052 ASTER data, study area was cut extract by mask.

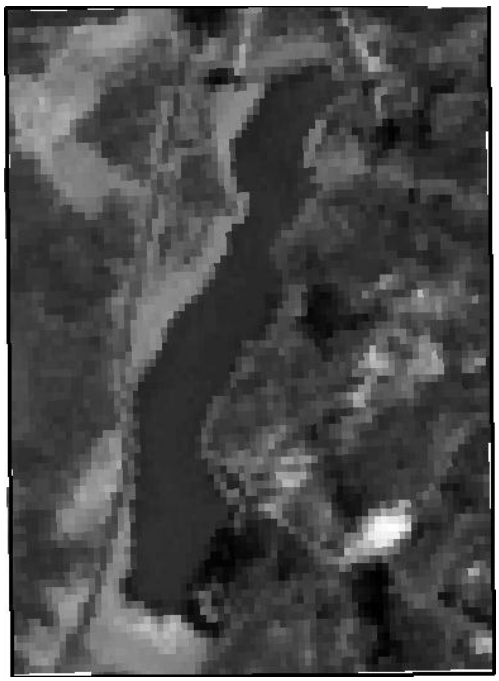

Figure 9a. An example of Granule ID 07022001084052 of Non-orthorectified image.

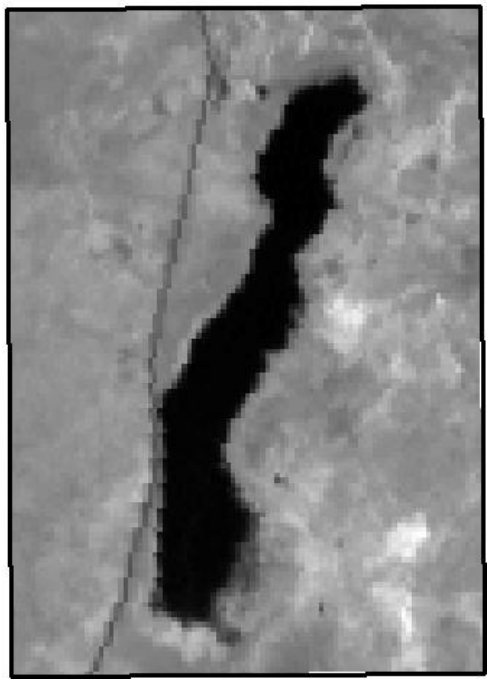

Figure 9b. An example of Granule ID 07022001084052 orthorectified image.

3.2.4. Band Combinations

Images were enhanced using Composite Bands after those bands were changed according to false color image. (Figure 10). Within this process, VNIR (visible and near infrared) bands were created with three bands. Those are V1, V2, V3N and V3B (Table: 1)

Table 1. VNIR (Visible and near infrared) Band number

Subsystem	Band No	Spatial Resolution
VNIR	1	15 m
	2	
	3N	
	3B	

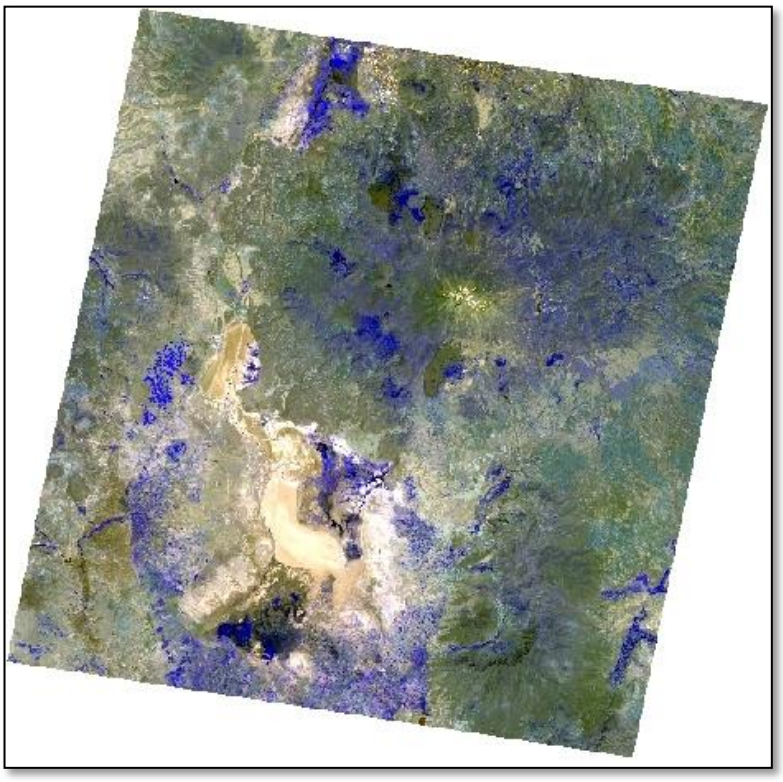

Figure 10.Composite Bands Granule ID 07022001084052

On this image, geomorphology and geology are not well interpreted. False color Composites are beneficial for visual analysis and Erciyes rock glacier change. False Color Composite is created band 3, band 2, and band 1 as red, green, and blue. (RGB) (Figure 11).

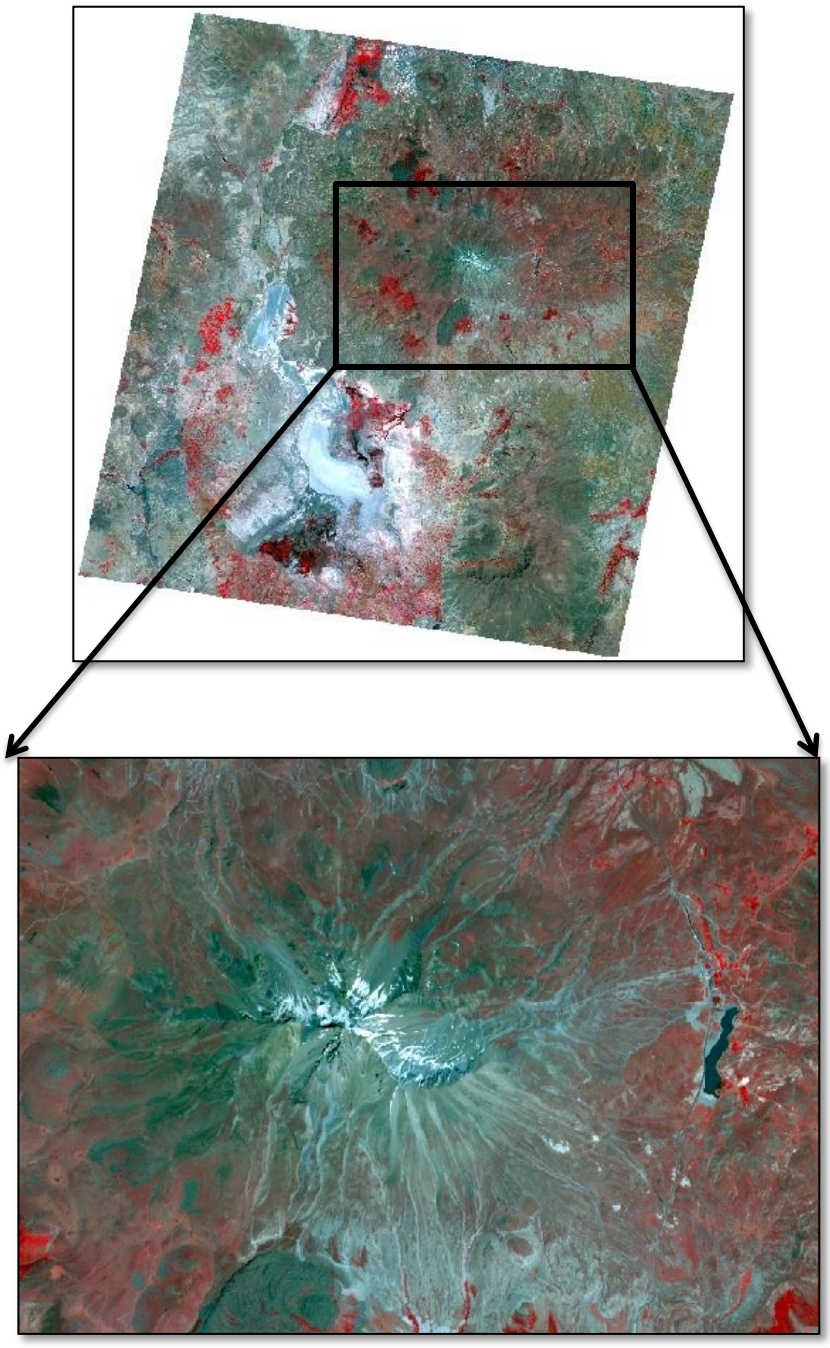

Figure 11. False Color Images (RGB) of Erciyes Rock Glaciers

Within analysis and interpretation of Erciyes rock glacier, a shape file was created in Arc Catalogue. Initially, boundary of Erciyes rock glacier was digitized from the composite images in Arcmap. (Figure 12).

Figure 12. Boundary of Erciyes rock glacier after digitizing

3.2.5. NDVI (Normalized Difference Vegetation Index)

For this process, data was obtained from composite bands. New composite bands were produced for NDVI. VNIR (visible and near infrared) V1, V2, V3N and V3B were used. NDVI tool were used for remote sensing visual interpretation. In this section, NDVI was applied for to distinguish rock glacier and glacial area. The NDVI is computed by from near infrared and visible red bands. According to, **NDVI = (NIR - Red) / (NIR + Red).**

For the 2012 image, feature class was created in Arc Catalogue. Boundary of Erciyes rock glacier was digitized from the NDVI in Arcmap. After that, area of rock glacier was calculated on the attribute table. (Figure 13).

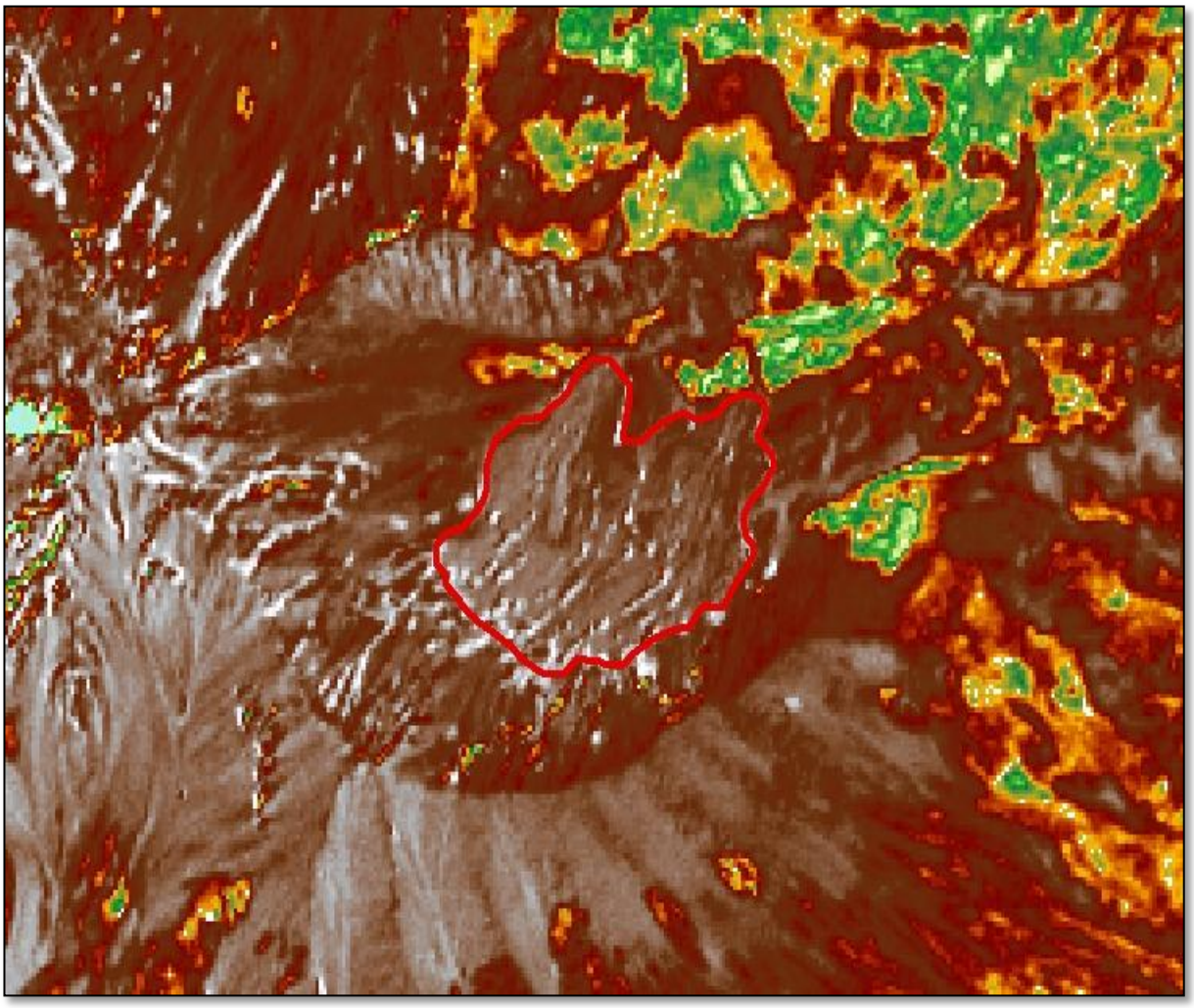

Figure 13. Digitizated image of NDVI from ASTER 2012

3.2.6. Slope and Aspect

In this process, 2012 VH data was used. In the Erciyes rock glacier, on the 2012 VH and 2001 VH data, study area was extracted by mask. After that, Erciyes rock glacier was computed by slope and aspect tools. Slope distributions and aspect of Erciyes rock glacier were calculated.

CHAPTER 4:RESULT

In this study, rock glaciers have been examined according to regional distributions. These are; Black sea region, Southeastern Anatolian region and Individual Mountains are determined. In this context, ASTER satellite images have been beneficiary. These images were acquired chronologically on 13.10.2002, 07.10.2003, 08.07.2005 and 09.10.2007. Acquired images were orthorectified with Silcast Laboratory Analysis. For Black sea region, a total of 25 rock glaciers were hand-digitized. After that, those were inventoried and mapped. They are Soğanlı mts. Rize mts. and Karaçal mts. Rock glaciers of Soğanlı Mountains are generally between 2820 m and 3048 m. Additionally, aspects of rock glaciers are commonly towards N, NE and NW. The biggest rock glacier is 0.24 km² on the Soğanlı mountains (Figure. 14).

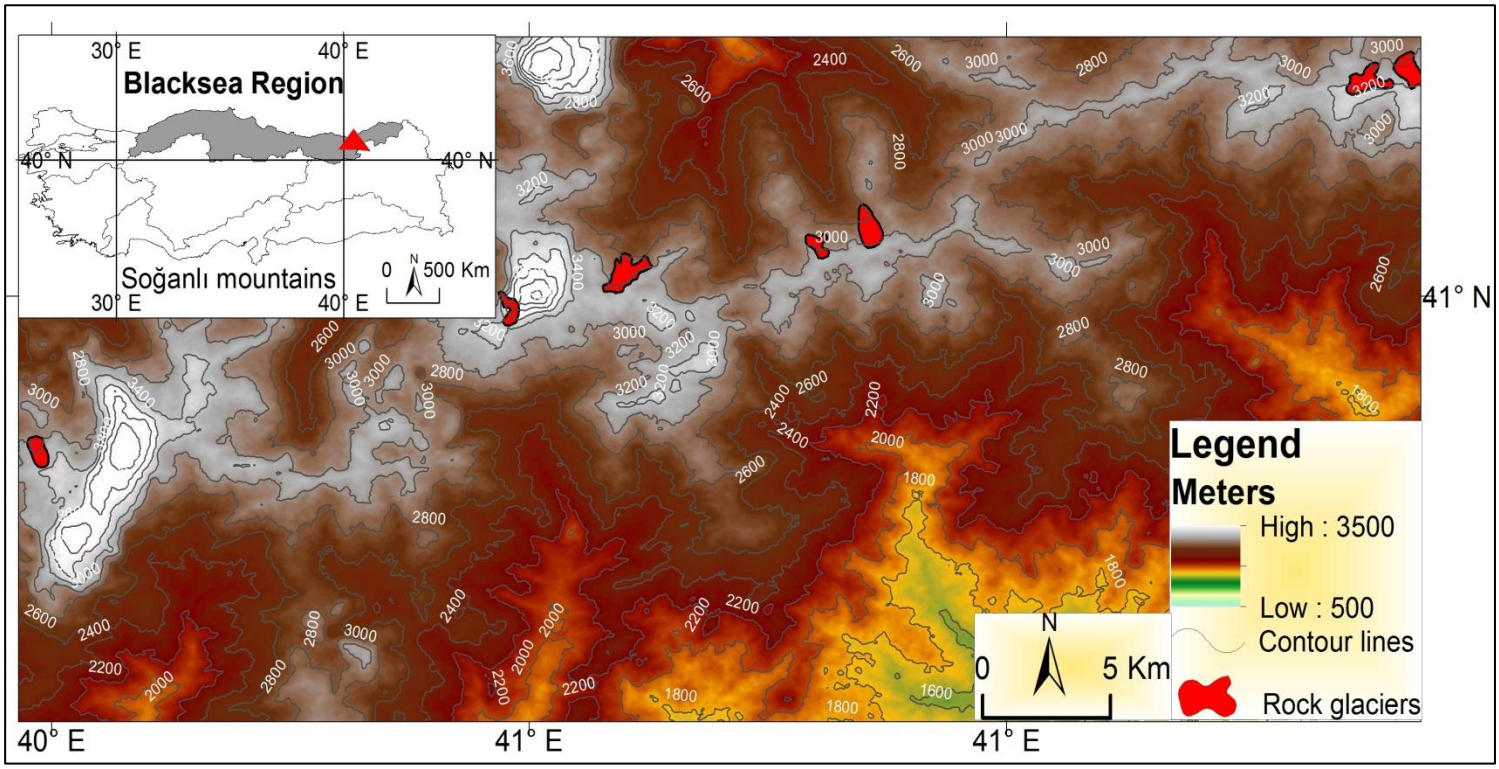

Figure 14. Rock glaciers of Soğanlı Mountain in the Black Sea Region

Rize mountain elevations are between 2832 m and 3259 m. Aspect of rock glaciers are towards N, NW and NE, the biggest rock glacier area is statistically 0,64 km². (Figure 15).

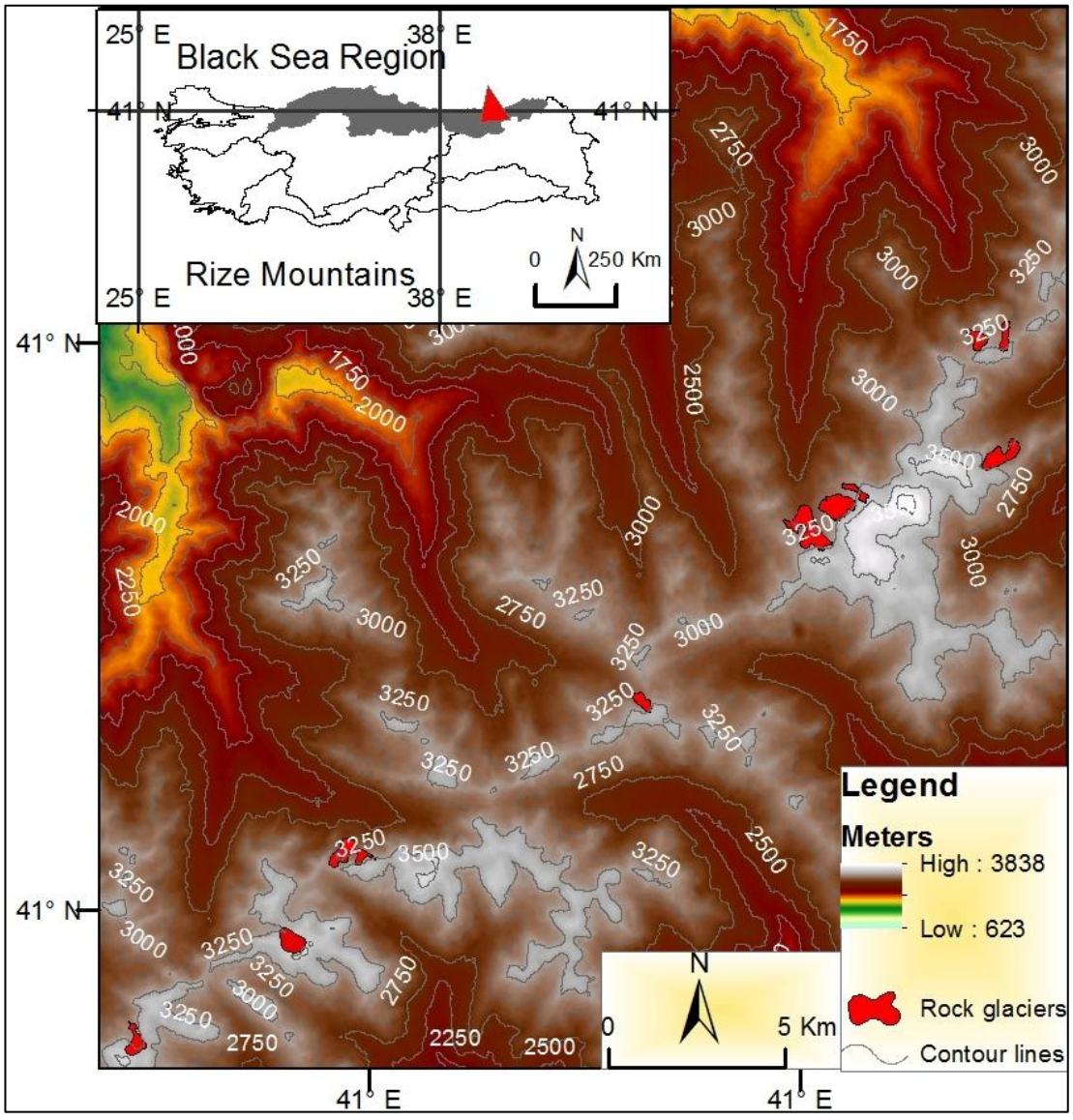

Figure 15. Rock glaciers of Rize Mountain in the Black Sea Region

For the Karaçal mountains, elevations range between 2740m and 3030m. Aspects of rock glaciers are towards E and NE. The biggest rock glacier in this area is 0.42 km².(Figure.16).

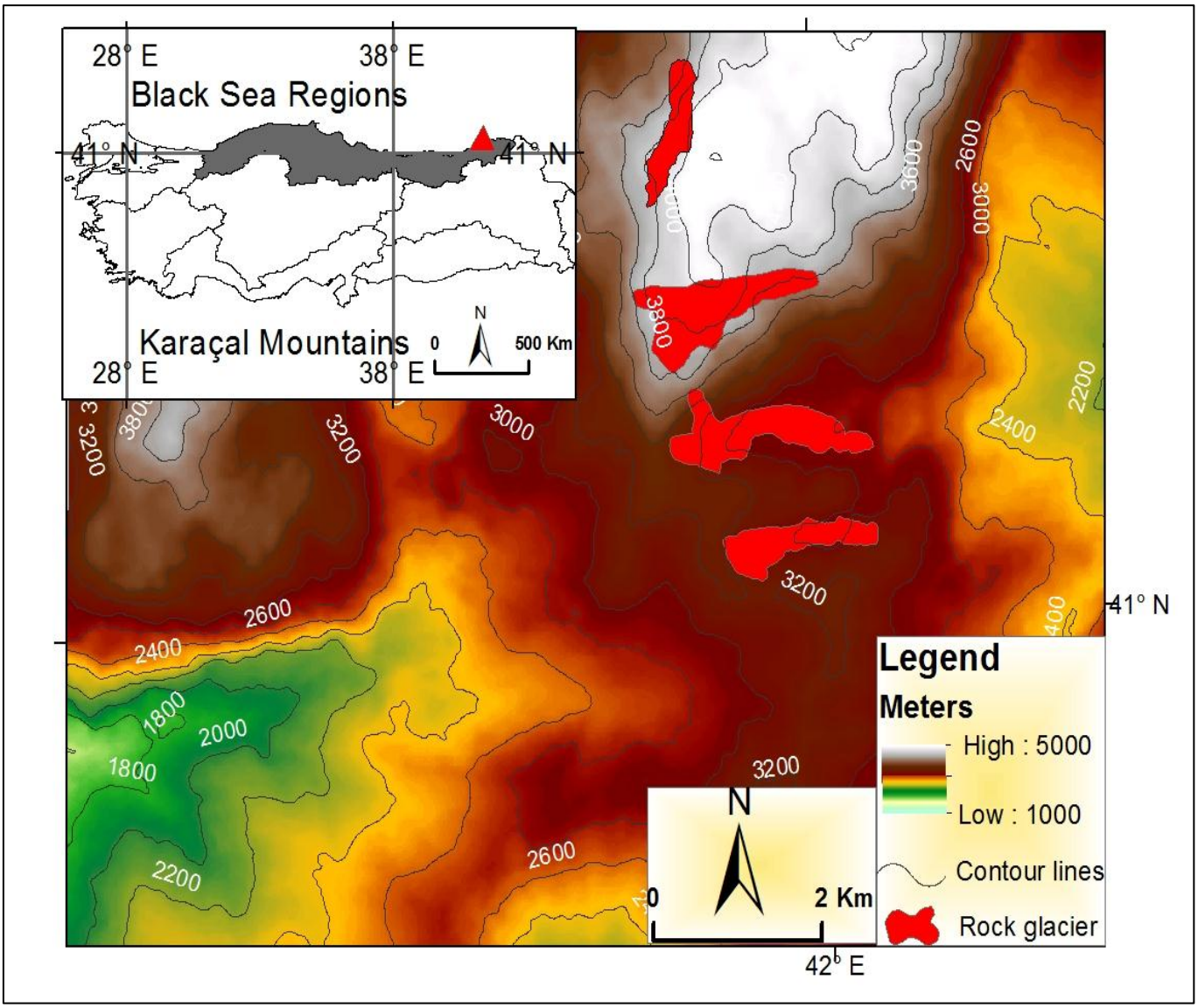

Figure 16. Rock glaciers of Karaçal Mountains in the Black Sea Region

For Southeastern Anatolian regions, on the Kavuşşahap Mountains and Hasanbeşir Hill there are total 14 rock glaciers. Elevation rate is between 3286 m and 2910 m. Generally, it has been situated on the N and NE side of the Kavuşşahap Mountains. The biggest area of rock glaciers is 0.13km². (Figure 17).

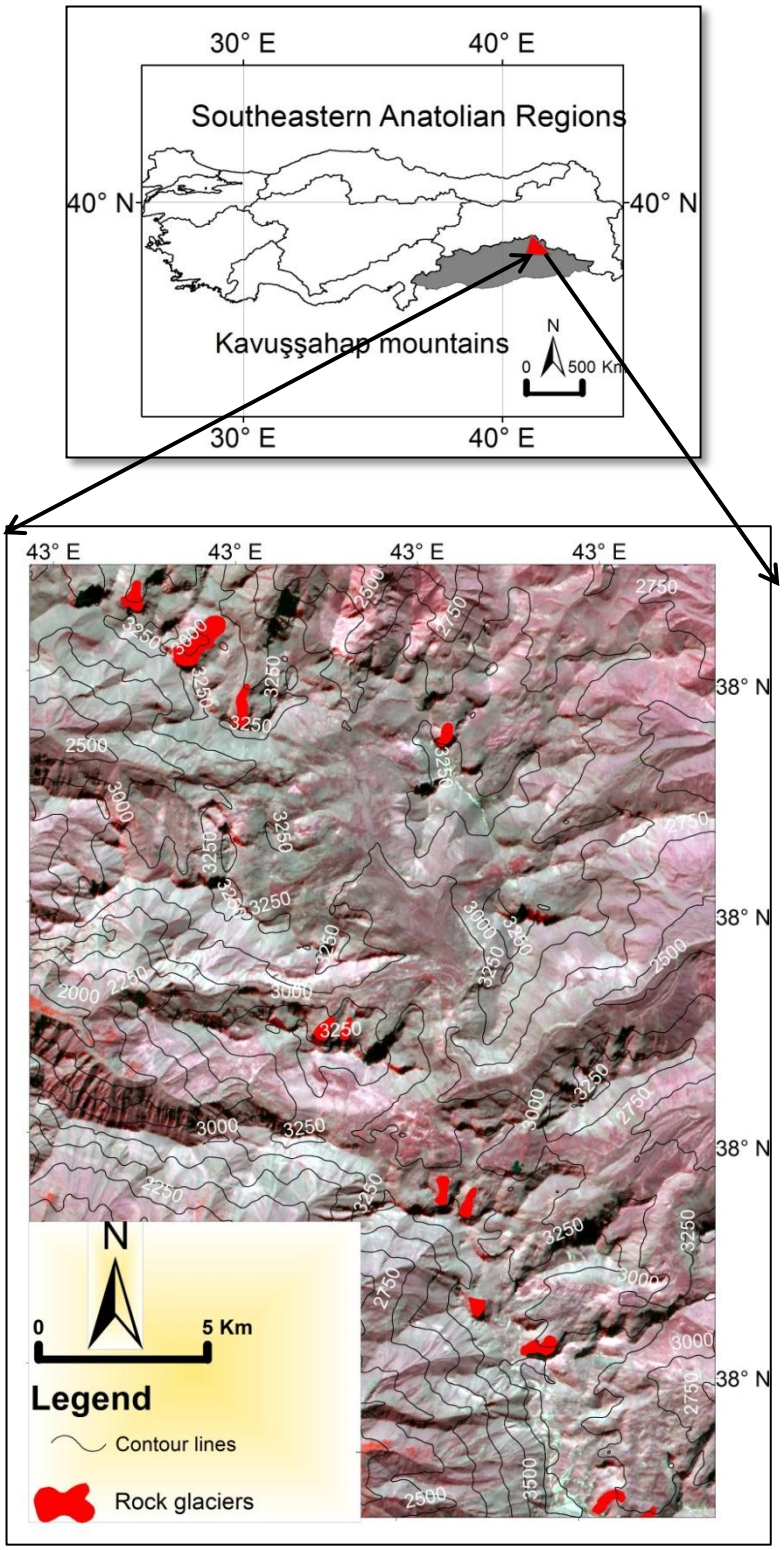

Figure 17. Rock glaciers of Kavuşşahap Mountains in the Southeastern Anatolian Region

The individual mountains are Erciyes, Mercan and Esence mountains. It has total 13 rock glaciers. Generally, it was located on the N, NE and NW. Mercan Mountain elevation is between 2890 m and 3200 m. The biggest area of rock glaciers on Mercan Mountains is 0,55km². (Figure 18.)

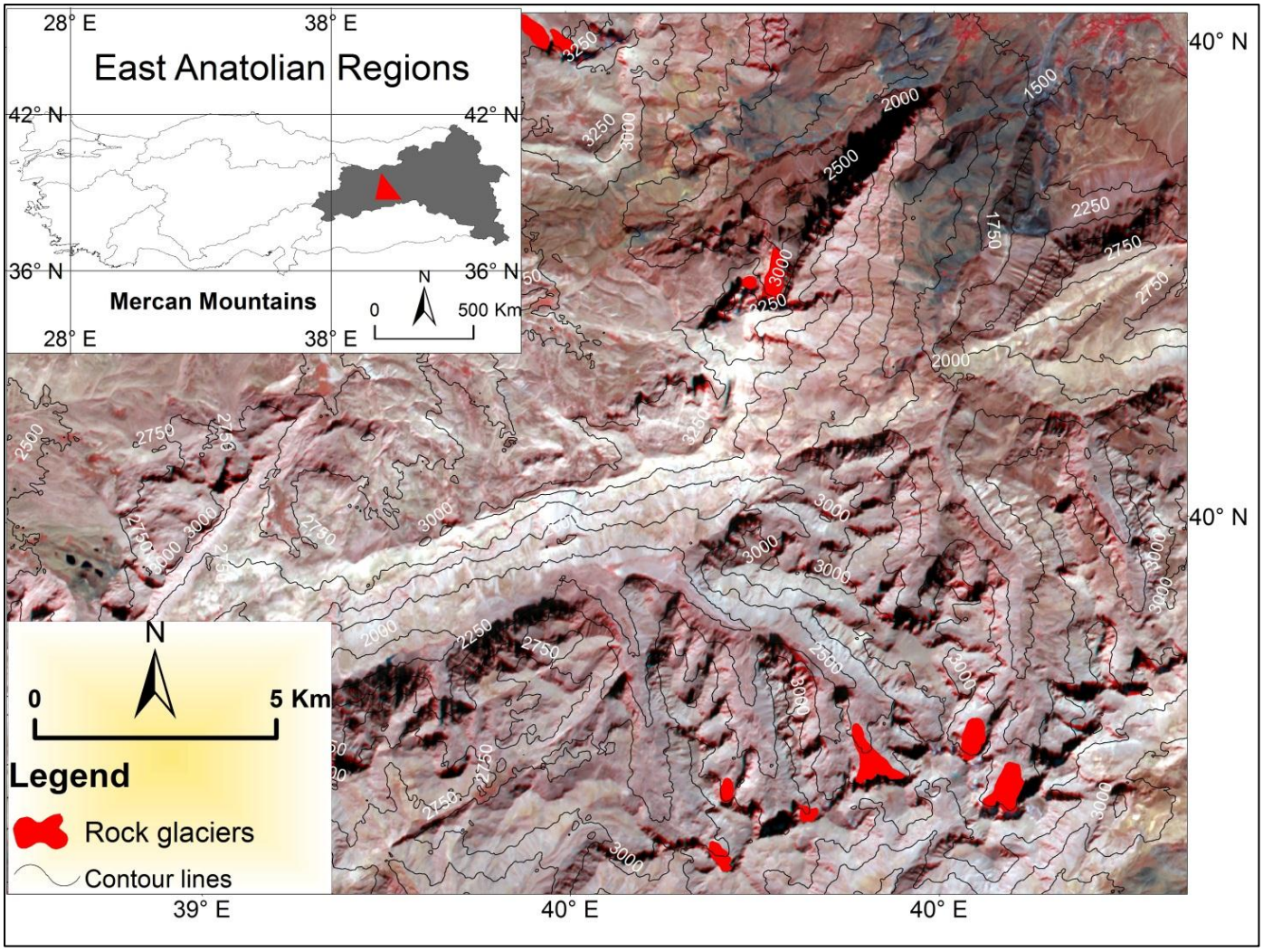

Figure 18. Rock glaciers of Mercan Mountains in the East Anatolian Region

Esence Mountains elevation is between 3130m and 3160m. The biggest of rock glacier is 0,15km². (Figure 19).

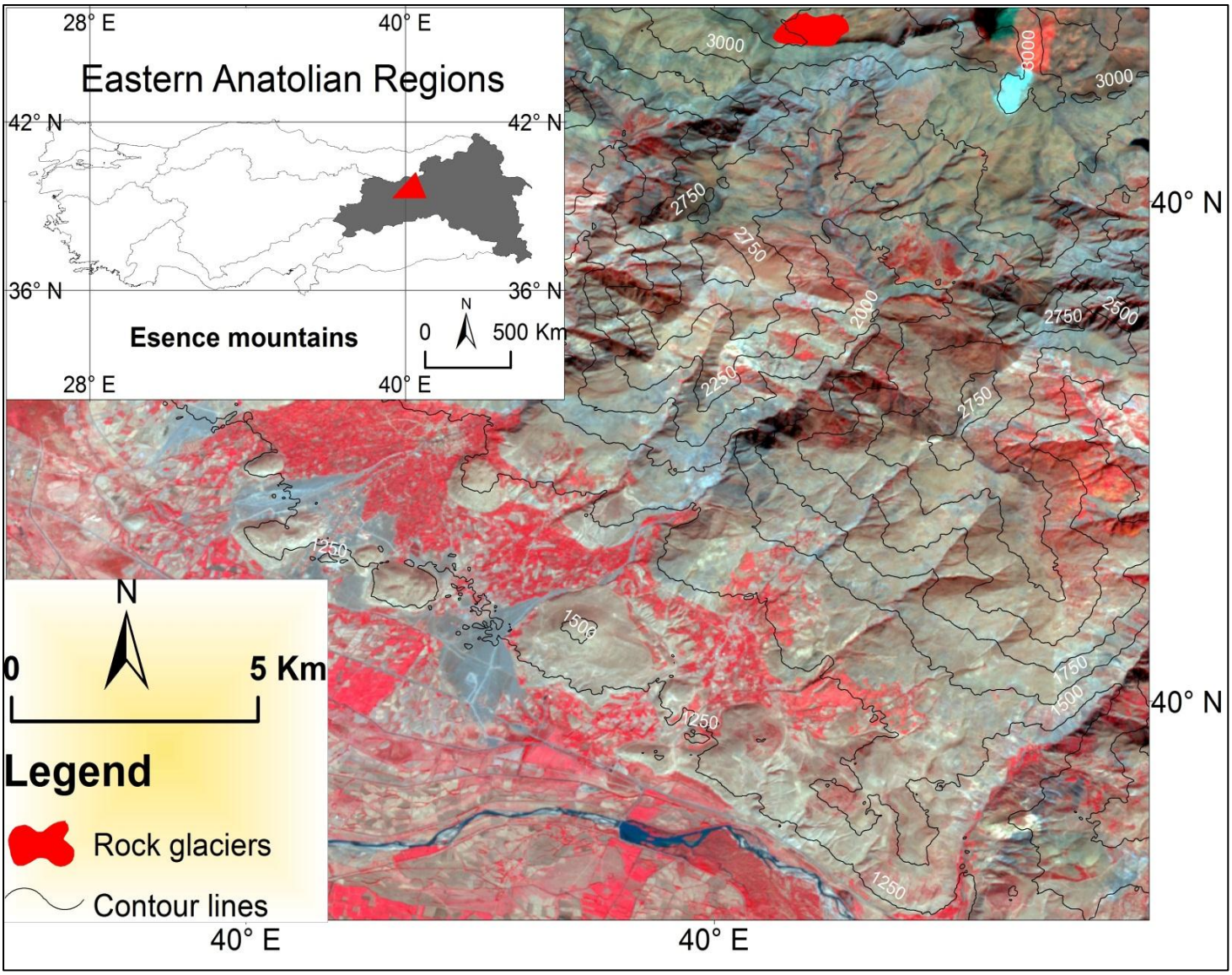

Figure 19. Rock glaciers of Esence Mountains in the Eastern Anatolian Region

According to Sarıkaya (2011), Rock glacier in Turkey table was extracted (Table 2). It is Erciyes rock glacier which is analyzed specifically.

Table 2: Rock Glaciers in Turkey modified from Sarıkaya (2011)

The name of Region	The name of Moutains	Site	Coordinates		Aspects	Area	Elevation	ASTER Acquisition date
Southeastern Anatolian Mountains			Lat.(N)	Long.(E)		km²	m	
	Kavuşşahap							
		Hasanbeşir	38,2228	42,8409	N	0,11	2910	13.10.2002
		Hasanbeşir	38,222	42,8520	NE	0,13	2919	13.10.2002
		Hasanbeşir	38,2118	42,8642	NE	0,11	2993	13.10.2002
		Hasanbeşir	38,2025	42,8772	NE	0,15	2975	13.10.2002
		Kavuşşahap	38,1983	42,9242	NE	0,1	3074	13.10.2002
		Kavuşşahap	38,1442	42,8976	NE	0,05	3025	13.10.2002
		Kavuşşahap	38,1437	42,9022	NE	0,02	3091	13.10.2002
		Kavuşşahap	38,1422	42,9093	NE	0,07	2970	13.10.2002
		Kavuşşahap	38,1150	42,9254	N	0,09	3067	13.10.2002
		Kavuşşahap	38,1128	42,9311	NE	0,04	3093	13.10.2002
		Kavuşşahap	38,0944	42,9340	N	0,03	3264	13.10.2002
		Kavuşşahap	38,0883	42,9465	NE	0,05	3230	13.10.2002
		Kavuşşahap	38,0600	42,9635	NE	0,07	3286	13.10.2002
Eastern Blacksea Anatolian Regions								
	Eastern Black sea Anatolian Mts.	Soğanlı Demirkapı	40,5235	40,4412	NE	0,09	2948	09.10.2007
		Soğanlı Kırklar	40,5593	40,5761	NE	0,2	2828	09.10.2007
		Soğanlı Kırklar	40,5509	40,5511	NE	0,05	3048	09.10.2007
		Soğanlı Kırklar	40,5671	40,6288	NW	0,07	2889	09.10.2007

		Soğanlı Kırklar	40,5693	40,6351	N	0,07	2820	09.10.2007
		Soğanlı At	40,6016	40,7508	NE	0,24	2991	09.10.2007
		Soğanlı At	40,6026	40,7606	NW	0,24	2979	09.10.2007
		Soğanlı At	40,6061	40,7669	NE	0,14	2890	03.07.2003
		Rize Verçenik	40,7197	40,9321	N	0,15	3159	03.07.2003
		Rize Tatos	40,7417	40,9782	NW	0,1	3259	03.07.2003
		Rize Tatos	40,7616	40,9935	NE	0,05	2909	03.07.2003
		Rize Göller (Hunut)	40,7930	41,0817	NW	0,08	3053	03.07.2003
		Rize Kaçkar	40,8293	41,1327	NW	0,25	2935	03.07.2003
		Rize Kaçkar	40,8351	41,1399	NW	0,29	3035	03.07.2003
		Rize Kaçkar	40,8391	41,1437	NW	0,07	3117	03.07.2003
		Rize Kaçkar	40,8493	41,1778	NE	0,64	2947	03.07.2003
		Rize Kaçkar	40,8443	41,1846	NE	0,13	3121	03.07.2003
		Rize Kaçkar	40,8709	41,1814	NW	0,07	3083	03.07.2003
		Rize Kaçkar	40,8715	41,1889	N	0,12	3041	03.07.2003
		Rize Altıparmak	40,9377	41,2333	E	0,2	2929	03.07.2003
		Rize Altıparmak	40,9393	41,2236	NW	0,14	2832	03.07.2003
	Karaçal Mountains	Karaçal	41,3529	41,9894	E	0,5	2740	08.07.2005
		Karaçal	41,3455	41,9925	E	0,42	2803	08.07.2005
		Karaçal	41,3376	41,9945	E	0,06	3030	08.07.2005
		Karaçal	41,3620	41,9857	NE	0,09	2805	08.07.2005
Indiviual Mountains								
	Erciyes	Üçker Valley	38,5288	35,4694	E	0,94	2960	23.07.2012
	Mercan	Avcı	39,4486	39,5993	N	0,35	2892	07.10.2003

		Avcı	39,4585	39,5904	NE	0,28	2876	07.10.2003
		Avcı	39,4548	39,5739	NW	0,55	2820	07.10.2003
		Avcı	39,4479	39,5536	NE	0,19	3013	07.10.2003
		Avcı	39,4488	39,5461	N	0,38	2751	07.10.2003
		Avcı	39,4519	39,5357	N	0,47	2889	07.10.2003
		Avcı	39,4405	39,5344	N	0,23	2943	07.10.2003
		Mercan Akbaba	39,5394	39,5574	NE	0,18	2690	07.10.2003
		Mercan Akbaba	39,5411	39,5467	N	0,24	2770	07.10.2003
		Mercan Akbaba	39,5411	39,5415	NE	0,04	3001	07.10.2003
		Mercan	39,5830	39,4950	NW	0,03	2891	07.10.2003
		Mercan	39,5823	39,5004	NW	0,04	2960	07.10.2003
	Esence	Kesiş	39,7897	39,7591	NW	0,15	3130	07.10.2003
		Kesiş	39,7944	39,7335	NE	0,08	3190	07.10.2003
		Kesiş	39,7777	39,7657	E	0,05	3157	07.10.2003

Three of the geomorfological valleys were monitored around the Erciyes Mountains (3917m), Üçker Valley, Öksüzdere Valley and Aksu Valley. It was determined that rock glaciers are located on the Üçker Valley. The rock glacier on the Üçker Valley is selected especially because it is one of the most avaible of all rock glaciers. It lies entirely in the directions of South-north. Area of rock glacier ranges from 2900 m to 3200 m. It has composite clasts. It was identified gravel and boulders (Figure 20). Also, average of temparature is 25°C. In summer, permafrost area is not accesible, so that permafrost boundary was not concluded.

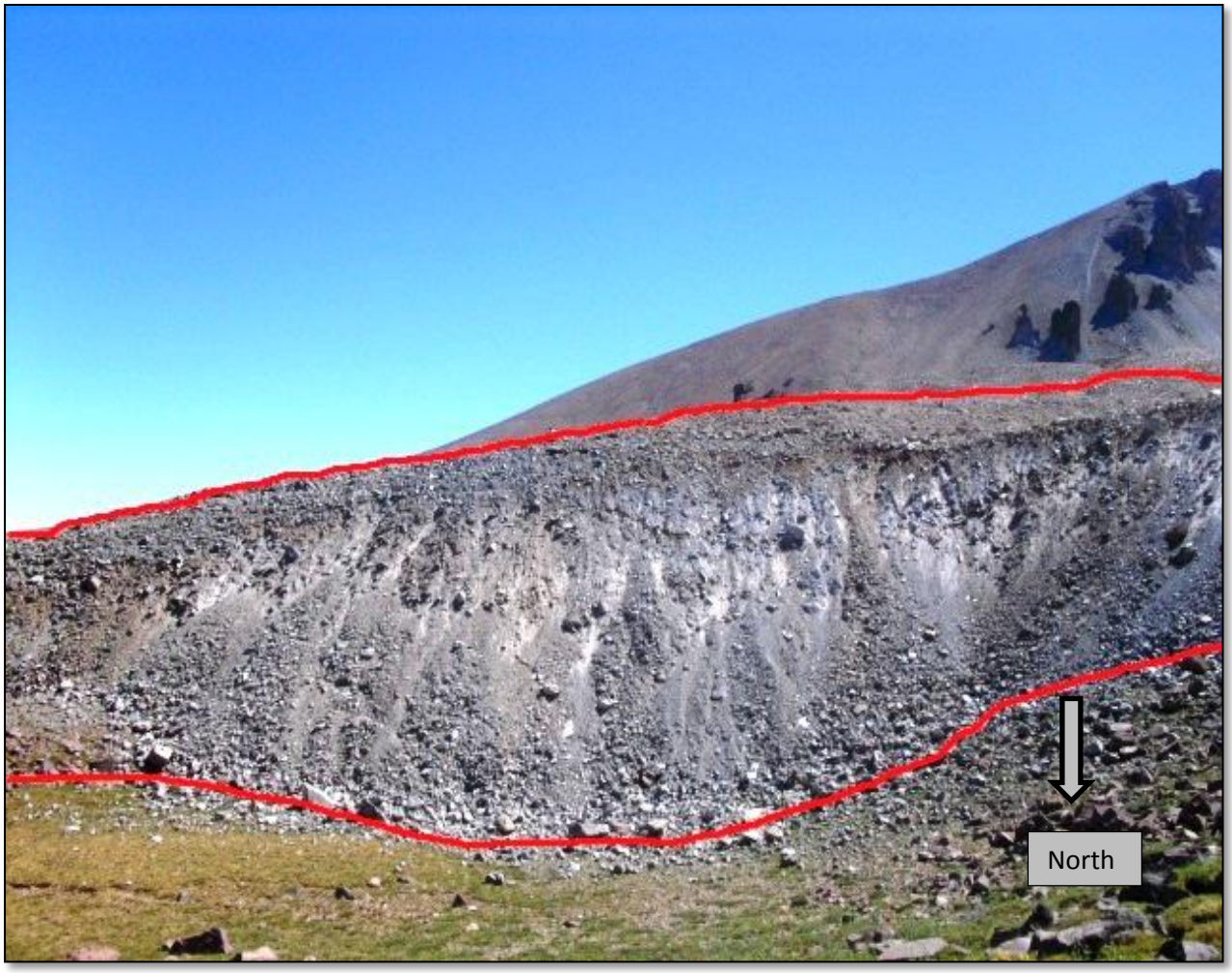

Figure 20. Boulders on Erciyes Rock glacier from looking west

Morphology of rock glacier was identified. Accordingly, Erciyes rock glacier was identified as an active rock glacier. It has no vegetation on the surface. Areas of rock glacier has slope and step front. According to Barsch (1998) classifications, rock glaciers were determined (Table 3). According to Sarıkaya (2011), characterization of the rock glacier was extracted. Another name of Erciyes Rock glacier was identified as Üçker Rock glacier. (Table 4). It is featured by front slope and composed of boulders.

Table 3. Morphological classification of Rock glacier (Modified from Barsch, 1998; Van Overloop et al., 2001)

Morphology of Rock glacier	Physical features
Active	Absence of vegetation
	Unstable surface
	Steep fronts
	Slope Angle
Inactive	Flat regions
	Contains ground ice

Table 4: Erciyes Rock Glacier

Rock glacier Name	Mountain	Latitude (N)	Longtitude (E)	Status	Aspects	Minimum elevations	Maximum elevations
Üçker Rock Glacier	Erciyes	38,5288	35,4694	Active	East	2900 m	3200 m

4.1. GIS Analyses Result

In this section, Erciyes rock glacier was approved for detailed examinations. Movement of rock glacier was studied for area changing within 11 years. Area of Erciyes rock glacier was calculated in GIS environment from acquired ASTER imagery. ASTER imagery was preferred because of high resolution. GIS and RS are the best progress for permafrost and periglacial formations. Two different times, 02.07.2001 and 23.07.2012, was used. Previously, distortions were fixed by SILCAST programmer. Composite bands are applied for image interpretations. After that, image enhancements are completed for detailed landform analysis. Lately, band combinations were used for image interpretations and calculations. False color was applied acquired from ASTER 2012 image. Normalized difference vegetation index (NDVI) was used on the 2012 images. During digitization of boundary of rock glacier, RGB band combinations were used.

4.1.1. Rock Glacier Change

On the 2001 images, the rock glacier has 0.88 km² area on the Üçker Valley, in other words, on the southern of Erciyes Mountains. (Figure 21)

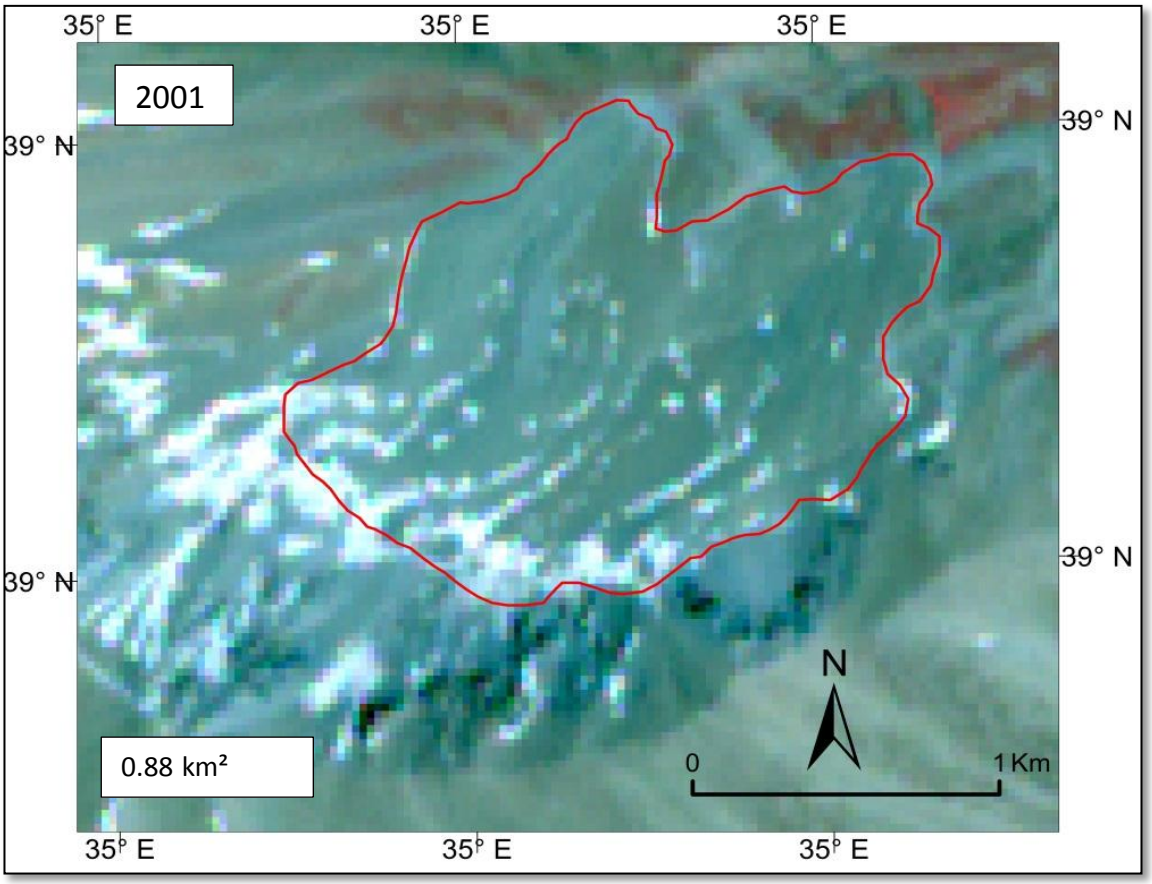

Figure 21. Digitized Outlines of Erciyes Rock glacier in 2001 from ASTER imagery with false color (RGB).

It corresponds to 4.24 km as perimeter. On the 2012 images rock glacier has 0.8 km², area. It has as perimeter about 4.12 km. (Figure 22)

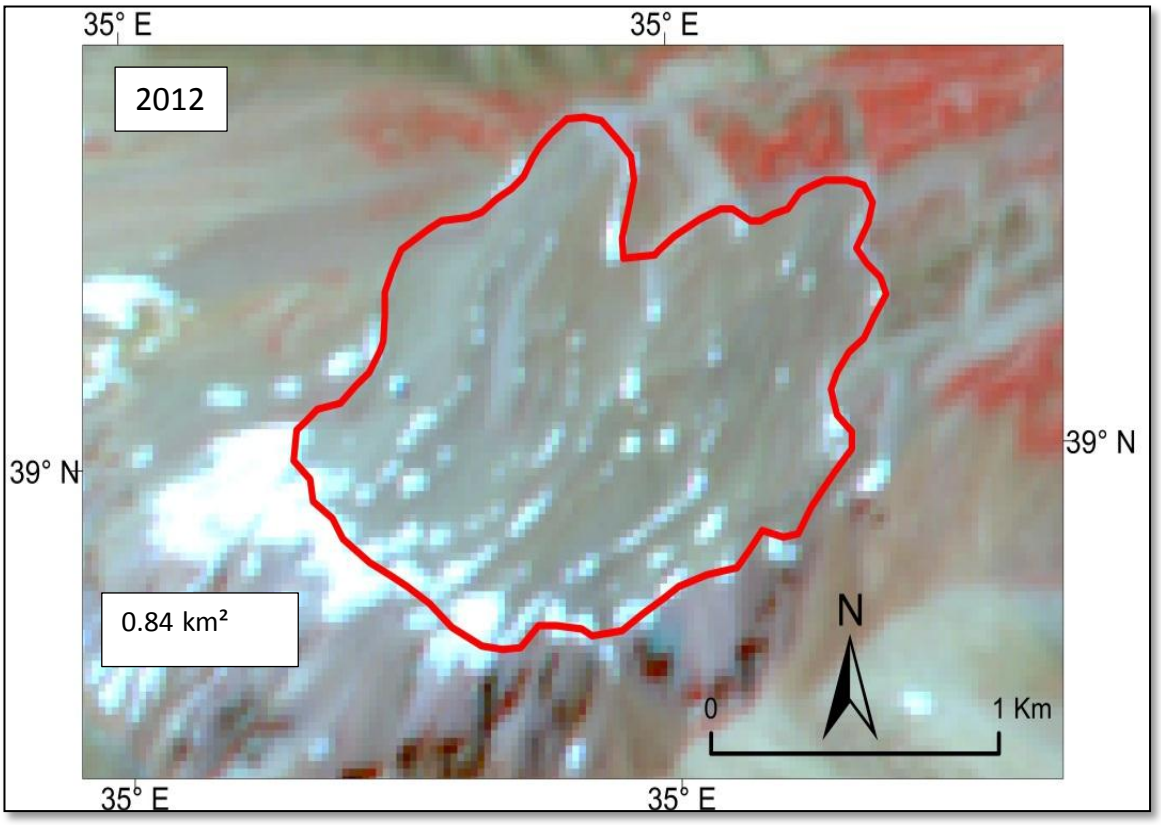

Figure22. Digitized outlines of Erciyes Rock glacier 2012 ASTER imagery with False Color image (RGB)

Two images were compared and comparison displays that rock glacier is retreated. Total changes of area were -0.04 in 11 years. A total change of area is -4.5%. Also, total area retreat rate is -0.0036 km²/year.

(Table 5). Rock glaciers changes between 2001 and 2011

Year	Area (km²)	Variation in Area (km²)	Variation rate %	Variation rate km²/year	Time (year)
2001	0.88				
2012	0.84	-0.04	-4.5%	-0.0036	11

4.1.2.Surface Geomorphology Analysis

Aspect and slope analysed in the Üçker rock glacier demostrates obvious differenced around of other geomorhological anlayses.

4.1.2.1.Slope Results

Distributions of elevations and slope value were compared, Üçker rock glacier was stated on the medium slope with 3100 m. Slope values show that rock glacier has not flat regions. Consequently, rock glacier is still active. (Figure 23.)

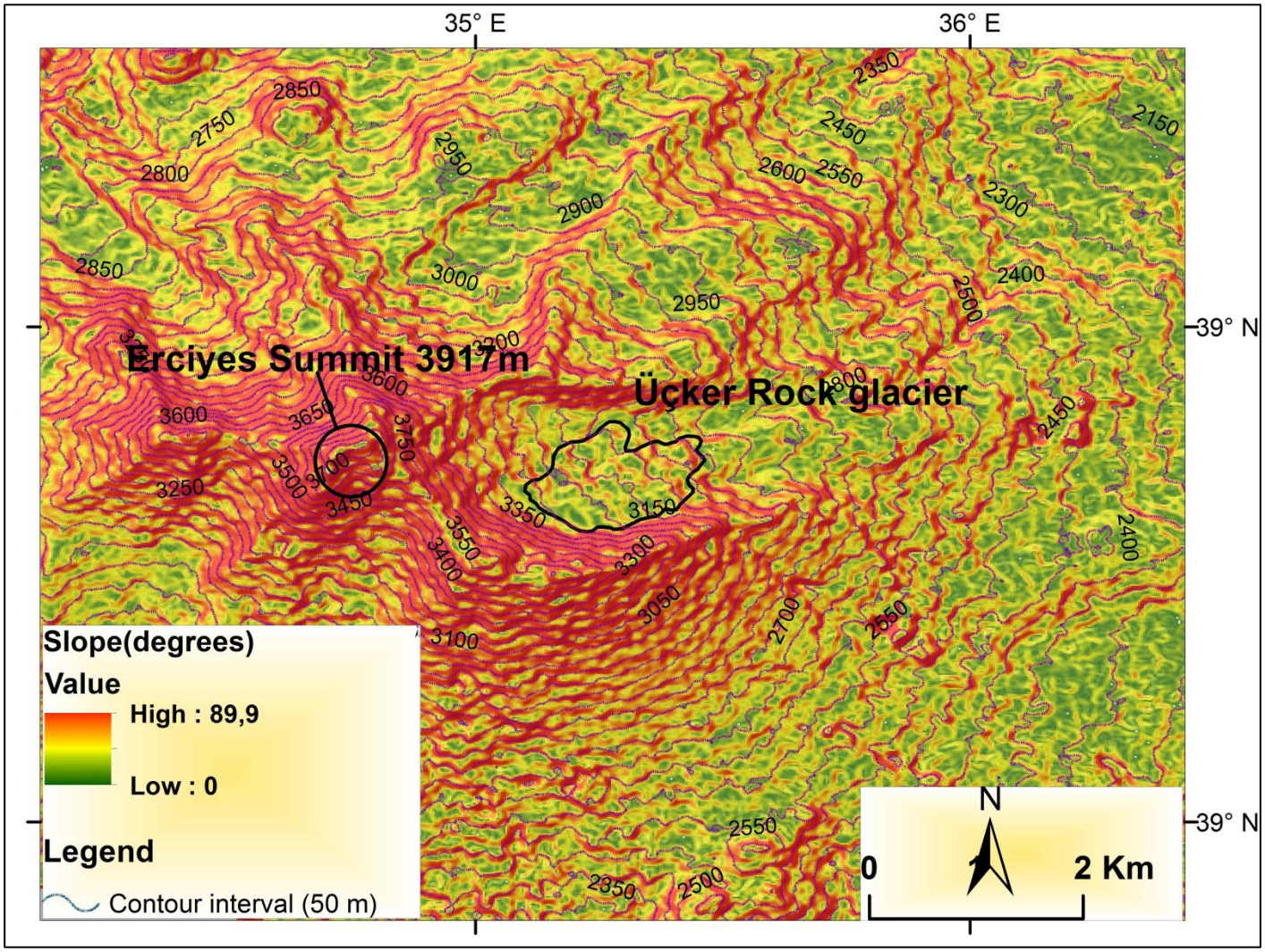

Figure 23. Slope map of Üçker Rock glacier with elevation value from ASTER imagery 2012.

4.1.2.3. Aspect Results

Small rock glaciers occurred on the high mountain side. And, they are formed on the dry side of mountain. As a result, Üçker rock glacier has been forming on the southern side of Erciyes Mountain and northerneast of Erciyes Mountain within permafrost environments. In my analysis, the direction of Üçker rock glacier did not change between 2001 and 2012. (Figure 24)

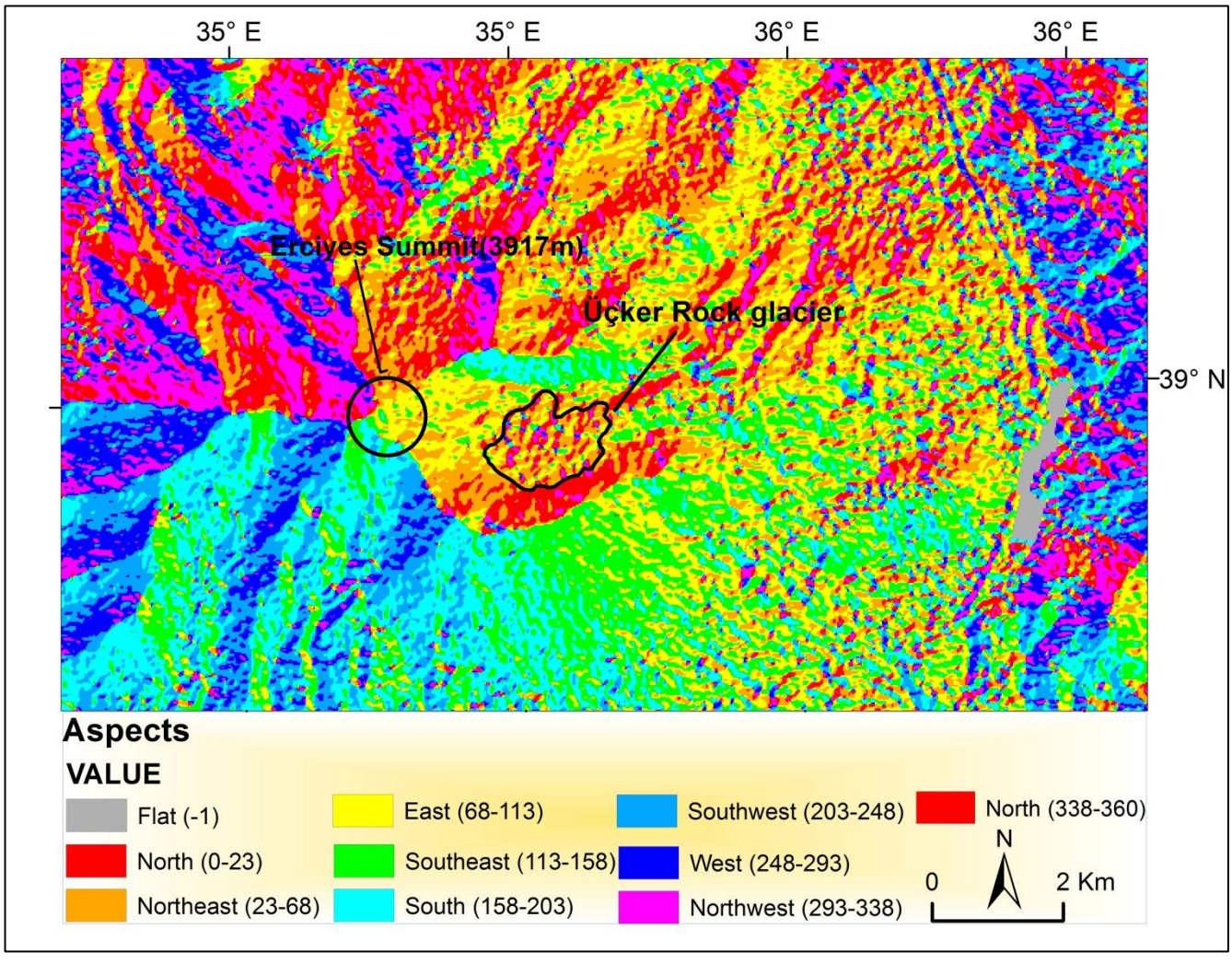

Figure 24. Aspect map of Erciyes Rock glacier from ASTER imagery 2012.

CHAPTER 5: CONCLUSION

The rock glaciers are subheading of glacial geomorphology that is a remarkable study in recent years. This study supports the distributions of rock glaciers in Turkey which have been monitored by GIS and RS. Specifically, morphology of Erciyes rock glacier is examined by field work and GIS. In Turkey, a total of 55 rock glaciers were mapped. They are distributed in the Black sea region, southeastern Anatolian region and individual mountains. Our statistical result of regional distributions of rock glaciers shows fascinating evidence. Results exhibit that each region has unique features. (1) Eastern Black Sea region is formed at higher elevations than the others. In these regions, rock glaciers are located over 3000 m. The highest of rock glaciers altitude is defined as 3500 m. They are situated on the Karaçal Mountain. (2) In Southeastern Anatolian region, rock glaciers are located between 3000 m and 3200 m. The highest altitude of rock glacier, 3300 m is identified on the Kavuşşahap Mountain. (3) In individual Mountains, the highest altitude of rock glacier has 3500 m on the Esence Mountain, while the highest elevation of Mercan Mountain has 3100 m. Rock glaciers develop on the directions of north and northeastern. Within this context, we theorized formations of rock glaciers and regional distributions of rock glaciers in Turkey. This distribution is monitored by lithology. This topography is statically exhibited by elevations. We concluded that aspects of rock glaciers influence the size of rock glaciers. We inferred that rock glaciers are not formed on every mountain. Various reasons are believed to affect. These are climate, glacierization and suitable topography. Rock glaciers get together on the continental areas. In other words, they are formed in high elevations range systems. Observation of ASTER images, when level of glacierization is highest, rock glaciers slightly are not found. For aspects, we observed rock glaciers are not convenient for the directions of South and Southeast. In this study, GIS and RS methods are effective and convenient. Also, higher resolutions have developed the results.

For the analysis of rock glacier features, various direct techniques are used. GIS and RS techniques gave reliable information. Conversely, rock glaciers are confused with other geomorphological features like rock fall deposits. So, field work was applied on the Erciyes rock glacier. In this field work, activity of rock glaciers is observed.

We concluded, Erciyes rock glacier is fed by rock wall. For future studies, geophysical technique is more suitable for the inner structure of rock glacier as digging, Bottom Temperature measurements and Bore Hole deformations. These applications were not used because it was not an adequate time. We analyzed creep movement of Erciyes rock glacier. We concluded Erciyes rock glacier elevation is between 2900 m and 3200 m. Features of Erciyes rock glacier show that it is still active. Increase in slope is effective on the activity of Erciyes rock glacier. This indicates that elevation and slope regions are close to each other. Directions of rock glacier are southern and northeastern side of Erciyes Mountain. Therefore, formation of rock glacier is not suitable. In this study, time acquisition and resolution are considered. Erciyes rock glacier lack climate stations. Information of present climate is not obtained. Erciyes rock glacier covered an area of about 0.88 km² in 2001. It had an area of about 0.84 km² in 2012. It is observed that rock glacier is retreated about 0.04 km² (~4 hectare) in eleven years.

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