

**REPUBLIC OF TURKEY
MUĞLA SITKI KOÇMAN UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED
SCIENCES**

**DEPARTMENT OF GEOLOGICAL
ENGINEERING**

**PROVENANCE ANALYSIS AND PETROGENETIC FEATURES
OF GRANITIC PEBBLES OBSERVED AS DROPSTONES IN
THE LATE ORDOVICIAN GLACIAL SUCCESSIONS WITHIN
THE TAURIDE-ANATOLIDE PLATFORM, TURKEY**

MASTER OF SCIENCE THESIS

EMMANUEL DAANOBA SUNKARI

JULY 2017

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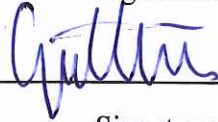
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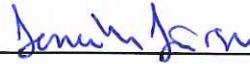
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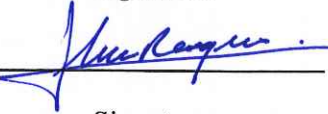


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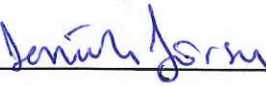
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30/06/2017

(Signature)

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ÖZET

TOROS - ANATOLİT PLATFORMUNDA GEÇ ORDOVİSİYEN BUZUL İSTİFLERİNDE ÇÖKMETAŞI OLARAK İZLENEN GRANİTİK ÇAKILLARIN KAYNAK KAYALARI VE PETROJENETİK ÖZELLİKLERİ

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Toros-Anatolit Platformunda (TAP), Geç Ordovisiyen (Hirnantiyen) buzul istiflerinde çökmetaşı olarak gözlenen granitik bileşimli çakıllar, kumtaşı/çamurtaşı ardalanmalı diyamiktitlerin matriksinde izlenir. Önceki jeokronolojik çalışmalara bağlı olarak granitik bileşimli çakılların kristallenme yaşları; 576.5 ± 3.3 Ma (monzogranit-DPK44), 576.7 ± 5.7 Ma (protomilonit-DPK27), 598.4 ± 7.5 Ma (altere granit-DPK72), 717.5 ± 8.0 Ma (meta-granit-DPK30), 789.5 ± 3.7 Ma (meta-granit DPK17A) ve 964.6 ± 4.6 Ma (meta-granit-DPK46) olarak belirlenmiştir (Gürsu, 2015). Bu tez çalışmasıyla; öncel çalışmalarda U-Pb yöntemiyle jeokronolojik yaşları belirlenen Silifke-Ovacık (Orta Toroslarda), Kozan Baraj-Göze, Feke-Saimbeyli-Gökmenler, Feke-Saimbeyli-Ceralan ve Tufanbeyli-Kayapınarı-Adana'da (Doğu Toroslarda) yüzeylenen granitik çakılların, petrojenetik ve izotopik özelliklerinin belirlenmesi ve jeokimyasal/izotopik olarak Gondvana'nın kuzey sınırındaki kaynak kayaları ile ilişkisinin ortaya çıkarılması amaçlanmıştır.

Jeokimyasal olarak, granitik çakıltaşları alkali/kalkalkali özellik gösterir. Granitik çakılların ana ve eser element bileşimlerindeki değişim, kaynakasal açıdan heterojenlik, ve kabuksal asimilasyon süreçleri ile bağlantılı olabileceği göstermektedir. Granitik çakıllar petrojenetik özellikleriyle Grup A (DPK17A, DPK30, DPK46) ve Grup B (DPK27, DPK44, DPK72) olarak iki gruba ayrılmıştır. N-MORB'a göre normalize edilmiş çoklu element değişimleri, Grup A'daki (DPK30, DPK46) ve Grup B'nin DPK27'deki iki numunenin, yüksek alan değerlikli elementlerine (YADE) kıyasla büyük iyon yarıçaplı litofil elementlerde (BIYLE) zenginleşme sergilediğini göstermektedir. DPK30 ve DPK46 örneklerinde Ağır Nadir Toprak Elementlere (ANTE) nazaran Hafif Nadir Toprak Elementlerce (HNTE) kısmen zenginleşmeye izlenir. Ancak, DPK27 örneği Orta Nadir Toprak Elementler (ONTE) ve ANTE'e nazaran BIYLE'ce belirgin bir fakirleşme gösterir. DPK17A, DPK44 ve DPK72 örnekleri, BIYLE'e nazaran YADE'ce zenginleşme ve Rb, Sr, Nb, Ti ve Eu elementlerce ise negatif yönelimler gösterirler. Nadir Toprak Elementlerce (NTE) ise ONTE ve ANTE'e nazaran HNTE'ce zenginleşmişlerdir.

DPK46 dışındaki Grup A örneklerinin pozitif $\epsilon\text{Nd}_{(T)}$ değerleri yay ile ilişkili kaynağı, Grup B örneklerinin negatif $\epsilon\text{Nd}_{(T)}$ verileri ise A-tipi kaynağa işaret etmektedir. Bununla birlikte, DPK46 örneği jeokimyasal olarak mafik bir kaynak gösterirken, $\epsilon\text{Nd}_{(T)}$ verileri belirgin kıtasal kabuk kaynağını göstermektedir.

Örneklerin, kristallenme yaşları (576.5 ila 965 Ma), T_{DM} yaşlarına göre daha gençtir ve eski kabuksal malzemelerin mafik magmalarla oluşumu sırasında karışması ile oluştuğu gösterir. Granitik çakılların petrojenetik özellikleri, A Grubu numunelerinin ada yay kaynaklı olabileceğini, B Grubu örneklerin ise A-tipi kaynaklardan türetildiğini göstermektedir. Granitik çakılların petrografik, petrojenetik, izotopik ve jeokronolojik verilerine göre, Sina Yarımadası (Sa'al Metamorfik Kompleksi ve Feiran-Solaf Metamorfik Kompleksi) ile Mısır'ın Doğu Çölünden Geç Ordovisiyen dönemde buzullaşma süreçleri ile Toros-Anatolit Platformu'na taşınmış olduğu gösterir.

Anahtar Kelimeler: Geç Ordovisiyen, Buzul Istifler, Granitik Çakıldaşları, Toros-Anatolit Platformu, Sinai Yarımadası, Doğu Mısır Çölü

ABSTRACT

PROVENANCE ANALYSIS AND PETROGENETIC FEATURES OF GRANITIC PEBBLES OBSERVED AS DROPSTONES IN THE LATE ORDOVICIAN GLACIAL SUCCESSIONS WITHIN THE TAURIDE- ANATOLIDE PLATFORM, TURKEY

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The granitic pebbles observed in the Late Ordovician (Hirnantian) glacial deposits in the Tauride-Anatolide Platform (TAP) are bounded by a matrix of sandstone/mudstone alternations of diamictites. Previous geochronological studies (Gürsu, 2015) revealed that the individual granitic pebbles were dated as 576.5 ± 3.3 Ma (monzogranite-DPK44), 576.7 ± 5.7 Ma (protomylonite-DPK27), 598.4 ± 7.5 Ma (altered granite-DPK72), 717.5 ± 8.0 Ma (meta-granite-DPK30), 789.5 ± 3.7 Ma (meta-granite- DPK17A) and 964.6 ± 4.6 Ma (meta-granite-DPK46). This thesis study, examines the petrology and mineralogy of the granitic pebbles from Silifke-Ovacik area (Central Taurides) and Kozan Dam-Gözle, Feke-Saimbeyli-Gökmenler, Feke-Saimbeyli-Ceralan, Tufanbeyli-Kayapınarı-Adana areas (Eastern Taurides) that were previously geochronologically dated by U-Pb method to reveal their geochemical/isotopic relationship with source rocks in the northern margin of Gondwana.

Geochemically, all the granitic pebbles belong to the sub-alkaline series and display alkaline/calc-alkaline affinities. The variation in the major and trace element compositions of the individual granitic pebbles may be associated with source compositional heterogeneity and/or crustal assimilation processes. The petrogenetic features of the granitic pebbles show two groups of relations; Group A (DPK17A, DPK30, DPK46) and Group B (DPK27, DPK44, DPK72). The N-MORB-normalized multi-element patterns show that two samples in Group A (DPK30, DPK46) and DPK27 of Group B display enrichment in large ion lithophile elements (LILE) compared to high field strength elements (HFSE). Slight LREE enrichment against HREE are observed in DPK30 and DPK46. However, DPK27 distinctly displays clear depletion in LREE against MREE and HREE. One Group A sample (DPK17A) and two other Group B samples (DPK44 and DPK72) display slightly enriched patterns for HFSE than LILE and pronounced negative anomalies in Rb, Sr, Nb, Ti and Eu elements. The REE patterns of these samples show considerable enrichment in LREE against MREE and HREE.

Positive $\epsilon\text{Nd}_{(T)}$ values of Group A samples except DPK46 indicate island arc-related source, whereas negative $\epsilon\text{Nd}_{(T)}$ values of Group B samples indicate A-type source. However, whilst the sample DPK46 shows a geochemically mafic source, its $\epsilon\text{Nd}_{(T)}$ shows a distinct continental crustal source.

The crystallization ages of the dated individual granitic pebbles (ranging from 576.5 to 965 Ma) are younger than T_{DM} ages and are consistent with mixing of older crustal materials to the mafic magmas during their genesis. The petrogenetic features of the individual granitic pebbles suggest that Group A samples might have been derived from island arc sources, whereas Group B samples were probably derived from A-type sources. Therefore considering their petrographic, petrogenetic, isotopic and geochronological features, the individual granitic pebbles might have been transported to Tauride-Anatolide Platform (TAP) from the Sinai Peninsula (Sa'al Metamorphic Complex and Feiran-Solaf Metamorphic Complex) and Eastern Desert of Egypt during the Hirnantian glacial event.

Keywords: Late Ordovician, Glacial Successions, Granitic Dropstones, Tauride-Anatolide Platform, Sinai Peninsula, Eastern Desert

I dedicate this noble piece of academic research to my Dear Mother, Janet Sunkari
who has been my source of inspiration in life.

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SYMBOLS AND ABBREVIATIONS

^{143}Nd	Neodymium isotope (143)
^{144}Nd	Neodymium isotope (144)
^{86}Sr	Strontium isotope (86)
^{87}Sr	Strontium isotope (87)
^{88}Sr	Strontium isotope (88)
ANS	Arabian Nubian Shield
A-type	Alkaline type
CT	Central Taurides
DPK	Sample Identity
ET	Eastern Taurides
E-MORB	Enriched Mid-Ocean Ridge Basalts
Fm.	Formation
FSMC	Feiran-Solaf Metamorphic Complex
Ga	Billion years
GPS	Global Positioning System
HBr	Hydrogen Bromide
HCL	Hydrochloric acid
HF	Hydrogen Fluoride
HFSE	High Field Strength Elements
HREE	Heavy Rare Earth Elements
ITU	Istanbul Technical University
KRC	Katerina Ring Complex
LA-ICP-MS	Laser Ablation Inductively Coupled Plasma Mass Spectrometry
LC	Lower Crust
LILE	Large Ion Lithophile Elements

LREE	Light Rare Earth Elements
Ma	Million years
METU	Middle East Technical University
MERLAB	Central Laboratory
NIST SRM	National Institute of Standards Technology Standard Reference Material
N-MORB	Normal Mid-Ocean Ridge Basalts
OIB	Ocean Island Basalts
ORG	Ocean Ridge Granites
ppm	Parts per million
Rb-Sr	Rubidium-Strontium isotopes
REE	Rare Earth Elements
Sm-Nd	Samarium-Neodymium isotopes
SMC	Sa'al Metamorphic Complex
SYN-COLG	Syn-Collision Granites
TAP	Tauride-Anatolide Platform
T _{DM}	Depleted Mantle Model Age
TÜBİTAK	The Scientific and Technological Research Council of Turkey
UC	Upper Crust
U-Pb	Uranium-Lead
USGS	United States Geological Survey
UTM	Universal Traverse Mercator
VAG	Volcanic Arc Granites
WPG	Within Plate Granites

1. INTRODUCTION

The Late Ordovician glaciation (Hirnantian), which is largely observed in northern Gondwana, is one of the extensive glacial events known in the world despite the fact that it was abrupt, < 1 Ma (details in Brenchley et al., 1994; Ghienne, 2001, 2003). During the glaciation, the approaching ice sheets expanded and progressively covered the main parts of Gondwana sedimentary basins initiating an extension of the Late Ordovician glacial record (details in Deynoux, 1985; Ghienne, 2003; Ghienne et al., 2007). The relicts of the ice-rafted units are largely preserved and exposed in many parts of the world including central northern Africa, central Sahara region, northwest and west Africa, Arabia, south America and Europe (details in Ghienne, 2001, 2003). The author suggested that the correlative proximal glacio-marine deposits were mainly reported from the northern margin of Gondwana in Mauritania, Morocco, Algeria, Tunisia, Niger, Libya, Jordan, Iran, Arabia, Turkey, and the peripheral extensions in some parts of the European continent such as Iberia, America and Cadomia following the end of the Hirnantian glaciation.

In Turkey, the Late Ordovician glacial successions in the Tauride-Anatolide Platform (TAP) were previously documented by Göncüoğlu and Kozlu (2000), Monod et al. (2003), Paris et al. (2007) and Ghienne et al. (2010) as representing the distal parts of the Hirnantian glacial deposits in the northern margin of the Arabian Platform. The comprehensive studies by these researchers focused on the Late Ordovician glacial deposits that crop out in the Central Taurides (CT), Eastern Taurides (ET) and the South Anatolian Autochthon Belt (SAAB) in southeastern Turkey.

In previous studies, the Hirnantian glacial deposits in the (TAP) were described as members of the Halıyaylasi Formation, which included both Late Ordovician glacial-related deposits and non-glacio-marine deposits by Ozgul et al. (1973) and Dean and Monod (1990). However, Monod et al. (2003) and Ghienne et al. (2001, 2010), introduced the Halevikdere Formation in order to differentiate between the glacial deposits and the non-glacial Ordovician and Silurian units. The Halevikdere Formation representing Late Ordovician glacial succession in TAP has been defined by Monod et al. (2003) and then accepted by the other researches such as Paris et al. (2007), Ghienne et al. (2010), Gürsu (2015) and Gürsu et al. (2017).

According to Monod et al. (2003) and Ghienne et al. (2010), the Late Ordovician ice-related deposits in the Taurides of the TAP are subdivided into three parts; lower, middle and upper units. In the CT, the Late Ordovician units cropping out in the Ovacık-Silifke, Anamur-Akyaka and Kemer areas rest unconformably on the Early Ordovician Seydisehir Formation (details in Monod et al., 2003; Ghienne et al. 2010). The lower unit is composed of shallow-marine coarse-grained sandstones, and continues with well-sorted, cross-bedded sandstones including ripple sandstones especially in the Ovacık-Silifke area (Demirtaşlı 1984; Monod et al., 2003). The middle unit in the CT consists of abundant allochthonous fine to moderate-grained dropstone-related granitic and quartzitic pebbles followed by sandstone-siltstone-shale intercalations of the upper unit and transition into black Silurian shales (details in Demirtaşlı, 1984; Monod et al., 2003 and Ghienne et al., 2010).

In the ET, the Late Ordovician successions have been a subject of interest by numerous researchers (e.g., Ozgul et al., 1973; Goncuoglu and Kozlu, 2002; Monod et al., 2003; Ghienne, 2010; Gürsu, 2015; Gürsu et al., 2017). The studies suggest that the lower unit in here overlies the Early Ordovician Seydisehir Formation which is composed of alternating dark shales, siltstones interlayered with quartz-arenites (e.g., Goncuoglu and Kozlu, 2002).

However, Monod et al. (2003) did not agree with this and suggested that the lower unit is represented by a disorderly succession of massive, poorly sorted sandstones having a marginal erosional contact with muddy sandstones that might have been deposited by glaciers. These lower units progressively grade into shales of the shallow marine siliciclastic rocks of the Late Ordovician (Katian?) Sort Tepe Formation by Goncuoglu and Kozlu (2000) and Monod et al. (2003). The basement of the latter is characterized by coarse-grained conglomeratic sandstones, scattered granitic pebbles and sandy diamictites and followed by coarse-grained laminated sandstones, dropstones and distal glaciomarine sediments (details in Monod et al., 2003; Ghienne et al., 2010). The upper units have a gradual upward-fining succession and are represented by fine to medium-grained sandstones, sandy diamictites with quartz gravels and grades upward into black siliceous shales of the Puscutepe Formation (details in Monod et al., 2003).

Moreover, the Late Ordovician glacio-marine successions in the SAAB have been previously documented in detail by Monod et al. (2003) and Ghienne et al. (2010). Apart from the documented evidence of the presence of ice-related Hirnantian sediments in both the CT and the ET including the SAAB, the depositional ages of the lonestones (ice-rafted fragments of sedimentary pebbles) and crystallization ages of the granitic pebbles with provenance of the diamictites have been reported on the detrital zircons and magmatic zircons by using LA-ICP-MS geochronological studies (details in Gürsu, 2015 and Gürsu et al., 2017). Based on these studies, the dropstone-related granitic pebbles were geochronologically dated as 576.5 ± 3.3 Ma, 576.7 ± 5.7 Ma, 598.4 ± 7.5 Ma, 717.5 ± 8.0 Ma, 789.5 ± 3.7 Ma and 964.6 ± 4.6 Ma. The use of the term dropstone in this thesis denotes coarse-grained granitic pebbles found within the matrices of sandy/muddy diamictites that were carried by the glacial sheets to the TAP. Recently, Gürsu (2015) and Gürsu et al. (2017) discussed the provenance of the Late Ordovician successions in TAP and SAAB by using zircon U-Pb geochronology and geochemical features of the dated granitic pebbles and suggested Arabain Shield provenance for the diamictites and lonestones and Sinai Peninsula (Nubian Shield) for the provenance of the granitic pebbles observed in the CT and ET (details in Gürsu, 2015; Gürsu et al., 2017).

1.1. Aim and Scope

The study area is divided into two parts namely; Central Taurides-CT (Silifke-Ovacik) and Eastern Taurides-ET (Kozan dam-Gözü, Feke-Saimbeyli-Gökmenler, Feke-Saimbeyli-Ceralan, and Tufanbeyli-Kayapınarı-Adana areas). Field studies including finding and collection of the unique granitic pebbles from the Late Ordovician successions in these areas of the TAP were conducted by Dr. Semih GÜRSU during his post-doctoral study. The study aims to investigate the petrogenetic features of the individual granitic pebbles by using new isotopic data (Rb/Sr and Sm/Nd) and their previously published geochemical data. The scope of this thesis is;

1. Clarification of the provenance of the dated granitic pebbles by re-evaluating their geochemical data with combinations of their isotopic features (Rb/Sr, Sm/Nd) that are observed as granitic dropstones within the matrices of the glacial diamictites in the Central and Eastern Taurides.
2. Correlation of their geochemical and isotopic signatures with available data of the equivalent rocks previously dated by the various researchers that crop out in the Nubian Shield (especially Sinai Peninsula).

2. GEOLOGICAL SETTING

2.1. Regional Geology

Turkey is tectonically divided into different post-Alpine tectonic terranes separated by each other from distinct suture zones (details in Göncüoğlu, 2010) (Figure 2.1). According to the researcher, these terranes include from north to south; Rhodope-Istranca Composite terrane, Istanbul-Zonguldak Composite terrane, Intra-Pontide Ophiolite Belt, Sakarya Composite terrane, North Anatolian Ophiolite Belt, Tauride-Anatolide Platform, Southeast Anatolian Suture Belt, the Arabian Plate and the SE Anatolian Autochthon. The study areas belong to the Tauride-Anatolide platform (TAP).

In the Taurides, the Lower Paleozoic succession starts with early Cambrian siliciclastic sequences and continue with clastic-carbonate units (e.g., Dean and Monod, 1970; Ozgul, 1984). These units are conformably overlain by Early Ordovician siliciclastic deposits of the Seydisehir Formation (Monod et al., 2003; Ghienne et al., 2010). Studies have proven that most of the Ordovician units in the Taurides especially at the central part (Silifke-Ovacik area) begin with the Early Ordovician Seydisehir Formation and in the ET, they begin with the Late Ordovician (Katian) Sort Tepe Formation (Goncuoglu and Kozlu, 2000; Monod et al., 2003; Ghienne et al., 2010). The studies also indicated that the Seydisehir Formation and Sort Tepe Formation are unconformably overlain by the Late Ordovician (Hirnantian) Halevikdere Formation in both the CT and ET.

Detailed columnar sections of the Late Ordovician successions in TAP are given in section 2.2 Local Geology.

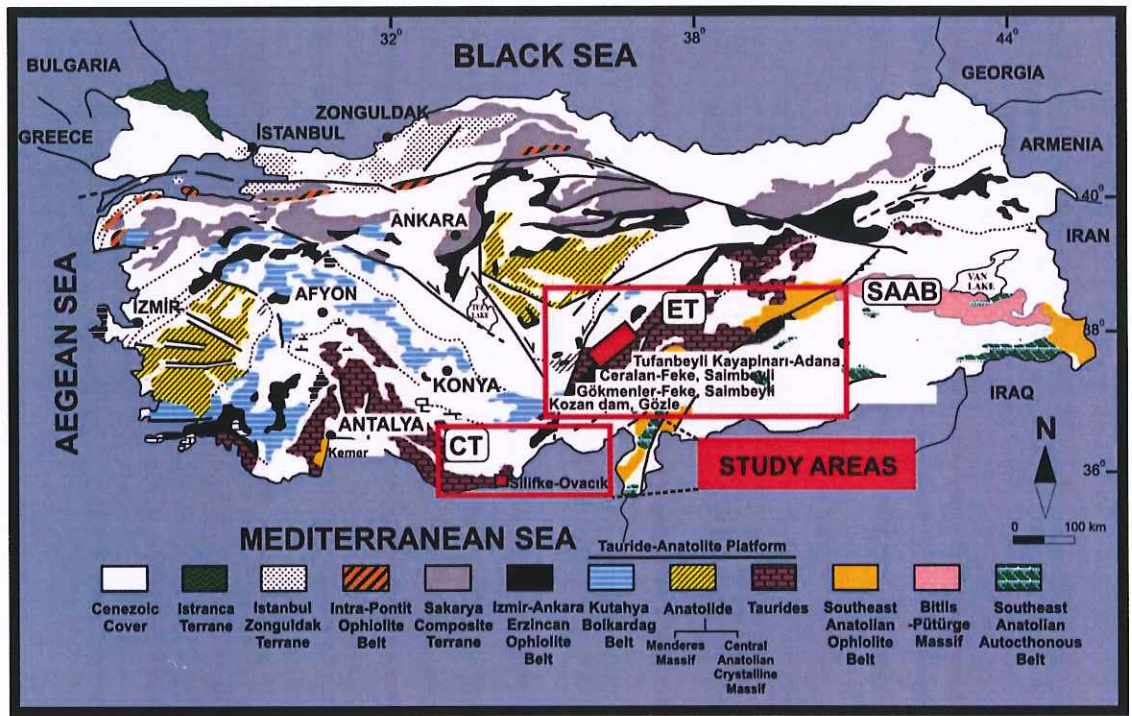


Figure 2.1. Terrane map of Turkey showing the glacial successions in the CT, ET and the SAAB (terrane map taken from Göncüoğlu, 2010; the studied sections are taken from Gürsu, 2015; Gürsu et al., 2017)

2.2. Local Geology

The dropstone-related granitic pebbles were mainly found in the CT (Silifke-Ovacik) and the ET (Kozan dam-Gozle, Feke-Saimbeyli-Gokmenler, Feke-Saimbeyli-Ceralan and Tufanbeyli-Kayapinari-Adana) areas as previously declared by Gürsu (2015) and Gürsu et al. (2017). Columnar sections used in describing the lithological features and sample locations are taken from Gürsu (2015) and Gürsu et al. (2017).

2.2.1. Central Taurides (CT)

2.2.1.1. Silifke-Ovacik

The ice-related deposits in this area were previously reported by Monod et al. (2003). The researcher mentioned that the Late Ordovician glaciomarine deposits are located 30 km to the southwestern part of Silifke-Ovacik area near Hırmanlı village. In this locality, only one granitic pebble DPK72 (37S 0556944/4007127-UTM) was collected by Gürsu (2015) for zircon U-Pb geochronological studies. Columnar section of the area is given in Figure 2.2.

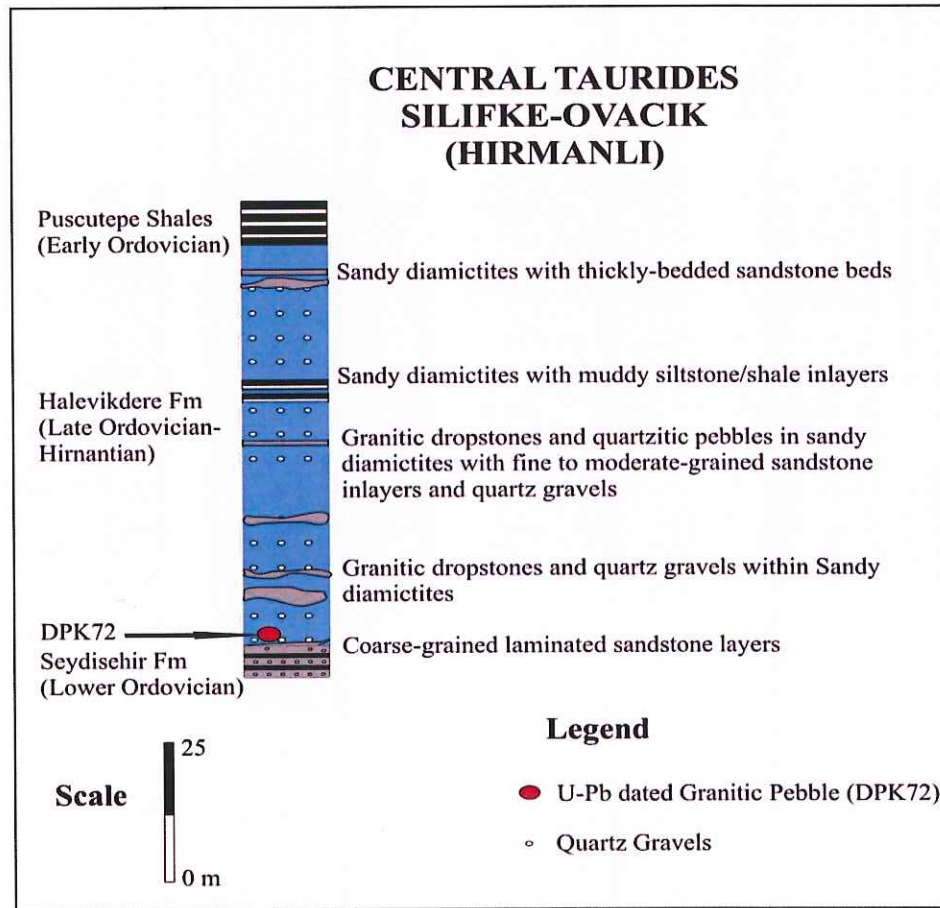


Figure 2.2. Columnar section of the Silifke-Ovacik (Hırmanlı) area in the CT (taken from TUBITAK Report by Gürsu, 2015; Gürsu et al., 2017)

2.2.2. Eastern Taurides (ET)

2.2.2.1. Kozan dam-Gözle (Adana)

The glacial deposits in the Kozan area were reported by Özgül et al. (1973) around the Kozan dam and along the Kozan-Feke road. Gürsu (2015) found one granitic pebble DPK46 (36S 0754441/4179647-UTM) in the lower boundary of the unit for LA-ICP-MS-U-Pb dating and petrogenetic studies (Figure 2.3).

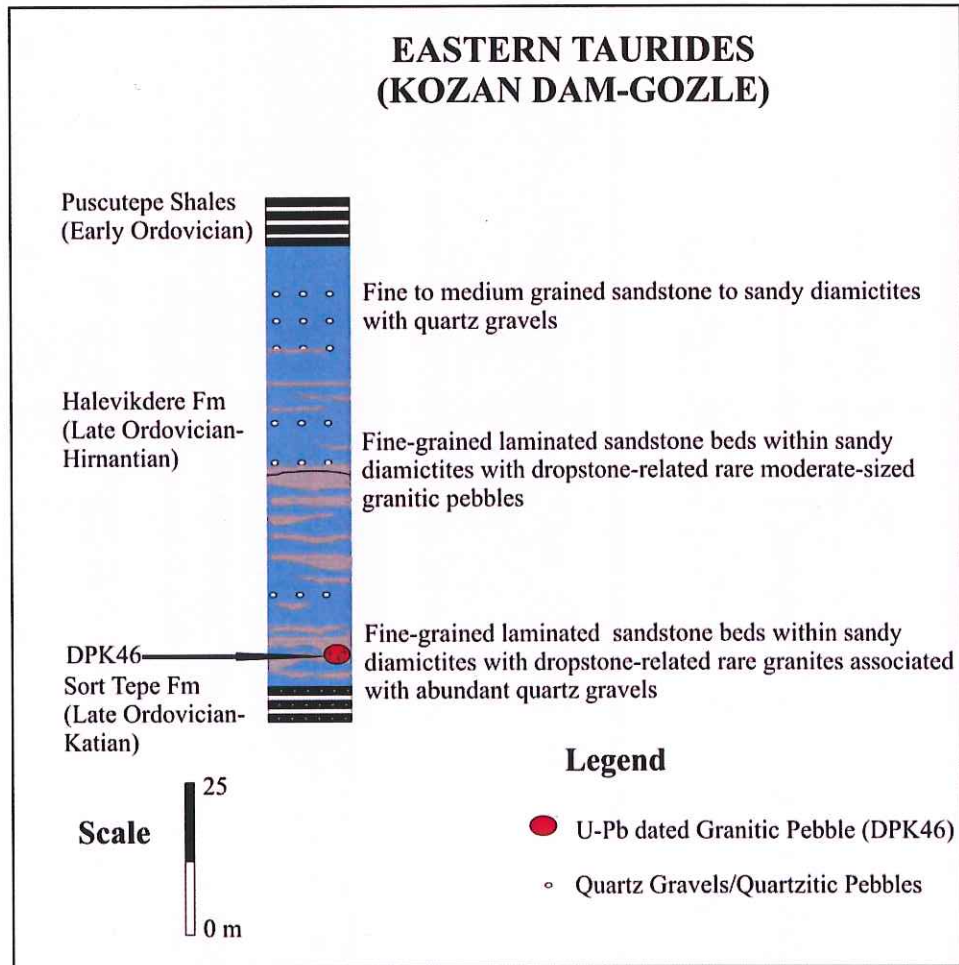


Figure 2.3. Columnar section of Late Ordovician (Hirnantian) glacial succession in the Kozan-Gözle areas (ET) (taken from TUBITAK Report by Gürsu, 2015; Gürsu et al., 2017)

2.2.2.2. Feke-Saimbeyli- Gökmenler (Adana)

The granitic pebble DPK44 (37S 0236704/4211923-UTM) used in this study was previously collected from the middle unit of the Late Ordovician (Hirnantian) Halevikdere Formation by Gürsu (2015). Columnar section of the area is given in Figure 2.4.

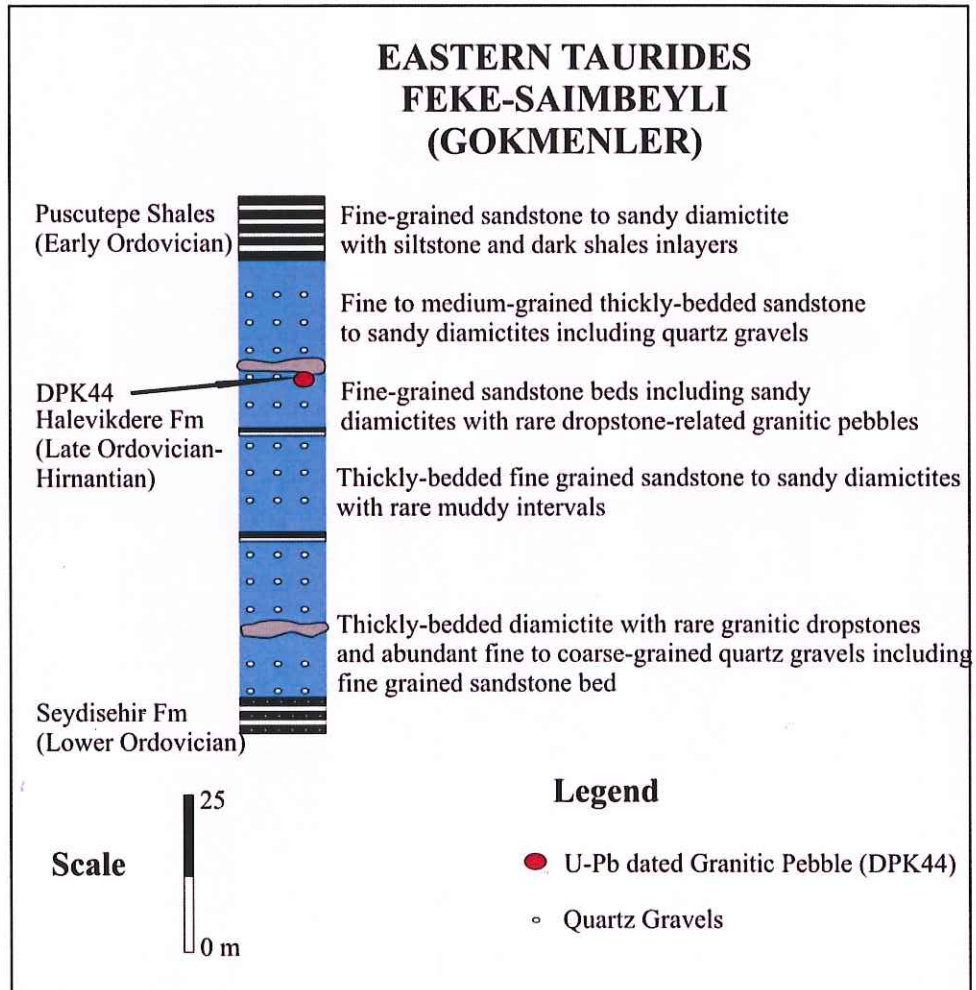


Figure 2.4. Columnar section of the Late Ordovician (Hirnantian) glacial succession in Feke-Saimbeyli-Gökmenler (ET) (taken from TUBITAK Report by Gürsu, 2015; Gürsu et al., 2017)

2.2.2.3. Feke-Saimbeyli-Ceralan (Adana)

Two unique granitic pebbles DPK27 (37S 0237556/4217693-UTM) and DPK30 (37S 0237557/4217682-UTM) were collected from the middle beds of the Halevikdere Formation (Figure 2.5) for U-Pb dating by Gürsu (2015). Columnar section of the area is given in Figure 2.5.

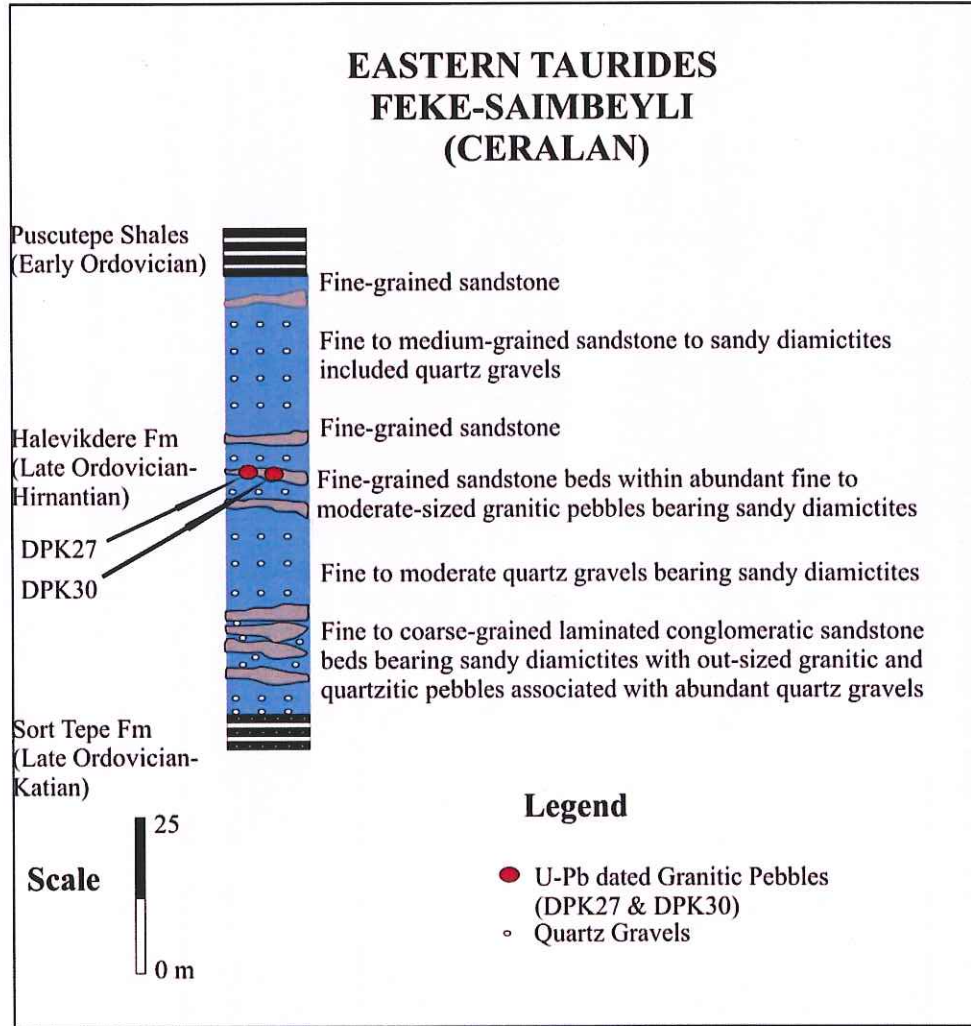


Figure 2.5. Columnar section of Late Ordovician (Hirnantian) glacial succession in Ceralan area (ET) (taken from TUBITAK Report by Gürsu, 2015; Gürsu et al., 2017)

2.2.2.4. Tufanbeyli-Kayapinari (Adana)

One huge granitic pebble DPK17A (37S 0260307/4249566-UTM) used for U-Pb dating was collected from the lower boundary of the Halevikdere Formation by Gürsu (2015) for U-Pb geochronological studies. Columnar section of the area is given in Figure 2.6.

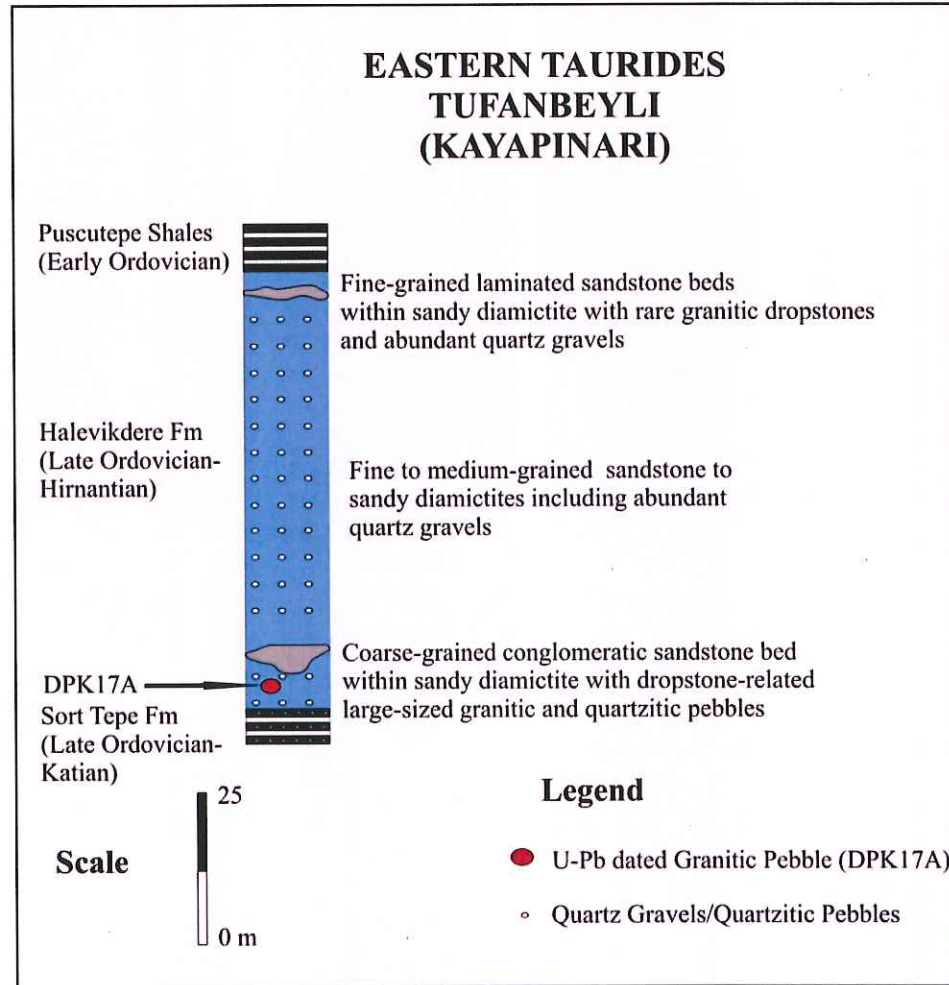


Figure 2.6. Columnar section of the Late Ordovician (Hirnantian) glacial succession in the Kayapinari, Tufanbeyli area (ET) (taken from TUBITAK Report by Gürsu, 2015; Gürsu et al., 2017)

2.3. Previous Dating/Geochronological Studies

All the studied granitic pebbles in this thesis were geochronologically dated by Gürsu (2015) using zircon U-Pb method and summarized in Table 2.1 below.

Table 2.1. U-Pb crystallization ages of the individual granitic pebbles with their GPS coordinates
(Gürsu, 2015)

Granitic Pebble	U-Pb crystallization age	GPS Coordinates (UTM)
DPK17A	789.5±3.7 Ma	37S 0260307/4249566
DPK27	576.7±5.7 Ma	37S 0237556/4217693
DPK30	717.5±8.0 Ma	37S 0237557/4217682
DPK44	576.5±3.3 Ma	37S 0236704/4211923
DPK46	964.6±4.6 Ma	36S 0754441/4179647
DPK72	598.4±7.5 Ma	37S 0556944/4007127

2.4. Mineralogy-Petrography of the Studied Granitic Pebbles

The mineralogical and petrographic features of the six individual granitic pebbles were previously determined by Gürsu (2015). Based on his evaluations, all granitic pebbles preserve their original granitic textures, but have undergone low-grade metamorphism (exception of DPK72) evidenced by recrystallized quartz and mica around the crystal boundaries as previously mentioned by Gürsu (2015). The following mineralogical compositions and petrographic features are taken from Gürsu (2015) as follows;

2.4.1. DPK17A-(meta-granite)

The sample displays hypidiomorphic inequigranular texture with evidence of coarse granoblastic fabrics of alkali feldspars, plagioclase, quartz and biotite with accessory/minor apatite, zircon, titanite and undetermined opaque minerals. The alkali feldspars display perthitic textures. The plagioclase grains are locally sericitized. Quartz is anhedral to subhedral showing undulose extinction. Sub-grain boundaries are developed within recrystallized grains along the crystal boundaries as a result of low-grade metamorphism. Biotite appears to be chloritized along the crystal boundaries due to the low-grade metamorphism.

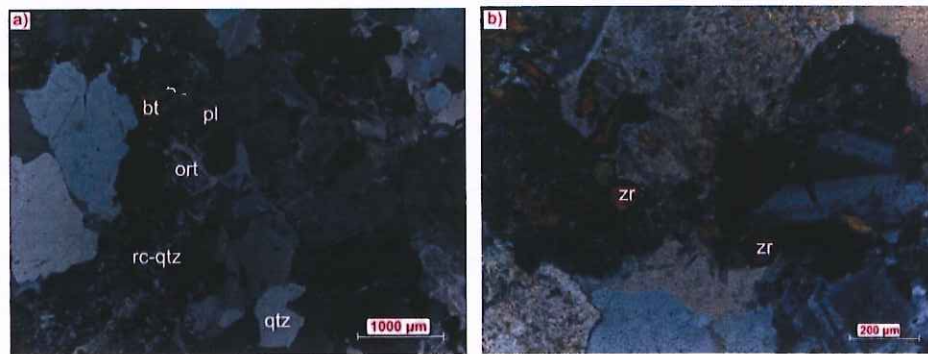


Figure 2.7. Photomicrographs of the sample DPK17A a) General texture of the sample (granoblastic) surrounded by qtz-quartz, pl-plagioclase, ort-orthoclase, bt-biotite, rc-qtz-recrystallized quartz, XPL-2.5x magnification, b) Accessory zircon displayed in XPL, 10x magnification (Gürsu, 2015)

2.4.2. DPK27-(megacrystic granite)

This megacrystic granite displays coarse-grained protomylonitic texture. Major minerals present in the sample include euhedral coarse-grained porphyrocrysts of alkali and plagioclase feldspars embedded in a fine-grained aggregate of altered muscovite, sericite, recrystallized quartz, biotite and Fe-chlorite. Apatite and zircon are present as the minor mineral phases. The megacrystic granite has been strongly deformed and the alkali feldspars appear to be resilient than the earlier groundmass.

The intensity of the deformation resulted in foliation of the alkali and plagioclase feldspars with distinct wavy structures (S-type).

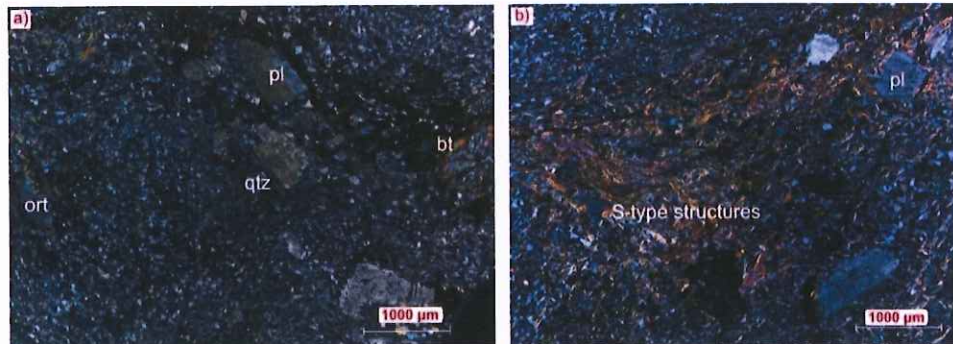


Figure 2.8. Photomicrographs of the sample DPK27 a) General view of the specimen showing protomylonitic texture with porphyrocrysts of feldspars surrounded by recrystallized quartz, plagioclase, less abundant quartz and biotite, XPL- 2.5x magnification, b) Dynamic deformation showing S-type wavy structures and secondary alteration products, XPL-10x magnification (Gürsu, 2015)

2.4.3. DPK30-(meta-granite)

This sample has a medium-grained hypidiomorphic granular texture consisting of orthoclase (K-feldspars), plagioclase, biotite and less abundant anhedral quartz as major constituents whilst the minor minerals include apatite, zircon, titanite and unidentified opaque minerals. The alkali feldspars typically display perthitic textures. Retrograde sericite and chlorite appear to substitute for the feldspars and biotite.

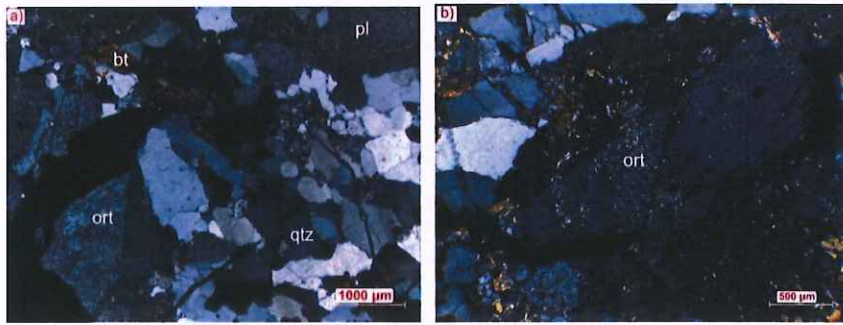


Figure 2.9. Photomicrographs of the sample DPK30 a) Granular texture of the sample surrounded by pl-plagioclase, ort-orthoclase, qtz-quartz, bt-biotite, XPL-2.5x magnification, b) ort-orthoclase displaying perthitic texture, XPL-2.5x magnification (Gürsu, 2015)

2.4.4. DPK44-(monzogranite)

The monzogranite is a coarse-grained hypidiomorphic granular rock dominated by alkali feldspars, plagioclase, biotite and anhedral quartz crystals with subordinate opaques, apatite and zircon. The alkali feldspars display perthitic textures (sodic albite patches within the alkali feldspars) and enclose other phases. Plagioclase commonly forms polysynthetic twins with the grains locally sericitized along the planes of the twins. Biotite observed in this specimen forms subhedral bladed tabular crystals and dominated by brown colors but occasionally chloritized. Quartz mostly displays undulose extinction indicating the deformational phases.

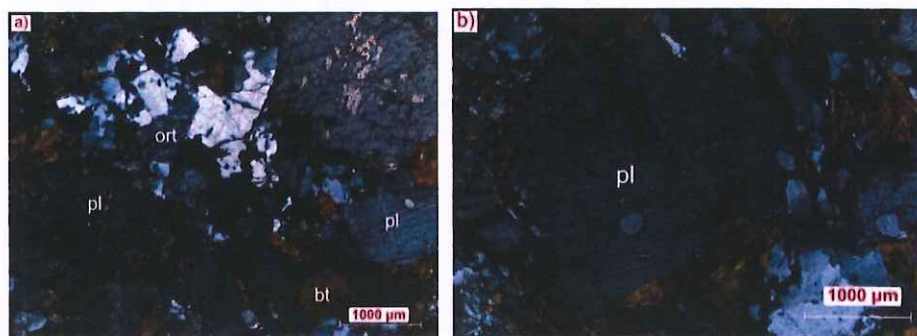


Figure 2.10. Photomicrographs of the sample DPK44 a) General texture of the sample with the constituent minerals, XPL-2.5x magnification, b) pl-plagioclase displaying polysynthetic twinning with the grains locally sericitized along the planes of the twins, XPL-2.5x magnification (Gürsu, 2015)

2.4.5. DPK46-(meta-granite)

The fine to medium-grained meta-granite displays granoblastic texture and is primarily composed of alkali feldspars, plagioclase, biotite and anhedral quartz including apatite, zircon, $\pm$ titanite and undetermined opaque minerals as the accessory minerals. The alkali feldspars display perthitic textures indicating narrow bands of albite in them. Plagioclase commonly displays polysynthetic twinning. Quartz in the sample displays undulose extinction. Alteration products of the feldspars and biotite include sericite and chlorite, respectively. As a result of low-grade metamorphism, these minerals are located along cleavage planes and fractures in the rock where intense deformation has occurred with ample evidence of recrystallized quartz along the crystal boundaries.

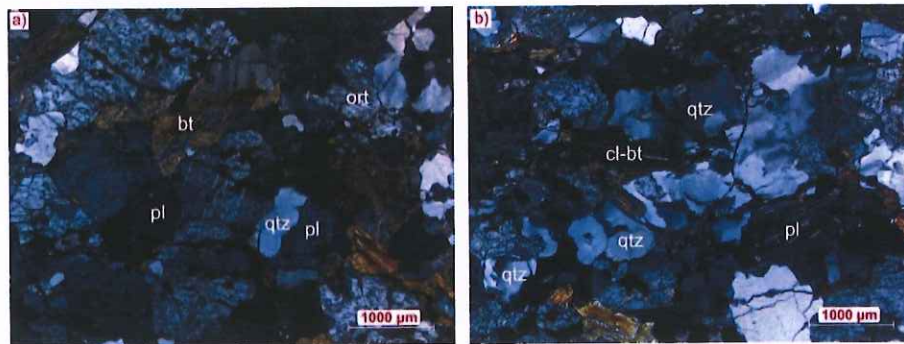


Figure 2.11. Photomicrographs of the sample DPK46 a) Granoblastic texture showing qtz-quartz, pl- plagioclase, ort-orthoclase, bt-biotite minerals, XPL-2.5x magnification, b) cl-bt-chloritized biotite, qtz-quartz displaying undulose extinction and plagioclase showing polysynthetic twinning (Gürsu, 2015)

2.4.6. DPK72-(altered granite)

This altered granitic sample displays granoblastic texture. It is mainly composed of alkali feldspars, plagioclase, biotite and anhedral quartz. Minor minerals include apatite, monazite and unidentified opaques. Occasional alteration of the feldspars and biotite to sericite and chlorite, respectively is common in the sample. The sample is

slightly deformed with minor fractures and recrystallized quartz rims around the crystal boundaries.

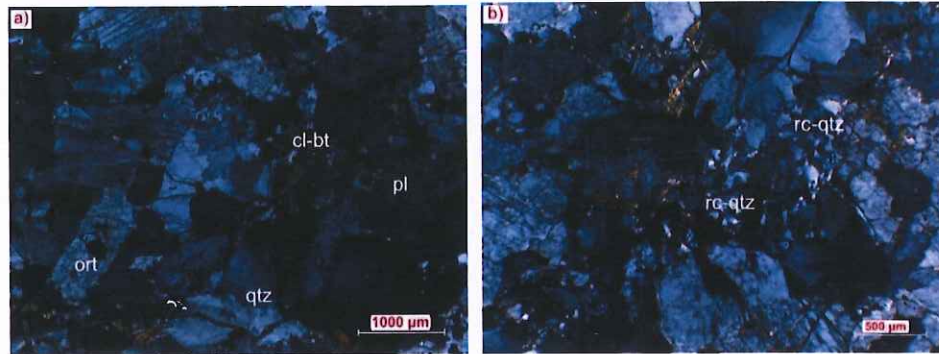


Figure 2.12. Photomicrographs of the sample DPK72 a) General texture of the sample, XPL-2.5x magnification, b) rc-qtz-recrystallized quartz around crystal boundaries, XPL-2.5x magnification (Gürsu, 2015)

3. SAMPLING AND ANALYTICAL METHODS

3.1. Fieldwork

The field study for this study and collection of the individual granitic pebbles were previously carried out in 2015 by Gürsu (2015). Six individual rounded/subrounded granitic pebbles were found and collected from six different locations in the CT (DPK72) and ET (DPK17A, DPK27, DPK30, DPK44 and DPK46) of the TAP (one of them from the CT and the rest from the ET) (Figure 2.1) to determine their crystallization ages by using LA-ICP-MS U-Pb dating and their geochemical features. Gürsu (2015) used the abbreviation DPK## for the sample identities, which is preserved in this study.

3.2. Analytical Methods

A total of six individual granitic pebbles from the CT and ET of the TAP were previously collected for thin-section analysis and whole rock geochemistry. The whole rock geochemical analyses were carried out on powder samples of the six individual granitic pebbles at the ACME Analytical Laboratories Ltd. in Vancouver, Canada by Gürsu (2015). In this thesis, the same sample powders were analyzed in the Central Laboratory of Middle East Technical University MERLAB (METU, Ankara, Turkey) for Rb-Sr and Sm-Nd isotopes to identify their petrogenetic features. The geochemical patterns of the granitic pebbles with combinations of their newly analyzed Rb-Sr and Sm-Nd isotopes were also evaluated. The sample preparation for whole rock geochemical analyses were presented in detail in Gürsu (2015).

Whole rock analysis of the isotopic compositions of Strontium (Sr) and Neodymium (Nd) was performed at the Radiogenic Isotope Laboratory of Central Laboratory /

Middle East Technical University, Ankara, Turkey. Details of the analytical procedures including accuracy, precision, standards and correction procedures are described in Köksal and Göncüoğlu (2008). The chemical treatment analysis prior to the isotopic analysis were performed based on international standards. S. Köksal described the method used in this study as follows;

“Concentrations of the Sr and Nd isotopes were determined using Thermo-Fisher Triton thermal ionization mass spectrometer and standard errors presented in 2-sigma level. Approximately 120 mg of the sample powders were digested with 4 ml of 52% HF on a hot plate ($>100^{\circ}\text{C}$) for four days and later redigested with 4 ml 6 N HCl overnight. The samples were then dried and later one-third fraction dissolved in 2 N HCl for Pb-chromatography and the rest dissolved in 2.5 N HCl for Sr and Nd chromatography. In determining the Sr and Nd isotopic concentrations, firstly, various element separations were performed on the acid-dissolved fractions of the samples. Sr was separated in 2 ml volume BioRad AG50 W-X8 (100-200 mesh) resin in Teflon columns using a 2.5 N HCl medium. Excess Ba left in the fraction was segregated from the remaining using 5 N HNO_3 . The Rare-earth element (REE) portion in the samples was eventually enriched with 6 N HCl in the Teflon columns. The Nd fraction in the REE was separated in 2 ml HDEHP (bis-ethyexyl phosphate) coated biobeads (BioRad) resin by using 0.22 N HCl in the Teflon column. The strontium fraction was loaded on single Re filaments using 0.005 N H_3PO_4 whilst the Nd fraction was measured from Re double filaments using the same 0.005 N H_3PO_4 with a tantalum oxide activator. Internal normalization of $^{86}\text{Sr}/^{88}\text{Sr}$ ratios was such that $^{86}\text{Sr}/^{88}\text{Sr} = 0.1194$ and the $^{143}\text{Nd}/^{144}\text{Nd}$ ratios were normalized to a value of 0.7219. The calibrated NIST SRM 987 standard was quoted as $^{87}\text{Sr}/^{86}\text{Sr} = 0.710256 \pm 8$ ($n = 2$) and the La Jolla Nd standard was measured as $^{143}\text{Nd}/^{144}\text{Nd} = 0.511850 \pm 4$ ($n = 2$) with no bias correction. For a check on quality control of the isotopic analyses, G2 USGS standard was used following the same procedure and the measurement yielded $^{87}\text{Sr}/^{86}\text{Sr} = 0.709775 \pm 10$ ($n=2$) and $^{143}\text{Nd}/^{144}\text{Nd} = 0.512224 \pm 3$ ($n=2$), respectively”.

4. GEOCHEMISTRY

4.1. Major, Trace and Rare Earth Elements (REE) Variations

The whole rock major, minor, trace and rare earth elements (REE) are taken from Gürsu (2015).

Geochemically, the granitic pebbles display sub-alkaline affinity as previously declared by Gürsu (2015) and Gürsu et al. (2017). All the studied granitic pebbles display major element compositional variations (DPK17A-75.96 wt.% SiO₂, 12.82 wt.% Al₂O₃, DPK27-73.39 wt.% SiO₂, 13.47 wt.% Al₂O₃, DPK30-72.03 wt.% SiO₂, 15.07 wt.% Al₂O₃, DPK44-66.79 wt.% SiO₂, 15.85 wt.% Al₂O₃, DPK46-68.47 wt.% SiO₂, 16.13 wt.% Al₂O₃ and DPK72-79.33 wt.% SiO₂, 11.88 wt.% Al₂O₃) (see details in Table 4.1; Figure 4.1). The analyses show that the individual granitic pebbles are enriched in alkali elements and fairly depleted in Fe₂O₃, MgO, CaO, TiO₂, P₂O₅, MnO and Cr₂O₃ (Table 4.1; Figure 4.1). The variable alkali enrichment in the individual granitic pebbles is consistent with their mineralogical compositions in regard of their enrichment in feldspars.

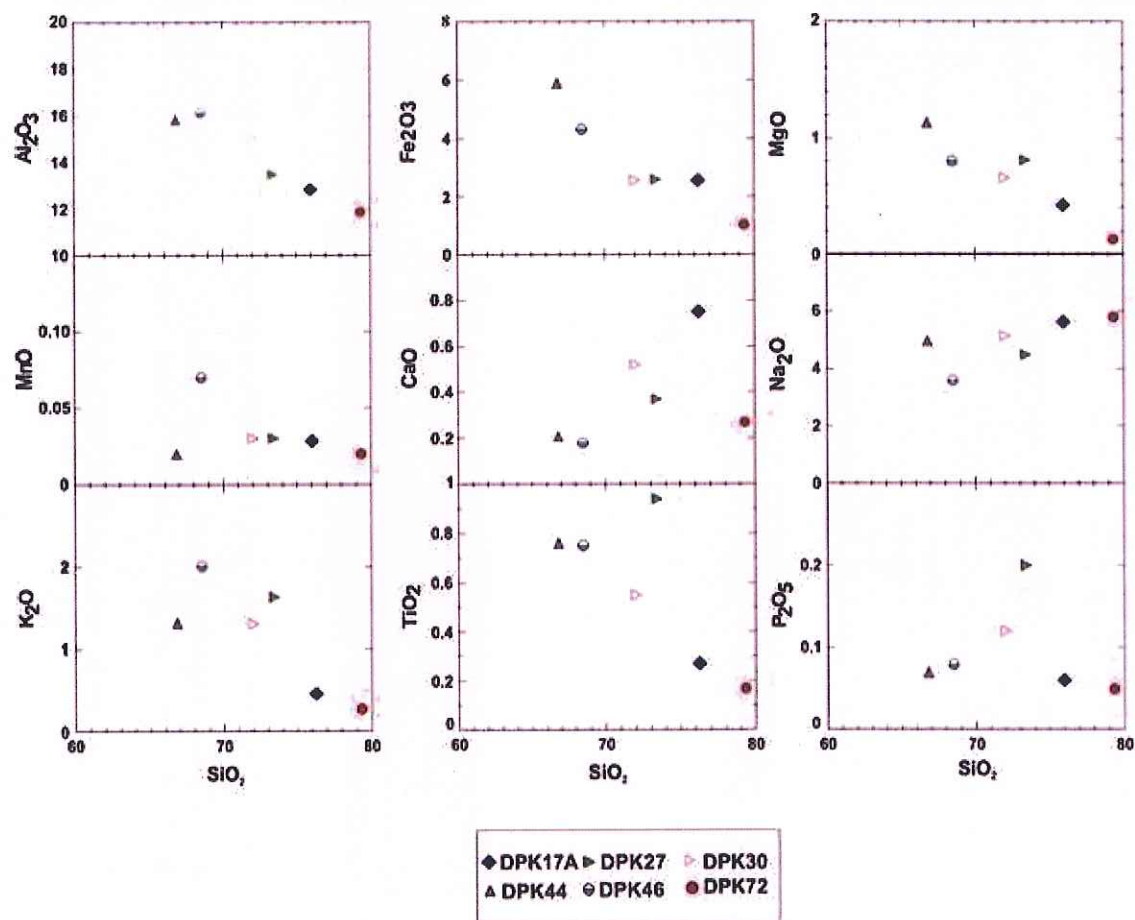


Figure 4.1. Major element variation diagrams

Table 4.1. Geochemical data of the analyzed granitic pebbles (data taken from Gürsu, 2015; normalization values are from Sun and McDonough, 1989)

Sample	DPK17A	DPK27	DPK30	DPK44	DPK46	DPK72
Name	Meta- granite	Granite- protomylonite	Meta-granite	Monzogranite	Meta- granite	Altered granite
Major Elements (wt.%)						
SiO ₂	75.96	73.39	72.03	66.79	68.47	79.33
Al ₂ O ₃	12.82	13.47	15.07	15.85	16.13	11.88
Fe ₂ O ₃	2.46	2.59	2.56	5.87	4.30	1.05
MgO	0.42	0.81	0.66	1.13	0.80	0.13
CaO	0.76	0.37	0.52	0.21	0.18	0.27
Na ₂ O	5.61	4.46	5.13	4.95	3.58	5.80
K ₂ O	0.47	1.64	1.31	1.32	2.01	0.27
TiO ₂	0.28	0.94	0.55	0.76	0.75	0.17
P ₂ O ₅	0.06	0.20	0.12	0.07	0.08	0.05
MnO	0.03	0.03	0.03	0.02	0.07	0.02
Cr ₂ O ₃	0.002	0.002	0.002	0.006	0.002	0.002
LOI	1.00	1.90	1.90	2.80	3.50	0.90
Total	99.86	99.83	99.85	99.81	99.85	99.89
Trace Elements (ppm)						
Ga	14.4	17.1	12.1	15.0	15.3	13.2
Hf	5.8	6.1	3.4	6.4	3.0	4.0
Nb	11.2	9.9	6.3	16.1	6.6	10.3
Rb	15.5	40.5	42.5	34.7	56.4	14.4

Sr	125.1	82.6	191.8	149.8	75.3	124.7
Ta	0.8	0.7	0.5	1.1	0.2	0.9
Th	5.3	6.7	3.0	9.9	4.4	15.7
U	0.9	1.2	0.6	1.5	0.6	2.0
V	8.0	31.0	48.0	73.0	77.0	11.0
Zr	198.5	225.8	123.2	213.6	112.1	137.4
Y	22.8	39.1	3.5	23.8	3.7	11.4
Ti	1679	5635	3297	4556	4496	1019

Rare Earth Elements-REE (ppm)

La	21.1	4.2	2.7	12.6	3.9	22.1
Ce	49.0	8.5	4.8	31.3	9.4	49.5
Pr	6.13	0.98	0.54	3.89	1.13	5.39
Nd	25.5	4.3	2.5	15.4	5.0	20.0
Sm	5.33	1.55	0.57	3.93	1.42	4.59
Eu	1.36	0.63	0.18	0.72	0.45	1.11
Gd	4.84	4.36	0.75	3.77	1.77	3.65
Dy	4.49	6.49	0.71	3.87	0.81	2.59
Ho	0.93	1.44	0.14	0.85	0.14	0.47
Er	2.96	3.97	0.48	2.71	0.41	1.33
Tm	0.44	0.62	0.08	0.42	0.05	0.19
Yb	3.22	3.94	0.56	3.18	0.40	1.46
Lu	0.51	0.63	0.10	0.48	0.07	0.23
ΣREE	126.6	42.6	14.2	83.7	25.2	113.1
Eu/Eu*	0.81	0.75	0.86	0.57	0.86	0.83

(La/Yb) _N	4.70	0.76	3.45	2.84	6.99	10.85
(La/Sm) _N	2.56	1.75	3.06	2.07	1.77	3.11
(Gd/Yb) _N	1.24	0.92	1.11	0.98	3.66	2.07
(Dy/Yb) _N	1.83	0.43	1.13	1.37	3.94	6.49
La/Yb	6.55	1.07	4.82	3.96	9.75	15.14
Zr/Ti	0.12	0.04	0.037	0.047	0.025	0.13
Zr/Y	8.71	5.77	35.2	8.97	30.3	12.05
Nb/Th	2.11	1.48	2.1	1.63	1.5	0.66
Nb/Y	0.49	0.25	1.8	0.68	1.78	0.9
Sm/Yb	1.66	0.39	1.02	1.24	3.55	3.14

The use of trace and REE in petrogenetic studies has long been proven to be the best tool since these elements can tell when a melt is differentiated or contaminated by other materials during its ascent (Whalen et al., 1987). The petrogenetic features of the granitic pebbles show two groups of relations; Group A (DPK17A, DPK30, DPK46) and Group B (DPK27, DPK44, DPK72).

Group A samples display the lowest Th (3.0- 5.3 ppm) and Nb (6.3-6.6) contents than all the other samples except DPK17A, which has moderate Nb content (11.2) (Figure 4.2). This variation in the Nb content of the sample DPK17A when correlated with its Group A counterparts is interpreted to be as a result of extensive crustal input since Nb is enriched in crustal sources (Rudnick and Gao, 2003). However, Group B samples display the highest Th (15.7-9.9 ppm) and Nb (16.1-10.3 ppm) contents with the sample DPK27 surprisingly having low Th content (5.3 ppm) and moderate Nb content (9.9 ppm) than the others indicating limited influence of crustal materials to its magma (Figure 4.2). The Y values of all the samples are lower than 40.00 ppm but very fair in Group A samples (3.5-3.7 ppm) excluding DPK17A,

which displays moderate Y value (22.8 ppm) like the Group B samples (11.4-39.1 ppm) suggesting the influence of crustal materials in their genesis (Figure 4.2).

Zr contents in Group A samples are low (112.1-123.2 ppm), but that of DPK17A (198.5 ppm) is within the range of Group B samples (137.4- 225.8 ppm) (Figure 4.2). Rudnick and Gao (2003) suggested that Zr contents above 132 ppm in granitoids may imply significant influence of crustal components in their magmas. Therefore, the high Zr content of the Group B samples including DPK17A of Group A is consistent with a larger input of crustal components during their evolution. The La contents are significantly low in Group A samples (2.7- 3.9 ppm), but DPK17A inexpertly has very high La value (21.1 ppm) that is characteristic of a rock that has been affected by crustal mixing. Nevertheless, the La contents of Group B samples show higher values (12.6- 22.1 ppm) with the exception of the sample DPK27 which displays low La value (4.2 ppm) (Figure 4.2).

With low Zr/Ti ratios (0.025-0.037), the samples making up Group A display moderate Nb/Th ratios (1.5-2.11) with DPK17A however having much higher Zr/Ti ratio (0.12) (Figure 4.2). The Group B samples also show low to moderate Nb/Th ratios (0.66-1.63) with low Zr/Ti ratios (0.04-0.047), but DPK72 rather displays higher Zr/Ti ratio (0.13) than all the analysed samples suggesting the extensive influence of felsic materials during its genesis (Figure 4.2). Two samples (DPK17A and DPK27) from Group A and Group B respectively, have low Nb/Y values (< 0.5) whilst the other samples in Group A show higher values (1.78-1.80) than the Group B samples (0.25-0.90), suggesting crustal contamination in Group B samples than Group A samples (see Table 4.1; Figure 4.2).

The Zr/Y ratios in the studied samples are pronouncedly low in Group B samples (5.77-8.97), but the Zr/Y ratios are very high in Group A samples (30.30-35.20) excluding DPK17A, which is having a low Zr/Y value (8.71) as in the Group B samples, further suggesting crustal mixing effects for DPK17A and Group B samples (Figure 4.2). The La/Yb ratios show moderate values in the Group A samples (4.82-9.75) whereas Group B samples display lower La/Yb values (1.07-3.96) apart from DPK72, which has the highest La/Yb ratio (15.14), implying extensive contribution

of crustal materials during its genesis (Figure 4.2). The Sm/Yb values of Group A samples changed from (1.02-3.55) whereas those of Group B samples changed from (0.39-1.24) excluding the sample DPK72, which displays high Sm/Yb ratio (3.14) (Figure 4.2).

In all, the trace element variations in the individual granitic pebbles suggest that Group A samples show limited crustal contamination except DPK17A, whereas Group B samples display extensive crustal mixing as in DPK17A. Also, the continental crustal mixing seem to be limited in DPK27 than its equivalent Group B samples.

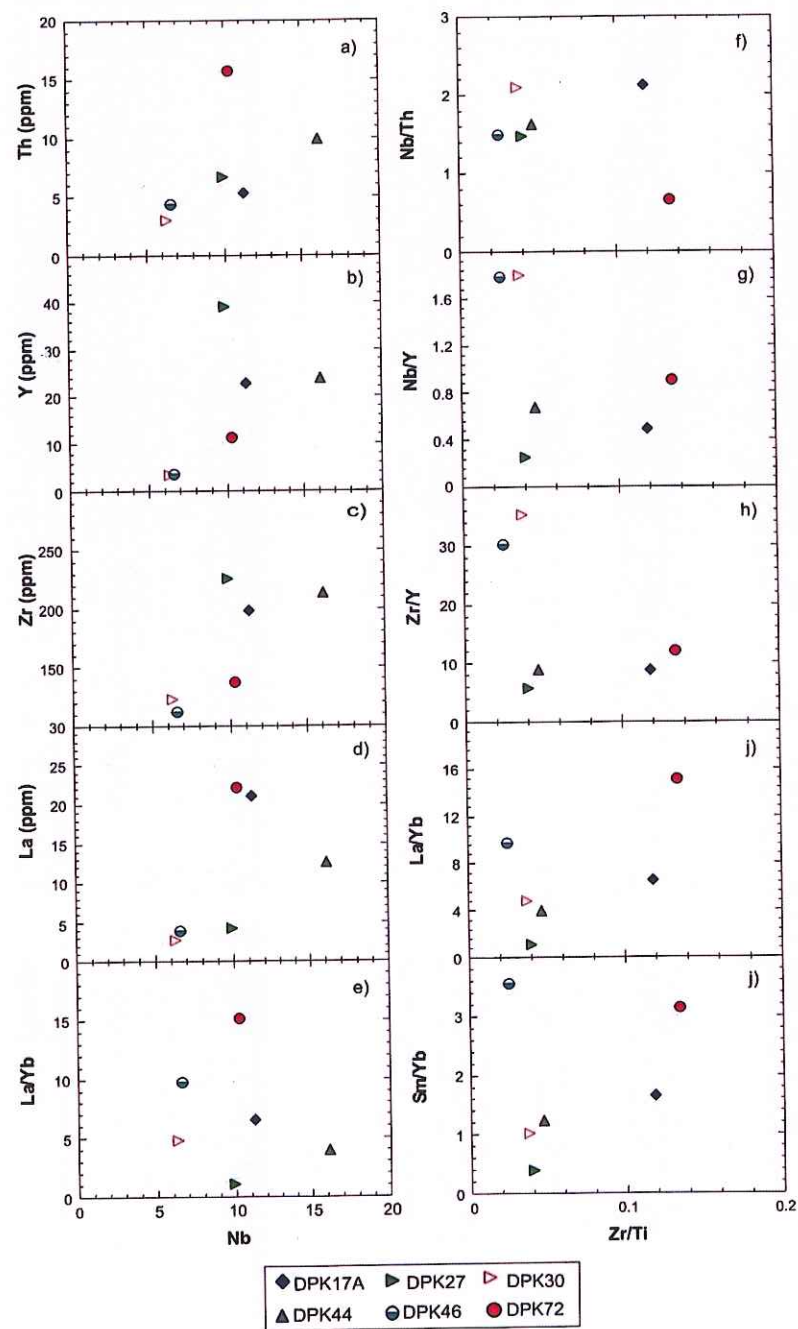


Figure 4.2. Trace and REE variation diagrams against Nb and Zr/Ti

The studied granitic pebbles have been normalized to N-MORB values of Sun and McDonough (1989) on the multi-element diagrams in order to check their source characteristics. In the N-MORB normalized multi-element diagram involving Group A samples, large ion lithophile elements (LILE) such as Ba, Rb and Sr display enrichment against the high field strength elements (HFSE) (Figure 4.3 a). Sr however displays a negative anomaly in the meta-granitic sample DPK17A. The Group A samples also display pronounced anomalies in Nb, La, Ce, Nd, Sm and HREE having positive Ti anomalies especially in DPK30 and DPK46. Contrary, the meta-granitic sample DPK17A displays a steep slope compared to the flat HREE patterns in the N-MORB normalized diagram (Figure 4.3 a). The total REE abundance in the Group A samples is very low (14.2-25.2 ppm) except DPK17A, which displays the highest total REE abundance ($\Sigma\text{REE} = 126.6$ ppm) among all the analyzed samples. The samples in this group are pronouncedly depleted in MREE and HREE relative to slight enrichment in LREE (DPK30- $\text{La} = 1.1 \times \text{N-MORB}$, $\text{Sm} = 0.21 \times \text{N-MORB}$, $\text{Yb} = 0.15 \times \text{N-MORB}$; DPK46- $\text{La} = 1.56 \times \text{N-MORB}$, $\text{Sm} = 0.54 \times \text{N-MORB}$, $\text{Yb} = 0.13 \times \text{N-MORB}$), but the meta-granitic sample DPK17A has LREE/HREE and LREE/MREE ratios higher than the MREE/HREE ratios $[(\text{La}/\text{Yb})_{\text{N}} - 7.96 \times \text{N-MORB}$; $(\text{La}/\text{Sm})_{\text{N}} - 4.16 \times \text{N-MORB}$ and $(\text{Gd}/\text{Yb})_{\text{N}} - 1.25 \times \text{N-MORB}]$ (Figure 4.3 a).

Group B samples display enrichment in LILE (except Sr in the megacrystic granitic sample DPK27) and HFSE in the N-MORB normalized diagram (Figure 4.3 b). The samples DPK44 and DPK72 have a negative LILE to HFSE slope, but this is not very smooth as there are scatters (mainly depletions) in some elements including Nb and Ti (Figure 4.3 b). However, the megacrystic granitic sample DPK27 displays considerable depletion in La, Ce, Nd, Sm and Eu elements in the N-MORB normalized diagram when correlated with the other samples (Figure 4.3 b). Total REE abundance in Group B samples is in the range of 42.6 ppm to 113.1 ppm (Gürsu et al., 2017). A steep negative REE slope ($\text{La} > \text{Yb}$) with considerable enrichment in LREE against the MREE and HREE is observed in Group B samples (DPK44- $\text{La} = 5.04 \times \text{N-MORB}$, $\text{Sm} = 2.43 \times \text{N-MORB}$, $\text{Yb} = 1.04 \times \text{N-MORB}$; DPK72- $\text{La} = 8.84 \times \text{N-MORB}$, $\text{Sm} = 1.75 \times \text{N-MORB}$, $\text{Yb} = 0.48 \times \text{N-MORB}$) save for the megacrystic granitic sample DPK27 which displays pronounced depletion in LREE than the

MREE and HREE $[(La/Yb)_N - 1.30 \times N\text{-MORB}, (La/Sm)_N - 2.85 \times N\text{-MORB}, (Gd/Yb)_N - 0.91 \times N\text{-MORB}]$ (Figure 4.3 b). The enrichment in MREE and HREE against the LREE of the sample DPK27 is interpreted to be as a result of alteration processes/low-grade metamorphism than crustal input.

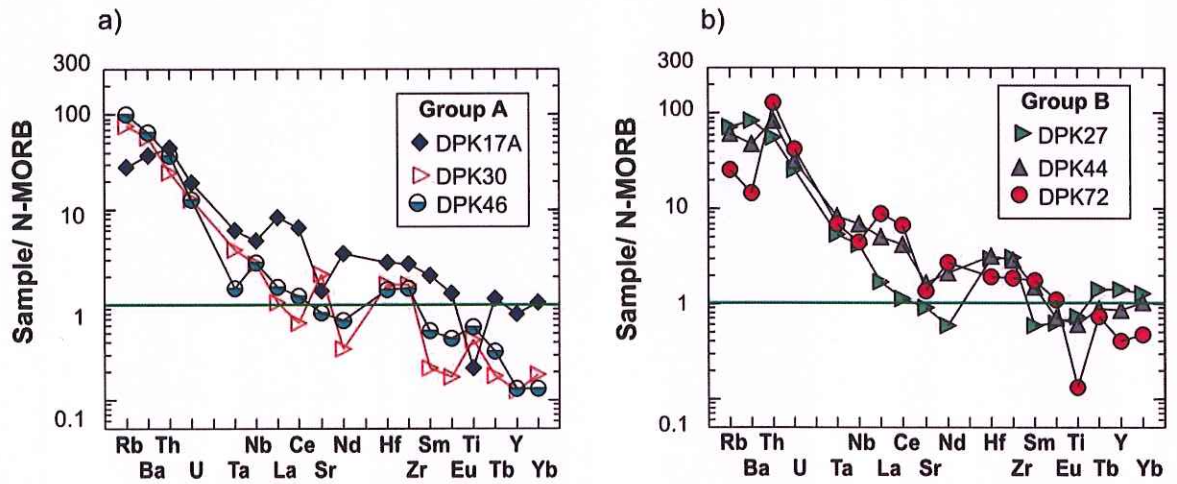


Figure 4.3. N-MORB normalized multi-element variation diagrams of the individual granitic pebbles (normalization values taken from Sun and McDonough, 1989)

4.2. Rb/Sr and Sm/Nd isotopes

In this study, whole rock Rb/Sr and Sm/Nd analyses are used to interpret the source characteristics of the individual granitic pebbles.

The Rb, Sr, Sm and Nd isotopic compositions, initial $^{143}\text{Nd}/^{144}\text{Nd}$ and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios and depleted mantle model ages (T_{DM}) of the individual granitic pebbles are presented in Table 4.2. The initial $(^{87}\text{Sr}/^{86}\text{Sr})_{\text{T}}$ ratios and $\epsilon_{\text{Nd(T)}}$ were re-calculated by using the U-Pb crystallization ages of the rocks that are recently published data of Gürsu (2015) and Gürsu et al. (2017). The T_{DM} model ages are determined by using the 2-stage model ages of Liew and Hoffmann (1988) and single-stage model age of Goldstein et al. (1984) by Serhat Koksai. The petrogenetic features of the Rb-Sr and Nd-Sm isotopes of the individual granitic pebbles including the relevant diagrams in

this thesis are evaluated and interpreted by Semih Gürsu. Among the Group A samples, DPK46 has very low $^{87}\text{Sr}/^{86}\text{Sr}_{(\text{T})}$ ratio (0.693566) implying alteration or low-grade metamorphism or fluid-ingress effects on the rock (Figure 4.4; Table 4.2).

On the $\epsilon\text{Nd}_{(\text{T})}$ vs $^{87}\text{Sr}/^{86}\text{Sr}_{(\text{T})}$ diagram, the Group A samples have positive $\epsilon\text{Nd}_{(\text{T})}$ ranging from +0.8 to +3.7 with moderate $^{87}\text{Sr} / ^{86}\text{Sr}_{(\text{T})}$ ratios that are in range from 0.707649 to 0.708213 (Figure 4.4). The Group B samples all have negative $\epsilon\text{Nd}_{(\text{T})}$ ratios (-8.4 for DPK27; -5.2 for DPK44; -2.8 for DPK72) with moderate to high $^{87}\text{Sr}/^{86}\text{Sr}_{(\text{T})}$ ratios (0.705988 for DPK27; 0.711616 for DPK44; 0.713623 for DPK72) (Figure 4.4). Although DPK46 has very low $^{87}\text{Sr}/^{86}\text{Sr}_{(\text{T})}$ ratio, its $\epsilon\text{Nd}_{(\text{T})}$ ratio is about -14.6, which may show the effect of alteration/low-grade metamorphism/fluid-ingress processes on the Sr and Nd isotopes (Figure 4.4).

Table 4.2. Rb/Sr and Sm/Nd isotopic composition of the granitic pebbles from the TAP

Samples and Crystallization Ages (Ma)	Rb (ppm)	Sr (ppm)	$^{87}\text{Rb}/^{86}\text{Sr}$	$^{87}\text{Sr}/^{86}\text{Sr}$	t(Ma)	$(^{87}\text{Sr}/^{86}\text{Sr})_T$	Nd (ppm)	Sm (ppm)	$^{147}\text{Sm}/^{144}\text{Nd}$	$^{143}\text{Nd}/^{144}\text{Nd}$	$(^{143}\text{Nd}/^{144}\text{Nd})_T$	$\epsilon_{\text{Nd}(T)}$	$T_{\text{DM}}(\text{Ga})$
DPK17A (789.5±3.7)	15.5	125.1	0.36	0.712257	789.5	0.708213	25.5	5.33	0.13	0.512465	0.511810	3.7	1.12
DPK27 (576.7±5.7)	40.5	82.6	0.49	0.717660	576.7	0.705988	4.3	1.55	0.22	0.512290	0.511466	-8.4	1.94
DPK30 (717.5±8.0)	42.5	191.8	0.64	0.714218	717.5	0.707649	2.5	0.57	0.14	0.512402	0.511753	0.8	1.30
DPK44 (576.5±3.3)	34.7	149.8	0.67	0.717128	576.5	0.711616	15.4	3.93	0.15	0.512212	0.511629	-5.2	1.68
DPK46 (964.6±4.6)	56.4	75.3	2.17	0.723471	964.6	0.693566	5	1.42	0.17	0.511735	0.510648	-14.6	2.75
DPK72 (598.4±7.5)	14.4	124.7	0.33	0.716476	598.4	0.713623	20	4.59	0.14	0.512270	0.511726	-2.8	1.50

Note: $\lambda(\text{Rb})=1.42 \times 10^{-12} \text{ y}^{-1}$, $\lambda(\text{Sm})=6.54 \times 10^{-12} \text{ y}^{-1}$, $\epsilon(\text{Nd})=[(^{143}\text{Nd}/^{144}\text{Nd})_{\text{sample}}/^{143}\text{Nd}/^{144}\text{Nd}_{\text{(CHUR)}}-1] \times 10000$. The ϵ values were calculated for $\epsilon_{\text{Nd}(0)}$ relative to present day chondrite values of $^{143}\text{Nd}/^{144}\text{Nd}_{\text{(CHUR)}}=0.512638$, $^{147}\text{Sm}/^{144}\text{Nd}_{\text{(CHUR)}}=0.1967$, $^{87}\text{Sr}/^{86}\text{Sr}_{\text{(CHUR)}}=0.7045$. T_{DM} is model age (after Goldstein et al. 1984). Rb, Sr, Sm and Nd concentrations are taken from Gürsu (2015)

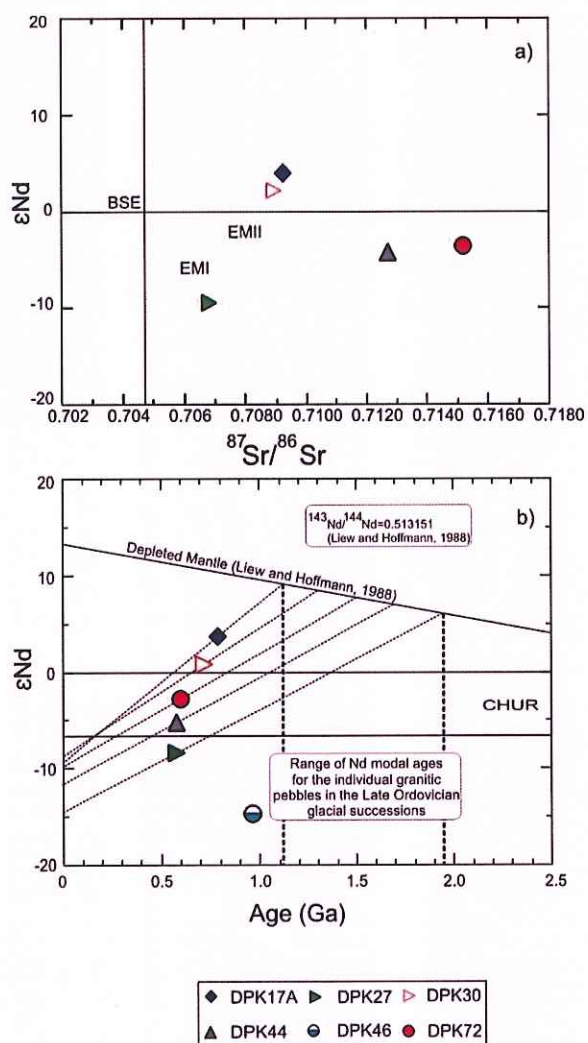


Figure 4.4. a) ϵ_{Nd} versus $^{86}Sr/^{87}Sr$ diagram and b) ϵ_{Nd} versus crustal residence ages (T_{DM}) of the granitic pebbles

4.3. Source Characteristics of the Granitic Pebbles

From the geochemical patterns of the investigated granitic pebbles, it is observed that they might have been derived from mafic sources and mixed with felsic sources especially in Group B samples and DPK17A of Group A. To check their source characteristics, various diagrams including La, Nb, U, Th and Yb with reference to upper crust (UC), lower crust (LC), normal mid-ocean ridge basalts (N-MORB), enriched-mid-ocean ridge basalts (E-MORB) and ocean island basalts (OIB) were used in this study.

The Nb/U, Nb/Th and La/Yb ratios of the studied samples increase from Group A to Group B samples and may represent mafic-dominant source than crustal-dominant source (Figure 4.5). However, one Group A sample (DPK17A) and two Group B samples (DPK44 and DPK72) are pronouncedly enriched in Nb/U, Nb/Th and La/Yb ratios indicating extensive mixing of continental crustal sources to their mafic sources and can support their A-type sources (Figure 4.5). On the other hand, the continental crustal mixing with the mafic-dominant source of the sample DPK27, which belongs to Group B seems to be limited when correlating it with the other granitic pebbles (Figure 4.5). The low Nb/U, Nb/Th and La/Yb ratios in Group A samples may support mafic-crustal sources in their genesis (Figure 4.5), which are characteristics of rocks derived from arc type sources.

The positive $\epsilon_{\text{Nd}(T)}$ for the other Group A samples (+3.7-DPK17A and +0.7-DPK30) show mafic-dominant source characteristics but lower when correlated with N-MORB data and resemble island-arc type sources (Sun and McDonough, 1989). However, negative $\epsilon_{\text{Nd}(T)}$ values for Group B samples (-8.2-DPK27, -5.2-DPK44 and -2.8-DPK72) imply extensive crustal mixing with their mafic magma sources during their genesis (Figure 4.4). T_{DM} model ages of the studied individual granitic pebbles are higher than their crystallization ages (1.12 Ga for DPK17A - 789.5 ± 3.7 Ma; 1.94 Ga for DPK27 - 576.7 ± 5.7 Ma; 1.30 Ga for DPK30 - 717.5 ± 8.0 Ma; 1.68 Ga for DPK44 - 576.5 ± 3.3 Ma; 2.75 Ga for DPK46 - 964.6 ± 4.6 Ma; 1.75 Ga for DPK72 - 598.4 ± 7.5 Ma) (Figure 4.4). These old T_{DM} model ages also support limited to extensive mixing of crustal materials to the mafic mantle sources in their genesis as observed in the $\epsilon_{\text{Nd}(T)}$ vs $^{87}\text{Sr}/^{86}\text{Sr}(T)$ diagram (Figure 4.4).

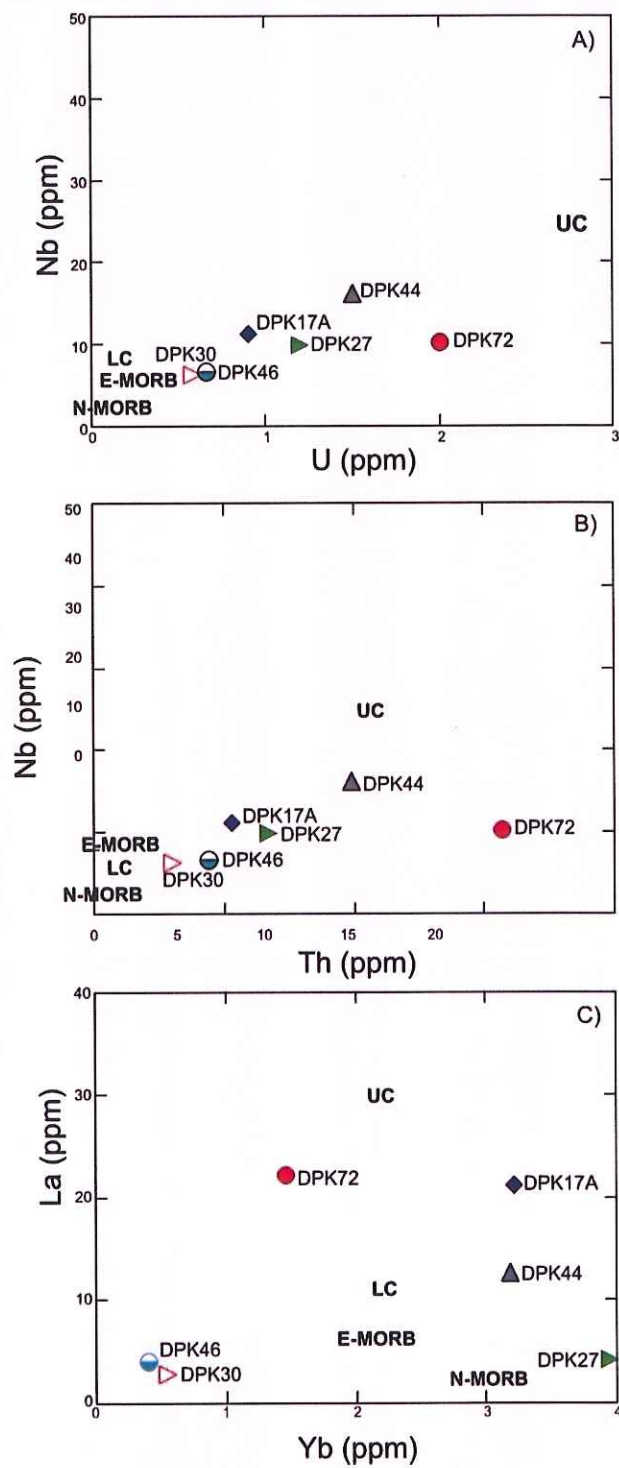


Figure 4.5. Source characteristics diagrams of the studied granitic pebbles a) Nb-U, b) Nb-Th, c) La-Yb variation diagrams (UC, LC data are from Taylor and McLennan, 1985; OIB, N-MORB and E-MORB data are from Sun and McDonough, 1989)

4.4. Tectonic Environments of the Studied Granitic Pebbles

All the studied granitic pebbles plot within the subduction-related Volcanic Arc Granite (VAG) fields in the Rb vs Y+Nb and Ta vs Yb diagrams of Pearce et al. (1984) (Figure 4.6 a, b).

However, Gürsu et al. (2017) reported that Group A samples might have been derived from island arc-related sources, whereas Group B samples were probably derived from A-type granitic sources. Similarly, arc-related mafic source characteristics for two of the Group A samples (DPK17A and DPK30) are being supported by their positive $\varepsilon\text{Nd}_{(T)}$ ratios ranging from +0.8 to +3.7.

In addition, their T_{DM} ages (1.11 to 1.30 Ga) are consistent with their juvenile arc-related source characteristics as previously declared by Gürsu (2015) and Gürsu et al. (2017). The low $\varepsilon\text{Nd}_{(T)}$ ratios for Group B samples with T_{DM} ages (higher than 1.68 Ga) suggest older crustal source mixing effect with their mafic sources and support A-type source characteristics in their genesis than arc-related sources.

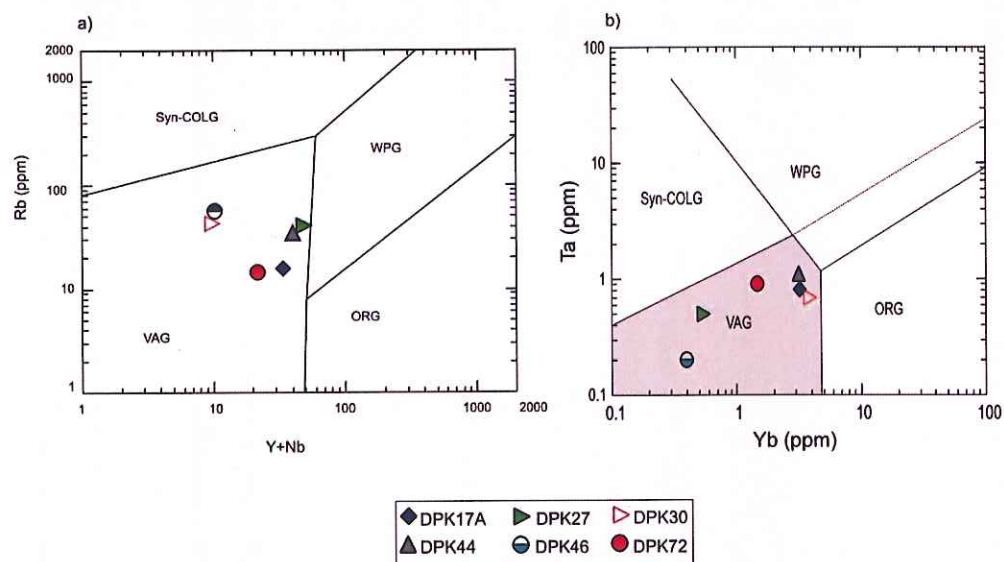


Figure 4.6. Tectonic discrimination diagrams of the studied granitic pebbles a) Rb vs (Y+Nb) diagram (Pearce et al., 1984) b) Ta vs Yb diagram (Pearce et al., 1984)

5. DISCUSSION

5.1. Correlation of the Granitic Pebbles with Equivalent Rocks

The provenance of the individual granitic pebbles has been recently discussed in detail by Gürsu (2015) and Gürsu et al. (2017). The researchers mentioned that the individual granitic pebbles in the TAP might have been derived from Late Neoproterozoic granitoids/meta-granitoids in the Sinai Peninsula and the Eastern Desert of the ANS during the Hirnantian glaciation based on their zircon U-Pb ages. During the Middle-Late Ordovician period, southern Turkey, where the granitic pebbles were deposited was paleogeographically positioned at the western peripheral of Gondwana in close proximity to the Arabian plate with the distal part in north Africa (Scotese, 2001). The sub-rounded morphology of most of the granitic pebbles previously collected by Gürsu (2015) further suggests that during the Late Ordovician (Hirnantian) glaciation, the equivalent rocks might have been eroded, transported within a limited range of distance and later deposited in the northern and northeastern margin of Arabia, exposed in the Taurides of the TAP in Turkey and other distal parts of the Late Ordovician glacio-marine successions (details in Gürsu, 2015; Gürsu et al., 2017). Besides, the juvenile crystallization ages of all the granitic pebbles, which span from 964-576 Ma, can support the provenance area of juvenile ANS, because juvenile magmatic activity are only documented in northern Gondwana except from ANS (details in Johnson et al., 2011).

Petrogenetic studies including isotopic and geochemical data of the equivalent rocks in the ANS are not readily available. The oldest crystallization age 964.6 ± 4.0 Ma is reported for the sample DPK46 (Gürsu, 2015 and Gürsu et al., 2017). Similar geochronological ages from meta-granitic rocks (962 - 977 Ma) have been recently documented in the Sinai Peninsula of the ANS (e.g., Eyal et al., 2014). The possible meta-granitic provenance rocks in this area are mainly outcropped in the Agramiya formation within the Sa'al Metamorphic Complex (SMC), which evolved from the

Sa'al island arc and represent island arc affinity (details in Eyal et al., 2014). These rocks can be geochronologically and geochemically correlated with the sub-rounded meta-granitic pebble DPK46 observed in the matrix of diamictites that crop out in the ET as previously documented by Gürsu (2015) and Gürsu et al. (2017) (see Table 5.1). The similarity in their crystallization ages and their island arc tectonic environment (Figure 5.1) may indicate that the granitic pebble DPK46 might be eroded from the meta-granitoids in the Sa'al Metamorphic Complex during the Late Ordovician glacial event. However negative $\epsilon\text{Nd}_{(T)}$ ratio of DPK46 (-14.6) is not supportive for the arc related source as observed in the Sa'al Metamorphic Complex.

Calc-alkaline to tholeiitic Cryogenian magmatism has been reported from the Feiran-Solaf Metamorphic complex, which characterizes the second episode of island arc magmatism in the Sinai Peninsula (details in El-Shafei and Kusky, 2003; Abu El-Enen and Whitehouse, 2013; Eyal et al., 2014; Gürsu et al., 2017). This stage of magmatism lasted between 804 - 785 Ma and the granitoids mainly mafic-intermediate intrusives, evolved in the Elat-Feiran island arc system as stated by these researchers. The 789.5 ± 3.7 Ma aged probable island arc granitic pebble DPK17A in the ET might be comparable to the meta-granitoids in the FSMC based on similar geochronological ages and their arc geochemical signatures as previously reported by Gürsu (2015) and Gürsu et al. (2017) (see Table 5.1; Figure 5.1). The terminal stage of island arc formation in the Sinai Peninsula occurred between 0.79 - 0.73 Ga though it ended around 0.60 Ga elsewhere in the ANS (e.g., Eyal et al., 2014; Eliwa et al., 2014; Ali et al., 2015). During this time span, tonalitic/granodioritic rocks intruded the Elat (Taba) - Feiran island arc system (e.g., Eliwa et al., 2014; Ali et al., 2015). The tonalitic gneisses were dated as 719 ± 10 Ma, 725 ± 9.0 Ma whilst the granodioritic gneisses evolved around 720 ± 7.0 Ma and 744 ± 10 Ma in Wadi Beitan and Gabal Dara, Northern part of the Eastern Desert of Egypt (Eliwa et al., 2014; Ali et al., 2015). Both geochronological age and island arc geochemical signature (Figure 5.1) of the 717.5 ± 8.0 Ma dated sub-rounded meta-granitic pebble DPK30 from the Feke-Ceralan area in the ET suggest a genetic relation with the tonalitic and granodioritic rocks in the Wadi Beitan and Gabal Dara areas in the Eastern Desert of Egypt as declared before by Gürsu (2015) and Gürsu et al. (2017). The positive $\epsilon\text{Nd}_{(T)}$ values of the equivalent tonalitic and granodioritic

gneisses presented by Eliwa et al. (2014) and Ali et al. (2015) are comparable with that of the sample DPK30 further constraining their genetic similarity.

The oldest alkaline/peralkaline mafic granitic intrusions in the Katerina Ring Complex are dated as 596 ± 6.0 Ma, 593 ± 2 Ma and 602 ± 4.0 Ma and between 605–593 Ma in the northern part of the Eastern Desert of Egypt (details in Katzir et al., 2007; Moussa et al., 2008; Eyal et al., 2010; Moreno et al., 2012, 2014; Moghazi et al., 2015; Ali et al., 2016). These geochronological ages are similar to the recent dating of alkali granitic intrusions as 596 ± 3.0 Ma in the Katerina Ring Complex and at 600 ± 3.0 Ma in Gabal Dara in the Northern segment of the Eastern Desert of Egypt as previously mentioned by Gürsu (2015) and Gürsu et al. (2017). Their geochronological ages and A-type geochemical signatures can be correlated with the 598.4 ± 7.5 Ma dated sub-rounded granitic pebble DPK72 (Table 5.1; Figure 5.1). The observed similarities in the crystallization ages and A-type geochemical signatures of the equivalent rocks with the sample DPK72 may suggest that the granitic pebble DPK72 might have been derived from these Neoproterozoic meta-granitic rocks in the Sinai Peninsula prior to the Late Ordovician (Hirnantian) glacial event (detail in Gürsu et al., 2017).

The majority of magmatic rocks in the ANS are mostly of alkali granitic sources and evolved in the Hijaz and Asir terranes between 0.68 – 0.59 Ga (Duyverman et al., 1982; Cooper et al., 1979; Johnson et al., 2001; Moghazi et al., 2015). In the Sinai Peninsula, alkaline magmatism mainly occurred between 578 to 602 Ma (e.g., Kröner et al., 1990; Kolodner et al., 2006; Ali et al., 2009; Be'eri-Shlevin et al., 2009; Moreno et al., 2012; Abu El-Enen and Whitehouse, 2013). The A-type monzogranitic rocks derived from mafic sources previously reported by Be'eri-Shlevin et al. (2009) and Eyal et al. (2010) crystallized around 578 ± 8.0 Ma in Iqna and 582 ± 6.0 Ma in the Katerina Ring Complex. The dated ages of these monzogranitic intrusives in the Iqna and Katerina Ring Complex of the Sinai Peninsula can be well correlated with the monzogranitic pebble DPK44 (576.5 ± 5.3 Ma) in Feke-Gokmenler area of the ET as previously reported by Gürsu, (2015) and Gürsu et al. (2017) (see Table 5.1). This genetic correlation is supported by the A-type geochemical signatures (Figure 5.1) of the equivalent rocks and the sample DPK44 indicating that the pebble might have evolved from alkali granitic rocks in

the Iqna and Katerina Ring Complex before 0.58 Ga as previously declared by Gürsu (2015), Gürsu et al. (2017).

Prior to the end of 635 Ma in the Sinai Peninsula, there was a major metamorphic quiescence with magmatic activities in major shear zones including Nugrus/Najd Shear zone in the Nubian shield and the Qazaz-Ajjaj Shear zone in the Arabian Shield of the ANS only active between 630-570 Ma (Moghazi et al., 2004; Johnson et al., 2011; Meyer et al., 2014; Hassan et al., 2016; Gürsu et al., 2017). The stage of magmatism in these areas was accompanied by minor and major deformational phases with the minor deformation associated with A-type granites in the Qazaz-Ajjaj Shear Zone whilst the major deformation occurred in cataclastic rocks in the Nugrus/Najd Shear Zone (Be'eri-Shlevin et al., 2009). The less-deformed A-type granitoids documented in Qazaz-Ajjaj Shear Zone were dated as 575 ± 10 , 581 ± 4.0 and 584 ± 3.0 Ma (see Table 5.1; Kennedy et al., 2011 and Hassan et al., 2016). However, the highly deformed granitoids known as Nakhil granitoids cooled around 578 ± 15 Ma and 594 ± 12 in the Eastern Desert of the Nubian Shield along the Nugrus/Najd Shear Zone (details in Sultan et al., 1990; Moghazi et al., 2004). The granite protomylonitic sample (DPK27) in Feke-Ceralan area of the ET previously dated as 576.7 ± 5.7 Ma by Gürsu (2015) geochronologically correlates well with the A-type granitic intrusives derived from mafic sources along the Qazaz-Ajjaj and Nugrus/Najd Shear Zones (see Table 5.1). However, positive $\varepsilon_{\text{Nd(T)}}$ ratio of Nakhil granitoids (Sultan et al., 1990) restricts the provenance of the sample DPK27 as in the Eastern Desert and is still a mystery of its provenance.

In all, the geochronological ages and geotectonic environments of the island arc granitoids and A-type granitoids in the Sinai Peninsula and the North Eastern Desert, may be the provenance of the studied individual granitic pebbles and corroborate well with the previous findings of Gürsu (2015) and Gürsu et al. (2017). The geochronological ages and tectonic environments of the equivalent granitoids cropped out in the Sinai Peninsula and the North Eastern Desert including those of the studied individual granitic pebbles found in the matrix of the diamictites in the TAP are presented in Table 5.1.

Table 5.1. Summary of equivalent rock units from the Sinai Peninsula and North Eastern Desert of the Arabian Nubian Shield

Granitic Pebble (TAP)	Crystallization Ages (Ma)	Tectonic features (in this study)	Provenance of the studied granitic pebbles (Northern margin of Gondwana-Sinai Peninsula)	Crystallization Ages (Ma)	Tectonic Environment of the Equivalent granitoids	References
DPK17A	789.5±3.7	Island Arc	Feiran Solaf Metamorphic Complex	804.8±4.7 785.0±7.0 and 792±7.0	Island Arc	El-Shafei and Kusky (2003), Abu El-Enen and Whitehouse (2013), Eyal et al. (2014)
DPK27	576.7±5.7	A-type	Mylonitized granite in Qazaz-Ajjaj Shear zone	584±3.0	A-type	Hassan et al. (2016)
			Leucogranites in Nugrus/Najd Shear zone	594±12	A-type	Moghazi et al. (2004)
			Nakhil granitoids	578±15	A-type	Sultan et al. (1990)

Table 5.1 (continuation)

DPK30	717.5±8.0	Island Arc	Elat (Taba) Metamorphic Complex - Tonalitic gneiss in Wadi Beitan	719±10	Island Arc	Ali et al. (2015)
			Elat (Taba) Metamorphic Complex - Granodioritic gneiss in Wadi Beitan	725±9.0	Island Arc	Ali et al. (2015)
			Elat (Taba) Metamorphic Complex- Granodiorites in Gabal Dara	720±7.0	Island Arc	Eliwa et al. (2014)
DPK44	576.5±5.3	A-type	Syenogranites in Katharina Ring Complex	582±6.0	A-type	Be'eri-Shlevin et al. (2009)
			Syenogranites in Iqna	578±8.0	A-type	Be'eri-Shlevin et al. (2009)
			Alkali feldspar granites in Katerina Ring Complex	583±6.0	A-type	Eyal et al. (2010)
DPK46	964.6±4.6	Island Arc	Agramyia formation, Sa'al Metamorphic Complex	962±10 Ma - 977±7.0 Ma	Island Arc	Eyal et al. (2014)

Table 5.1 (continuation)

DPK72	598.4±7.5		Syenogranites of the Katerina Pluton	596±6.0 593±2.0	A-type	Katzir et al. (2007)
			Peralkaline granites in the Katerina Ring Complex	602±4.0	A-type	Moreno et al. (2014)
			Iqna granite	594±6.0	A-type	Eyal et al. (2010)
			Alkali feldspar granite in Gabal Dara	600±3.0	A-type	Eliwa et al. (2014)
			Alkali granite in Katerina Ring Complex	596±3.0	A-type	Eliwa et al. (2014)
			Aluminous Alkali feldspar granites in Katerina Ring Complex	605±3.0	A-type	Moreno et al. (2012; 2014)
			Gattar (North Eastern Desert)	595±3.0	A-type	Ali et al. (2016)
			Abu Harba (North Eastern Desert)	597±7.0	A-type	Ali et al. (2016)
			Missikat (North Eastern Desert)	593±16	A-type	Ali et al. (2016)
			Jabal Sayad Complex (Hijaz)	593±1	A-type	Moghazi et al. (2015)

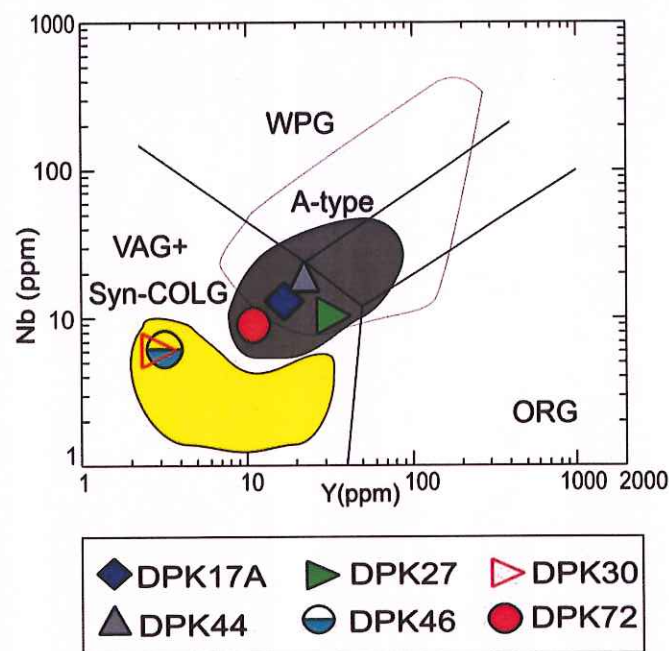


Figure 5.1. Nb vs Y Tectonic discrimination diagram of the six granitic pebbles correlated with limited data of equivalent rocks in the Sinai Peninsula and the North Eastern Desert (after Pearce et al., 1984; A-type source data from Whalen et al., 1987 and Eby, 1992). The yellow circle illustrates the range of island arc granitoids in the Sinai Peninsula with the island arc granitic pebbles in this study and the dark-grey circle denotes the range of A-type granites in the Sinai Peninsula with the A-type granitic pebbles in the TAP. The data of equivalent rocks is taken from (Moghazi et al., 2004; Katzir et al., 2007; Be'eri-Shlevin et al., 2009; Eyal et al., 2009; Abu El-Enen and Whitehouse, 2013; Eliwa et al., 2014; Hassan et al., 2016; Moreno et al., 2012, 2014; Ali et al., 2015)

5.2. Flow Directions of the Ice Sheets During the Late Ordovician Glaciation

From the geochronological, geochemical and isotopic data alongside the tectonic settings of the individual granitic pebbles in the matrix of diamictites in the TAP, it is evident that they might have evolved from Late Neoproterozoic granitoids in the Sinai Peninsula and the Eastern Desert of the Nubian Shield as previously documented in detail by Gürsu (2015) and Gürsu et al. (2017).

Based on their new U-Pb geochronological data, the main transport directions of the ice flows were presented by Gürsu (2015) and Gürsu et al. (2017). They propose the

northwestern part of the Arabian -Nubian Shield as their major provenance areas during the Late Ordovician glaciation in the CT and ET (Figure 5.2). Based on their model, the glacial sediments including fragments of sedimentary rocks (lonestones) and granitic pebbles in ET and CT of TAP might have been eroded and then transported by Late Ordovician Ice Sheets from the Eastern Desert, Sinai Peninsula and northwestern Arabian Shield (Figure 5.2).

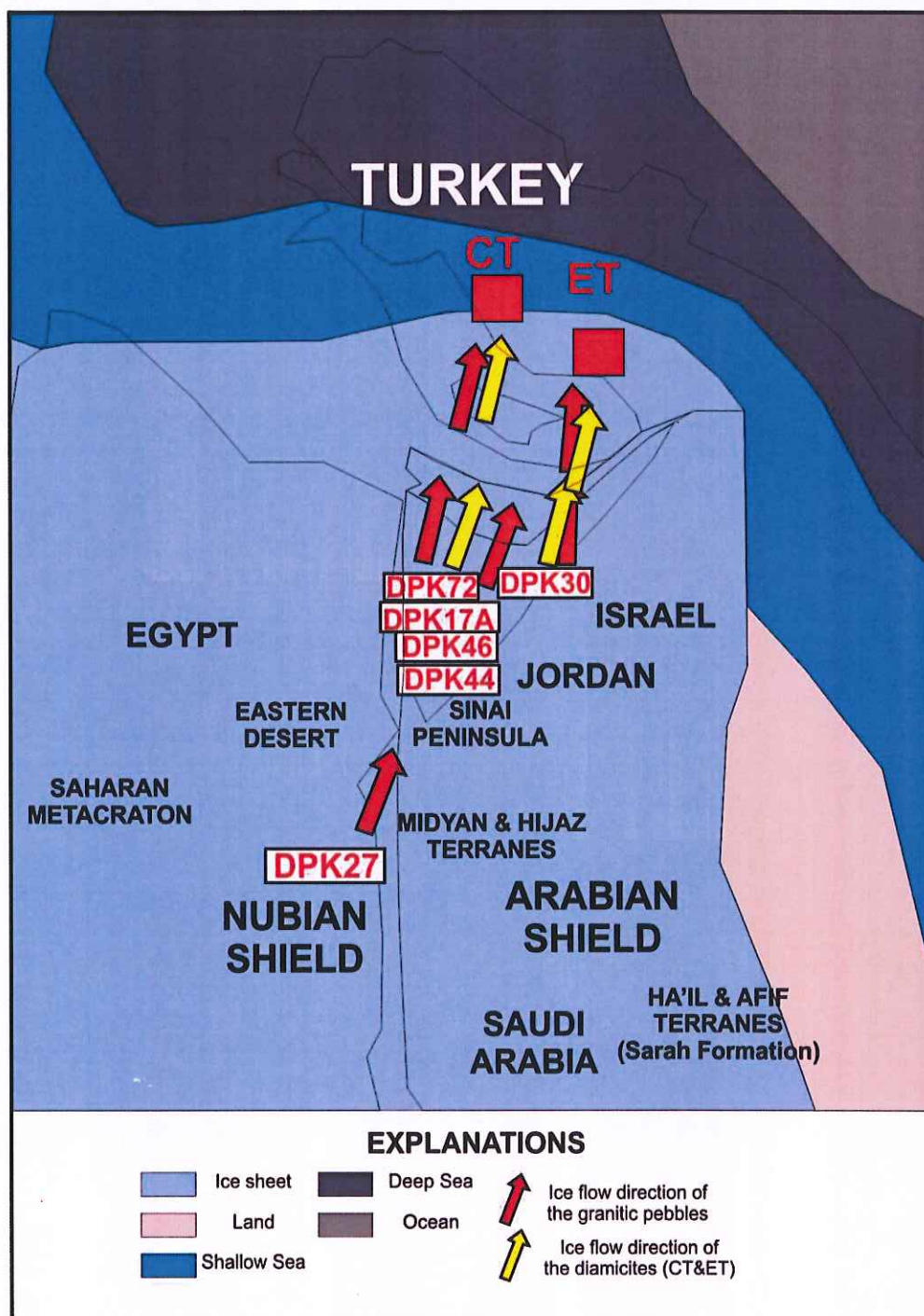


Figure 5.2. Schematic reconstruction of the flow directions of the ice sheets during the Late Ordovician glaciation (taken from Gürsu et al., 2017)

6. CONCLUSIONS AND RECOMMENDATION

The ice-rafted granitic pebbles in the Late Ordovician (Hirnantian) glacial units cropped out in the TAP in Turkey are mainly composed of granitic dropstones in the matrices of sandy/muddy diamictites. Gürsu (2015) and Gürsu et al. (2017) dated the individual granitic pebbles as 576.5 ± 3.3 Ma (DPK44), 576.7 ± 5.7 Ma (DPK27), 598.4 ± 7.5 Ma (DPK72), 717.5 ± 8.0 Ma (DPK30), 789.5 ± 3.7 Ma (DPK17A) and 964.6 ± 4.6 Ma (DPK46) and proposed a provenance for the individual granitic pebbles. In this thesis, their provenance was checked by re-evaluating the geochemical data with Rb-Sr, Nd-Sm isotopes and to correlate them with available data of equivalent rock units that are exposed in the Sinai Peninsula representing the northern margin of Gondwana.

The following conclusions are drawn from this thesis;

- Geochemically, all the granitic pebbles belong to the sub-alkaline series and display alkaline/calcalkaline affinity.
- The petrogenetic features of the granitic pebbles show two groups of relations; Group A (DPK17A, DPK30, DPK46) and Group B (DPK27, DPK44, DPK72).
- In the N-MORB normalized multi-element diagrams, one sample (DPK27) belonging to Group B and two samples (DPK30 and DPK46) of Group A display depletion in Nb, La, Ce, Nd elements and HFSE (U, Th, Zr, Hf). They have low REE abundance and only slight enrichment observed in LREE for DPK27. One sample (DPK17A) of Group A together with two other Group B samples (DPK44 and DPK72) are depleted in Nb, Ti elements and display enrichment in LREE/HREE ratios.

- The positive $\epsilon\text{Nd}_{(T)}$ data (+0.8 to +3.7) of Group A samples except DPK46 imply arc-related sources for their genesis. The negative $\epsilon\text{Nd}_{(T)}$ (changing from -2.8 to -8.4) of Group B samples suggest A-type source characteristics for their genesis. The unexpected highly evolved $\epsilon\text{Nd}_{(T)}$ data (-14.6) for DPK46 imply crustal-dominant source characteristics, although its geochemical patterns are similar to mafic-dominated sources.
- The geochemical, isotopic data and petrogenetic features suggest that Group A samples might have been derived from arc-related sources, whereas Group B samples might have been derived from A-type granitic sources.
- The geochemical, isotopic signatures and their tectonic settings combined with previously dated U-Pb ages of the individual granitic pebbles show that they might have been derived from equivalent Late Neoproterozoic granitoids/meta-granitic rocks cropped out in the Sinai Peninsula (Sa'al Metamorphic Complex and Feiran-Solaf Metamorphic Complex), in the Eastern Desert of Egypt and support the findings of Gürsu (2015) and Gürsu et al. (2017).

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Speaking			X
Understanding			X
Reading			X
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Writing			X
Speaking		X	
Understanding		X	
Reading			X

Scientific Researches

1. Gürsu S., Möeller A., Usta D., Koksall S., Ates S., **Sunkari E.D.**, Goncuoglu M.C. (2017) LA-ICP-MS U-Pb dating of detrital and magmatic zircons of glacial diamictites and pebbles in Late Ordovician sediments of the Taurides and Southeast Anatolian Autochthone Belt, Turkey: Indications for their Arabian-Nubian provenance, *The Journal of Geology*, Vol. 125: 165-202 DOI: 10.1086/690199.
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Hobbies

1. Gymnastics
2. Cooking