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Late Pleistocene Calcretes from Central Anatolia (Lakes Eymir and Mogan, Gölbaşı Basin): Comparison to Quaternary Calcretes from Turkey

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ABSTRACT: This study is the first to report the radiocarbon ages, mineralogical, morphological, geochemical and stable isotope compositions of calcretes from Neogene sediments around lakes Eymir and Mogan in the Gölbaşı Basin of Central Anatolia. Morphologically different forms of calcretes in the Gölbaşı Basin include powdery, nodular, fracture infill, laminar and hardpan types. Calcite is the dominant mineral of calcrete compositions; the diagnostic features of dessication cracks, random fractures, MnO linings and dense sparitic infillings are observed. Chemical analyses show arid conditions with mean annual precipitation of <50 mm. $\delta^{13}C$ compositions of the calcretes range from -6.77‰ to -9.32‰ PDB, typical for most pedogenic calcretes, reflecting the development under seasonally arid climates and C3-dominated vegetation cover. $\delta^{18}O$ values are between -5.57‰ and -7.80‰ PDB, indicating the formation from meteoric water in a vadose zone environment. The results suggest that the Middle Pleistocene was arider and warmer, favouring the formation of palygorskite in association with the different forms of calcrete occurrences, whereas the Late Pleistocene was dryer and cooler, supporting the development of calcretes.
KEY WORDS: calcrete, micromorphology, stable isotopes, mineralogy, Central Anatolia.

0 INTRODUCTION

Calcrete formation is a terrestrial product within the zone of weathering in which calcium carbonate ($CaCO_3$) accumulates and/or replaces preexisting soil, rock, sediment or weathered material to yield a substance that may ultimately develop into an indurated mass (Eren, 2011; Wright and Tucker, 1991; Salomons et al., 1978; Goudie, 1973). The broad definition of calcretes (Wright and Tucker, 1991) is a near-surface, terrestrial accumulation of predominantly calcium carbonate, which occurs in a variety of forms from powder to nodule to highly indurated, resulting from the cementation and displacive/replacive introduction of calcium carbonate into soil profiles, bedrock and sediments in areas where vadose and shallow phreatic groundwaters become saturated in calcium carbonate. Pedogenic and/or groundwater calcretes are widely recognized and studied to reconstruct the Quaternary paleoclimates.

During the last few years, Quaternary calcrete deposits of Turkey have attracted a large amount of attention; particulary from the northwest region (Kadir et al., 2010), Southwest Anatolia (Alçiçek and Alçiçek, 2014), Central Anatolia (Göz et al., 2014; Küçükuysal and Kapur, 2014; Küçükuysal et al., 2013), and Southeast of Turkey (Kaplan et al., 2014, 2013; Eren, 2011). These studies have increased our knowledge of the field occurrences, mineralogical, geochemical, and stable isotopic compositions of these calcretes, and Quaternary calcretes in Turkey have shown correlative similarities in many aspects (e.g., nodular forms, calcite and dolomite minerals associated with smectite and palygorskite occurrences). However, the calcretes from the Neogene sediments around Lakes Eymir and Mogan in Central Anatolia have not yet been studied in this respect. This paper aims to (1) document the mineralogical, morphological, stable isotopic compositions and radiocarbon ages of the calcretes from Gölbaşı area and (2) establish cross-link on the recent findings with the other Quaternary calcretes of Turkey, and of Europe, and Mediterranean region.

1 GEOLOGICAL SETTINGS

The studied sections are located in Gölbaşı Basin, south of Ankara, Central Anatolia (Fig. 1a), which is characterised by two alluvial barrier lakes of Mogan and Eymir (Fig. 1b). The lakes were originally part of a fluvial single system but then divided by alluvial fans. The water level of Lake Mogan is approximately 3 m higher than that of Lake Eymir and its flow direction is towards Lake Eymir (Yağbasan, 2007). The lakes are fed by several streams and two irrigation reservoirs, located in the southern and western part of the basin, respectively. The water table in the basin is near surface (~2 m) (Yağbasan, 2007) and the groundwater contribution in the basin is as important as the pedogenesis in terms of calcretisation.

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The stratigraphic units exposed in the Gölbaşı Basin are predominantly fluvial sediments consisting of reddish-brownish mudstones with calcretes of different maturity stages and forms. The creeks which feed the lakes behave as a bridge between the carbonate-rich Triassic blocks and the basin and provide the carbonate sources to the basin (Fig. 1b). Calcrete profiles with a variety of forms and colors are widely recognized in its Neogene sediments. They are identified as the product of interaction between pedogenic and groundwater processes. The oldest unit in the study area is the Emir Formation (Early Triassic, Akyürek, 1981; Akyürek et al. 1980, 1979a, b), which is characterized by a diverse array of rocks, including muscovite-quartz, sericite-chlorite-quartz, sericite-chlorite, and calc-schists, phyllite, metavolcanics, and metaconglomerate (Akyürek et al., 1997). Overlying this unit is the Early–Late Triassic Elmadağ Formation, which is composed of metaconglomerate, metasandstone, sandy limestone, sandstone, limestone, agglomerate and metavolcanics (Akyürek et al., 1997). The Imrahor limestone member is also Middle–Late Triassic (Akyürek et al., 1997). Limestone blocks of Permian age also exist in the basin, succeeded by Neogene deposits of Gölbaşı Formation, which consists of conglomerate, sandstone and mudstone lithologies. The youngest unit is Quaternary alluvium of sand and gravel (Akyürek et al., 1997). Selected sections for this study are from Gölbaşı Formation shown in Fig. 1b.

The modern climate conditions in the basin are "continental", dominanted by cold and rainy/snowy days in winter and hot and dry weather in summer. According to Yağbasan (2007), the arithmetic average of the annual precipitation in the basin is 333.9 mm and the annual average evaporation is 1 092.2 mm. With respect to the modern climatic conditons, the basin is semi-arid in terms of precipitation and is dominated by steppe type vegetation cover.

Five different sections were surveyed in Gölbaşı Basin (Fig. 2). The section from the first site is a 145 cm long calcrete-bearing section in which calcretes occupy in the forms of hardpan to powder, nodule to lamina from bottom to top in a decresing maturity order (Fig. 2). Carbonate accumulation horizon (Bk) developed in calcareous fluvials having Munsell color of 10YR4/4, whereas calcretes are in color range of 2.5Y9/2 to 5Y9/2. The carbonated fraction of this section decreases towards the top of the section. Six calcrete samples were taken from Site 1 for this study (E-14C-1, E-14C-2, E14C-3, E-14C-4, E-14C-5 and E-14C-6). The thickness of the section from Site 2 is 180 cm (Fig. 2). Carbonate dissemination changes towards the top from hardpan to nodular and powdery forms. The color of the host mudstone is 10YR6/2, and that of the calcretes is 10YR9/2. The maturity stages of the calcretes are similar to Site 1, and decreases towards the top of the section. Two nodules were sampled from this site. A 200 cm thick calcrete-bearing section was investigated from Site 3 (Fig. 2), which contains hardpan to nodular calcretes. The nodules are more indurated with respect to the noduled form seen in other sites. The color of the host mudstone and calcretes within are 2.5Y4/4 and 7.5Y8/2, respectively. Only one sample (E5C-1) was taken from this site. The section from Site 4 is 180 cm thick and includes calcretes of hardpan and nodular forms (Fig. 2). Three samples are from this section, and the maturity stage is high. The Munsell color of the calcretes is approximately 7.5Y8/2. The last section is from Site 5 where a 70 cm calcrete-bearing section was surveyed (Fig. 2). Nodular and powdery forms of calcretes are observed from this section where the host mudstone is in 10YR5/4 color and the calcretes are 2.5Y9/2. Calcrete dissemination towards the top is also recognized in this section. Four calcrete samples were evaluated from this site.

2 METHODOLOGY

Five geological profiles were surveyed and sampled (Fig. 2). Each site has similar physical characteristics. Calcretes mostly occupy the tops of the profiles with variety of forms as powdery, nodular, fracture-infill, tubular, laminar and hardpan. Each sample underwent mineralogical, micromorphological and stable isotopic analysis. The physical appearances of the

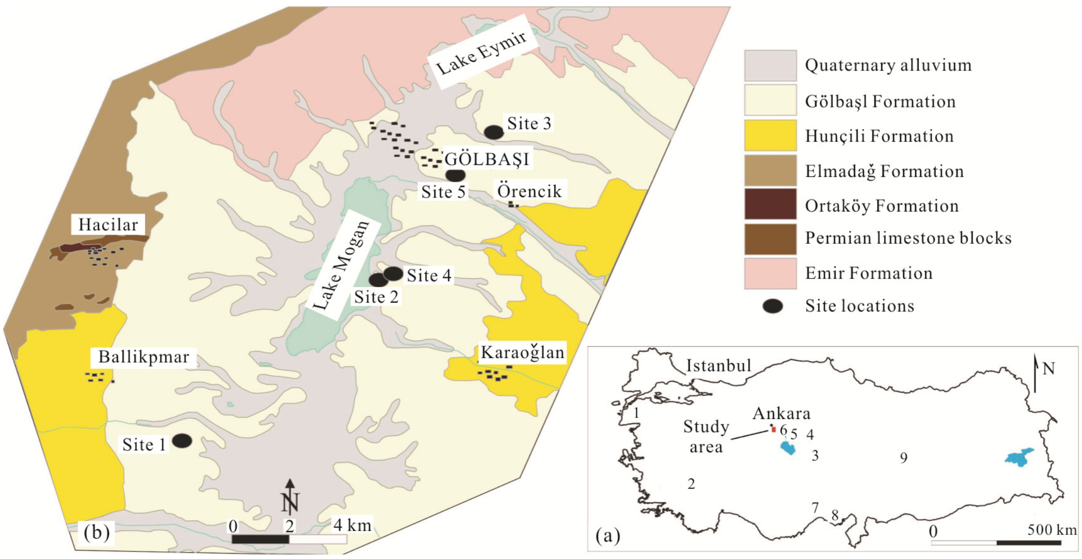

Figure 1. Geological map of the study area showing the site locations (b) (Akyürek et al. 1997). Inset (a) shows the location of the study area and the literature locations discussed on Table 2.

calcretes such as the Munsell color, size, shape and the form are recorded as field observations. Thin sections were prepared to evaluate the petrographic properties of the studied calcretes (Retallack, 2001; FitzPatrick, 1993) and the micromorphological characteristics of the calcretes were defined (FitzPatrick, 1993; Wright and Tucker, 1991; Machette, 1985).

Mineralogical compositions of the samples studied were analyzed at the General Directorate of Mineral Research and Exploration by Bruker D8 Advance X-ray diffractometer (XRD) Cu-target from 2°–70° (2θ) for bulk powder samples. Combined procedures of Thorez (1976), Jackson (1979), Brindley (1980), Tucker (1988), and Moore and Reynolds (1989) were followed during the preparation of the powders for X-ray diffraction. Mineralogical analysis were performed on the entire set of samples. Major oxide compositions of the samples from Site 1 were detected at the General Directorate of Mineral Research and Exploration by Thermo ARL X-ray Flourescence.

Stable isotope analysis (δ^{18}O and δ^{13}C) of carbonates were carried out at the Enviromental Isotope Laboratory in University of Arizona. They were measured using an automated carbonate preparation device (KIEL-III) coupled to a gas-ratio mass spectrometer (Finnigan MAT 252). Powdered samples were reacted with dehydrated phosphoric acid under vacuum at 70 °C. The isotope ratio measurement is calibrated based on repeated measurements of NBS-19 and NBS-18 and precision is ±0.1‰ for δ^{18}O and ±0.08‰ for δ^{13}C (1σ).

Radiocarbon (RC) ages of the calcretes studied were determined in the Beta Analytical Inc. by Accelerator Mass Spectrometry on powdered carbonates. The carbonate material was cleaned by physical abrasion to remove the outer surfaces and adhering carbonate material and then acid etched to have primary carbonates to be dated. This method is often employed for Quaternary materials. Uncalibrated "conventional dates" of the samples are used comparatively in this study to provide chronological framework for the interpretation because pedogenic and/or groundwater calcretes can record progressive overprinting and multiple intervals of dissolution-reprecipitation, yielding RC ages that provide an average value of all crystals present in the fraction (Deutz et al., 2001).

3 RESULTS

3.1 Micromorphological Features

Thin sections of the nodular calcretes were analysed to observe their micromorphological properties. These nodules consist of a dense calcite matrix over that contain rock and mineral fragments (Fig. 3a). Thin, anastomosing fractures and microcracks are also observed, likely due to dessication (Fig. 3b). Sparitic dense infilling of some fractures exist (Fig. 3c). Dendritic forms of MnO_2 linings are recognized around randomly oriented fractures (Fig. 3d) and also exist as clusters and thin lines overgrown on sparites within pore spaces (Figs. 3d, 3e and 3f). The walls of the openings are coated with fine-sized carbonate minerals (Fig. 3f). The investigated calcretes mostly resembles beta-type because of the pre-mentioned inorganic features, however, some of the planar openings are similar to faunal and/or faunal passages.

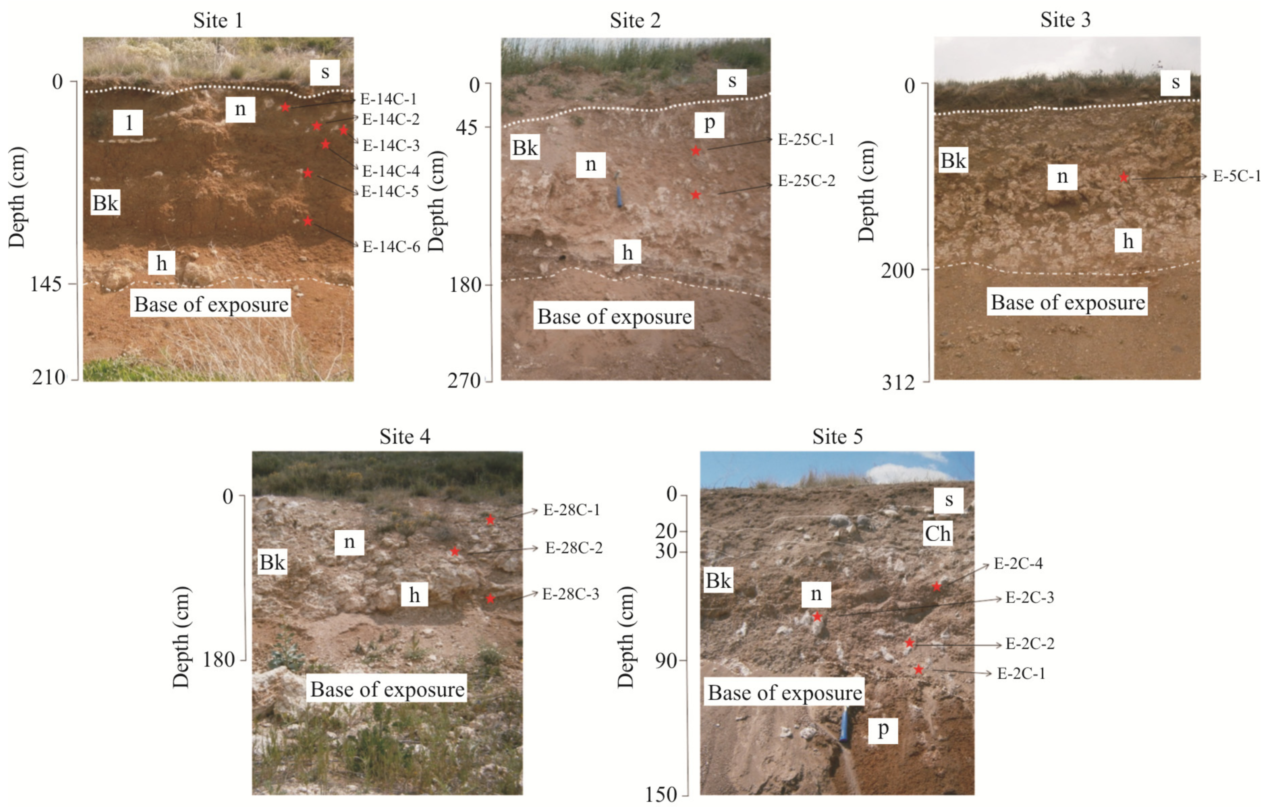

Figure 2. Pictures showing the studied sections: Site 1 samples E-14C-1 to E-14C-6; Site 2 samples E-25C-1 and E-25C-2; Site 3 sample E-5C-1; Site 4 samples E-28C-1 to E-28C-3, and Site 5 samples E-2C-1 to E-2C-4. Abbreviations: p. powdery; n. noldular calcrete; l. laminar calcrete; h. hardpan; s. recent soil; Bk. soil horizon.

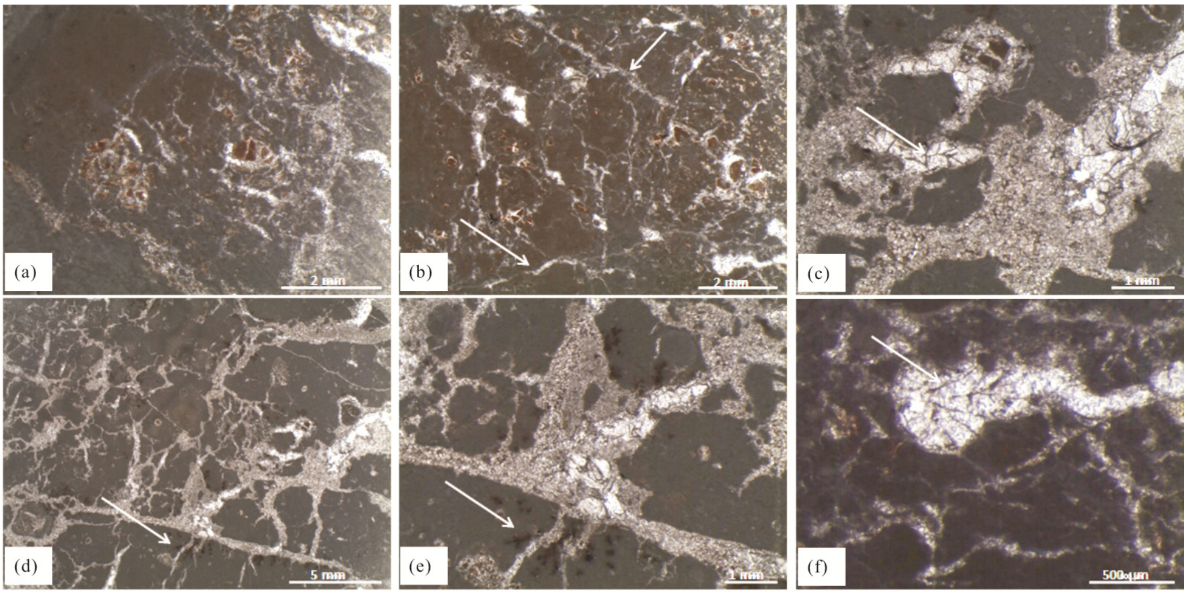

Figure 3. Photomicrographs of (a) dense calcite matrix, (b) thin unparallel fractures, (c) sparitic dense infilling of the fractures (d), (e) dendritic and cluster forms of MnO_2 linings, (f) sparitic infilling of the pore space.

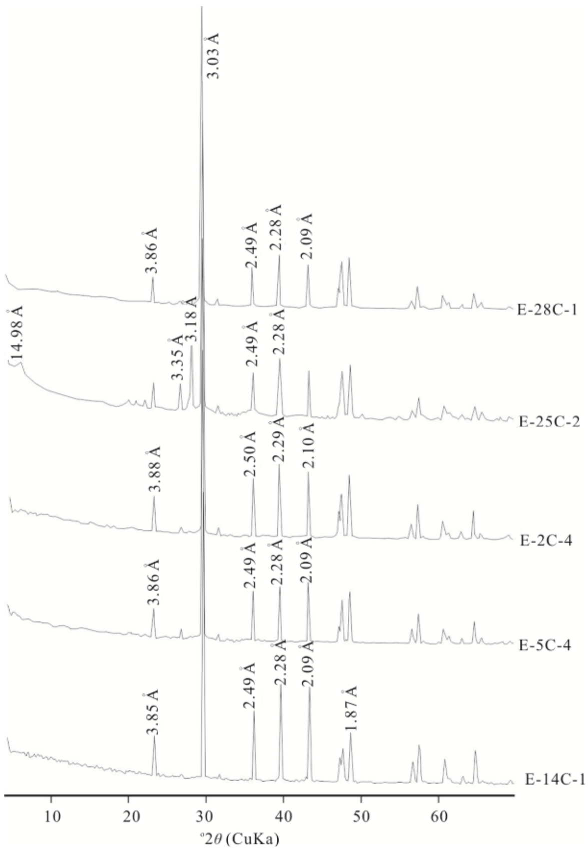

Figure 4. Representative XRD pattern for bulk calcretes from the study area.

3.2 Mineralogical Characterization

XRD analyses show that calcite is the predominant mineral in the calcretes, followed by quartz and low amount of clay (Fig. 4). The amount of calcite slightly increases from bottom to top of the profiles of sites 1, 2, 4 and 5 (Site 3 has only one representative sample). Calcite, quartz and clays were detected with their basal reflections at 3.03 , 3.35 and 14.98 Å, respectively (Fig. 4). Absence of the clay mineral palygorskite is a distinguishing feature for these Late Pleistocene calcretes in the study area. This is a common mineral observed in Middle Pleistocene calcretes from Central Anatolia (Küçükuysal and Kapur, 2014; Küçükuysal et al., 2013).

3.3 Geochemical Study

The calcretes from Site 1 were analysed by thermo ARL X-ray flourescence after being dried at 105 ºC. The weight percentage of CaO amount ranges from 46.5 wt.% to 52.1 wt.% with low amounts of SiO_2, Al_2O_3 and Fe_2O_3. The calcretes are rich in CaO and also shows the presence of accessory amounts of quartz with low SiO_2. Among the molecular weathering ratios, calcification was employed to estimate the relative difference between each calcrete levels. Calcification is a process related to the enrichment of CaO and MgO relative to Al_2O_3 and calculated as a ratio of $(CaO+MgO)/Al_2O_3$ (Sheldon and Tabor, 2009; Retallack, 2001, 1997). This measurement shows an increasing calcification towards the top of the section, as expected in arid environments. The degree of chemical weathering in soils increases with mean annual precipitation (MAP) (P, mm) and mean annual temperature (MAT) (T, °C) (Kovács et al., 2013). According to Sheldon et al. (2002), mean annual precipitation can be related to the chemical index of alteration without potassium (CIA-K) as geochemical climofunction by Equation (1)

$$\text{MAP (mm/y)}=14.265(\text{CIA-K})–37.632 \quad (1)$$

where $\text{CIA-K}=100\times[Al_2O_3/(Al_2O_3+CaO+Na_2O)]$, (Kovács et al., 2013). The calcretes from Site 1, as expected, show an average value less than 50 mm/year. This should be the case for such formations since they are the products of arid to semi-arid climates.

3.4 Isotopic Data

In a respective order, calcrete samples from samples E-2C

-4 (Site 5), E-5C-1 (Site 3) and E-28C-1 (Site 4) have RC ages of 18 870±70, 43 130±690 and >43 500 ka BP and are assumed to date the Late Pleistocene interglacials.

The stable isotopic ratios of oxygen and carbon from carbonates record changes in climatic conditions and plant cover (Alonso-Zarza and Arenas, 2004; Purvis and Wright, 1991; Cerling, 1984; Goudie, 1983). The stable isotope compositions of the samples studied were measured in terms of the sample availability and relative to standards Vienna Pee Dee Belemnite (VPDB) and are expressed with delta notation (δ) in parts per thousand (‰ or per mil) (Table 1). The calcretes from Site 1 (E-14C series) have the isotopic characteristics with narrower range in both $\delta^{13}C$ (-8.80‰ to -9.09‰) and $\delta^{18}O$ (-5.67‰ to -6.30‰) VPDB. The calcretes from Site 2 (E-25C series), unfortunately, could not be analysed for their isotopic compositions. Site 4 calcretes (E-28C series) have $\delta^{18}O$ compositions between -6.88‰ and -5.57‰; $\delta^{13}C$ compositions ranging from -9.32‰ to -8.81‰ VPDB. Similarly, Site 5 calcretes (E-2C series) show stable isotope compositions of $\delta^{18}O$ and $\delta^{13}C$ ranging from -8.13‰ to -6.43‰ and -7.84‰ to -6.87‰ VPDB, respectively.

The $\delta^{18}O$ values are almost identical and vary within a narrow range, reflecting the formation under the influence of meteoric water by medium-elevation precipitation (Gong et al., 2005; Alonso-Zarza and Arenas, 2004; James and Choquette, 1984). $\delta^{13}C$ compositions of the calcretes are similar to that of soil carbonates, reflecting dominant influence of C3-vegetation (Bajnoczi et al., 2006; Alonso-Zarza, 1999; Cerling, 1992, 1984; Wright and Tucker, 1991). The region during Late Pleistocene was likely covered with trees, shrubs and/or cool-season grasses in semi-arid climatic conditions (Bajnoczi et al., 2006; Alonso-Zarza, 1999; Wright and Tucker, 1991; Cerling, 1984).

4 DISCUSSION

Despite the widespread occurrence of Quaternary calcretes across Turkey, especially in the areas where seasonal aridity is pronounced, a limited number of the studies on these types of rocks exist (Table 2). Not all, but some of the studies listed discuss the mineralogical compositions of the calcretes, and some present the stable isotopic compositions, even with the formation temperature calculations. However, all of the studies describe the calcrete types and forms in terms of macro-morphological characteristics, such as calcretes with nodular and tubular forms or dolocretes with fracture-infilling forms.

Nine areas with calcrete occurrences in Turkey are investigated for their phsico-chemical properties. The calcretes in Çanakkale District from NW Turkey are observed by Atabey et al. (2004) and Kadir et al. (2010). The selected papers for the Quaternary calcrete occurrences in SW Turkey which also sedimentologically express the Çal and Karacasu Basin properties are Alçiçek and Alçiçek (2014) and Alçiçek and Jiménez-Moreno (2013). The Quaternary calcretes from Central Anatolia have taken great attention by many scientists with different aspects of the calcretes; Ankara by Küçükuysal and Kapur (2014), Küçükuysal et al. (2013); Kırşehir by Atabey et al. (1998); and Cappadocian Volcanic Province (CVP) by Göz et al. (2014), Gürel (2009), Kadir et al. (2014, 2013). However, the mostly studied region is southern Turkey; from Adana Basin and Mersin areas, the studies arised are Atalay (1996), Eren (2011, 2007), Eren et al. (2008), Göz et al. (2014), Kaplan et al. (2014, 2013), Kapur et al. (2000, 1993, 1990, 1987), Kadir and Eren (2008), Eren and Hatipoğlu-Bağcı (2010).

Unfortunately, no available literature on the occurrence of the calcretes in eastern Turkey are recognized, except Atalay (1996), which only discussed the presence of calcretes within buried and exhumed paleosols. Ages of the calcretes are only reported from Central Anatolia (Middle Pleistocene, 761±120 to 419±64 ka BP; Küçükuysal et al., 2013) and Mersin and Adana (Middle Pleistocene, 250–782 ka BP; Özer et al., 1989). Except the recent data from the study area, the age of the other calcretes discussed are assumed to be Quaternary in terms of their stratigraphical positions and physico-chemical similarities with the calcretes of known ages.

The existing published literature demonstrates that the publication framework regarding the Quaternary calcretes of Turkey is developmental. The records suggest dry periods during the Pleistocene and Holocene favoured the formation of calcretes developed with very similar physico-chemical properties across Turkey. This similarity presents significant evidence in understanding the climate drivers that cause the formation of calcretes. The field occurrences of the calcretes are similar across Turkey, commonly in powdery to nodular forms with the intermediate maturity stage, however, they are also in laminar and hardpan forms as the maturity increases. They are generally found in mudstones of alluvial fans, similar to the studied calcretes in Gölbaşı Basin.

Mineralogically, calcite is the dominant carbonate mineral in all calcretes discussed here whereas dolomite is also found accompanying calcite in central and northwestern part of Turkey. Palygorskite is the authigenic phase mineral found in the Quaternary calcretes with fiber bundles grown over calcite and dolomite crystals forming bridge-like structures pointing vadose zone depositional environment. The inverse covariance between palygorskite and smectite reveals that the Mg required

Table 1 $\delta^{13}C$ and $\delta^{18}O$ compositions of the calcretes studied

Site ♯	Sample	$\delta^{13}C$	$\delta^{18}O$
Site 1	E-14C-1	-8.97	-6.17
	E-14C-2	-8.89	-5.99
	E-14C-3	-8.80	-5.67
	E-14C-4	-8.88	-6.29
	E-14C-5	-9.09	-6.30
	E-14C-6	-9.01	-6.21
Site 4	E-28C-1	-8.81	-6.88
	E-28C-2	-8.72	-5.57
	E-28C-3	-9.32	-6.88
Site 5	E-2C-4	-7.61	-8.13
	E-2C-3	-7.84	-7.06
	E-2C-2	-7.05	-6.43
	E-2C-1	-6.87	-7.80

Table 2 List of the recent calcrete studies from Turkey with selected key references

#	Site name	Location	Calcrete type/form	Available stable isotope compositional range	Associated minerals	Selected key references
1	Çanakkale	NW Turkey	Dolocrete/powdery, nodular, fracture-infill	$\delta^{13}C$= -6.77‰ to -5.59‰ PDB $\delta^{18}O$= -5.81‰ to -2.88‰ PDB	Dolomite Palygorskite	Kadir et al., 2010
2	Denizli, Çal Basin	SW Turkey	Calcrete/nodular, laminar, tubular	$\delta^{13}C$= -9.15‰ to -6.17‰ PDB $\delta^{18}O$= -8.89‰ to -7.06‰ PDB	No information	Alçiçek and Alçiçek, 2014
3	CVP	Central Anatolia	Calcrete/nodular, tubular, massive and fracture-infill	$\delta^{13}C$= 3‰ to 4.97‰ PDB $\delta^{18}O$= -10.69‰ to -10.00‰ PDB	Calcite, palygorskite; gypsum, sepiolite	Göz et al., 2014 Gürel and Kadir, 2006
4	Kırşehir	Central Anatolia	Calcrete/nodular, tabular fracture-infill, hardpan	$\delta^{13}C$= -9.44‰ to -5.00‰ PDB $\delta^{18}O$= -10.40‰ to -6.37‰ PDB	Calcite palygorskite	Kadir et al., 2014 Atabey et al., 1998
5	Karahamzalı, Ankara	Central Anatolia	Calcrete/nodular, powdery, tubular, fracture- infill, hardpan	$\delta^{13}C$= -7.8‰ to -7.11‰ PDB $\delta^{18}O$= -5.02‰ to -3.97‰ PDB	Calcite, dolomite; Palygorskite	Küçükuysal and Kapur, 2014
6	Bala, Ankara	Central Anatolia	Calcrete/nodular, powdery, tubular, fracture-infill	$\delta^{13}C$= -9.22‰ to -5.96‰ PDB $\delta^{18}O$= -8.56‰ to -7.03‰ PDB	Calcite palygorskite	Küçükuysal et al., 2013
7	Mersin	S Turkey	Calcrete/nodular, powdery, fracture-infill; hardpan, pisolithic crust	$\delta^{13}C$= -9.00‰ to -6.34‰ PDB $\delta^{18}O$= -6.82‰ to -4.31‰ PDB	Calcite Palygorskite	Eren, 2011, 2007; Kadir and Eren, 2008; Eren et al., 2008; Eren and Hatipoğlu-Boğci, 2010
8	Adana Basin	S Turkey	Calcrete/nodular, tubular, fracture-infill, laminated, hardpan, conglomeratic crust	$\delta^{13}C$= -10.00‰ to -7.7‰ PDB $\delta^{18}O$= -5.7‰ to -3.8‰ PDB	Calcite Palygorskite	Kaplan et al., 2014, 2013; Atalay, 1996; Kapur et al., 2000, 1993, 1990, 1987
9	Malatya, Harran plains	SE Anatolia	Calcrete/nodular, hardpan	No information	No information	Atalay, 1996

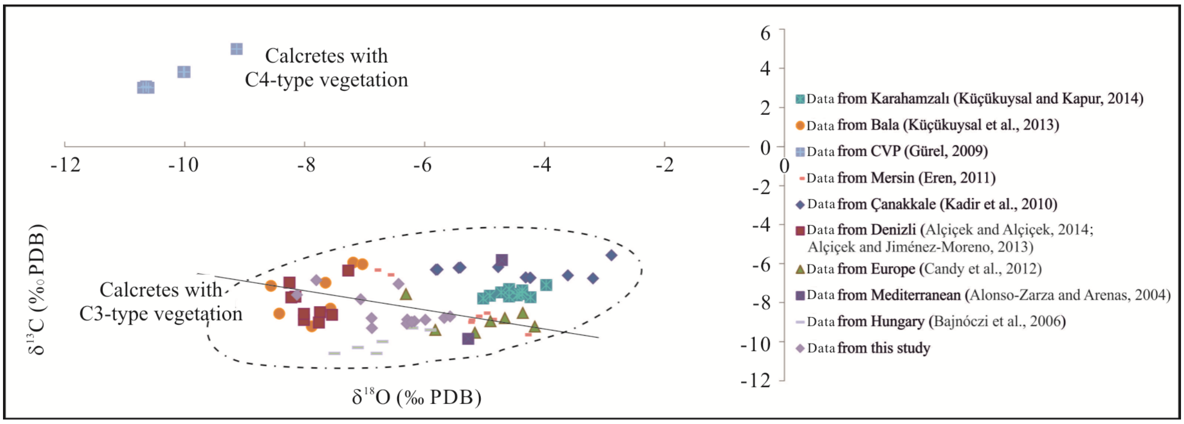

Figure 5. A cross plot of stable isotope values of the studied calcretes, Quaternary calcretes from Turkey, and those from the Mediterranean, western and southern Europe, and Hungary. Line indicates a rough inverse covariation.

for the formation of palygorskite was supplied by the degradation of smectite. Relatively younger calcretes from Gölbaşı Basin, the subject of this study, do not include palygorskite in their compositions.

Micromorphological invesitgations on the pre-studied calcretes from Turkey show that they have pedogenic textures like desiccation cracks, floating grains, alveolar septal structures, fenestral opening, porosity rims, MnO coatings. The studied calcretes from Gölbaşı Basin only shows desiccation cracks with floating grains and MnO coatings. Any remnant from biological activity has not been recognized in this study and requires further investigations.

Most of the studies in Table 2 employed stable isotopic compositions of the calcretes to understand the Paleoclimatological conditions at the time of their formation. According to the re-evaluation of stable isotope data of all the calcretes, $\delta^{13}C$ compositions of the calcretes represent the influence of soil-derived meteoric water and the presence of C3-plant community dominantly, while the values from CVP are enriched in ^{13}C and more positive to show C4 plant abundance. $\delta^{18}O$ compositions of all the calcretes fall in the same range with the pedogenic calcretes and imply the formation from the influence of meteoric water under vadose zone depositional environment.

The calcretes from this study are compared both with the calcretes re-evaluated in this paper and the Quaternary calcretes from northeastern Spain (Alonso-Zarza and Arenas, 2004), Hungary (Bajnoczi et al., 2006) and western-southern Europe (Candy et al., 2012) (Fig. 5). All calcretes plot in a close areas are of pedogenic origin with C3-type vegetation cover. The inverse covariation between $\delta^{13}C$ and $\delta^{18}O$ values of present study (line in Fig. 5) may be due to the fact that the driest periods were relatively cooler rather than warmer (Eren, 2011). This is consistent with the absence of palygorskite in the composition of the studied calcretes.

5 CONCLUSION

In the Gölbaşı Basin, Central Anatolia, Late Pleistocene calcretes are widespread with a variety of forms due to the interaction between pedogenic and groundwater processes. Petrological observations and geochemical data observed from calcretes in the region suggest a mean annual precipitation less than 50 mm and formation under seasonally arid and relatively cool climatic conditions by the factors of percolating vadose zone soil water under predominantly C3-type vegetation during the Pleistocene.

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