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Paleoglaciations in Anatolia: – A Schematic Review and First Results –

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Abstract: Anatolia is situated in the Eastern Mediterranean region between 36° – 42°N and 26° – 45°E. The geological records of paleoglaciations in the high terrains of Anatolia are key archives to quantify paleoclimate change in the Eastern Mediterranean area. The climate of the Eastern Mediterranean region is influenced by three main atmospheric systems: the main middle to high latitude westerlies, the mid-latitude subtropical high-pressure systems, and the monsoon climate.
Glacial geological studies in Turkey have started in the late 19th century. Glacial deposits are found mainly in the eastern, northeastern and southern part of the Anatolian Peninsula. Anatolia is the fundamental element to understand the interactions between paleoenvironment, climatic variations, and development of the human societies. As the Taurus and Black Sea Mountains are sensitively situated for the paleoclimatic reconstructions, a chronostratigraphic framework on the paleoglaciation should be elaborated. The timing of the Last Glacial Maximum (LGM) in Anatolia is still unknown. Our first results from Kavron Valley (Kaçkar Mountains, NE Turkey) are encouraging for the reconstruction of paleoglaciations in Turkey and related paleoclimatological interpretations although it is presently difficult to pinpoint the classical Last Glacial Maximum – Younger Dryas – Little Ice Age moraine sequences in the field.

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[Die früheren Vergletscherungen in Anatolien: – Ein schematischer Rückblick & erste Ergebnisse –]

Kurzfassung: Die spezielle geographische Lage der Türkei nordöstlich vom Mittelmeer zwischen 36° und 42° N, bzw. zwischen 26° und 45° E macht sie für Klima- und Paläoklimastudien zu einem besonders zentralen und sensiblen Gebiet. Der Vergletscherungsgeschichte von Anatolien kommt demzufolge eine Schlüsselrolle bei der Bewertung von Klimaveränderungen im östlichen Mittelmeerraum zu.
Bereits aus dem späten 19. Jahrhundert sind glazialgeologische Studien aus der Türkei bekannt. Vergletscherungsspuren sind vorwiegend in den östlichen, nordöstlichen und südlichen Gebirgszügen von Kleinasien vorhanden: in den Gebirgen am Schwarzen Meer, im Taurus, in den ostanatolischen Bergen, dem Uludag und auf isolierten Vulkanen wie Erciyes, Süphan und Ararat.
Das Klima im östlichen Mittelmeerraum ist hauptsächlich durch drei atmosphärische Strömungen geprägt: westliche Höhenströmungen der mittleren und höheren Breiten, subtropische Hochdruckgebiete der mittleren Breiten und der Monsun. Der Transport von Feuchtigkeit ist die zentrale Bestimmungsgröße für die Niederschlagsverteilung in diesem Gebiet.
Für die Feuchtigkeitszufuhr in die Gebirge Kleinasiens während der pleistozänen Kaltzeiten sind Lage und Maxima der Jetstreams wichtig. Gletscher und ihre Ablagerungen sind in diesem Zusammenhang zentrale Archive für Klimarekonstruktionen. Amplitude und Frequenz von eiszeitlichen Gletscherschwankungen müssen möglichst präzise erfasst werden, um Aussagen über die eiszeitliche atmosphärischen Zirkulationen – wie in den Alpen

– machen zu können. Dies ist für Kleinasien auch zudem wichtig und interessant, weil diese Gegend seit Jahrtausenden intensive besiedelt ist. Das Alter der letzten maximalen Vereisung in Anatolien ist bisher unbekannt. Unsere ersten Ergebnisse aus dem Kavrontal (Kaçkar Gebirge, NE Türkei) sind vielversprechend in bezug auf die Rekonstruktion früherer Vergletscherungen in der Türkei und daraus folgenden Interpretationen über die paläoklimatologischen Verhältnisse. Es ist im Augenblick jedoch schwierig die im Gelände unterscheidbaren Moränensequenzen mit den klassischen Vereisungsstadien (Letztes Glaziales Maximum, Jüngere Dryaszeit, Kleine Eiszeit) zu verknüpfen.

Introduction

The Earth's climate has always been changing and the magnitude of these changes has varied from place to place and from time to time (Goossens & Berger 1985). The term "climatic change" is a general expression that encompasses all forms of climatic inconsistency, regardless of their statistical nature or physical causes (Mitchell 1966). An abrupt climate change is a discontinuity in climate caused by abrupt and, apparently, permanent changes during the period of record from one average value to another (Goossens & Berger 1985).

Present climatic conditions are the key to understand past climates. The physical principles and rules which apply today, and which form the basis for our understanding of the climate system, we assume, apply equally well to the past. Because of this, the large-scale features of today's atmospheric circulation patterns were almost certainly present in the past, although they may have been geographically displaced, of different intensity, or subject to different seasonal or inter-annual changes (Wigley & Farmer 1982). More important variations in these features must have occurred in the past, especially in response to the dramatic changes in the global boundary conditions, which accompanied (or caused) for instance the last glacial–interglacial transition. As the glaciers are the sensitive climate archives of high latitudes and altitudes, they should have produced geological evidence of the dramatic changes in the global boundary conditions (among others: Broecker 2001).

In a study of climate change during the Quaternary Period, Anatolia merits special attention for several reasons. Anatolia is situated in the Eastern Mediterranean region (located between 36°–42°N and 26°–45°E). As it lies between generally humid and generally arid areas, this peninsula is extremely sensitive to even minor changes in precipitation. In addition, Anatolia is located in a tectonically and seismically active zone and it has experienced continuous settlement at least for 10,000 – 12,000 years, and possesses a rich record of human occupation, in the form of both archeological remains and written documents (Erinç 1978). The geological records of paleoglaciations in the high terrains of Anatolia are key archive to quantify paleoclimate change in the Eastern Mediterranean region. Currently, there is no sufficient information about the paleoglaciations in Anatolia.

Last Glacial Maximum (LGM) is a period of time during which the most recent glaciation cycle was at its peak with maximum global ice volume during Marine Isotope Stage 2 (MIS2). This glaciation is extensively mapped and referred to as Wisconsinian, Weichselian or Würmian, depending on the location of studies in North America, northern Europe, or the Alps. Due to the lack of detailed mapping and dating in paleoglaciation studies in Turkey, the timing of the LGM remains still open there. We follow here, as a hypothesis to the LGM during MIS2.

The aim of this paper is to portray a schematic summary of glacial geological studies in Turkey, the current atmospherical circulation patterns and thus climate in the Eastern Mediterranean region and Anatolia. Furthermore we aim to map and date the LGM – Younger Dryas – Little Ice Age paleoglacial sequence with an example from the Kavron Valley, (Kaçkar Mountains, NE Turkey).

Glacial Geology in Turkey: A Schematic Summary

Glacial geological studies in Turkey have started in the late 19th century. The first observations on the presence of glaciers and glacial deposits are made in the 1840's in the southeastern part of the Taurus (Ainsworth 1842) and Eastern Black Sea Mountains (Koch 1846). In fact, the scientific studies did not begin until the 20th century. Penther's photographs of the glacier on Mount Erciyes and his high-resolution map are the oldest known documents about a glacier in Turkey (Penther 1905). However additional studies in the other parts of the country did not follow these early initiatives. During the period from the 1905's until the foundation of the Turkish Republic including the 1st World War, there was a considerable hiatus before additional studies were carried out. The description and mapping of glaciers and glacial deposits began during the 1930's. At the beginning of the 2nd World War, Bobek (1940) made an exhausting study of glaciers in the Buzul Mountains of the Southeastern Taurus that included good photographic documentations of the glaciers. Bobek's work was the first in which the glaciated areas of Turkey were studied in the context of Pleistocene stratigraphy. No other detailed studies were made during the war, except for Blumenthal (1938) and Louis (1938, 1944). In the years following World War II, especially the research by Erinç is recognized as that of the pioneer Turkish glaciologist with detailed studies of Turkish glaciers (Erinç 1944, 1949, 1949a, 1949b, 1951, 1952a, 1952b, 1953, 1955, 1955a, 1955b, 1957, 1959, 1978; Erinç et al. 1955, 1961), including the discovery of the glaciers in Mount Kaçkar and Mount Süphan. By the 1960's foreign scientists became more and more interested in the previously studied areas and Turkish scientists started to study this subject. Apart from local studies, several scientists have made observations in a regional context about the glaciers and glacial deposits in Turkey and/or Mediterranean region (Louis 1938, 1944; Erinç 1952a, 1952b, 1953; Blumenthal 1958; Kaiser 1965; Messerli 1967, 1980; Birman 1968; Klaer 1969, 1977, 1978; Horvarth 1975; Kurter 1980, 1991; Somuncu 1989; Williams & Ferrigno 1991; Zreda et al. 2001; Çiner 2004). All these studies are mainly qualitative geographical and geomorphological field descriptions. Except for some pioneering work, age determinations remained relative. The most recent study on occurrence and genetic facies analysis of glacial deposits is by Çiner et al. (1999) for the Central Taurus Mountains. However, the age of the investigated deposits remains still unknown.

Glacial deposits are found mainly in the eastern, northeastern and southern part of the Anatolian Peninsula (Fig. 1, Tab. 1). They are located in the eastern part of the Black Sea Mountains (Palgrave 1872; Kossmat 1910; Krenek 1932; Leutelt 1935; Lembke 1939; Stratil-Sauer 1927, 1935, 1961, 1964, 1965; Erinç 1944, 1949a, 1949b; Yalçınlar 1951; Gall 1966; Planhol & Bilgin 1964; Löffler 1970; Dogu et al. 1993, 1994, 1996, 1997), in the western part of Black Sea Mountains (Erinç et al. 1961), Taurus Mountains (Maunsell 1901; Künne 1928; Bobek 1940; Planhol 1953, 1956; Izbirak 1951; Onde 1954; Erinç 1955, 1955a, 1955b; Spreitzer 1939, 1956, 1957, 1958a, 1958b, 1959a, 1959b, 1960, 1969, 1971a, 1971b; Yalçınlar 1954, 1955; Bilgin 1960; Wright 1962; Messerli 1967; Bilgin 1969; Arpat & Özgül 1972; Schweizer 1972, 1975; Delannoy & Maire 1983; Dogu 1993;

Dogu et al. 1999; Çiner et al. 1999), in the Eastern Anatolian Mountains (Klaer 1965; Bilgin 1972; Atalay 1984), Uludag (Louis 1944; Pfannestiel 1956; Erinç 1957; Messerli 1967; Birman 1968) and on isolated extinct volcanic cones in the interior parts such as Mount Erciyes (Penther 1905; Philippson 1906; Bartsch 1935; Blumenthal 1938; Erinç 1951; Messerli 1964, 1965; Güner & Emre 1983), Süphan (Erinç 1952a, 1952b), Ararat (Parrot 1834; Abich 1870; Rickmer-Rickmers 1895; Ebeling 1899; Oswald 1899; Blumenthal 1956; Imhof 1956; Arkel 1973). Morainic deposits that are not subjected to any alteration are assigned to the "Würmian (= Last) Glacial Period", whereas the altered deposits are assigned to the older glaciation periods (Erinç 1952b; Erol 1984; Kuzucuoglu & Roberts 1998).

There are various types of actual glaciers in Turkey such as ice caps, cirque and valley glaciers above the snow line. There are also glacierets below this line, nourished by the snow avalanches from the higher slopes. In many places they turn into rock glaciers in their lower parts (Erinç 1952b; Kurter & Sungur 1980; Erol 1984; Kurter 1991). These glaciers occur in higher elevations of the coastal range along the southeastern shore of the Black Sea (Fig. 2), in the middle and southeastern Taurus Mountains (especially the southeastern ranges and Aladag and Bolkar Mountains in the central part), and Mount Erciyes, Süphan and Ararat (Erinç 1952b; Messerli 1967; Kurter & Sungur 1980; Kurter 1991) (Fig. 1 & Tab. 1). The best-known place for the glacial activity is the Buzul Mountain Range (Eastern Taurus Mountains). There is Turkey's most important concentration of glaciers. The number of the glaciers exceeds twenty, including small cirques. All these glaciers are situated on the northern, shady slopes of the mountains (Erinç 1952b).

Climate of Anatolia

The climate of the Eastern Mediterranean region is influenced by three main atmospheric systems; (1) by the main middle to high latitude westerlies to the north and northwest, (2) by the mid-latitude subtropical high-pressure systems that generally extend from the Atlantic across the Sahara, and (3) by the monsoon climates of the Indian subcontinent and East Africa. In winter, the region is affected by the strong ther-

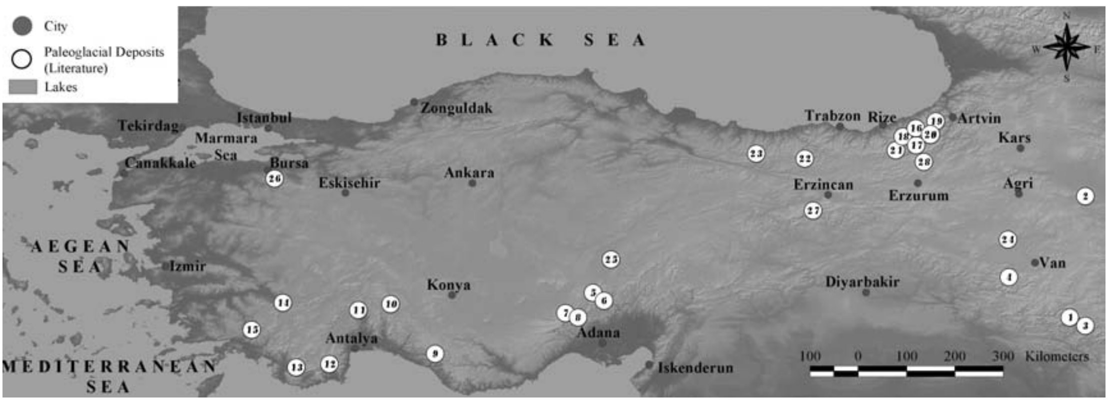

Fig. 1: Locations of Paleoglacial deposits in Turkey.

Abb. 1: Verbreitung fossiler Gletschersedimente in der Türkei.

Tab. 1: Location and types of recent glaciers and paleoglacial deposits in Turkey. Recent and Würmian Snowline altitudes are also indicated where available (modified after Messerli 1967, Kurter 1991, Çiner 2004).

Tab. 1: Lokalitäten und Gletschertyp der heutigen und der früheren Vergletscherungen in der Türkei. Die heutige und die letzteiszeitlichen Schneegrenzen sind für jene Gebiete eingetragen wo sie bekannt sind (verändert nach Messerli 1967, Kurter 1991, Çiner 2004).

No.	Name of the Mountain Range	Name of the Peak	Altitude (m)	Glacier Names	Type of Glacier	Area (km2)	Length (km)	Actual & *(Würmian)* Snowline Altitude (m)
1	Cilo	Uludoruk	4135	Uludoruk	Valley	8.0	4.0	3600 *(2800)*
				Mia Hvara	Valley	2.5	1.5	
				5 small glaciers	Valley to Mountain	0.3 to 1.0	0.2 to 0.5 each	
2		Mount Ararat	5165	11 Glaciers	Ice Cap	10.0	1.5 to 3.0	4300 *(3300)*
3	Sat	Dolampar	3794	Geverok	Valley	0.8	1.0	3500 *(2800)*
				Unnamed	Valley	0.1	0.4	
4	Kavuşsahap	Hasanbeşir	3503	Nortwest	Mountain	0.06	0.3	3400 *(3100)*
5	Aladağ	Demirkazık	3756	Lolut	Valley	0.5	1.0	3450 *(2700)*
6		Mamerdiğin	3407	No recent Glacier				3450 *(2700)*
7	Bolkardağ	Gökboyun	3524	No recent Glacier				3650 *(2650)*
8		Medetsiz	3524	North	Mountain	0.06	0.3	3200 *(2650)*
9	Geyikdağ	Geyikdağ	2850	No recent Glacier				3200
10	Dedegöldağ	Dipoyraz	2997	Several Glacierets	Cirque	0.3	up to 0.2	3400
11	Isparta	Davras & Barla	2700	No recent Glacier				2500
12	Beydağları	Beydağ	3086	No recent Glacier				3600 *(2650)*
13	Akdağ	Akdağ	3016	No recent Glacier				3500 *(2550)*
14	Honaz	Honaz	2571	No recent Glacier				3600 *(2550)*
15	Gölgelidağ	Sandıras	2295	No recent Glacier				2350
16	Rize	Kaçkar	3932	Kaçkar I	Valley	0.8	1.3	3500 *(2400)*
				Kaçkar II	Valley	0.5	0.7	
				Kaçkar III	Valley	0.3	0.1	
				Krenek I, II	Cirque	0.3	0.5	
				Dübe	Cirque	0.01	0.1	
17		Hunut	3560	No recent Glacier				2650
18		Verçenik	3710	Sinançor	Valley	0.05	0.3	3500 *(2700)*
				Dilektepe	Valley	0.14	1.0	
19	Altıparmak	Lazgediği	3353	Kırmızıgedik	Cirque	0.3	1.0	2650
20	Bulut	Kindevul	3562	Avucur	Cirque	0.015	0.15	2650
21	Soğanli	At	3395	Few Glacierets				2400
22	Gavur	Karadağ	3331	Avlıyana	Mountain	0.045	0.15	3500
23	Giresun	Karagöl	3107	Northwest	Mountain	0.08	0.4	2900
24		Mount Süphan	4058	South	Valley	3.0	1.5	4000 *(3300)*
25		Mount Erciyes	3916	Northwest	Valley	0.11	0.38	4000 *(2850)*
26		Mount Ulu	2543	No recent Glacier				2350
27	Erzincan	Mercan	3368	No recent Glacier				3600 *(2700)*
28	Erzurum	Mescid	3239	No recent Glacier				3600 *(2700)*

Fig. 2: Kaçkar-I Glacier (center) and Kaçkar-II Glacier (left) in the Kaçkar Mountain.

Abb. 2: Der Gletscher Kaçkar-I (Mitte) und der Gletscher Kaçkar-II (Links) im Kaçkar Gebirge.

mal high-pressure system, which covers a large part of the Asian continent (Siberian High) (Fig. 3).

There is a link between the monsoon and Mediterranean cyclonic systems, however complicated and not fully understood. One of the features of the monsoon system and one of its determining factors is the intensity of the Siberian High. This is primarily a winter feature and the penetration of cyclones over the Mediterranean region is determined in part by the intensity of this "Siberian control mechanism" of the general monsoon circulation in winter (Wigley & Farmer 1982).

During winter, the North Atlantic Oscillation (NAO) dominates atmospheric variability in the subtropical Northern Hemisphere (Fig. 4). NAO is characterized by an oscillation of the "atmospheric mass" between the Arctic and the subtropical Atlantic (Hurrell et al. 2001). When the NAO is in its positive phase, low-pressure anomalies over Iceland and Arctic combine with high-pressure anomalies across the subtropical Atlantic to produce stronger–than–average westerlies across the mid-latitudes (Fig. 4). During this phase, the climate is colder and drier than average over the northwestern Atlantic and the Mediterranean, whereas climate is warmer and wetter than average in northern Europe and the Eastern United States (Visbeck 2002). During its negative phase, the Icelandic low-pressure center and high-pressure center over the subtropical Atlantic are both weakened (Hurrell et al. 2001). This low NAO index results in higher precipitation ratios in the Eastern Mediterranean region (Fig. 4). All these

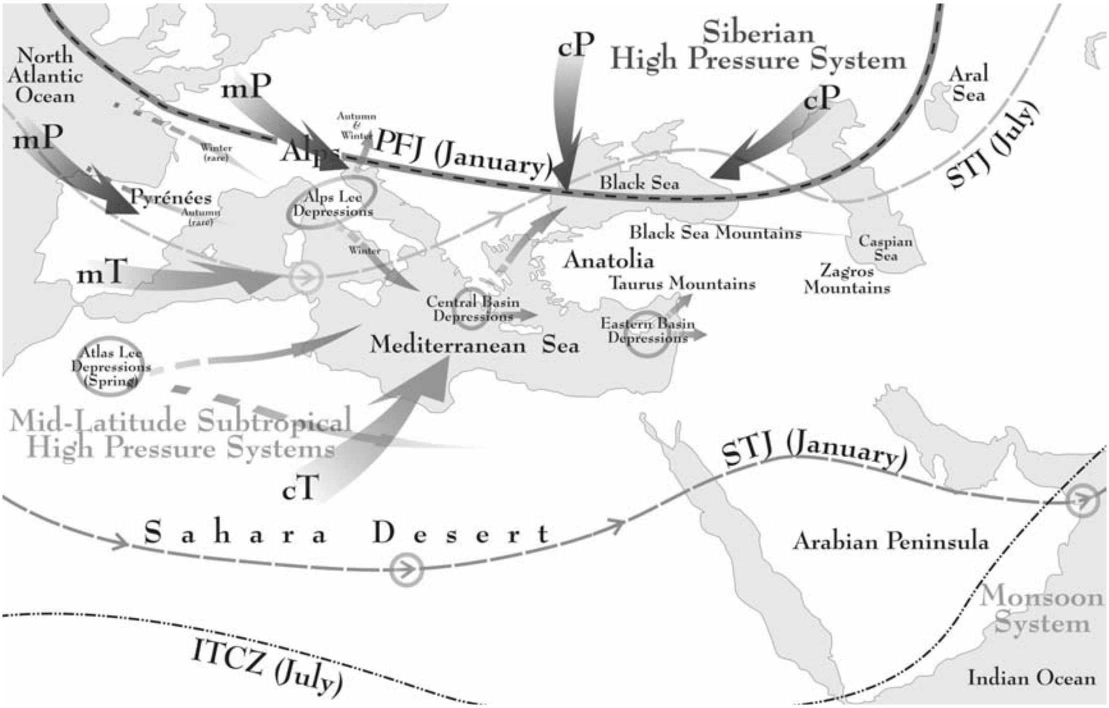

Fig. 3: Mean Positions of the Polar Front Jet (PFJ), Subtropical Jet (STJ) and Intertropical Convergence Zone (ITCZ) in winter and summer in the Mediterranean Region, schematically located Low Pressure and High Pressure Systems that influence the climate in the Eastern Mediterranean Region. (cP: Continental Polar Air Mass; mP: Marine Polar Air Mass; cT: Continental Tropical Air Mass; mT; Marine Tropical Air Mass) (modified from Wigley & Farmer 1982).

Abb. 3: Karte des Mittelmeergebietes mit nördlichen und südlichen Nachbargebieten und den wetterbestimmenden atmosphärischen Zirkulationsmuster: PFJ = Polar Front Jet; STJ = Subtropical Jet; ITCZ = innertropische Konvergenz; schematische Lage von wetterwirksamen Tief- und Hochdruckgebieten; cP = kontinentale polare Luftmassen; mP = marine polare Luftmassen; cT = kontinentale tropische Luftmassen; mT = marine tropische Luftmassen (verändert nach Wigley & Farmer 1982).

factors may be modified by the Mediterranean itself (as a heat and/or moisture sink or source) and by local topographic effects.

The transport of moisture is the most critical factor determining the precipitation pattern in the Eastern Mediterranean Region (as elsewhere). Marine Tropical Air Masses (mT) carry the hot and humid air from the tropical North Atlantic. Continental Tropical Air Masses (cT) convey the dry and hot air from Northern Africa. Passing over the Mediterranean Sea, they can acquire moisture and condensate it onto the southern coasts of Anatolia. Marine Polar Air Masses (mP) bring the humid and cold air from the polar North Atlantic. They have a more pronounced influence when they advance over the Mediterranean Sea. Continental Polar Air Masses (cT) transport the dry and cold air from Siberia. Over the Black Sea, they can take up moisture and condensate it onto the northern coasts of Turkey (Fig. 3).

Precipitation in the region, although mainly associated with cyclonic disturbances that originate in the Mediterranean Basin, is strongly

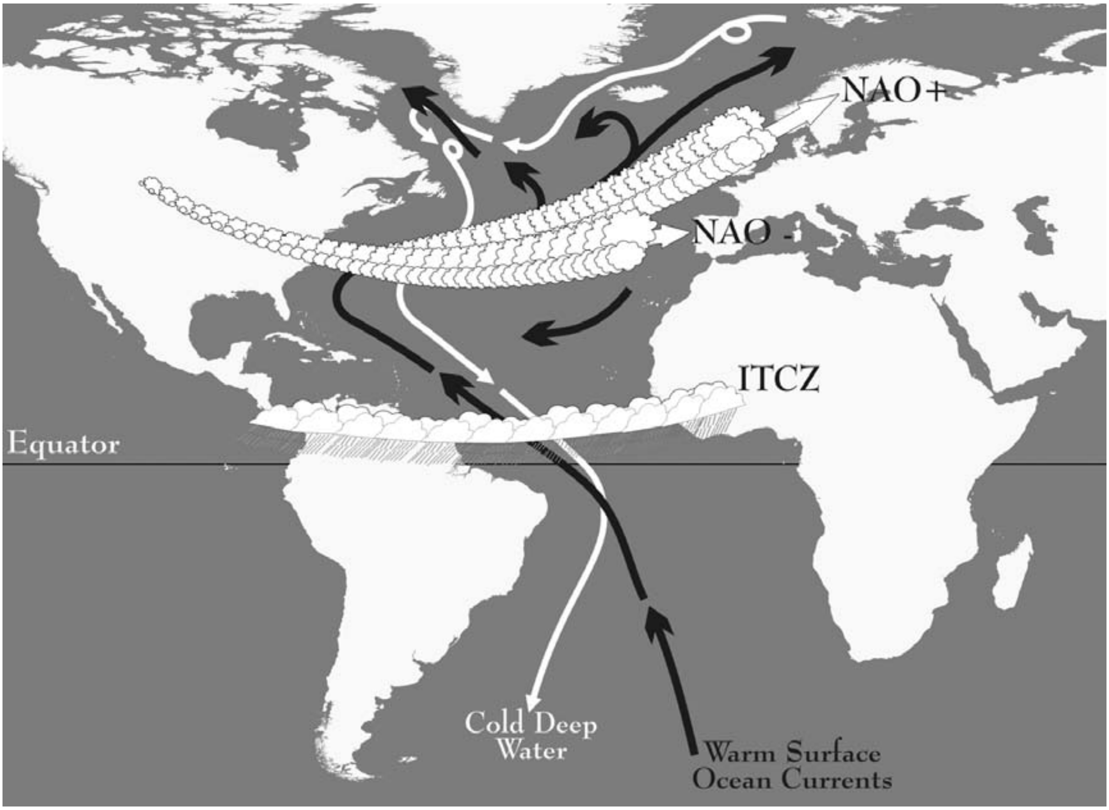

Fig. 4: Modes of Climate Variability in the Atlantic Sector (NAO: Path and the strength of winter storms depending on the dominant phase; ITCZ: Intertropical Convergence Zone in winter; White arrows: Cold, deep ocean currents; Black arrows: Warm surface currents) (Redrawn from Visbeck 2002).

Abb. 4: Karte des nördlichen und mittleren Atlantiks mit den wichtigen atmosphärischen Strömungmustern und deren Wirkungsgürteln; ITCZ: innertropische Konvergenz im Winter; hauptsächliche atlantische Meeresströmungen: weiße Profile = Tiefenwasser; schwarze Profile = warmes Oberflächenwasser (umgezeichnet nach Visbeck 2002).

influenced by local orographic effects (Fig. 3). There are four regions of cyclogenesis. The main region is the Western Mediterranean where the "Gulf of Genoa" is producing depressions that only occasionally move eastward far enough to affect the Eastern Basin. Atlas Mountains lee depressions, which form in spring do not bring rainfall: to the contrary, they are associated with hot, dry, windy conditions, especially those which follow a north African trajectory eastward into Egypt. For the Mediterranean and Near East, central and eastern basin depressions (Cyprus Lows) – both are winter and spring phenomena – are most important (Wigley & Farmer 1982). Rain and snowfall patterns over the region are extremely complex. Especially, high terrains of Anatolia play a physical important role on the atmospherical circulation in the region. The positions of the Taurus and Black Sea Mountains form an obstacle as well as a corridor (Kuzucuoglu & Roberts 1998; Somuncu 1989). Consequently, pronounced precipitation maxima occur there also due to the orographic effects of these Mountains (Fig. 5).

In the Eastern Black Sea Region, a dramatic drop in rainfall occurs as one moves 130-km inland from Rize (annual mean of 2200 mm) to Erzurum (annual mean of 400 mm) (Fig. 5). Both Rize and Erzurum are situated to the north of the Mediterranean climate boundary. A pronounced rain shadow is noticeable in central Turkey (WIGLEY & FARMER 1982). The snow line in Anatolia as suggested in the literature, is now between 3100 to 3400m depending on the increasing continentality from West to East. The limit is about 3100 to 3200m on the Eastern Black Sea Mountains, and 3400 to 3500 m on the Taurus Mountains in the south. In Central Anatolia permanent snow limit is about 3500 m and towards the east it raises to 3700 m on Süphan and to 4000 m on Ararat Mountains (ERINÇ 1952a; MESSERLI 1967; KURTER & SUNGUR 1980; KURTER 1991; SOMUNCU 1989).

The Problem

Although first observations on the presence of glaciers and glacial deposits are made in the 1840's in the southeastern part of the Taurus and Eastern Black Sea Mountains, the studies did not begin until the 20th century. The description and mapping of glaciers and glacial deposits began during the 1930's. Most of the results of these studies, however, are dependent more on general observation and theoretical assumptions than on direct field data. A summary statement is simple: examination of glacial features in Turkey contributes little to the interpretation of the Pleistocene-Holocene paleogeography and climate, and investigations of glacial features are incomplete and a sound chronology is non-existent (KAYAN 1999).

The complexity of the climate in the Eastern Mediterranean Region means that our understanding of today's climate is also still incomplete. The large-scale circulation features that influence the region are highly variable on all time scales. The positions of the jetstreams and jet maxima are important in determining surface pressure patterns and rainfall patterns but relationships are by no means simple. In very broad terms, roughly 10° south of the equatorward margin of the Polar Front Jet (PFJ) zone

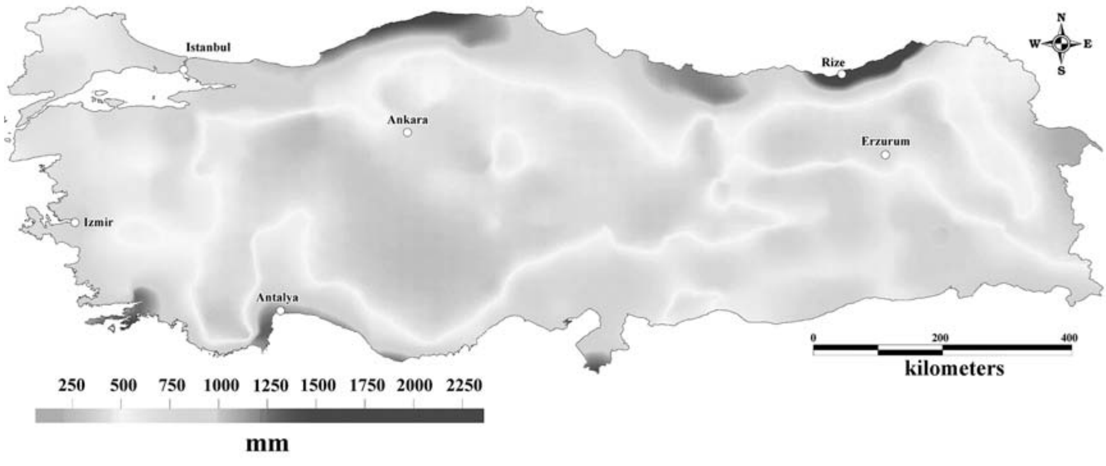

Fig. 5: Distribution of Average Annual Precipitation in Turkey from 1970 to 2001.

Abb. 5: Verteilung des durchschnittlichen Jahresniederschlages in der Türkei zwischen 1970 und 2001.

marks the boundary between surface cyclonic activity and the poleward extent of the subtropical highs.

Regions to the southwest and northeast of the jet maxima tend to be regions of greater rainfall than the southeastern and northwestern sectors (Wigley & Farmer 1982). So the determination of the positions of the jetstreams and jet maxima during glaciations (especially during LGM) is crucial for our understanding of the transport of moisture during a cold period in the Eastern Mediterranean region. To answer this question, we simply need to know amplitude and frequency of paleoglacier advances in Anatolia: we need to map the geometry of the former ice bodies and how they relate to moisture input and we need to date such events through the establishment of moraine chronologies.

At least during the last phase of the Würmian glaciation, as suggested in the literature, the build-up of ice in the central part of the Alps was related to precipitation by southerly winds, similar to today's foehn weather pattern (Fig. 6). Thus, whereas southerly circulation and the advection of moist air masses from the relatively warm Mediterranean Sea became predominant, the maritime influence of the North Atlantic on Western Europe was strongly reduced during the LGM (MIS2), and continentality increased markedly at the same time.

This configuration can be considered as the main reason for the missing or limited ice advances in the Vosges, Pyrenees, and Massif Central. Finally, the build-up of the Fennoscandian ice sheet can be explained by the split of the storm track over the Mediterranean, with one branch heading north toward Scandinavia (Florineth & Schlüchter 2000).

At around the Last Glacial Maximum, Anato-

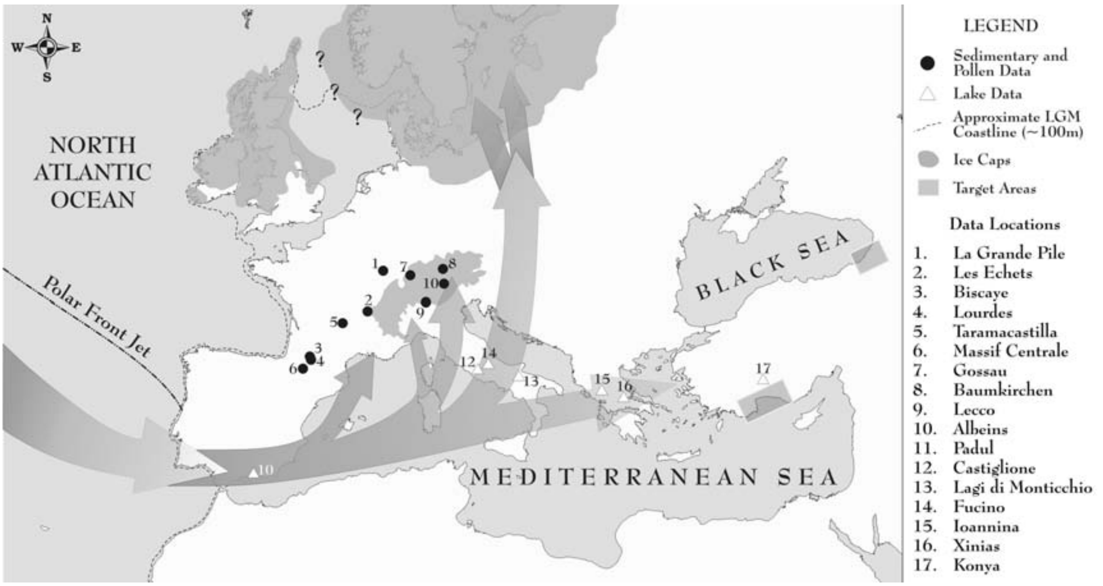

Fig. 6: Map of Europe and the Mediterranean Sea during the LGM (MIS2) with the assumed characteristics of the winter atmospheric circulation pattern (modified from Florineth & Schlüchter 2000).

Abb. 6: Karte von Europa und des Mittelmeergebietes während des Letzten Gletschermaximums (LGM = MIS2) mit interpretierter, vorherrschender Winterzirkulation (verändert nach Florineth & Schlüchter 2000).

lia experienced a substantial expansion of cold steppe vegetation at the expense of forest and woodland (Erinç 1978; Erol 1981; Zeist & Bottema 1982; Zeist & Bottema 1991; Atalay 1998; Özdogan 1998; Kuzucuoglu & Roberts 1998). Coinciding with this, closed lakes were far more extensive than at present. For example, the level of the Lake Van was more than 70m above its present level (Landmann et al. 1996). A combination is best explained by a reduction in evaporation, and evapotranspiration losses, accompanied by higher catchment runoff (Kuzucuoglu & Roberts 1998). This pattern of LGM atmospheric circulation is consistent with the southward displacement of the westerly jet stream at least to the latitude of northern Spain (Sarnthein 2001) and a similar shift in the build-up and prevailing tracks of the precipitation-bearing mid-latitude cyclones to a new position south of the Alps (Fig. 6). The more southerly position of the westerlies would lead to prevailing southerly circulation in the Alps due to cyclonic circulation over the Mediterranean Sea and also to increased precipitation along the jet stream axis, which explains the high lake levels throughout the Eastern Mediterranean area (Florineth & Schlüchter 2000).

With regard to the Last Glacial Maximum (LGM) it is not only an issue to determine the maximum aerial cover of ice since the Last Interglacial but it is also as much a question of when it occurred; was it early during Oxygen Isotope Stage (OIS) 4 and therefore going with reconstructions from the Spanish Pyrenées (Marti 1992; Bordonau 1992) or was it late during OIS 2 and, then coinciding with maximum ice cover in the Central Alps (Furrer 1991). Again the structure of the Last Glacial Cycle is the key issue (Tzedakis et al. 2002).

First Results

Kavron valley is situated in the Kaçkar Mountain range in northeastern Turkey (Number 16 in Fig. 1 & Tab. 1). It is a north south oriented, typically U-shaped glacial valley approximately 12km in length. The U-shaped morphology extends down to an altitude of approximately 1600m. Kaçkar Mountain is the highest peak of the mountain range (3932m) and possesses the 2nd largest glacier of Turkey (Fig. 2). Kavron valley consists of a main valley and three tributary valleys. These tributary valleys are connected to the main valley by moraine bastions, which formed by the accretion of the glacial deposits due to a bedrock obstacle. The tributary valleys are Derebasi (Fig. 7), Mezovit and Ifrit Meadows.

We have mapped the Quaternary geology of this valley system. Quaternary geological deposits include basal tills, washboard moraines, moraines, moraine bastions, snow-avalanche ridges, rock glaciers, alluvial plain and alluvial fan deposits. Roche moutonnées and polished bedrock provide evidence of glacial erosion in this area. Moreover moraine ridges, snow avalanche ridges, moraine bastions and glacial lakes comprise the glacial morphological features observed in the Kavron Valley. Unfortunately huge active rock glaciers that developed following glacial activity obscure the relicts of glaciers in the uppermost parts of this valley system (Fig. 7 & 8). In the field it is presently difficult to pinpoint the classical LGM – YD – Little Ice Age (LIA) moraine sequence. Especially the presence glacial advance during LIA is in Anatolia still unclear. Whether recent moraines on the mouth the Kaçkar glacier represent LIA (Fig. 2) or relicts of LIA is completely destroyed by intensive rock glacier activity (Fig. 7 & 8) remains still open.

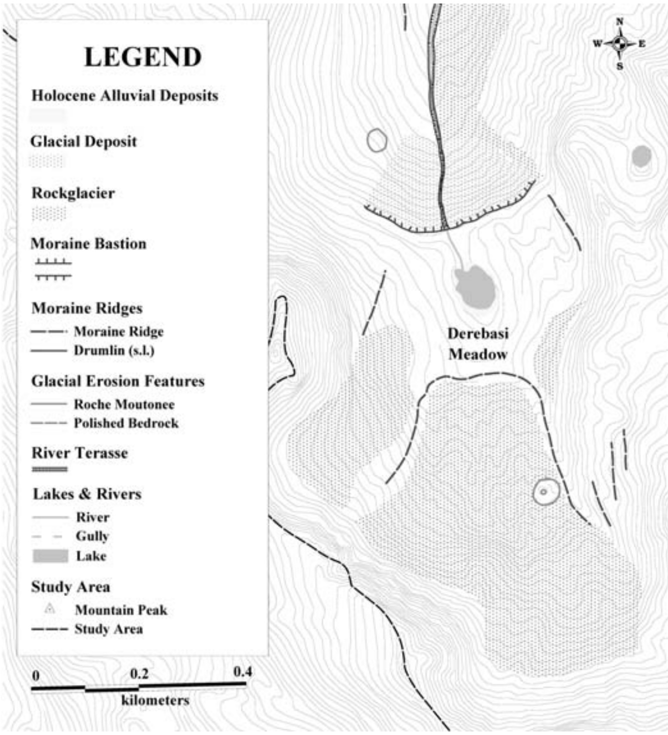

Fig. 7: Quaternary Geological Map of the Derebasi Meadow.

Abb. 7: Die quartärgeologische Karte des Alps Derebasi.

Fig. 8: Huge Rock Glacier on the Upper Most Part of Derebasi Meadow.

Abb. 8: Die Entwicklung der grössten Blockgletscher in der Alp Derebasi.

Conclusions

The large-scale circulation features that influence the Eastern Mediterranean Region have been highly variable at all time scales. These features play a determining part in present and past climatic conditions in the region and relatively small changes in any of these might cause significant climate changes. Much greater variations in these features must have occurred in the past, especially in response to the dramatic changes in the global boundary conditions, which accompanied (or caused) the end of LGM (=Termination I, Wigley & Farmer 1982). As glaciers react sensitively to these changes and as they produce a distinct geological record of their changes in mass balance, they constitute a crucial and direct geoarchive of climate change. To retrieve the relevant information from Anatolian Mountains, glacier oscillations need to be quantified in amplitude and frequency: moraines produced by the Anatolian glacial activity, need to be mapped and dated.

During LGM, the Oceanic Polar Front Jet gradually moved southward (Fig. 6), reaching as far as the latitude of Spain (42°-46°N) in the North Atlantic (Sarnthein 2001). Such southerly excursion of the jet could have resulted in increased precipitation over the Mediterranean region, and more frequent penetration of cyclones eastward across the Anatolia and Middle East. For instance, a prevailing eastward direction of the depressions generated by the Cyprus lows in early Holocene times could explain the differences in the vegetational history of southeastern Turkey. In the Lake Van area, the expansion of trees took place between 6500 and 3500 B. P.; desert-steppe vegetation indicates that the early Holocene climate of southeast Turkey had a very arid character (Zeist & Bottema 1982, 1991; Bottema 1978, 1995, 1997). If in early Holocene times, the preferred tracks of the Eastern Basin depressions were to the east (Fig. 3), southeastern Turkey would have received little precipitation. A subsequent shift to a more frequent northeastward direction of the cyclone tracks would have brought more precipitation to eastern Anatolia. In this respect it should be mentioned that the mountain ranges in eastern Turkey run in a southwest-northeast direction. As a consequence, moisture loaded southwesterly winds can penetrate far into the interior. With prevailing westerly winds precipitation may have been transported into East Anatolia less easily (Zeist & Bottema 1982).

In this context, Anatolia is the fundamental element to understand the interactions between paleoenvironment, climatic variations, and development of the human societies (e.g. Çatal Höyük and the Fertile Crescent). Climate change, above all the possibility of abrupt climate change, has to be verified from paleorecords. Its importance for the society within the ongoing discussion on global environmental change is of timely relevance. At a global scale, there is a substantial need to evaluate the existing data and advance research on the paleoglaciation in Anatolia (Schlüchter 1989). As the Taurus and Black Sea Mountains are sensitively situated for the paleoclimatic reconstructions, a chronostratigraphic framework on the paleoglaciation should be elaborated. Although it is presently difficult to pinpoint the classical LGM – YD – LIA moraine sequence, our results from the Kaçkar Mountains are encouraging for the reconstruction of glaciations in Turkey and related paleoclimatological interpretations.

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