This is a publisher-deposited version published in : http://oatao.univ-toulouse.fr/
Eprints ID : 18357

To cite this version : Khalaf, Sakher and Revel, Jean-Claude and Guiresse, Agnès Maritchù and Kaemmerer, Michel *Some calcareous soils developed on recent quaternary basalt in southeast Syria.* (1999) In: Global Climate Change and Pedogenic Carbonates. Lewis Publishers, pp. 213-224. ISBN 9781566704588

GLOBAL CLIMATE CHANGE AND PEDOGENIC CARBONATES

EDITED BY

RATTAN LAL
JOHN M. KIMBLE
H. ESWARAN
B.A. STEWART

LEWIS PUBLISHERS
Boca Raton London New York Washington, D.C.

Library of Congress Cataloging-in-Publication Data

Global climate change and pedogenic carbonates / edited by Rattan Lal
... [et al.].
p. cm.
Includes bibliographical references.
ISBN 1-56670-458-8 (alk. paper)
1. Soils—Carbonate content. 2. Soils and climate. 3. Climatic
changes. I. Lal, R.
S592.6.C36G59 1999
631.4'1—dc21 99-35811
CIP

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming, and recording, or by any information storage or retrieval system, without prior permission in writing from the publisher.

All rights reserved. Authorization to photocopy items for internal or personal use, or the personal or internal use of specific clients, may be granted by CRC Press LLC, provided that $.50 per page photocopied is paid directly to Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923 USA. The fee code for users of the Transactional Reporting Service is ISBN 1-56670-458-8/99/$0.00+$.50. The fee is subject to change without notice. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

The consent of CRC Press LLC does not extend to copying for general distribution, for promotion, for creating new works, or for resale. Specific permission must be obtained from CRC Press LLC for such copying.

Direct all inquiries to CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, Florida 33431.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation, without intent to infringe.

© 2000 by CRC Press LLC

Lewis Publishers is an imprint of CRC Press LLC

No claim to original U.S. Government works

International Standard Book Number 1-56670-458-8
Library of Congress Card Number 99-35811
Printed in the United States of America 1 2 3 4 5 6 7 8 9 0
Printed on acid-free paper

CHAPTER 13

Some Calcareous Soils Developed on Recent Quaternary Basalt in Southeast Syria

S. Khalaf, J.C. Revel, M. Guiresse, and M. Kaemmerer

I. Introduction

In the Haurane region, in southern Syria, there are Quaternary basalt effusions that are recent but of varying ages in climates where the rainfall varies between 400 and 80 mm/year. Calcareous soils are developing on this basalt.

The purpose of this study is therefore to determine the origin of $CaCO_3$ and to seek a relationship between certain pedogenesis factors such as age, climate and relief and the morphology of the secondary calcite precipitations.

II. Location and Climate

A. Geographic Situation

The soils studied are in south-east Syria, in the Haurane region (Figure 1). This region consists of a set of sub-regions which, going from east to west, are the Safa, Haraa, the Haurane plateau itself with, in the middle, the northern part of the Jabal ad Duruz and, lastly, the Leja. It is situated between longitudes 39°60' and 42° East, and latitudes 36° and 37°45' North.

The two main factors governing the evolution of the soils are age and climate. This region is purely volcanic, made up essentially of basalt and andesites from volcanic systems of various ages. This study is limited to lava flows and the soils that have developed on flows attributed to the recent Quaternary period.

B. Climate and Bioclimate

1. Winds

The winds are an essential element in the climate since they bring rainfall. The data concerning the winds are scarce and sometimes old (Safadi, 1956). The prevailing winds are westerly winds which bring rain from the Mediterranean. When they blow from the north-west the temperature falls. Hot, dry south-westerly winds from the Sahara may blow in the spring. Similar easterly and south-easterly winds also blow from Saudi Arabia and Iraq. These easterly winds often carry dust and precede the heavy storms in the autumn.

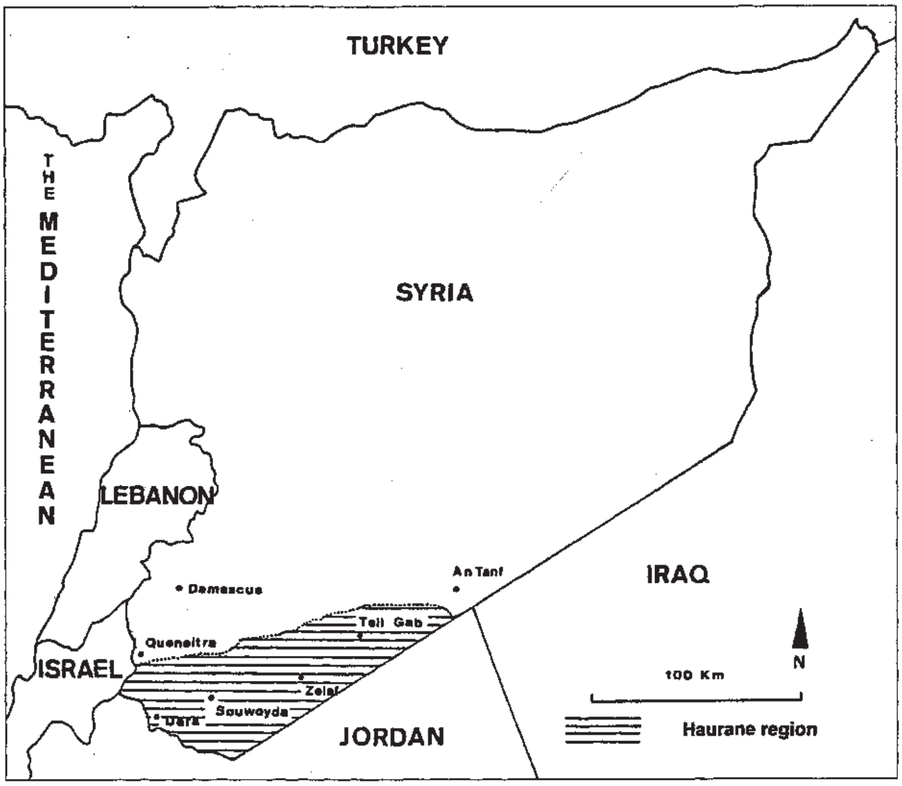

Figure 1. Representation of the studied area in Syria.

2. Temperature

The temperature data are relatively dense for the western zone which is cultivated, but there are no readings for the eastern part. The temperatures were intrapolated, and range between 15.5°C and 18.5°C from El Qunaytirah at an altitude of 950 m and Der'a at an altitude of 500 m. The maximum recorded at Der'a is 45°C, but given the absence of data for the eastern zone, it can be assumed the maximum temperatures are even higher than that. In 1994, we recorded a temperature of 45°C on September 15 on the edge of the Safa. It is therefore probable that higher temperatures are reached during July and August, the hottest months. The lowest temperature, -6°C, was recorded at Damascus. The annual amplitudes, between minimum and maximum, can reach 50°C. The daily amplitudes, between day and night, get higher as one goes eastwards, where the climate is increasingly dry.

3. Precipitation

The rainfall data are scarce for the eastern part of the zone, but more numerous for the western part. In the northern part of Haraa, the rains from the Mediterranean are seriously attenuated by the heights of the Anti Lebanon. Further south, in the region under study, the Golan plateau allows the rains to pass through to the region of Shahba. The Leja and the Jabal ad Duruz receive approximately 400 mm of rain a year. This mountain range, whose northern end is situated in the region of Shahba, forms another barrier which prevents the rains from going further eastwards. At Barek, about ten kilometers east of Jabal ad Duruz, the annual rainfall only amounts to 250 mm. Then, going further eastwards the isohyets appear to be very close together. According to Safadi's data (1956), there is less than 100 mm/year rainfall at the level of the Safa mountains.

Most rain falls between November and March, with the heaviest rainfall in January. In May, there are only a few millimeters of rainfall. Then from June to September there is an absolute drought. The rains in December, January and February are relatively abundant and continuous, whereas the November, March and April rains are very heavy and stormy. However, going eastwards, in the Haraa region and particularly in the Safa region, there are just two storms a year, one in the spring and the other in the autumn, and some years one of these rains does not materialize, which means that a whole year can go by with only one period of rainfall. Rain therefore represents the essential gradient in the climatic variations, and rainfall rapidly goes from 400 mm y^{-1} in the Leja in the west, to an estimated 80 mm y^{-1} in the Safa.

According to the xerothermic index, the Leja region has an attenuated semidesert climate with between 200 and 250 biologically dry days. In the Haraa to the north of Jabal ad Duruz, the climate becomes markedly semidesert with a xerothermic index comprised between 250 and 300; lastly, on the edges of the Haraa and in the Safa mountains, the climate is desert with a xerothermic index comprised between 300 and 355.

C. Geology

The geological references are old and scarce: there are the works of Safadi (1956) and of Russian geologists Kraznov et al. (1966). These latter authors identified the various lava flows for which they gave a relative age.

In the region of interest (Figure 2), the zone to the north of the Jabal ad Duruz is identified as being basalt of the old Quaternary period. All the other flows are assumed to be of the recent Quaternary period. However, in the absence of an absolute dating, a certain number of questions can be raised. Indeed, according to these authors the lava flow at Qraa can be dated to the Middle Bronze age on the basis of Dubertret (1933). But, according to the works of Echallier and Revel (1996), this flow is necessarily older than the town of Kirbet el Umbachi which was founded in the Middle Bronze age. As a general rule, the authors classified the relative age of the flows according to their apparent freshness. This morphology is therefore one of the essential parameters.

III. Morphology of the Lava Flows and Soils

The morphological appearance of the flows can be indicative of age. Indeed, the greater the age the more the reliefs are attenuated by erosion of the crags and filling of the hollows. The parent rock/soil ratio and the soil evolution are characteristics that could provide useful information. So, in the rest of

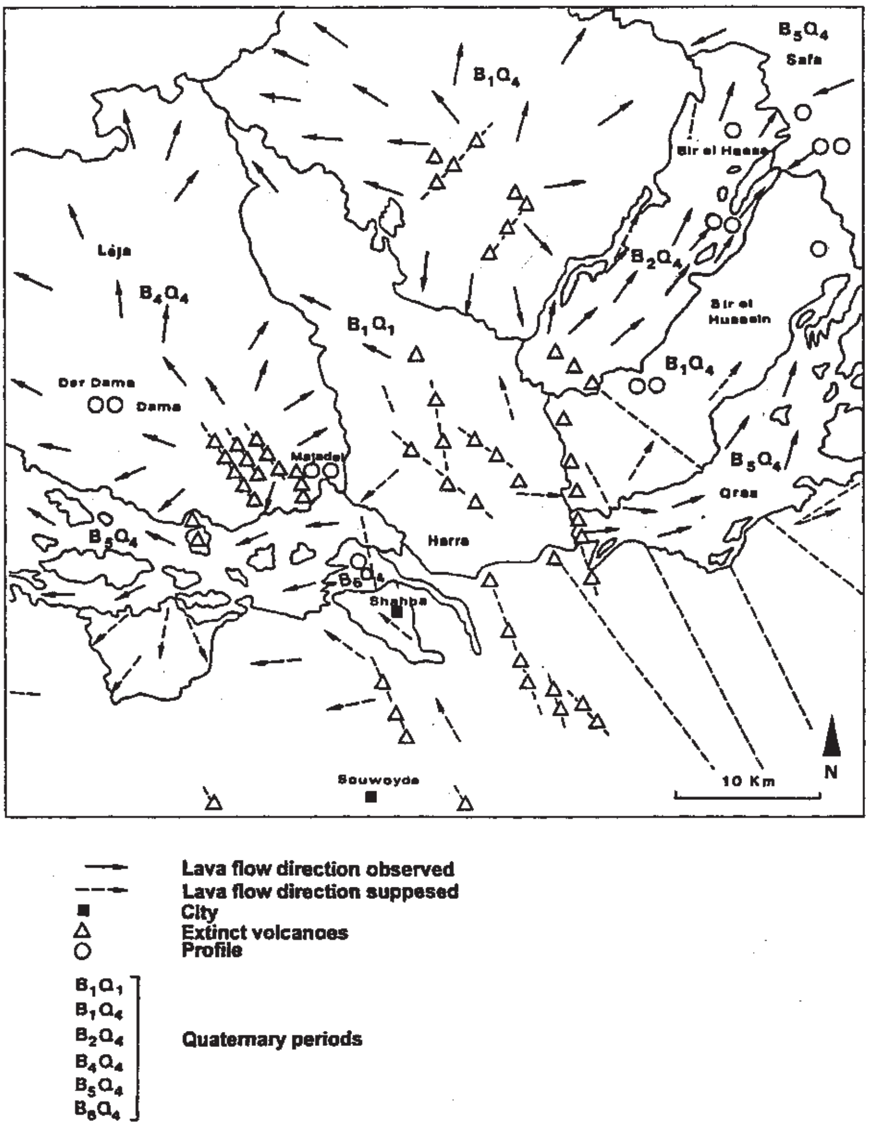

Figure 2. Geological map of the studied area with location of profiles.

Table 1. Results of the analysis performed on the studied profiles

Profile	A	Lf	Lg	Sf	Sg	pH	% $CaCO_3$	% O.M.	% Na/T
SL3	39	34	15	2	4	8	1.3	0.63	5
SL4	40	38	12	3	2	8	1.4	1.1	6.25
SL5	50	20	13	5	5	7.5	1.4	0.5	1.5
SL6-1-	55	18	11	5	5	8.1	1.4	1	6
SL6-2-	62	19	6	2	9	8.1	1.4	0.75	2
CH4-1-1 10-25 cm	18	22	9	23	22	8	36	0	20
CH4-1-1 25-45 cm	35	15	8	13	29	8	24	0	20
CH4-1-3 45-100 cm	23	25.5	14	13	23.5	7.9	33	0	10
CH4-2- 0-110 cm	24	26	11	16	16	8	38	0	21
SH6-1- 0-30 cm	44	31	5	7	8	8.7	14	0.5	6
SH6-2- 30-60 cm	46	28	8	6	8	8.8	18.6	0.5	13
SH6-3- 60-115 cm	36	33	5	9	13	8.8	25	0.5	23

Granulometry: A: clay (0-2 μm); Lf: fine silts (2-20 μm); Lg: coarse silts (20-50 μm); Sf: fine sands (50-200 μm); Sg: coarse sands (200-2000 μm); Na/T: Exchangeable sodium/Total cation exchange capacity of the clay fraction.

this chapter, each lava flow will be described along with the associated soils (Table 1) starting from the most recent to the oldest.

A. The Most Recent Flow at Shahba (B6 Q4)

The most recent flow emanates from the volcanic systems located around the town of Shahba. The lava flow running westwards from Shahba is limited in size, excessively scoriaceous, with rocky outcrops and sorts of depressions completely filled with pozzolan and light and very blistered scoria. The surface cracks in the outcrops are filled with very fine earth. This earth is yellowish red (5YR 4/6) and has a clayey texture. The clay minerals are predominately kaolinite and illite, with a small amount of calcite and smectite.

Some yellowish red (5YR 4/6) fine earth was found at a depth in the scoria but it was not possible to isolate a sufficient amount of fine matter to perform a chemical analysis. The clay minerals are illite and kaolinite.

B. The Very Recent Basalt Flows (B5 Q4)

This concerns the flows at Majadel, Qraa and the Safa. Given the similar composition of these flows, only one description will be given. The upper part sometimes consists of ropy lava several centimeters thick. Underneath this there is a highly blistered basalt over some decimeters separating into large slabs. The deeper one gets, the rock is less and less blistered and the prismatic flow appears. The macromorphological appearance varies. There is sometimes a single chaotic flow revealing numerous spurs that isolate closed depressions and, more rarely, convex flows that are cracked in the center or on the periphery.

The rock appears to be bare but there is some fine earth in the small cracks. The pedological coverage in the depressions, however, is thicker and more continuous. Given the smallness of the zones covered by soil, there are no crops even in the wetter area in the west. There are many lava tunnels. Given the different appearances of the flows at Majadel and the Safa, the soils will be studied in both cases.

1. The Majadel Flow

- Flow lithosol (SL3): the fine earth accumulated in the cracks is 5 to 10 cm thick, of yellowish red (5YR 4/6) color, clayey texture and the rock is covered with lichen. The clay minerals are kaolinite and illite. The Na/T ratio is 5%, the pH is 8, and there is very little $CaCO_3$.
- The soil in the depressions (SL4) is 22 to 25 cm thick, of yellowish red color (5YR 4/6), and clayey texture. The clay minerals are kaolinite and illite. The Na/T ratio is 6.25%, the pH is 8, and there is very little $CaCO_3$.

2. The Safa Flow

- Flow lithosol (SS2): the fine earth in the cracks is light brown (7.5YR 6/4), and the texture is silty clay. The clay minerals are mainly kaolinite, illite, poorly crystallized smectite, and quartz. The Na/T ratio has a value of 10%, the pH is 8.8, and $CaCO_3$ is abundant in the fine earth and inframillimetric caliches are found under the blocks.
- The soil in the depressions (SS1) is 25 cm thick, light brown (7 5YR 6/7) in color and the texture is silty. The Na/T ratio is 19%, the pH is 8.2 and $CaCO_3$ is abundant in the fine earth and under the blocks breaking off from the parent rock.

C. The Recent Flow at Dama in the West (B4 Q4)

The flow on which the villages of Dama and Derdama are built is considered to be older than those above. The shapes of the flow reliefs are very marked but the ropy lava is not apparent. The basalt is blistered. The surface area filled by soils in the depressions is proportionally greater than in the above flows. In the western part villages are able to live from farming.

- Lithosol (SL5): the fine earth in the cracks is 10 cm thick, and of reddish brown (5YR 4/4) color. The texture is clayey. The clay minerals are kaolinite and illite. The Na/T ratio is 1.5%, the pH is 7.5, and there is only a very small amount of $CaCO_3$. The rocky outcrops are covered with lichen.
- Soil in the depression (SL6): there are two horizons:

  Horizon 1, from 0 to 18 cm: light brown color (7 5YR 6/4) with clay-silty texture. The clay minerals are kaolinite and illite. The Na/T ratio is 6%, the pH is 8.1 and there is only a very small amount of $CaCO_3$.

  Horizon 2, from 18 to 35 cm: brown color (5 YR 4/4) with a clay-silty texture and polyhedral structure. The clay minerals are also kaolinite and illite. The Na/T ratio is 2%, the pH is 8.1 and there is only a very small amount of $CaCO_3$.

D. Soils on the Old Flow at Haraa to the East (B2 Q4)

This flow runs in the dry part of the studied zone. Nearly all the flow is covered by soil, with only the rocks in much greater relief standing out. At least 80% of the surface area is covered by soil, therefore leaving only 20% of the rocks exposed. At the level of these outcrops the top of the lava is scoriaceous. To the east of the flow, on the surface of the soil there are many blistered blocks with a major axis of 10 to 30 cm, with a hematite patina.

The studied soil (CH4-1-) was situated between Bir el Hassa and Bir el Hussein in a very dry zone close to rocky outcrops and was 60 to 80% covered with stones. This profile breaks down into the following three horizons:

Horizon 1, from 0 to 25 cm: brown color (7 5YR 5/4), polyhedral structure and clay-silty texture. The clay minerals are smectite, attapulgite and kaolinite with a small amount of quartz. The Na/T ratio is 20%, the pH is 8 and there is a large amount of $CaCO_3$.

Horizon 2, from 25 to 45 cm: brown color (7 5YR 5/4), and clay-silty texture. It contains rounded blocks of blistered basalt with major axis of 10 to 20 cm and deteriorating into concentric rubble. There is 2 to 3 cm thick stalactite caliche under the blocks.

Horizon 3, from 45 to 100 cm: brown color (7 5 YR 5/4), clayey texture. The clay minerals are smectite, chlorite, attapulgite and kaolinite. This horizon is marked by the presence of a large number of friable clusters. The diameter of these clusters does not exceed 3 cm. The Na/T ratio is 10%, the pH is 7.9 and there is a large amount of $CaCO_3$.

In the zones which must have been depressions, the soil contains many fewer stones than on the surface and the profile is as follows (CH4-2-): 0 to 110 cm, light brown color (7 5 YR 6/4), silty-sandy texture. The clay minerals are kaolinite, attapulgite, calcite and a small amount of quartz. The Na/T ratio is 21%, the pH is 8, and there is a large amount of $CaCO_3$ throughout the profile.

E. Soil at Haraa on the Oldest Recent Quaternary Flow (B1 Q4)

According to Kraznov et al. (1966) the oldest recent Quaternary flow is the Haraa plateau which extends from Barek in the west to the Safa in the east between the previous flow and the Qraa. This flow has some rare rocky outcrops buried in a horizon of limestone accumulations brought up to the surface by erosion.

The whole consists of a reg or layer of gravel covering large surfaces which are difficult to distinguish from the soils that have developed on basalt that is much older still. The soil found here (SH6) has the following horizons:

Horizon 1, from 0 to 30 cm: yellowish red color (5 YR 5/6) and clay-silty texture. The clay minerals are smectite, chlorite, attapulgite, kaolinite and quartz. The Na/T ratio is 6%, the pH is 8.7, and as in all the other horizons in the profile $CaCO_3$ is present but in smaller quantities.

Horizon 2, from 30 to 60 cm: reddish color (2.5 YR 4/4), clayey texture. The clay minerals are smectite, attapulgite and kaolinite. The Na/T ratio is 13%, the pH is 8.8 and the $CaCO_3$ reaches a higher value than in the higher horizons. At the bottom there are blocks of basalt with a major axis of 10 cm and an onion skin cortex. The caliche can reach a thickness of 10 cm.

Horizon 3, from 60 to 115 cm: red color (2.5 Y 4/6), clayey texture, still with some basalt blocks with onion skin deterioration. Very numerous, very irregular limestone nodules up to 10 cm long, in upright position.

The clay minerals are smectite, attapulgite, kaolinite and chlorite. The Na/T ratio is 23%, the pH is 8.8, and the $CaCO_3$ content is higher.

F. Origin of the Carbonates

The origin of the carbonates should be sought in the products of basalt alterations. The basalt contains 9 to 10% $CaCO_3$, mainly in the feldspars close to the anorthite pole and also, above all, in the glasses. CaO therefore does not remain in the network of one silicate and, apparently by simple contact with rainwater, the basalt very rapidly gives off CaO which is carbonated by the CO_2 in the atmosphere. There are various possible explanations for the precipitation of calcite.

In the very clayey horizons with a prismatic structure, the calcite precipitates in the form of friable clusters bordering on aggregates. In the center, the friable clusters may be hardened. These clusters appear to increase with epigenesis of the clays. The attapulgite is then associated with it.

In the horizons containing the coarse elements the calcite precipitates at their base in the form of very impure caliche since it impregnates the clayey bottom matrix. These caliches take the form of coalescent stalactites whose thickness increases with the age of the flow.

IV. Discussion

According to the already-mentioned works of Echallier and Revel (1996), the soils on the Haraa flow ¾ the oldest of the recent Quaternary period ¾ has a very long history. According to these authors, a soil has become differentiated from the basalt and, while the local reworking phenomena allowed the depressions to be filled, the basalt was altered at depth to form balls with a major axis of 10 to 30 cm from the prisms. A period of erosion brought these blocks up to the surface, thus protecting the fine earth from further erosion. Then, as pedogenesis continued, the blocks on the surface were covered by the hematite film and those that remained in the soil were reduced to 10 cm at the most along the major axis. The caliches are often 10 cm thick.

However, according to Echallier and Revel (1996), the caliches observed in the Bronze Age vestiges (4,500 years old) were less than one millimeter thick. The pedogenesis on the two flows at Haraa must therefore have taken place over a very long period to allow the formation of thick caliches. The soils and flows at Haraa are therefore very old. This was also confirmed by the existence of a hematite film which in North Africa, in a climate where there is currently less than 100 mm y^{-1} rainfall, affects the Tensift formations (100,000 years old) or even older formations (Kaemmerer, 1987).

Whatever the climate, it appears that the ratio of soil to parent rock increases when the age of the flow increases. The essential pedogenesis process consists of an accumulation of fine earth in the cracks in the outcrops and on the surface of the depressions. This process can carry on for a long time since the soil on the Haraa flow is not particularly differentiated in the depressions and, on the contrary, has a marked alteration profile in the vicinity of rocky outcrops. It is as if, over time, the fine particles produced accumulate in the depressions, and then overflow towards the flows which were then subject to alteration. The rocky outcrop/fine material ratio therefore decreases over time.

The climate also has a major influence on the evolution of soils and alteration minerals. A great accumulation of $CaCO_3$ is noted in climates with less than 250 mm y^{-1} rainfall, and with 400 mm/year rainfall in the Leja a redistribution of $CaCO_3$ would be expected (Ruellan, 1969, 1971, 1980; Bock, 1984; Kaemmerer, 1987) but the calcite is not expressed (Table 2).

These earlier authors worked on calcareous materials, and found that the redistribution of calcite in the profile remains visible with the current rainfall of between 100 and 600 mm/year. On basalt, the release of CaO from the rock only produces calcite when the climate is drier and with a current annual rainfall of less than 250 mm. This was confirmed by Smolikowski (1997) who did not observe any accumulation of $CaCO_3$ on the soils that have developed on basalt in the Cape Verde islands with 280 mm/year rainfall. The thickness of the caliches under the basalt blocks appears to be consistent with the age of the flows: inframillimetric for B5 Q4, 2 to 3 cm in the developed soils on B2 Q4 and 10 cm in the soils at B1 Q4.

With the dryness of the climate, the Na/T ratio (exchangeable sodium/total cation exchange capacity of the clay fraction) increases but we never saw any efflorescence in the soils. Accumulations of nitrate and sodium sulfate have been observed in the lava tunnel in the el Kbir cave in the Haraa flow.

As pointed out by many authors (Ruellan, 1971; Bock, 1984; and Kaemmerer and Revel, 1991) the attapulgite remains linked to the neogenic calcite. It is therefore found to the east of the meridian that passes through Barek, to the east of the 250 mm y^{-1} rainfall isohyet (Pascal et al., 1989; Lang et al., 1990).

The other clay minerals also depend on the climatic factor. Kaolinite is present everywhere, probably due to the alteration of non-calcic minerals. The humid zones are characterized by illite, whereas smectite and chlorite are found in the driest zones where the solutions are more concentrated.

A special mention must be made relative to the quartz contained in the fraction smaller than 2 μm. It does not exist in the basalt and is found in the driest zone of the study either in the skeletal soils, or on the surface of the differentiated soils on basalt or on the whole soil profile of the filled depressions. Given that this quartz does not come from the basalt, it is probably carried by wind from the Sahara or Arabian desert. These distant transport phenomena have been described by many authors in dry regions but mainly to explain the carbonatation ($CaCO_3$) of soils on non-calcic soils (Gile et al., 1966; Ballais and Vogt, 1979; Fryrear, 1986; Rognon, 1991). The barrier formed by the Jabal ad Duruz no doubt prevents the dust from continuing to and falling in the western part.

Table 2. Summary of the various forms of limestone accumulation in the studied profiles

Profile	Form of limestone accumulations
SL3	Very little $CaCO_3$ in the fine earth
SS2 (Lithosol)	$CaCO_3$ is abundant in the fine earth; inframillimetric caliche under the blocks
SS2 (depression)	$CaCO_3$ is abundant in the fine earth
SL5	Very little $CaCO_3$ in the fine earth
SL6	Very little $CaCO_3$ in the fine earth
CH4-1- (0-25 cm)	Large amount of $CaCO_3$ in the fine earth
CH4-1- (25-45 cm)	Under the blocks; stalactitic caliche, thickness 2 to 3 cm
CH4-1- (45-100 cm)	Very large number of friable clusters; large amount of $CaCO_3$ present in the fine earth
CH4-2- (10-110 cm)	Large amount of $CaCO_3$ throughout in the profile (in the fine earth)
SH6 (0-30 cm)	Small amounts of $CaCO_3$ present in the fine earth
SH6 (30-60 cm)	Larger amount of $CaCO_3$ than above in the fine earth; the caliche can reach a thickness of 10 cm
SH6 (60-115 cm)	More $CaCO_3$ in the fine earth than above; very numerous, very irregular limestone nodules, vertically elongated and up to 10 cm long

V. Conclusion

The differentiation of soils on the basalt in south-east Syria depends on the climate and the age of the rocks.

Concerning the climate, the essential limit is the 250 mm/year isohyet:

- when it rains more the neogenic minerals formed from the basalt are kaolinite and illite;
- when the climate is drier than 250 mm/year the neogenic kaolinite formed from the non-calcic minerals is still present, but the characteristic minerals are smectite and above all the calcite/attapulgite pair;
- windborne exogenous quartz is very likely to be found in the driest zone.

Concerning the age of the flows, a few facts emerge:

- the older the flow, the more the surface of the flow is covered by loose soil, and the thicker it is;

- the older flows (B2 Q4 and B1 Q4) have a complex history as shown by the layer of debris and the hematite film;
- for the dry zones, the thickness of the caliches under the blocks of basalt is proportional to the age of the flow.

The forms differentiate from precipitation of the calcite coming from basalt or coming from dusts of wind. They present different sizes, from clay to sand and bigger sometimes. The caliches at the bottom of pebbles have a shape like stalactite coalescent and their thickness depends on the age of basalt. The clusters are formed in the cracks of the prismatic structure. They are constituted of white calcite crystal powder of the size of the silts. Sometimes the center of the cluster is hardened, especially when the age of basalt increases

References

Ballais, J.L. and T. Vogt. 1979. Croûtes calcaires quaternaires du piémont Nord des Aurés (Algérie). *Recherches Geos. Strasboug* 12:23-34.

Bock, L. 1984. L'intégration Chronospatiale des Accumulations Calcaires. Approche Morpho-pédologique et Geochimique Dans le Paysage Semi-Aride de l'Atlas Tellien (Algérie). Gembloux-Belgique. 448 pp.

Dubertret, L. 1933. Les grandes nappes basaltiques syriennes: Age et relations avec la tectonique. CR. Somme. *Soc. Géol.* Fr:178-180. Paris.

Echallier, J.C. and J.C. Revel. 1996. L'environnement ancien de Khirbet l'Umbachi (Syrie). Premières données morphopédologiques et hypothèses d'anthropologie. *L'Anthropologie*. Tome 100: 213-225. Paris.

Gile, L.H., F.F. Peterson, and R.B. Grossman. 1966. Morphological and genetics sequences of carbonate accumulation in desert soils. *Soil Science* 347-360.

Kaemmerer, M. 1987. Etude Des Sols et Des Encroûtements Calcaires Sur les Formations Alluviales Quaternaires du Sebou et de la Moyenne Moulouya. Thèse de docteur d'état, Pédologie, Université Paul Sabatier. Toulouse. 318 pp.

Kaemmerer, M. and J.C. Revel. 1991. Formation des mas friables et des nodules calcaires dans les sols argileux en région tempérée et semi aride. *Science du Sol* 1:1-12.

Kraznov, A.A., V.G. Kazmin, and V.V. Kulakov. 1966. The Geological Map of Syria, Ministry of Geology. Damascus, Syria.

Lang, J., M.L. Mahdoudi, and A. Pascal. 1990. Sedimentation-calcrete cycles in the mesozoix red formations from the central High Atlas (Telouest area) Morocco. *Palaeogeography, Palaeoclimatology, Paleoecology* 81:79-93.

Pascal, A., M.L. Mahdoudi, J. Lang, H. Paquet, and G. Millot. 1989. Palygorskites continentales épigéniques dans le jurassique moyen du Haut-Atlas Central (Maroc). Double signification des palygorskites dans les séries géologiques. *C.R. Acad. Sci.*, Paris, T. 309, Série II. p. 899-906.

Rognon, P. 1991. Field measurement of dust near the ground, correlated with surrounding soil in the Sahara and Sahel. *Zeitschrift Geomorph* 491-501Berlin. Stuttgart.

Ruellan, A. 1969. Le développement au cours du quaternaire des sols à profil calcaire différencié dans la plaine du Zebra (Maroc oriental). Interprétation paléoclimatique. In: Etudes Sur le Quaternaire Dans le Monde, VIIIe Congrés INQUA, Paris.

Ruellan, A. 1971. Contribution à la connaissance de sols des régions méditérranéennes: les sols à profil calcaire différencié des plaines de la Basse Moulouya (Maroc oriental). Mémoire ORSTOM No 54: Paris.

Ruellan, A. 1980. L'accumulation du calcaire dans les sols. Cristallisation- déformation-dissolution des carbontes. p. 401-411. In: Congrés SGF AGSO SFMC, Université Bordeaux III, 17-18 Novembre.

Safadi, C. 1956. Hydrogeology of the Volcanic Soil in the Southern Syria (Hauran). Thèse University of Nancy, France. 180 pp.

Smolikowski, B. 1997. Gestion de l'eau en milieu cultivé sahelien de montagne (Cap Vert). Thèse Université Paul Sabatier, Toulouse. 272 pp.