

## Geopedology Reports Historical Changes in Climate and Agroecology: A Case Study from Northwestern Iran

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**ABSTRACT** Global warming is claimed to be the cause of climate change, which is often held responsible for water shortage. Let geopedology represents the complex process of soil formation, out of which much can be learnt about paleoecology; soil formation being a dynamic interaction between the atmosphere, biosphere, lithosphere, and the hydrosphere. In a multidisciplinary sustainability-oriented study in northwestern Iran, geopedologic data were analyzed and cross-referenced with some historic and archaeological information to reconstruct paleoecologic conditions in several time periods, through which the changes both in climate since upper Pleistocene, and in landuse and their consequences in terms of land degradation could be concluded. The occurrence of a (sub-) surface layer of travertine, dated 27,000 y BP that is coated by a thin organic layer with traces of *rancienite* (*mineral*), dated 13,000 y BP, implies a humid environment, corresponding with the pluvial uppermost Würm. The geopedologic survey, supported by soil micromorphology, revealed that between 6,000 and 2,600 years ago the area was subject to cycles of erosion and sedimentation that have led to glacis formation. A type of climate that is characterized by the alternation of wet and dry periods is also supported by the occurrence of Petrocalcic and Argillic horizons in the soils. Cultivating rice, tobacco and cotton, which was practiced until over a century ago, also implies relatively wetter conditions. The study concludes that aridification has never been as degrading as it is today, due to the over-exploiting of the non-renewable fossil groundwater.

**Key words:** *Aridification, Geopedology, Global warming, Hamadan-Iran, Soil micromorphology*

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### 1 INTRODUCTION

In the past few decades, 'global warming' is considered as the cause of changes in climatic conditions, particularly in the (semi-) arid regions, where the shortage of water is remarkable. Noticeably, some researchers do not believe in the global change of climate, as it was reflected, among others, at the international congress on climate change, held in

Amsterdam, The Netherlands, in November 2000. Many researchers around the world have employed different ways to approve or deny the 'global' climate change. In this study, the role that geopedology can play is demonstrated. Geopedology--also known under the name 'soil geomorphology-- covers a wider field than pedology alone, for it explains the complex process of soil formation within a framework

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that is controlled by geomorphology. Soils in pedosphere only develop when there is a dynamic interaction between the atmosphere, biosphere, lithosphere and the hydrosphere.

In a multidisciplinary sustainability-oriented study in the semi-arid region of northwestern Iran (Farshad, 1997), where geopedologic analysis formed the basis of the research, historical climate and land use/cover changes, in relation with 'aridification' were investigated too. Aridification refers to the changes of soil moisture regime towards an increasing soil aridity, caused by disturbances in soil/topography/ vegetation/ climate system. Aridification is often accelerated and/or caused by over-extraction of groundwater, which leads to a worsening of the biophysical conditions (Terradaily, 2006).

The objective of this study is to demonstrate

the role that geopedological setting, that is, soil as related to geomorphology and hydrology, plays in reporting the history of a landscape.

## 2 MATERIALS AND METHODS

Following the geopedologic study conducted in the whole area of Hamadan-Komidjan (Figure 1), eight soil profiles in the key landscape units (hill-land, different levels of glacis, river terrace, and depression), out of over 110 observations (pits and auger-holes), were selected and studied (Table 1), not only morphologically (Figure 2), but also micromorphologically (Figure 3) and mineralogically (Figure 4 and 5), and archaeologically. Carbon dating was applied to the excavated relics, the relevancy of which was checked versus historical documents (Farshad *et al.*, 1999).

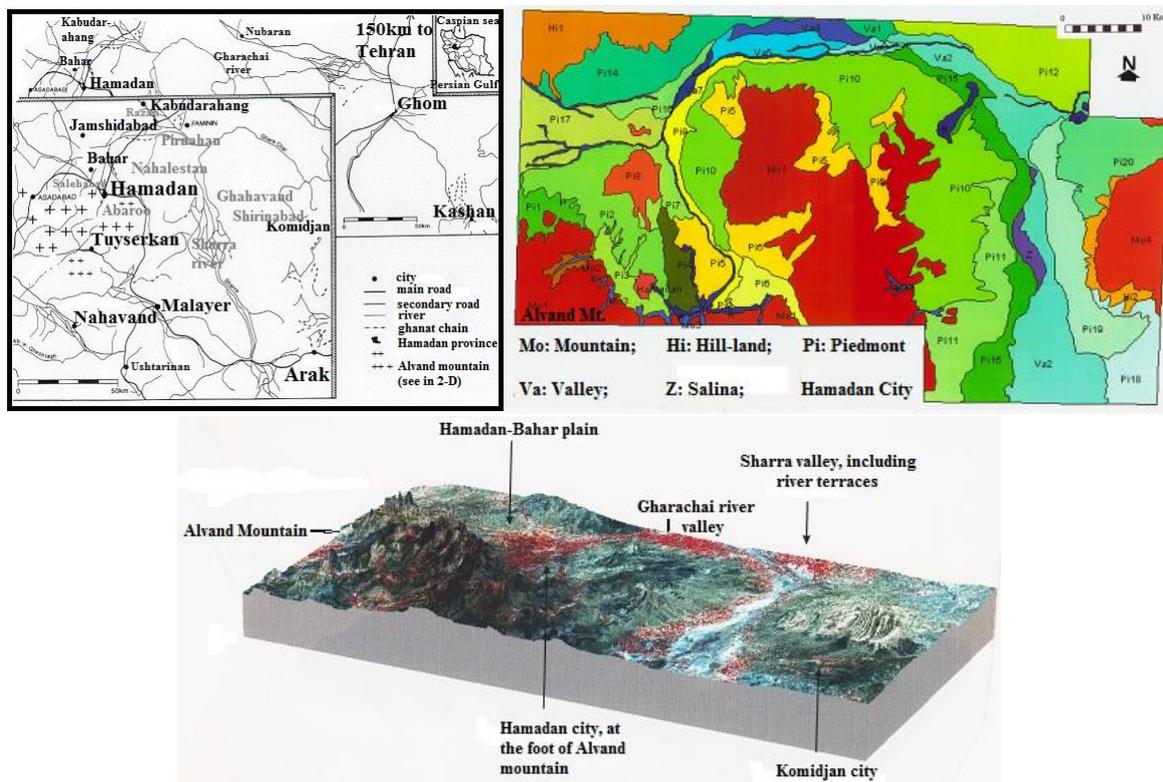


Figure 1 Location map; (above left), 2D; (above right) and 3D; (below) geomorphic units

**Table 1** Morphologic properties<sup>1</sup> of the selected soil profiles.

<i>Mech2 (Figure 3)</i> Abaroo village (34°42'N 48°34'E)	The soil is stratified and further characterized by a rather dark colour (10YR and 5Y 4/2), weak medium and fine subangular blocky structure and gravelly sandy loam and gravelly coarse sandy clay loam (Ap-Bw-C). The soil is classified as Loamy skeletal member of Typic Xerepts.
<i>Mech3(Figure 3)</i> Kabudar-ahang Razan territory (35°38'N 49°04'E)	This profile is quite similar to FA02 (here below). The soil is very deep, brown (7.5YR) A and Bk horizons over yellowish brown (10YR) C layer. The dominant texture is clay loam and light clay, with one or two thinner horizons with gravelly texture. Structure is weak (in A) and moderate (in B) medium subangular blocky; classified as Loamy and Fine Calcic Xerepts.
<i>FA02</i> In the vicinity of Jamshidabad village (35°02'N 48°28'E)	Very similar to the profile Mech3. The soil is very deep, brown (7.5YR) A and Bk horizons over yellowish brown (10YR) C layer. At 130cm depth lies a brown (10YR 4/6) 2Bt, with broken thin clay skins. The dominant texture is clay loam and light clay, with one or two thinner horizons with gravelly texture. Structure is weak (in A) and moderate (in B) medium subangular blocky. The soil is classified as Loamy and Fine Calcic Xerepts.
<i>FA11(Figure 2)</i> In Nahalestan depression <sup>2</sup> (34°54'N 48°27'E)	This soil profile was studied in the only surface in the Hamadan-Bahar area where alkaline soils occur. The soil is characterized by a Mollic-like epipedon over a rather thick brownish (7.5YR5/2) Bt with prism-like structure (Ah-Bt1-Bt2-Bt3-BC). The ground surface is finely cracked demonstrating the rounded tops of the columnar structural elements; classified as Fine, Mixed, Mollic Halaquepts.
<i>FA24(Figure 2)</i> in the glaciis at the foot of the Agh-tappeh (34°55'N 49°05'E) in the Shaltook- kari (meaning paddy cultivation) area (Figure 4) <sup>3</sup>	The soil is very deep (studied down to 195cm), dominantly brown (hue=7.5YR), except for the depth between 129 and 178cm (including Btb), where colour is greenish and/ or greyish olive (7.5YR 5.5/2 and 5Y6/2). Texture of the thick Bt is dominantly clay. The texture of the stratified layers below the depth of 178 cm (C layer) varies from sandy loam to sandy clay loam. Structure of the top 60 cm is blocky, followed by prismatic to the top of the buried horizon. From 129 cm downwards structure is described as massive, that is, in Btb and C (sub-) horizons; classified as Anthrosols (proposed name) <i>The archaeological features identified in the profile are as follows:</i> -Small pieces of pottery at two depths (60 -83 cm and 129 - 155 cm). -A fragment of bone at the depth of 60- 83 cm, lying on a piece of thin clay pottery. -Two pieces of brick, one at the depth of 60- 83 cm and another one at 160 cm depth. In traditional agriculture, it is still a common practice to add sand or clay to make heavy topsoil lighter for growing vegetables or heavier for growing rice. Also old roof debris (clay mixed with straw) are added to the topsoil, believed to improve fertility.
<i>FA18</i> Next to the abandoned Hajiabad village (34°51'N 49° 01'E)	The soil is moderately deep (at about 100 cm starts the lithic contact, an extremely hard rock), dominantly brown (hue=7.5YR), texture is silty clay to clay, and structure is prismatic parting to angular blocks, with common broken moderately thick clay skins on ped faces and in pores. Mottles are common distinct and concentrated in between 30 and 60 cm depths. The soil profile designated as A-Bt-Btg-Bt-R; classified as clayey member of Vertic Natraqualfs.
<i>FA18a</i> (not soil) Surrounding of Ghahavand village (now called town) at (34°51'N 49°00'E)	On the left (Sharra) riverbank, a thick layer of travertine is exposed with a poor vegetation cover, used as pasture. The detailed investigations on the travertine layer revealed several facts, which help better understanding of the landscape and the derived interpretations for agricultural aspects. The interior portion of the travertine (crème in colour) comprises calcite, some quartz and feldspars. This, on the basis of the results of carbon dating, goes back to ±30000 years before present (BP). The much thinner layer covering the crème-coloured layer, more whitish in colour is dated 27070 y BP. Finally, the dark coloured coat covering almost the entire surface of the travertine layer comprises some calcite, much of goethite (FeOOH) and a seldom mineral type, namely <i>rancieite</i> [(CaMg) Mn4O9, 3H2O]. The dark coloured coat is about 1 mm thick and was dated 13000 y BP, which corresponds with the uppermost Würm, in a pluvial period (Krinsley, 1970). On the down-facing surface of the travertine layer, in the coat covering the dark coating, there is some whitish half-ball-like in shape, which is light crème in colour and composed of calcite.

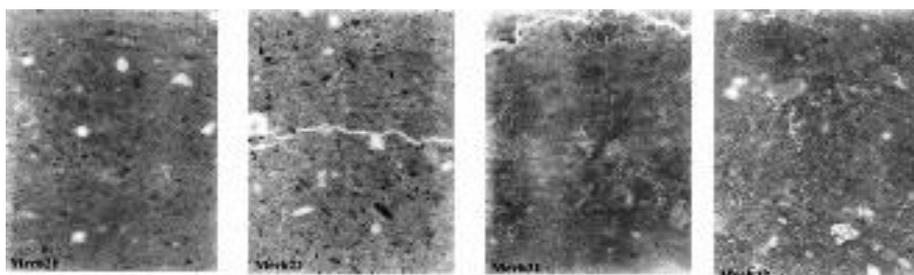
<sup>1</sup> Coordinates (in the left column, for each pit) refer to the area surrounding the given point (soil profile).

<sup>2</sup> The area is seasonally grazed. In the past, in winters, when irrigation water is not needed, the unused water of several ghanats (underground irrigation tunnels) was deviated and spread over this depression (Farshad and Zinck, 1998). The relics of a few artificial channels which led the excess water into the river are visible in the 1:50.000 scale B&W aerial photograph of 1958 (Farshad, 1997). In the centre of the depression, also relics of a castle on an elevated surface (artificial mound) are visible. The area is so intensively excavated by people that there is little left of the mound. Nobody knows when the castle was in use.

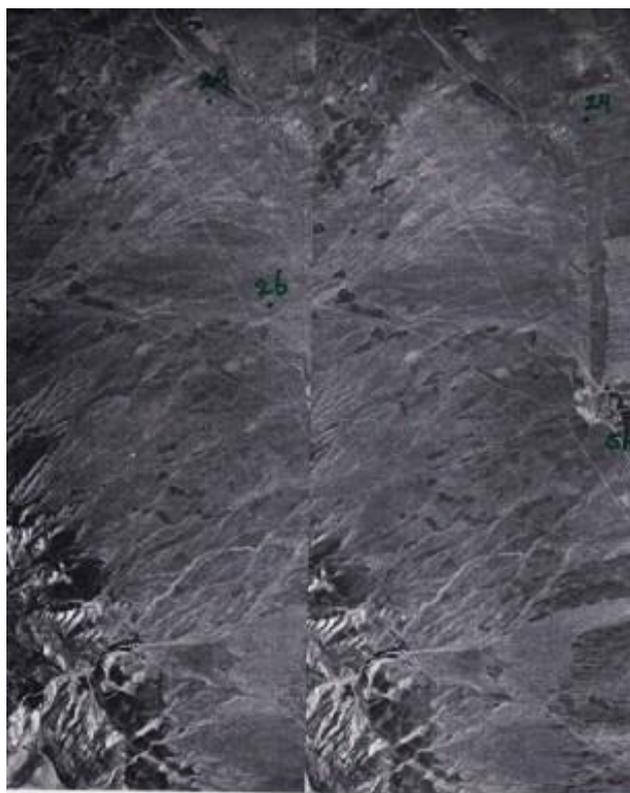
<sup>3</sup> Almost everybody mentioned that the tappeh (mound) is the remnant of a large settlement complex from the period of Solomon (over 900 years BC). Although this might not be literally true, it implies a distant past (Farshad and Barrera-Bassols, 2003). Several whitish low mounds occur in the area, which can be related to upper Jurassic whitish limestone. The area is a part of a bajada formed by coalescing alluvial fans, which originate from Jurassic and Oligo-Miocene formations. The Agh-tappeh and some other smaller mounds look like islands surrounded by fan deposits (Figure 2). The described soil profile is located in the middle part of the bajada, at the foot of the mound, where the slope is nearly level.



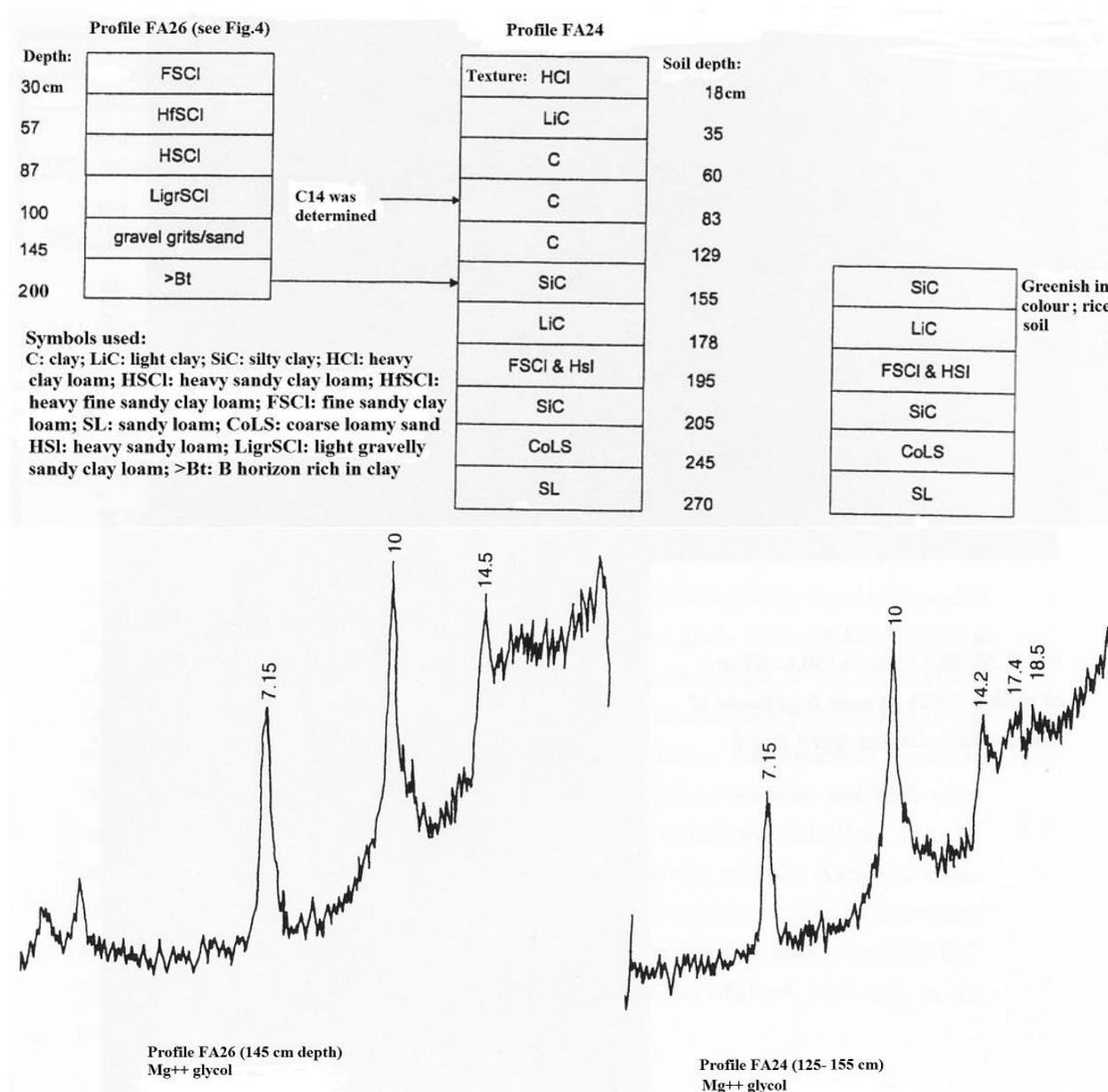
**Figure 2** Examples of soils: a) stratified material (Fluentic subgroup of Xerepts); b) Salic horizon; c) Columnar structure in FA11; d) an example of relict in FA24.



**Figure 3** Examples of the thin sections (Mech2 and Mech3; Table 1).



**Figure 4** Stereogram depicting the glacis (pit FA26 is studied here), stretching further down to Shirin-abad (Sh) territory and the Shaltook-kari area, where profile FA24 (Table 1) is studied.



**Figure 5** Schematic cross section of the piedmont where the pedostratigraphic correlation between profiles FA26 and FA24 is illustrated (above); below: two X-ray diffractograms prepared for the above soils (below).

### 3 DESCRIPTION OF THE AREA

To comply with objectives of the study as a whole (Farshad, 1997), a few areas were selected in Hamadan-Bahar, Sharra, Kashan and Yazd, to represent the (semi-) arid climatic conditions in Iran. In the present paper only Hamadan-Bahar and Sharra areas, hereafter referred to as the

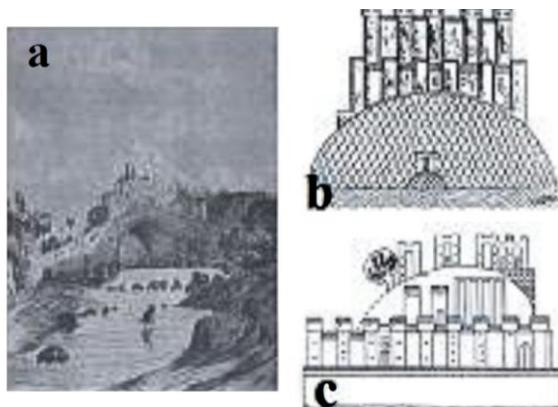
Hamadan-Komidjan area (Figure 1), will be dealt with.

In the Hamadan-Bahar area, believed to have been inhabited during the Medes kingdom (625-336 BC), several sites were studied. The area has been known for its agricultural potential since centuries. Hamadan, also known as *Ekbātana*

and *Hagmataneh*, has been mentioned in several ancient scripts and epigraphs, for example in the one related to the Assyrian king-- Tiglath-Pileser, 11th century BC. (Figure 6).

### 3.1 Geopedology

Hamadan (1750 m a.s.l.), the capital city of Hamadan Province, is located at the foot of the Alvand mountain peak in the central Zagros mountain range (Figure 1), about 400 km southwest of Tehran. Mountain, hill-land, piedmont and valley are the major geopedologic units distinguished in the study area (Farshad, 1997; Farzaneh, 2011). Very shallow rocky soils of the barren mountains and hills (Entisols) intergrade down slope into medium- textured and deeper soils (mainly Calcic Xerepts, also Petrocalcic Xerepts and Calcixeralfs) on the dissected upper glacia surfaces. These are then followed, on the lower glacia and finally in the valley, by finer textured and deep soils (Typic and Calcic Xerepts).



**Figure 6** Different drawings of the Median Palace on the Hagmataneh mound (after Kiani, 1989): a= depicts a part of Hamadan landscape (by Fladin); b=found on the Assyrian remains; c=reconstructed by Diakonev.

### 3.2 Climate

The average annual precipitation, on the basis of the data of 20 years (1964 -1983) is about 305 mm, most of which fall during December to May. From the total precipitation, 40-45% falls in

winter, 30% in autumn, 25% in spring and 1-5 % in summer. The maximum amounts of 45 mm, mainly as snow, and 39 mm, as rain fall in January and in May, respectively. Snow lies about 6-8 months in the mountainous parts. The mean annual precipitation in the higher altitudes is about 100 mm more than the amount that falls in lower located areas.

The mean monthly temperature in the Hamadan-Komidjan area varies between -5 °C in January and 24°C in June, with an annual mean of 10°C. The hottest month is July and the coldest months are January and February. A mean maximum temperature of 34.5°C occurs in July and a mean minimum temperature of -9.5°C in January.

The average annual evaporation from a class A pan for a period of 20 years (1964-1983) is 1870 mm. The highest evaporation takes place in July with 300 mm, while the lowest value is 13 mm in January.

The mean annual relative humidity is about 55%. Relative humidity drops from June to October, with a lowest value of 33% in July, while it is high from December to March, with a highest value of 80% in January.

The soil moisture regime is (dry) xeric, and the temperature regime is mesic (van Wambeke, *et al.*, 1986).

### 3.3 Water availability

Availability of water depends on the amount of precipitation, which varies within each year and also from year to year, and on the groundwater recharge, but also on the way people consume it. Estimation of available water is often difficult, especially when the area forms only a part of a watershed.

The water balance for the Hamadan- Bahar area and a part of the Sharra valley were established. The total water demand, including domestic uses, crop water needs, industrial and livestock consumption, amounts to 380 Mm<sup>3</sup> for the Hamadan- Bahar area. The available water,

including both surface and groundwater, was estimated 345 Mm<sup>3</sup>. This makes a negative balance of 34 Mm<sup>3</sup> year<sup>-1</sup>. In the same way, the water budget for a part of the Sharra area shows a deficit of more than 120 Mm<sup>3</sup>. For instance, in the village of Shirin-abad (Figures 1 and 4), an observation well showed a 13 m drop of groundwater level in a period of six years, between 1986 and 1991.

According to the Djamab report on the Hamadan- Bahar area (1990), there are 1747 (semi-) deep wells, 158 ghanats (Farshad and Zinck, 1998) and 389 springs, with annual discharges of 285, 27.5 and 27 Mm<sup>3</sup>, respectively. Thus, the highest discharge from the aquifers is through wells excavated in the recent years. This also holds true for the Sharra area. However, the rechargeability of the aquifers in the Hamadan-Bahar area is higher than in the Sharra area, because of the fractured Alvand granitic rocks, the long-lasting snow cover on the high Alvand peaks and the permeability of the piedmont materials (Jalali, 2006). The richest aquifers were those of the karstic limestone (Figure 7), which have dried because of intensive water extraction (Karami and Hayati, 2005).

### 3.4 Agroecological systems

An agroecological system comprises several entities and sub-entities which are supposed to be co-evolved under sustainable conditions. Changes in environmental conditions will affect the system, which means that the system must be adaptable to remain sustainable. It is a well-known fact that unaccounted changes in land cover and land use can lead to land degradation, which affects, among others, food security. In this study, radiocarbon dating helped integrate (ethno-) history, archaeology and the physical aspects which led to distinguish 5 periods, namely 5000-350 BC, 350 BC-AD1920, 1920-1960, 1960-1980 and 1980-present (Farshad and Barrera-Bassols, 2003). The

Medes were good at agriculture and cattle raising. It is recorded that the best kind of alfalfa was grown in Iran. The scientific names *Medicago sativa* and *Medicago falcate* (two varieties of alfalfa) refer to the Medes (Farshad, 2001). The crops which are not cultivated anymore are rice, cotton and tobacco. The best leather and woolen clothing in Iran was known coming from Hamadan. To simplify it further in terms of sustainability, two systems were modeled, namely the "traditional" and the "modern" (Farshad and Zinck, 2001). The traditional system included three interdependent production sectors (cultivation, animal husbandry, and rural crafts) within one household unit, whereas the modern one comprises of three independent production sectors (cultivation, animal husbandry and rural industry) belonging to separate household units. Production in traditional system was oriented toward family consumption; surpluses were exchanged among households in the same village. In the modern agricultural system production is market oriented and each sector specializes in delivering intermediate and final products.

The soils included in the Calcic and Typic subgroups are associated with a weakly developed fluventic character. Remarkable is that in the Keys to Soil Taxonomy (USDA, 1998), the Fluventic subgroup of the Xerepts is listed before the Calcic subgroup. Many soils being only weakly fluventic are thus classified as Fluventic, although they also bear a calcic horizon. Because of their large extent, Calcic Xerepts were classified at family level and, in some cases, at phase level.

The soils of the low-lying areas of the Sharra valley (in the Central Province, to the east of the Hamadan Province) are salt-affected (Salids and Natrixeralfs). In general, the soils are calcareous and have a low organic matter content, alkaline reaction (pH varies from 7.5 to 8.5), with calcium

carbonate accumulation somewhere in the upper 150 cm of soil, medium to fine texture, and low biological activity.



**Figure 7** A view of the Pirnahan (karstic) spring; dried out.

#### 4 RESULTS

Soil (micro-) morphologic features revealing climate change: The micromorphologic study helped differentiate petrocalcic from the travertine. It also helped mineralogical investigation on the black (organic) and whitish (calcitic) thin layer that coats the travertine, wherein the mineral *rancienite* was identified (Table 1). The striking micromorphologic feature, that helps distinguish the travertine, is the comparatively coarse calcite grains, interpreted as being related to karstic (spring) activity (Figures 8 a and b and 9).



**Figure 8** a) The exposed travertine on the surface; b) Coated travertine in the pit.



**Figure 9** Coated travertine specimen (up), micrograph of the thin section prepared from the specimen shown (down) under XPL (Crossed Polarizers) at magnification of x 2.5: a and c = Phenocrystals of calcite and b = dark layer containing organic material and some rancienite.

Soil morphology, that is, studying the buried horizons in several soil profiles, such as in FA31 (at  $\pm 130$  cm depth; dated  $\pm 6000$  y. BP), and in FA24 (at 130 cm depth;  $\pm 2600$  y. BP) indicated that glacia formation in the region was active between 2600 and 6000 years ago (Figures 4 and 5).

Stratification and fluventic property (Figure 2), which were also approved by micromorphologic study supported the process of (accumulation) glacia formation.

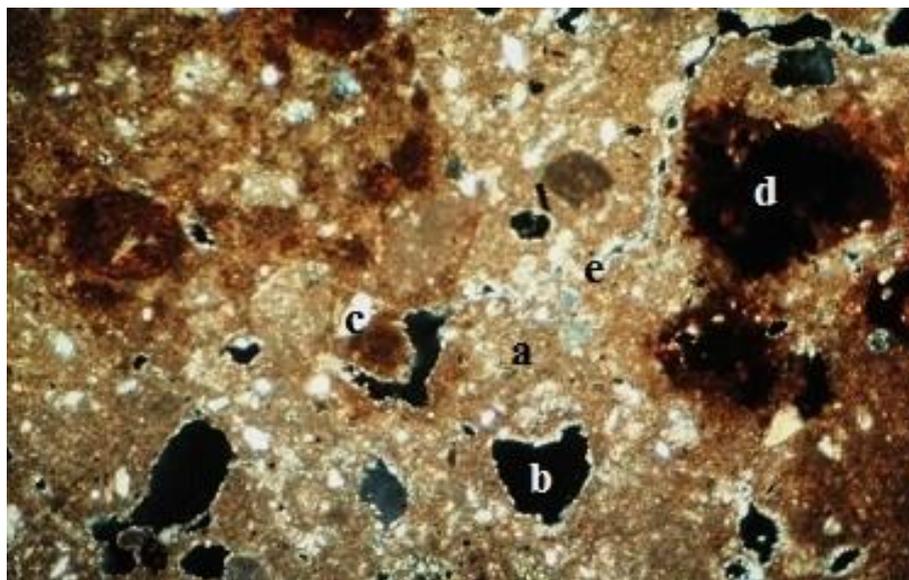
Studying profile FA24 revealed that the layer at  $\pm 130$ cm, which has a reduced colour and is associated with a lot of rusty colored mottles was a paddy filed, about 2600 years ago

(Figure 10). At this depth (130cm) micro-structure is weak subangular blocky, with curved planes, also channels, c/f  $10\mu\text{m}^{3/2}$ , open porphyric, silt size fine material, which is crystalline. Quartz, mica, calcite, micritic limestone are forming the coarse fragments. Infilled vughs are crossed by new vughs and short planary voids.

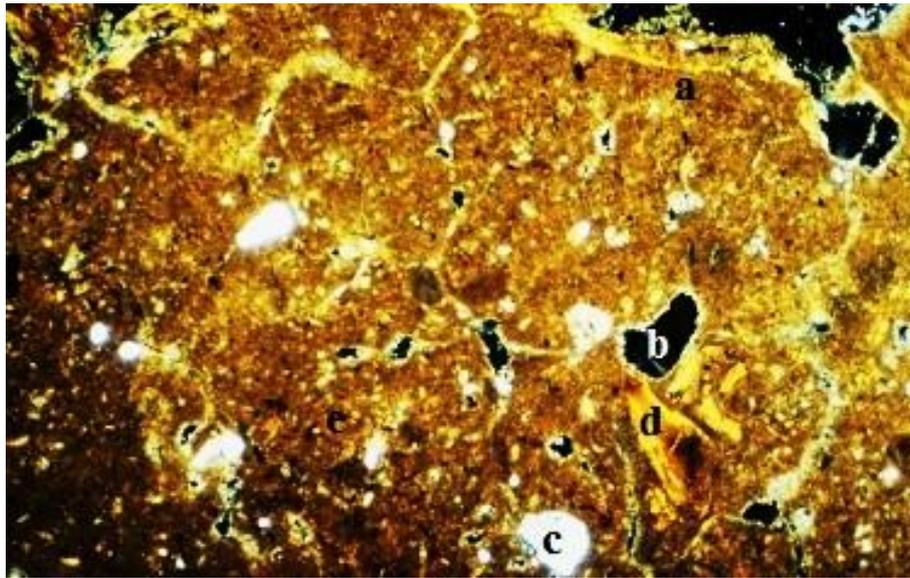
The same profile also demonstrates a seasonally contrasted moisture regime in later ages, supported by the presence of relatively coarse prismatic structure (depth 60-130cm). At 35cm depth, in the same profile micro-structure is subangular blocky, for a part vughy, c/f  $20\mu\text{m}^{3/2}$ , open porphyric, with fine material as

crystalline. Quartz, mica, calcite, limestone, shells of brachiopoda (pectens) are the coarse fragments, and it is weakly mottled. The occurrence of Petrocalcic and Argillic horizons in the soils of the area suggests a seasonal climate (USDA, 1975). Thin section from FA18, 3<sup>rd</sup> horizon shows strongly developed argillan and calcitan (Figure 11).

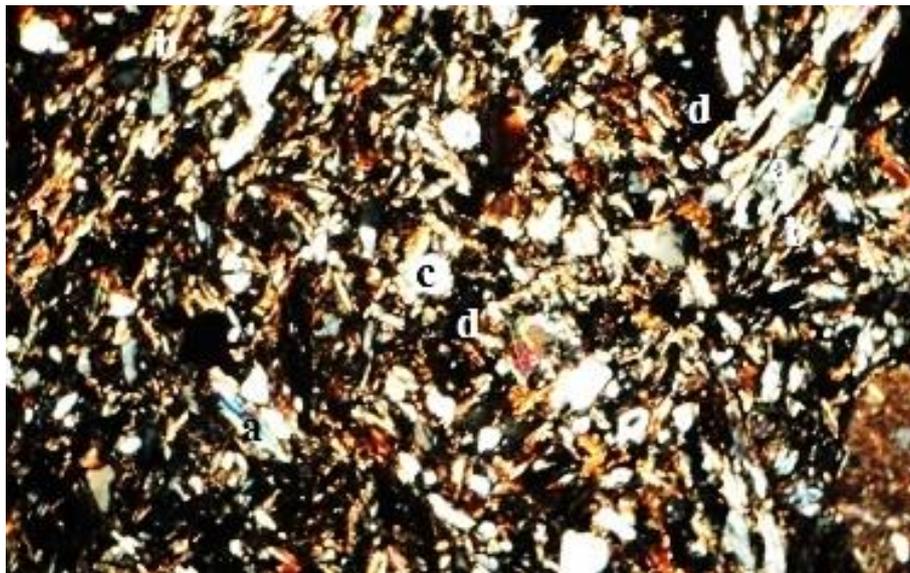
The occurrence of considerable amount of unweathered biotites in the soils of the area (Figure 12), particularly in the Hamadan-Bahar area, suggests a temperature regime not hotter than today, that is, mesic. Hotter temperature would have led to weathering of the biotite (Buol *et al.*, 1973).



**Figure 10** Micrograph of Profile FA24 (Table 1), depth 130 to 140 cm under XPL, magnification= $\times 2.5$ . a= groundmass (crystalline b-fabric); b=voids (curved planes, chains and vughs); c= grains; d= distinct and prominent, clear palmate and digitate mottles; e= silt-infillings.



**Figure 11** Micrograph of the third horizon of profile FA18 (Table 1) clearly depicting clay skins under XPL, magnification= x2.5. a= striated fabric (both porostriated and granostriated); b= voids; c= mineral grains; d= laminated clay pedofeature; e= fragments of clay features embedded in the matrix.



**Figure 12** An example of a soil where weakly to unweathered calcite (=a) and biotite (b) clearly are visible in the micrograph.

## 5 DISCUSSION

Studies in the fields of geopedology and soil (micro-) morphology, history, archaeology, and quaternary geology helped reconstruct the past

landscapes in several periods since uppermost Pleistocene, through which some conclusions regarding climatic conditions and land utilization could be drawn.

The geopedologic surveys, supported by micromorphology, reveal that after a pluvial period the area has been subject to cycles of erosion and sedimentation leading to the formation of extensive glacis, indicative of a climate type characterized by alternating heavily rainy (showery) and dry periods. This plus carbon dating on soil samples of a few buried horizons indicate that the formation of glacis in the region was active before 2600 years BP, at least in the time period between 6000 and 2600 years ago. According to the archaeological findings, since some twenty six centuries ago, rice, that can never be cultivated with the present climatic conditions, was grown in the *Shaltook kari* area (Table 1), in the proximity of the Shirin-abad village (Figures 1 and 4). Micromorphological study of the thin section of the buried horizon in Profile FA24, in the Shaltook kari area, complies with a wet condition. The occurrence of reddish mottles (visible in micrograph of Figure 10), with diffuse border, in an almost massive groundmass supports this idea too.

Historical studies revealed that alfalfa (*Medicago sativa*) was extensively cultivated during the Medes, about twenty seven centuries ago. Besides, in the period when the Persian empire encompassed (parts or the whole of) today's countries Iraq (including Mesopotamia), Pakistan, Afghanistan, Turkey, Syria, Israel, Egypt and many others (University of Tehran, 1971; Del Giudice, 2000) irrigated wheat and barley were produced in Mesopotamia. Cullen et al.(2000), who studied the climate change in the Mesopotamia and the collapse of the Akkadian empire (ruled Mesopotamia from the headwaters of the Tigris-Euphrates Rivers to the Persian Gulf during the late third millennium B.C.) concluded that the empire collapsed abruptly near  $4170 \pm 150$  calendar y B.P., perhaps related to a shift to more arid conditions.

The formation of travertine in the Sharra valley, dated 27000 y BP, is related to a wet condition. The black coating (containing organic carbon) on the bottom of the travertine layer (Figure 9), dated 13000 BP, implies a humid environment, and corresponds with the uppermost Würm, that is a pluvial period. The chemical analysis of a sample of this thin layer indicated the presence of *rancienite* mineral, indicative of wetness (Mohr *et al.*, 1972).

Micromorphologic study also reveals the presence of calcite minerals (light crème in colour) in this thin layer with half-ball-like surface.

On the other hand, the presence of petrocalcic and argillic horizons suggests a seasonal climate, characterized by alternating dry and wet seasons (USDA, 1975). However, as travertine occurs at localities where karst springs were active its formation can be related to the presence of huge springs. Pirnahan was the last karst spring that dried about 40 years ago (Figure 7).

A large area in the Sharra valley is affected by salinity and alkalinity. In contrast, there are no saline soils in the Bahar-Hamadan area, but alkaline soils (site of the profile FA11) on the lower piedmont (Nahalestan depression). In general, considering the extent of man-induced soil degradation, the Sharra valley, having been inhibited earlier than the Hamadan-Bahar area, probably because of the water from the Sharra river and from the springs such as the Pirnahan. The Hamadan- Bahar area is drained by the seasonal Absineh river, with a limited catchment area, and very much depending on snow-melting water.

It is also historically documented that a canal had to be established to convey water from the southern side of the Alvand Mountain to build the palaces of the Hagmataneh. The fascinating Median capital of Ecbatana and its fabulous palaces were described by Herodotus and Polybios some 600 years BC (Figure 6).

## 6 CONCLUSIONS

The conclusion may be that the present dry xeric moisture regime was much wetter in the past. Some earlier studies in Quaternary geology of Iran, reveals that during Würm these areas were peri-glaciated. Evidence of glaciation (as snowline/ -depression) in the Würm is recorded in both the Zagros (dominantly covering the entire western portion of Iran) and the Alborz mountain ranges (dominantly covering the northern portion, along the Caspian sea coastline), for instance in northern Kurdistan and in the Persian Azerbaijan (Seidan, 3615m.; Sabalan, 4812; Sahand, 3690m; above the city of Mianeh at 37°25'16"N 47°42'54"E). Earlier studies have shown that the snowlines locate almost always in altitudes higher than 3500 m a.s.l. In contrast, in the peri-glaciated areas, evidence of mud-flows and other materials resulted from solifluction are reported. Fossil slope breccias, presumably related to solifluction, have been reported to occur at an elevation of 2300 m. Remarkable is that at Marivan (35° 31' 18" N, 46° 10' 29" E, with an altitude of about 1300 meters) in western Iran, an oak-pistacio savannah dominant since about 13000 BP, which infers a Mediterranean climate type.

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## ژئوپدولوژی تغییرات تاریخی اقلیم و اکولوژی کشاورزی را نشان می‌دهد: مطالعه موردی از شمال غرب ایران

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چکیده غالباً تغییرات اقلیمی مؤثر در کمبود آب قابل استفاده را معلول گرم شدن جهانی می‌دانند. با توجه به اینکه ژئوپدولوژی معرف پدیده تشکیل خاک (حاصل تاثیر متقابل اقلیم، مواد آلی، پستی و بلندی، مواد تشکیل دهنده و زمان) است طی مطالعه جامعی در شمال غرب کشور، با جمع‌آوری داده‌های ژئوپدولوژیکی و تجزیه و تحلیل و مقابله آن‌ها با داده‌های تاریخی و باستانشناسی، شرایط اقلیمی و زیست محیطی ادوار گذشته (از پلیوستوسن بالا تا به‌حال) و اثر تغییرات در قالب تخریب اراضی بازسازی گردید. وجود لایه تراورتن با پوششی از مواد آلی با محتوای غالب کلسیت و مقداری کانی رنسیه نایت در خاک بسیار کم عمق با مساحت نسبتاً محدود در نزدیکی تپه باستانی همه کسی و حوالی چشمه کارستی پیرنهان نمایان‌گر دوره‌ای مرطوب است. آزمون زمان‌یابی، نسبت دادن این تشکیلات را به دوره وورم تائید می‌کند. مطالعه خاکشناسی با پشته‌یابی میکرومورفولوژی و کانی‌شناسی، هم‌چنین بر دوره‌ای بین ۶۰۰۰ تا ۲۶۰۰ سال پیش با آب و هوایی با تناوب دوره‌های خشک و مرطوب دلالت دارد. در این دوره شیب‌های دامنه‌ای تشکیل شده‌اند. وجود افق تجمع رس و آهک سخت شده و کانی بیوتیت (تجزیه نشده) در خاک و کشت یونجه، برنج، تنباکو و پنبه دلالت بر آب و هوایی مرطوب‌تر و گرمائی معتدل دارند. نتیجه نهائی این‌که تخریب اراضی در نتیجه پائین افتادن سطح آب زیرزمینی در هیچ دوره‌ای به خطرناکی امروزه نبوده است.

**کلمات کلیدی:** توسعه خشکی، ژئوپدولوژی، گرم‌شدن جهانی، میکرومورفولوژی خاک، همدان-ایران