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GLACIO-MECHANICAL EFFECTS AROUND ISPARTA PLAIN (SW TURKEY): EVIDENCE FOR LOWER-ALTITUDE GLACIAL EXTENT?

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Abstract: Past glacial loading and unloading cycles left pronounced effects on the bedrock over which they acted. These effects include large-scale ice-push pressure ridges, cirques, and glacio-mechanical effects such as pressuring the near surface rocks into the base rocks, creation of grooves and striae on the surface of the rocks, abrasion of the base rocks, creating blocks and chips. In this study, glacial effects from Isparta Plain of the Eastern Mediterranean region are presented. The Isparta Plain has been overlooked in the context of glacio-tectonics and glacio-mechanics so far; largely because of its geographic location, and its altitude (1500m). However, field evidence presented and discussed in this study indicates glacial events in the area had occurred. Decoding such evidence has significant implications in many areas of engineering geology and environment; including foundation design, mineral exploration and natural hazard assessment and control.

Keywords: Glaciation, Geomorphology, Glaciomechanical effects, Rock Mechanics, Isparta, Turkey

1. INTRODUCTION

Studying landforms and interpreting the cause mechanism for their occurrence is an important endeavor in earth science and engineering. Glaciation and glacial movements change land forms by exerting significant forces on earth's crust (Schumacher et al., 2013). Some of these changes are observable on land surface as glaciomechanical effects. Glaciomechanical effects include all the effects resulting from the forces generated as a result of glacial occurrence, glacial movements, and post-glacial uplift. Recognizing these effects in the field helps to understand the overall geo-setting of the area correctly, and have significant implications when designing engineering facilities, understanding a range of issues including the climatic issues, geodynamics of regions, slope stability, oil exploration, and groundwater investigations.

The purpose of this study is to investigate glacio-mechanical effects in Isparta Plain of Southwestern Turkey (Fig. 1) and highlight their role in the formation of the landscape in and around the plain. Although focus is on the Isparta Plain, in general, most of small-scale features observed and reported here, such as striae, are from Söbü Hill located on the northwest of the plain. The method of investigation is based on collecting field evidence of glacial presence, evaluating the evidence in terms of ice mechanics and relevant literature, as well as relating the evidence with similar occurrences elsewhere where both the presence and effects of glaciation are well established. As a result, it is hypothesized that glaciation affected the morphology and stress regime of the Isparta Plain. The study is the first in recognizing and reporting field evidence of glaciation in Isparta Plain and its vicinity which has been almost customarily described as a subsidence basin created by an extensional stress regime prevalent in the Eastern Mediterranean region (Karaman, 1988; Totic, 2009; Kalyoncuoglu, 2015).

2. THE STUDY AREA

The Isparta Plain is surrounded by West Taurus Mountains with unusually well-rounded tops and gently dipping wide valleys with smooth courses. The modern-age climate in Isparta is warm and temperate, with winters being rainier than the summers. The Köppen-Geiger climate classification is Csa, the temperature averages 11.9°C, and the average yearly rainfall is 537 mm (Fig. 2).

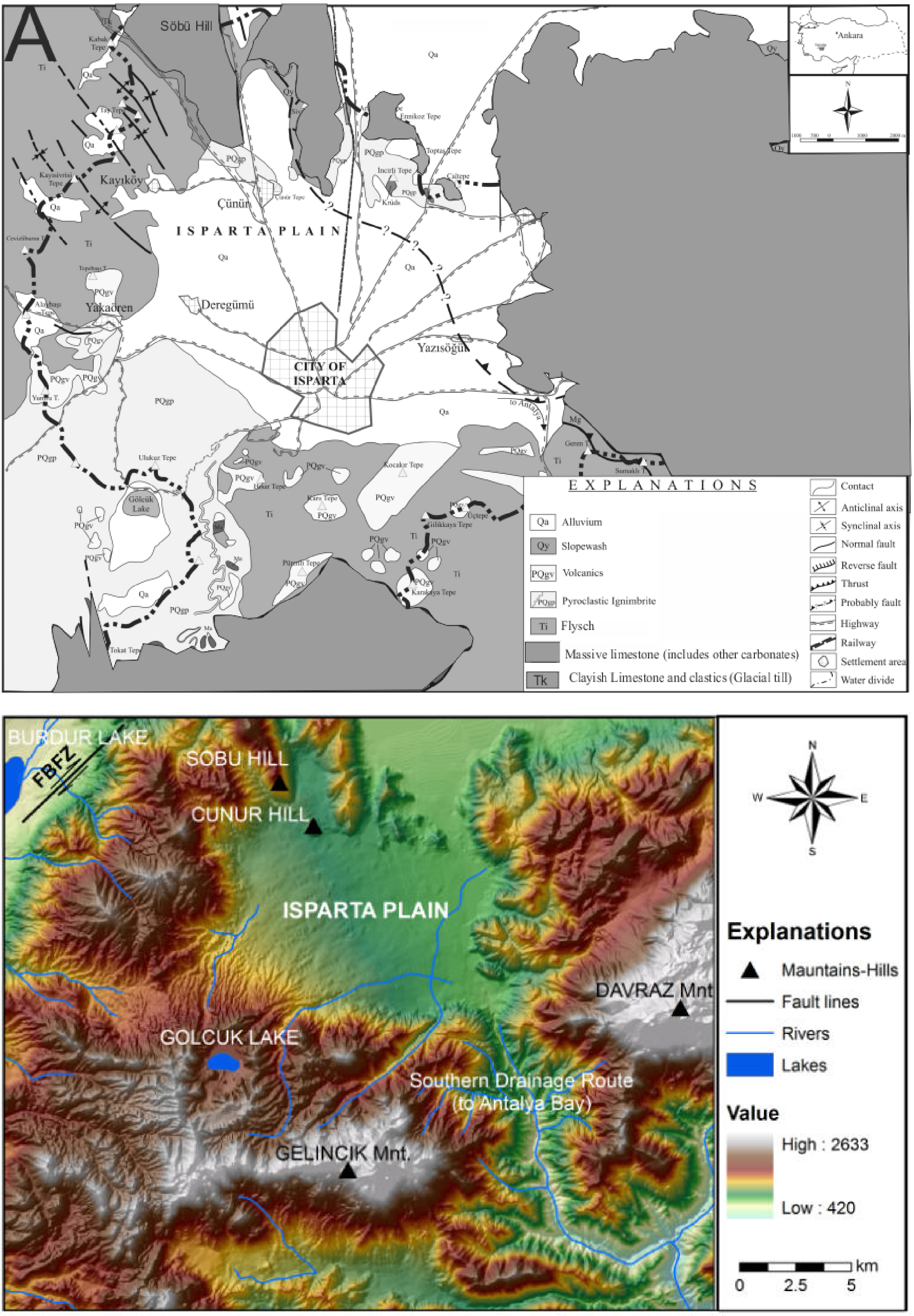

Figure 1. Geological map (revised from Demer 2008, A) and morphological features of the Isparta Plain (B).

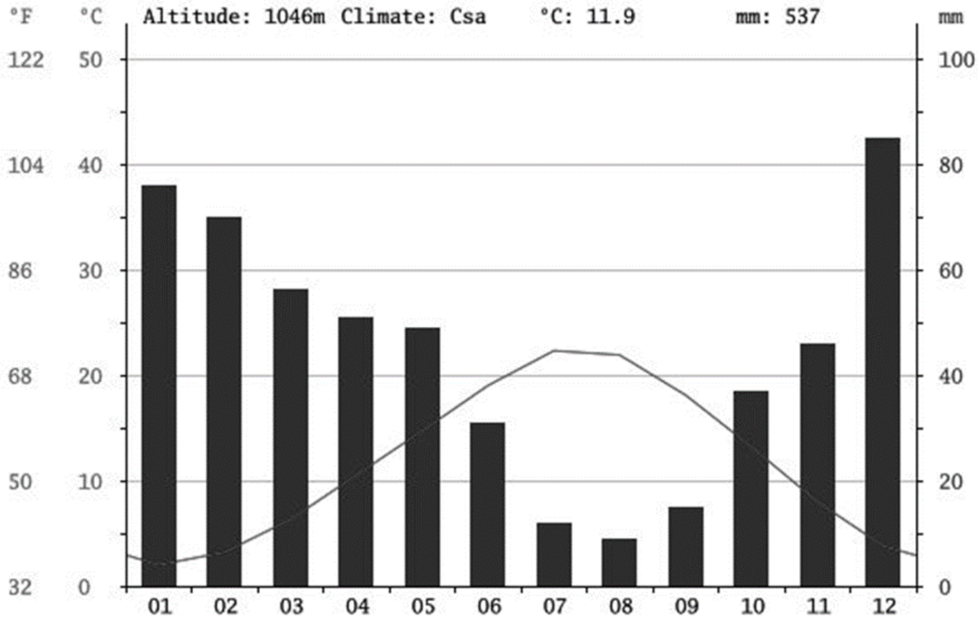

Figure 2. Current climate in Isparta Plain and vicinity (http://en.climate-data.org/location/2032/)

It has no present-day glaciers or permanent snow patches. Average The snow generally survives until August on the nearby Davraz Mountain (Elev. 2635m). The present direction of groundwater flow is generally from west to east (Karagüzel & Irlayıcı, 1998). The natural discharge route follows a southwesterly course which ends at about 100km away, at the Antalya Bay of Mediterranean, and northwesterly route which end up at the Burdur Lake.

Studies to date indicate the Isparta Plain was affected from at least two major episodes of deformation. An earlier phase, probably latest Cretaceous in age, resulted in the thrusting of deep-water sediments over shelf-edge units which originally lay to the northeast. Subsequent southwest-western folding and thrusting in the Tertiary era locally reversed the earlier stacking order (Waldron, 1984). The dominant lithology (Fig. 1) is ophiolitic rocks overlain by Jurassic-Cretaceous carbonate rocks in Isparta Plain. Eocene flysch, consisting of a sequence of sandstone, mudstone, claystone, and discontinuous limestone is exposed to the west of the Plain (Kayıköy formation). Miocene flysch consisting of a sequence of conglomerate, sandstone, claystone, and mudstone is exposed to south of Isparta (Ağlasun Formation). Plio-Quaternary andesite, tuff, pumice, and agglomerate can also be located in the south. Flat and pitted areas are covered with a Quaternary alluvium (Mutlutürk & Karagüzel, 2007; Karagüzel & Irlayıcı, 1998; Totic 2009). The area has been studied extensively for its volcanic (Özgür et al., 1990, 2008; Yağmurlu et al., 1997; Kazancı & Karaman 1988; Platevoet et al., 2008) and tectonic (Över et al., 2013) activities.

In these studies Isparta area is often amalgamated to the Burdur region, which is 50 km to the west of Isparta, most likely due to importance of earthquakes in that area and due to the well-known Fethiye-Burdur Fault Zone (FBFZ) (Barka & Reilinger 1997; Bozcu et al., 2007) owing to its potential for generating earthquakes. Seven earthquakes have been recorded over the last 90 years in the region between Burdur and Fethiye whose magnitudes are between 5.0 and 7.0 (Erdoğan et al., 2008). Because the Burdur area experienced several earthquakes, the earthquake based interpretations of geological structures is naturally the first thing to consider in studies related to the area. Över et al., (2013) studied the Plio-Quaternary to present day stress regime in the Burdur Basin. The authors state that "the NW–SE extension is probably responsible for the formation of the Burdur Basin during Plio-Quaternary time. This extension, which is probably caused by slab-pull force due to the subduction process along the Cyprus arc, produces a dominant normal motion along the FBFZ. The extensional stress regime ($\sigma_1=\sigma_v$) characterized by a NW–SE (N 136°E) σ_3 axis. Thus, the extensional stress regime deduced from inversions of focal mechanisms of earthquakes confirms that the present-day stress state is extensional in the Burdur Basin." There is some evidence (Temiz et al., 1997; Waelkens et al., 2000) that the extension also started during Pliocene in Burdura and Isparta region.

The glacial past of the Isparta Plain and its vicinity was first indicated by Erol (1973) who noted the existence of structures resembling to those carved by the ice wedges at elevations up to 980m around the Burdur Lake near the study area (Fig. 1). Erol (1973) noted that the wedge is "filled with pebbles, earth and sand". However, İzbırak (1973) commented that the occurrence of cirques at that elevation was not expected and the wedge formation in this locality was probably related to an earthquake generated fissure." Further research was recommended by Erol (1973). Such research evidently was not carried to date (Mutlutürk, pers. Com., 2013). Elsewhere in the West Taurus Mountains, in the Muslu Valley of Mt. Sandıras, lateral moraines and ice-abraded bedrock were reported at 1400 m. a.s.l. (Zahno et al., 2009; Sarıkaya et al., 2011). Latest research also shows that in latest Pleistocene or earliest Holocene, glaciers were extraordinarily extensive for that time with snow lines lower than today by more than 1400 meters (Zreda et al., 2011) in Western Turkey. Söbü Hill is about 1500 m, and the nearby Davraz Mountain is about 2635m. As well, cosmogenic exposure ages combined with glacier modelling support a local last glacier maximum (LGM) characterized by cold and wet conditions coinciding with the global LGM in the same general area (Hughes & Woodward, 2008). Thus, the occurrence of quaternary glaciation in the area's past is quite plausible from these perspectives alone. However, this study concerns with the field evidence of glaciation in the study area.

As a further note, the glacial sediments from the Isparta region must have partly ended in the Antalya Bay through the southern discharge route. Tezcan & Okyar (2006) report significant sea level changes and extensive presence of Late Quaternary deposits in the shelf of Antalya Bay. This provides further indirect evidence for glaciation/deglaciation in the general area. According to Sarıkaya et al., (2011), LGM in the western Taurus occurred around 20.4±1.3 ka.

The scope of this study encompasses the Isparta plain in general. The Söbü Hill in the plain is particularly (Fig. 3) the focus of detailed investigation for the small-scale glacial effects such as striae. All of the glacio-mechanical features described, with the exception of cirques and stone chips, which are located further east on the eastern flank of the Isparta Plain and on the flatter plains respectively, are observable on the flanks of the Söbü Hill (western perimeter of the Isparta Plain). The hill rises to about 1050m asl from the its lower end on the Western edge of Süleyman Demirel University (SDU) Campus, just outside the office of the department of civil works, and reaches to about 1400m with a gentle and uniform slope which is approximately 12 degrees on its southern flank. Geologically, it consists of upper-creteaceous – aged massive limestones, locally known as the Söbüdağ limestones (Sarıiz 1985, Özkan 1997). Its thickness is undetermined as it extends to depth, and its eastern border has a normal fault with the Isparta Plain. This fault line is invisible and studies are ongoing to determine characteristics of this fault (Mutlutürk 2013).

3. METHOD AND RESULTS

Isparta Plain and its vicinity are explored for field evidence of past glaciations. The evidence includes presence of multitude of glacial and glacio-mechanical features which can be grouped as: large scale features such as smooth hill tops and well-formed- smooth and wide valleys, cirques, ice flow channels and ice-margin flow channels, near surface blocks of abraided slabs being pressed into the base rocks (giving a tiling appearance), grooves on base rocks, striae, glacial till, blocks and chips of rock – following an order from larger- to smaller-sized features. These features are discovered, described, analyzed, and compared to glaciation literature as follows.

3.1. Cirques

The landscape surrounding the Isparta plain has many cirques. These armchair-shaped bowls (Flint 1971; Graf 1974), or hollows formed at glacier sources, are open downstream but bounded upstream by the crest of a steep slope (headwall) which is arcuate in plan around a more gently-sloping floor. At least part of the floor should be gentler than 20° and some of the headwall should be steeper than the main angles of talus (31–36°) (Evans & Cox 1974; Evans & Mindrescu 2014). Thus a cirque is characterized by measuring its size, orientation, length/width ratio (L/W), and length/height ratio (L/H), slope of its headwall and the slope of its floor (Graf 1976; Hughes et al., 2007). An example to well-developed cirque with its dimensional measurements made from a detailed topographic map are given in figure 4. In the upper parts of the crest there are areas steeper than 30 degrees, but in average the headwall has a slope of 25 degrees. Other examples of cirques can be observed along the path climbing Mt Davraz.

3.2. Blocks of abraided slabs being pressed into the base rocks-tiling appearance on surface

The Isparta Plain is flanked by smooth hills covered by Mesozoic limestone bedrocks. At most locations on these hills, surface rocks are compressed into the base bedrocks rocks, as a result compressive stress due to glacial load (Ates et al., 1997; Ber 2009), giving an appearance of laid-out flooring tiles (Fig. 5).

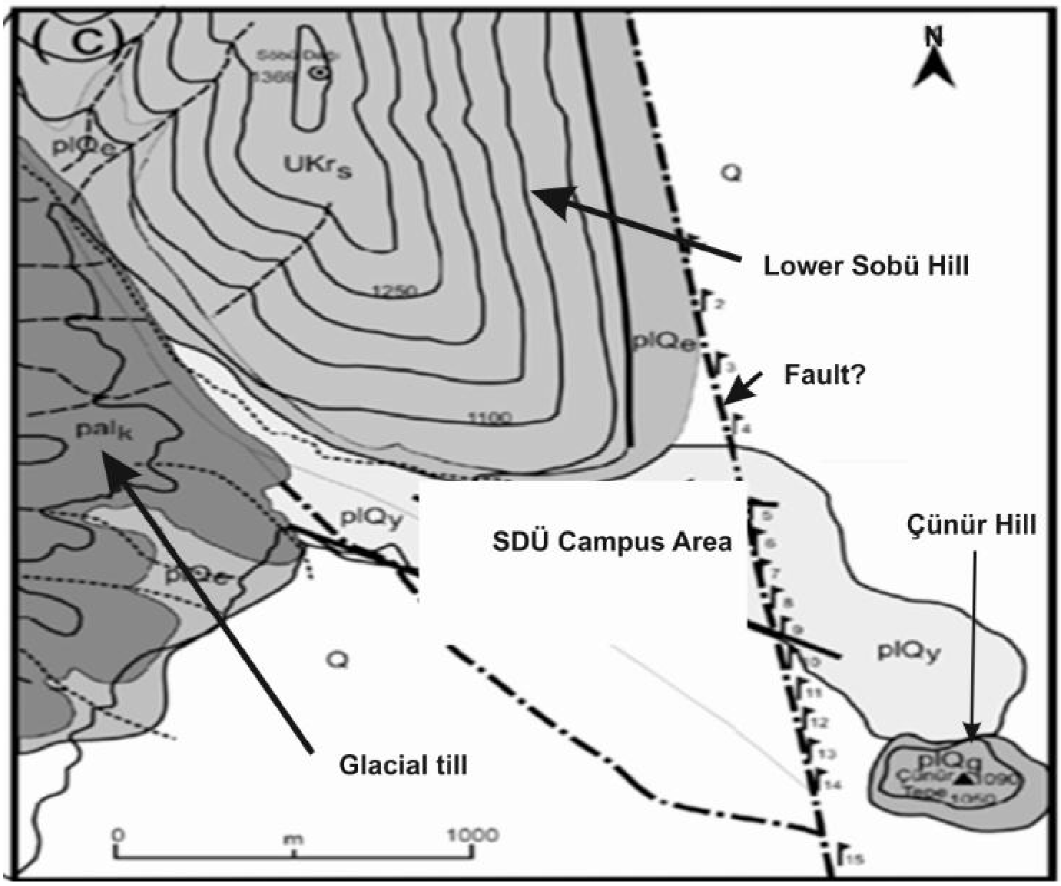

Figure 3. Close-up of geological and topographical features of Sobi Hill (Modified from Kanbur et al., 2008). UKrs: Upper Cretaceous carbonates-Söbüdağ limestone, palk: Paleogene clastics -Kayıköy formation, plQg: Plio: Quaternary Gölcük Volcanics, plQy.: Plio-Quaternary deposits, plQe: Plio-Quaternary slope deposits, Q: Quaternary plain deposits.

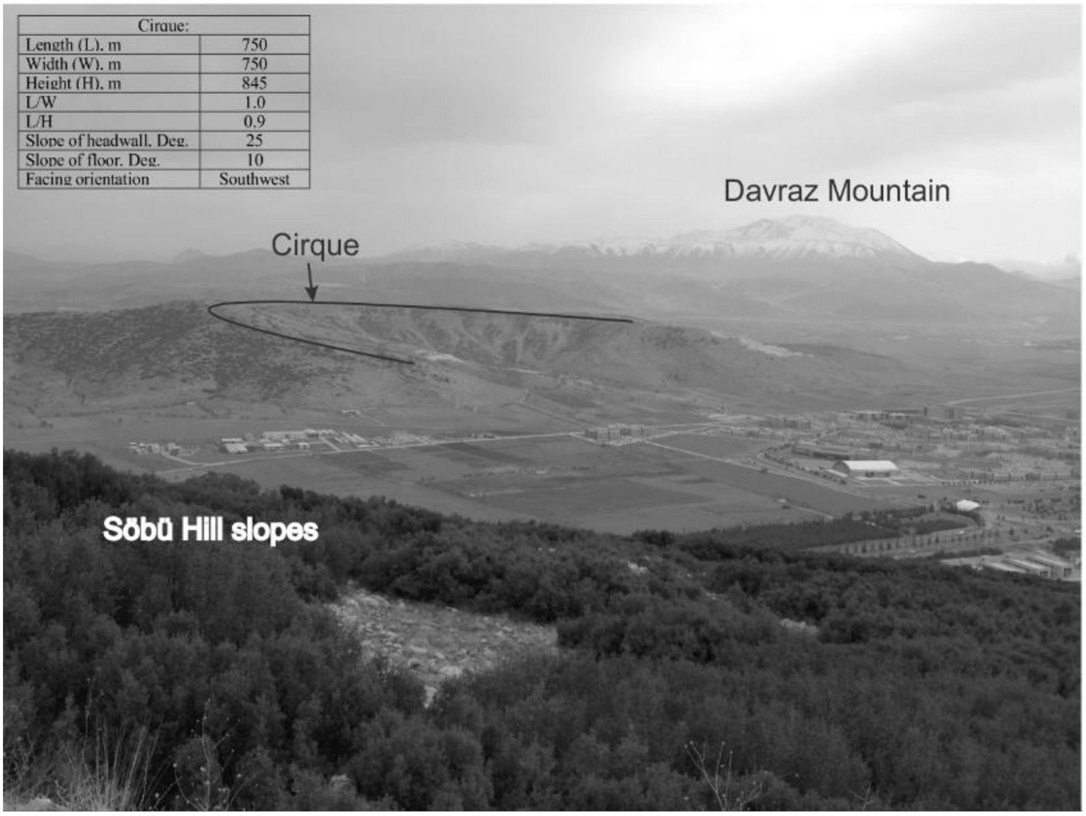

Figure 4. Picture of a cirque facing southwest in Isparta Plain (taken from Söbü Hill and looking east to Davraz Mountain).

There are multitudes of such tiling locations around the plain. Signs of rock deformation under compressive stress are observed on the Söbü Hill as well. Here, blocks of tiles are pressed well into the base rock, and have a flattened surface. Size of individual blocks varies, but 0.5 by 0.5m is common. The surface of tiles, especially at the joint locations, is covered by smaller stone blocks of usually about 5cm.

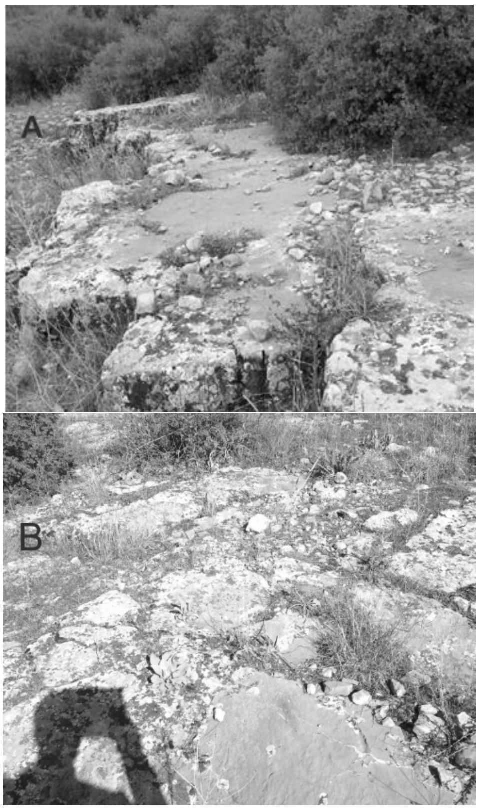

Figure 5. Examples of blocks of rock slabs pressed into the base rocks-tiling appearance

3.3. Ice-margin channels

On Söbü Hill and on other hills around the plain, the actions of glaciation created channels that give an appearance resembling steps on a slope, or wave-like appearance perpendicular to presumed direction of ice movement (Fig 6a). There, channels are measured 0.3m-3m apart and their frequency of occurrence is about 3-30/10m. These structures appear circumferentially around the Isparta Plain, and are not resulted from structurally-influenced weathering. The occurrence of such channels in the glaciated areas is a well-known phenomenon, and their presence is used to locate position of former ice margin and changes in its location. According to Kleman (1994) they are most coherent system of linear features formed during de-glaciation period.


Figure 6. Ice-margin channels on the slope of Söbi Hill

3.4. Grooves on base rocks, and block formation

Glacial groves are also commonly observed in the study area. They appear on base rock larger in width and depths compared to stria and occur in a direction parallel to the direction of ice movement (Fig. 7). On Söbü Hill, grooves vary in length and the trough depth. Groove in figure 7A has a trough depth about 20cm. In some locations grooves deepened through the joint locations and form large elongated blocks (Fig. 7B). These blocks were further downsized by action of ice and resulted in blocks smaller size as shown in figure 8.

The occurrence of grooves is indication that ice contained significant amount of basal debris, experienced basal melting and a high component of flow was achieved through basal sliding, exerted moderate level of effective normal pressure, and continued to transport rock debris towards the bed (Glasser & Bennett 2004). The grooves pictured in Figure 7 are only tens of meters away from start of the glacial till at the end of Söbü Hill slope.

3.5. Blocks

Fracturing in rock, due to differential stress generated by the presence and action of ice sheet, such as water pressure fluctuations at the base of glacier, establishes the starting point of block formation process. Pressure differences inducing temperature changes at the base may aid separation of rock and formation of blocks. Some of bocks get in to the mass of ice and get rounded in debris as ice moves. Examples of various-sized blocks from the study area are given in figure 8. Their size ranges from 5 to 15cm. Figure 7, especially figure 8A represent one of the best and most convincing glacial evidence in the area.

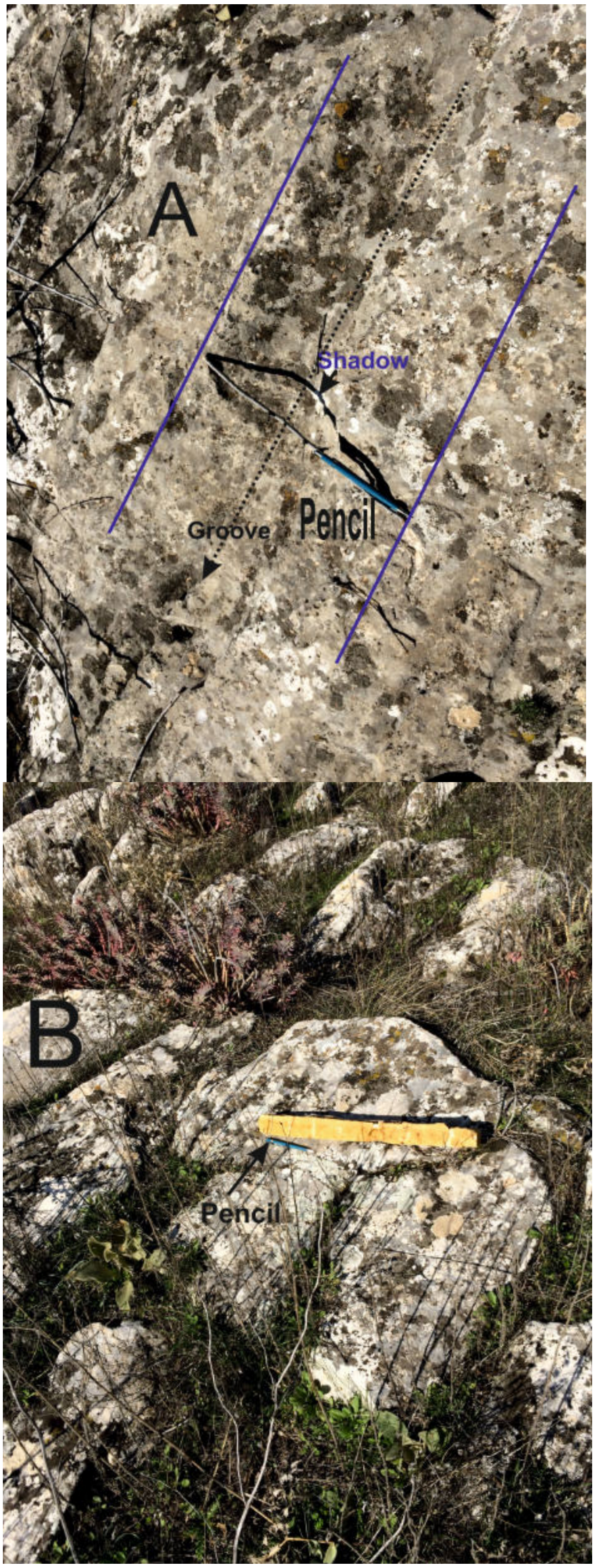

Figure 7. An example to observed groves (A). Note the shadow indicating depth of the groove and subsequent block development (B).

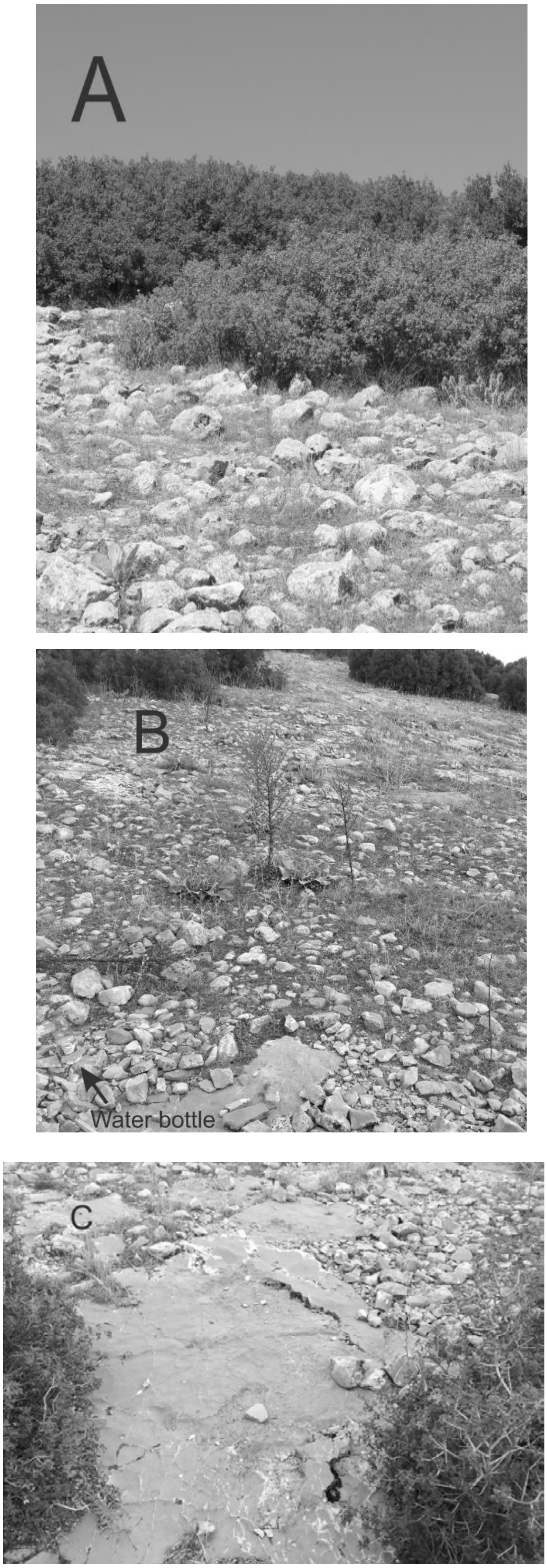

Figure 8 (A;B;C). Various sized (5-15cm) blocks on Söbü Hill.

3.6. Striae

Striae are multiple lines or scratches on a rock surface produced by the process of glacial abrasion as debris or clasts entrained in basal ice are dragged over rock acting as scratching tools. Individual striae are usually no more than a few millimeters in depth, but can be continuous over distances of several metres. The elevation and aspect of cirques are commonly used in paleoclimatic reconstruction because these are measures of the former regional snow line in an area (Evans 1977 and 1999; Glasser & Bennett 2004). These descriptions from literature fit well to the observations made in the study area. Striae on Söbü Hill are in the form of small grooves or scratches on bedrock surfaces, often continuous over several meters (Fig. 9). Some of the formations on figure 9 are true karren, ı.e., small solution pits, grooves and runnels; but, the white long scratches with distinct start-stop locations on figure 9 suggest these features are likely formed by in-ice debris during repeated ice movements.

Figure 9. Example of striae on Söbü Hill.

3.7 Rock chips and glacial till

The conditions become favorable to removal of loosened rock fragments when water pressure at the base of glacier increases and the effective stress decreases (Iverson 1991). The removed material can be found in the sediments in the form of rock chips, 5cm and less in size, in the flat central plain areas (Fig. 10) and at the toe of the slopes as parts of more chaotic-sized glacial till such as the one located on the southeastern side of the Söbü Hill (Fig. 11A).

The rock chips in the central plain are relatively uniform in size. They are produced as a result of frost weathering, but may have been carried and deposited during glacial melting. The composition of the formation depicted in figure 11A are quite different. Here, the heterogenic mixture of all particle size is evident by naked eye observation at site, and the material is composed of limestone rocks and soil. The formation is also described as Koctepe Formation (Tk) and composed of limestone clastics by previous researchers (e.g., Karaman 1994). Field observations confirm the previous descriptions and reveal that most of these clastics are sub-rounded and sub-angular shaped.

Figure 10. Chips scoured from limestone in the central plain area.

Figure 11B shows the results of sieve analysis performed on three samples taken from three different locations (about 100m apart each). The results confirm mixture of large intermediate and small grains; with pebble and larger-sized material being in dominance. Overall, the appearance, content, material matrix, and their location being at the toe of the Söbü Hill, are all in support that this formation is glacial till from the Söbü Hill.

4. DISCUSSION

The tiling appearance accompanied with the stone chips on Söbü Hill is the resultant of compressive deformation of this cyclic loading and unloading of the ice. As the ice thickness increases, the ice load increases as well (Y-Axis, Fig. 12), and the rock under the ice is compressed and follows curve 1 in Figure 10. When the glacier thickness decreased, as is the case during the inter-glacial warm periods, the underlying rock unloads with a permanent deformation (X-axis, Fig. 12). Thus, Cycle 2 starts with this permanent deformation. This cycle may repeat itself as the climate change during the following periods (curves 2 and 3). There are many locations, on Sobü Hill and elsewhere around the Isparta Plain, where glacial-load effects are observable. The highest point at Söbü Hill

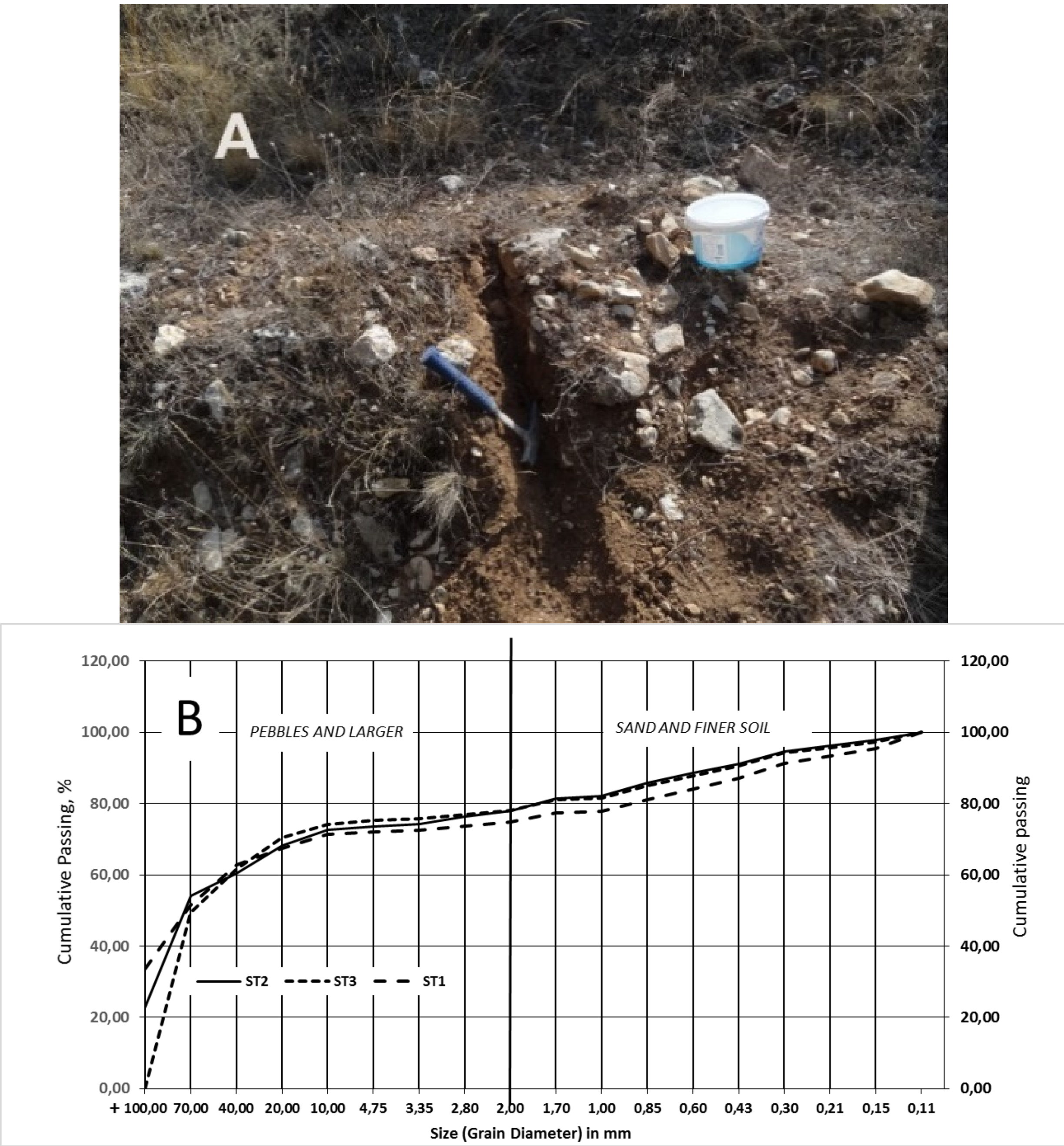

Figure 11 (A,B). Glacial till at the toe of Söbü Hill (A) and grain size distribution of three samples (B) from the glacial till area including the one pictured in A.

where glaciation effects are observable is at about 1500m, and the lowest point is at Isparta plain is at about 900m giving a thickness of 600m. The observed features are visible all around the Sobü Hill, thus the height of the hill over the plain corresponds to a minimum thickness. Therefore, the thickness of ice, and the ice load, would have been considerable even if it was less than that of the case in Canada. Also, a well-developed tiling of base rock is indicative of the high effective normal stress on the landform.

These conditions are typical of relatively thick ice sheets where sliding velocities are low and where there is little available basal meltwater (Glasser & Bennet 2004). For a 600m minimum ice thickness, the stress on the base of the ice corresponds to about 5,4MPa. Thus, the overall evidence suggests that there was considerable vertical load on the bedrock in Isparta region and, along with other icing conditions, it could result the compressive deformation observed on site today.

The unloading cycle (ablation) may produce a tensile deformation. This deformation, coupled with the tensile deformation caused by the flexure of the crust at the perimeter area of the glacier (Ates et al., 1997) may cause "*pop-ups" as is seen on the upper elevations of the Söbü Hill.*

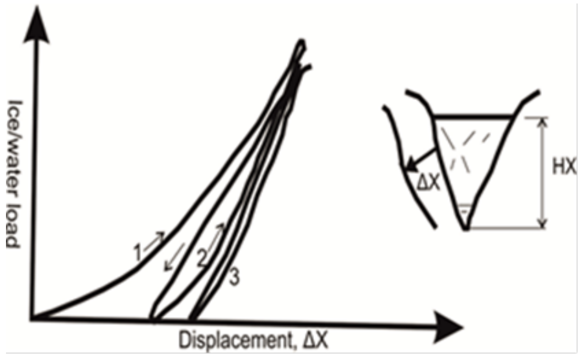

Figure 12. Permanent foundation deformation (ΔX) caused by repeated cycles (numbers with arrows shows repeated cycles) of glaciation/De-glaciation.

Another effect of glacio-mechanical ice is the wave-front like appearance (Fig. 6) represented by many through-like grooves in limestone rock perpendicular to the direction of the presumed ice advance. The groves are likely created during inter-glacial periods where the water and debris flows on the perimeter of the ice.

During ablation periods as the ice gets thinner, water and debris flows on the perimeter of the ice and deepens the grove. During accumulation periods further advances occur. The orderly occurrence of these multiple parallel glacio-mechanical features are observed frequently all around the Isparta plain, and provide further support to the idea of once-existed body of ice here. As well, there are many clearly observable grooves cut in rock parallel to the presumed ice flow direction. These vertical striae is created by granules and stones embedded in the moving sole of the glacier.

Ice-abraded limestone rocks can be seen on Söbü Hill and other flanks of the Isparta Plain. The abrasion came about as a result of heavy ice movement on the base rock. Poorly-sorted chips and blocks of rock on top of these tiles are commonly observed. The chips were formed due to once overlying ice/water pressure with subsequent temperature changes and uplift following de-glaciation.

Sediments accumulated near the center of the Isparta Plain provide further evidence for the glacial past. Here, the presence of both glacio-lacustrine and glacio-fluvial deposits can be seen. Here, outwash stone chips are noticeable at flat location near the lower end of the flanks. The chips (Fig. 10) are smaller-sized forms of the ones left on the slope of the areas like Söbü Hill. The homogeneously scattered rock chips in the field are from the bedrock which are plucked into the ice and then left upon de-glaciation. The chips were formed due to once overlying ice/water pressure with subsequent temperature changes and uplift following de-glaciation.

The findings of this study are in agreement with Zreda et al., (2011) who suggested that Pleistocene or earliest Holocene glaciers were extraordinarily extensive with snow lines lower than today by more than 1400 meters in parts of eastern Mediterranean in Turkey. As well, there have been consistent reports of lower altitude glaciations along the Mediterranean. Low altitude glaciations are reported further west along Mediterranean, in Croatia (Marjanac, In references list is Marjanac & Marjanac 2004) and in Montenegro (Hughes et al., 2010, 2011) and low glaciation is attributed to very high level of precipitation during the Pleistocene. The amount of precipitation in these regions remains higher than today. Similarly, Turkey's Mediterranean coast lies in a macroclimate zone, with winter being the wettest season, and 40% precipitation rate in winter and the majority of this being snowfall (Çiçek & Duman, 2015). The Isparta Plain is located just at the border between hot and humid coastal climate and drier interior; and today also has an annual average of 537 mm precipitation. In Isparta Plain, low glaciation can be attributed to very high level of precipitation during the Pleistocene, as well as its geographic location where an elevation of 2547m (Davraz Mt.) is attained within 100km distance. It serves as a catchment area for high precipitation emanating from hot and humid coastal areas nearby.

Overall, the multiple field evidence presented and discussed in this study related to the glacial effects supports the areas glacial past. The evidence may change the perspective about the formation of Isparta plain and general evolution of Eastern Mediterranean region. It may also have wider implications for sites elsewhere, including for example, ancient sites on planet Mars (Kargel 1992; Smellie & Chapman 2002).

5. CONCLUSIONS AND RECOMMENDATIONS

Many glacio-mechanical features are observed and documented for the first time in Isparta Plain which shows the morphology of the plain and its vicinity being significantly affected by past glaciation and related events. The glaciation/deglaciation and following uplift also must have an effect on today's extensional stress regime of the region which includes the Isparta plain. The findings will likely change the overall perspective regarding the formation of the Isparta plain and its vicinity; which, until now, is almost customarily described as a subsidence basin created by an extensional stress regime prevalent in Eastern Mediterranean region.

The determination of precise ice thickness in the Isparta region remains to be a topic for future research, and more needs to be done on the former geometry of possible ice mass in this area. It needs age-dating and glaciological reconstructions in order to verify the plausibility of data presented here. As well, the presence of a volcanic Çünür Hill in the area, among other preliminary evidence, indicate that the volcanism may also have been affective under the ice; interacting with, and modifying the effects, of ice. In such a case, the stress accumulation associated with ice age may be an important trigger and/or accelerator in the active Quaternary volcanism (Nakada & Yokose, 1992). Further studies in this respect are needed.

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REFERENCES

Ates Y., Bruneau D. & Ridgway W.R., 1997. *Continental glaciation and its potential impact on a used-fuel disposal vault in the Canadian Shield*. AECL (Canada) Report No: 10140. Scientific Document Distribution Office, AECL, Chalk River, Ontario, Canada. 85p.

Barka, A. & Reilinger, R., 1997. *Active tectonics of the Eastern Mediterranean region: deduced from GPS, neotectonic and seismicity data*. Annals of Geophysics, v. 40, n. 3.

Ber, A., 2009. *Vertical stress of Pleistocene continental glaciers and its hypothetical evidence in present relief of Northern Europe*. Polish Geological Institute Special Papers, 2(2009):7-12.

Bozcu, M., Yağmurlu, F. & Şentürk, M., 2007. *Some Neotectonic and Paleosismological features of the Fethiye-Burdur Fault zone, SW Anatolia.* Geological Engineering (Turkish) 31 (1) 2007.

Çiçek İ. & Duman, N., 2015. *Seasonal and Annual Precipitation Trends in Turkey*. Carpathian Journal of Earth and Environmental Sciences, May 2015, Vol. 10, No. 2, p. 77 - 84

Demer, S. 2008. *Investigation of hydrological, hydrogeochemical and isotope geochemistry of underground water, and problems associated with monitoring drinking water quality in Isparta and its vicinity, SW-Turkey.* PhD Thesis, 171p. - (In Turkish with English abstract)

Flint, R.F. 1971.*Glacial and Quaternary geology*. John Willey and Sons, Inc., New York. 892p.

Erdoğan, S., M., Yavaşoğlu, H, Tiryakioğlu, İ., Erden T., Karaman, H., Tari, E., Bilgi, S.T., Tüysüz, O., Baybura, T., Taktak, F. A., Telli, K., Güllü, M., Yilmaz, İ., Gökalp, E., & Boz,Y., 2008. *Monitoring of Deformations along Burdur Fethiye Fault Zone with GPS.* Journal of Earthquake Engineering Vol. 12, Iss. sup2. pp. 109-118.

Erol, O., 1973. *Quternary depositions in Burdur Basin.* In:Cumhuriyetin 50. Yılı Yerbilimleri Kongresi 17-19 Aralık 1973 p386-390. Maden Tetkik ve Arama Enstitüsü, Ankara. In Turkish.

Evans, I.S., & Cox, N.J., 1974. *Geomorphometry and the operational definition of cirques*. Area, Vol. 6., No.2, pp. 150-15.

Evans, I.S., 1977 *World-wide variations in the direction and concentration of cirque and glacier aspects.* Geografiska Annaler 59A, 75-151.

Evans, I.S., 1999. *Was the cirque glaciation of Wales time-transgressive or not.* Annals of Glaciology, 28, 33-39.

Evans I.S., & Mindrescu, M., 2014. *Cirque form and development in Romania: Allometry and the buzzsaw hypothesis.* Geomorphology 208, pp. 117–136.

Glasser, N.F., & Bennett, M.R., 2004. *Glacial erosional landforms: origins and significance for paleoglaciology*. Progress in Physical Geography 28, 1, pp. 43–75.

Graf, W.L., 1976. *Cirques as glacier locations*. Artic and Alpine Research, Vol. 8, No 1, pp. 79-90.

Graf, W.L., 1974. *Cirques as glacier locations*. Artic and Alpine Research, Vol. 8, No 1, pp. 79-90.

Hughes, P.D., & Woodward, J.C., 2008. *Timing of glaciation in the Mediterranean mountains during the last cold stage.* J. Quaternary Sci., Vol. 23 pp. 575–588.

Hughes, P.D., Gibbard P.L., & Woodward, J.C., 2007. *Geological controls on Pleistocene glaciation and cirque from Greece*. Geomorphology 88, 242-253.

Hughes, P.D., Woodward, J.C., Van Calsteren, P.C., Thomas, L.E., & Adamson, K.R., 2010. *Pleistocene ice caps on the coastal mountains of the Adriatic Sea*. Quaternary Science Reviews, 29(27), 3690-3708.

Hughes, P.D., Woodward, J.C., &Van Calsteren, & P.C., Thomas, L.E., 2011. *The glacial history of the Dinaric Alps, Montenegro*. Quaternary Science Reviews, 30(23), 3393-3412.

Iverson, N.R., 1991. *Potential effects of subglacial water-pressure fluctuation on quarrying*. Journal of Glaciology 37(125): 27-36.

Izbırak, R., 1973. *Discussion comments on "Burdur Havzası Quaterner Depoları" (Quaternary depositions in Burdur Basin).* In:Cumhuriyetin 50. Yılı Yerbilimleri kongresi 17-19 Aralık 1973 p386-390. Maden Tetkik ve Arama Enstitüsü, Ankara. In Turkish.

Kalyoncuoglu, U.Y., 2015. *In situ gamma source radioactivity measurement in Isparta plain, Turkey*. Environmental Earth Sci., 73.7 (2015): 3159-3175.

Karagüzel, R. & Irlayıcı, A., 1998. *Groundwater pollution in the Isparta Plain,* Turkey. Environmental Geology, 34 (4) June 1998. Pp.: 303-308.

Karaman, M.E., 1988**.** *Basic geological properties of Southern Isparta.* T.J.K. Bülteni 2, pp. 43-51 (in Turkish).

Karaman, M.E., 1994. *Geology and tectonic features between Isparta and Burdur area (SW Turkey*). Geological Bulletin of Turkey, 37, No.2, 119-134.

Kargel, J.S., & Strom, R.G., 1992. *Ancient glaciation on Mars.* Geology 20: 3–7.

Kazancı, N., & Karaman, M.E., 1988. *The sedimentolological and depositional mechanisms of Gölcük (Isparta) Pliyosen volcanoclastic series.* Akdeniz Üniversitesi Isparta Müh. Fakültesi Dergisi 4, 16-35, Isparta (in Turkish).

Kanbur, Z., Görmüş M., Kanbur Z., 2008. *Use of Refraction-Microtremor Technique (ReMi) of shallow S-wave truncation of the northern edge of Isparta urban area*. Journal of the Earth Sciences Application and Research Centre of Hacettepe University). 29 (2), 77–86.

Kleman, J. 1994. *Preservation of landforms under ice sheets and ice caps.* Geomorphology, 9(1), 19-32.

Marjanac, L. & Marjanac. T., 2004. *Glacial history of the Croatian Adriatic and coastal Dinarides*. Developments in Quaternary Sciences, 2, 19-26.

Mutlutürk, M., & Karagüzel, R., 2007. *The Landfill Area Quality (LAQ) Classification Approach and Its application in Isparta, Turkey*. Environmental & Engineering Geoscience, August, 2007, v. 13, p. 229-240.

Nakada, M. & Yokose, M., 1992. *Ice age as a trigger of active Quaternary volcanism and tectonism*. Tectonophysics, Vol. 212, Issues 3–4, Pages 321-329, ISSN 0040-1951, http://dx.doi.org/10.1016/0040-1951 (92)90298-K.

Özgür, N., Pekdeğer, A., & Schneider H.J., 1990. *Pliocene volcanism in the Gölcük area, Isparta/Western Taurides.* IESCA, 1990 Proceedings, 411-419.

Özgür, N., Yağmurlu, F., & Yilmaz, K., 2008. *Pleistocene eruptive chronology of the Gölcuk volcano, Isparta angle, Turkey*. Quaternaire, 19(2), 147-156.

Özkan, T., 1997. *Cretaceous/tertiary transition in Göltaş-Senirce-Çünür (Isparta) (Göltaş-Senirce-Çünür (Isparta) dolayında Kretase/Tersiyer Geçişi).* Istanbul Univ. Müh. Fak. Yerbilimleri Dergisi 10, pp. 29-37. In Turkish with English abstract and Summary.

Över, S., Yılmaz, H., Pınar, A., Özden, S., Ünlügenç, U.C., & Kamacı, Z., 2013. *Plio-Quaternary Stress State in the Burdur Basin, SW-Turkey*. Tectonophysics 588 (2013) 56–68.

Platevoet, B., Scaillet, S., Guillou, H., Nomade, S., Blamart, D., Poisson, A., Elitok, Ö., Ozgur, N., Yağmurlu, F., Yılmaz, K., 2008. *Pleistocene explosive activity of the Gölcük volcano, Isparta Angle, Turkey*. Quaternaire, 19(2), 147-156.

Sarıiz, K., 1985. *The genesis of Keçiborlu (Isparta) sulphur deposits and geology of the surrounding region.* Anadolu Üniversitesi Yayın No: 92, PhD Thesis, 127p. (In Turkish with English abstract).

Sarıkaya, M.A., Ciner, A. & Zreda, M., 2011. *Quaternary glaciations of Turkey. Quaternary glaciations—Extent and chronology—A closer look*: Amsterdam, Elsevier, Developments in Quaternary Sciences, 15, 393-403.

Smellie, J.L. & Chapman, M.G., 2002. Smellie, John Laidlaw, and Mary G. Chapman, eds. *Volcano-ice interaction on Earth and Mars.* No. 202. Geological Society, 2002, pp. 1-3.

Schumacher, M., Fernandez-Buglion, E., Hybertson, D., Buschmann, F., & Sommerlad, P., 2013. *Security Patterns: Integrating Security and Systems Engineering*. John Wiley & Sons, 448p.

Temiz, H., Poisson, A., Andrieux, J. & Barka, A., 1997. *Kinematics of the Plio-Quaternary Burdur-Dinar cross-fault system in SW Anatolia (Turkey).* Annales Tectonicae 11:102–113.

Tezcan, D. & Okyar, M., 2006. *Seismic stratigraphy of Late Quaternary deposits on the continental shelf of Antalya Bay, Northeastern Mediterranean*. Continental Shelf Research, Volume 26, Issue 14, September 2006, Pages 1595-1616

Totic, E., 2009. *The investigation of relations between physical and mechanical properties of the volcanic based isparta plain soil.* Ph. D. Thesis. Süleyman Demirel University Graduate School of Applied and Natural Sciences, Department of Geological Engineering. 204p.

Yağmurlu, F., Savasçin, Y., & Ergün, M., 1997. *Relation of Alkaline Volcanism and Active Tectonism within the Evolution of the Isparta Angle, SW Turkey*. The Journal of Geology, Vol. 105, No. 6 pp. 717-728.

Zahno, C., Akcar, N., Yavuz, V., Kubik, P.W., Schlu¨chter, C., 2009. Surface exposure dating of Late Pleistocene glaciations at the Dedegol Mountains (Lake Beysehir, SW Turkey). J. Quatern. Sci. 24, 1016–1028.

Zreda, M., Çiner, A., Sarıkaya, M.A., Zweck, C., Bayarı, & S., 2011. *Remarkably extensive glaciation and fast deglaciation and climate change in Turkey near the Pleistocene-Holocene boundary.* Geology, 39(11), 1051-1054.

Waelkens, M., Sintubin, M., Muchez, P., & Paulissen, E., 2000. *Archeological, geomorphological and geological evidence for a major earthquake at Sagalassos (SW Turkey) around the middle of the seventh century AD.* In: McGuire WJ, Griffiths DR, Hancock PL, Stewart IS (eds.) The archeology of geological catastrophes, Vol., 171. Geological Society of London, London, pp. 373–383.

Waldron, J.W.F., 1984. *Structural history of the Antalya Complex in the 'Isparta angle', Southwest Turkey*. Geological Society, London, Special Publications 17.1 (1984): 273-286.

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