Department of Energy
Washington, DC 20585

SEP 16 1992

Mr. Joseph J. Holonich, Director
Repository Licensing & Quality Assurance
Project Directorate
Division of High-Level Waste Management
Office of Nuclear Material Safety
and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Holonich:

The U.S. Nuclear Regulatory Commission (NRC) provided three comments and requested not-readily-available references (NRA) in their Phase I review letter of December 6, 1991 (enclosure 1) for Study Plan 8.3.1.5.1.4, "Analysis of the Paleoenvironmental History of Yucca Mountain Region." The NRAs that were requested are provided as Enclosure 2. Responses to the three comments identified in the NRC's letter are contained in Enclosure 3.

If you have any questions, please contact Mr. Chris Einberg of my office at 202-586-8869.

Sincerely,

John P. Roberts
Acting Associate Director for
Systems and Compliance
Office of Civilian Radioactive
Waste Management

Enclosures: on the shelf
1. Ltr, 12/6/91, Holonich to Roberts, w/encl
2. NRA References Requested by NRC (Not Record Material)
3. Responses to NRC Comments

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102.8
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NH03

9210050374 920916
PDR WASTE
WM-11 PDR

cc: w\enclosures
Alice Cortinas, CNWRA, San Antonio, TX

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P. Goicoechea, Eureka, NV
C. Schank, Churchill County, NV
F. Mariani, White Pine County, NV
V. Poe, Mineral County, NV
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C. Abrams, NRC

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

DEC 06 1991

Mr. John P. Roberts, Acting Associate Director
for Systems and Compliance
Office of Civilian Radioactive Waste Management
U. S. Department of Energy, RW 30
Washington, D.C. 20585

Dear Mr. Roberts:

SUBJECT: PHASE I REVIEW OF U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN FOR ANALYSIS OF THE PALEOENVIRONMENTAL HISTORY OF THE YUCCA MOUNTAIN REGION

On June 24, 1991, DOE transmitted the study plan entitled "Study Plan for Analysis of the Paleoenvironmental History of the Yucca Mountain Region" (Study Plan for Study 8.3.1.5.1.4) to the U.S. Nuclear Regulatory Commission (NRC) for review and comment. The NRC has completed its Phase I Review of this document using the Review Plan for NRC Staff Review of DOE Study Plans, Revision 1 (December 6, 1990).

The material submitted in the study plan was determined to be for the most part substantively consistent with the agreement on content resulting from the NRC-DOE agreements made at the May 7-8, 1986 meeting on Level of Detail for Site Characterization Plans and Study Plans. However, for a number of tests (e.g., Sampling Airborne Dust, p. 3-3), "No explicit requirements for tolerance, accuracy, or precision have been identified..." Either these requirements should be specified in the study plan or a definitive statement as to why they are not required should be provided. The missing information should be provided to NRC as soon as possible either in a revised study plan or in a letter.

In addition, eleven of the 28 technical procedures needed to support the activities in this study plan remain to be developed. The NRC staff did not consider that the lack of availability of those procedures compromised its ability to conduct its Phase I Review of the material provided. However, we request that DOE provide us with a schedule for the development of those procedures and that DOE notify us when the procedures are available for review.

Also, among the references listed for this study plan are some which have not been provided to NRC and are not readily available in the public domain. We therefore request that DOE provide us with the documents listed in the Enclosure to this letter.

A major purpose of the Phase I Review is to identify concerns with studies, tests, or analyses that if started could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute objections, as that term has been used in earlier NRC staff reviews of DOE's documents related to site characterization (Consultation Draft Site Characterization Plan and the Site Characterization Plan for the Yucca Mountain site). The Phase I Review of this study plan identified no objections with any of the activities proposed.

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ENCLOSURE 1

There is one technical matter related to the study plan that the NRC staff wishes to call to the attention of DOE. The use of yet-to-be-qualified existing borehole data has been identified as part of this study plan (Activity 8.3.1.5.4.2 - Surficial Deposits Mapping of the Yucca Mountain Area). DOE indicates (Section 3.2.3.3, p. 3-17) that such data "will be qualified as appropriate." Inasmuch as many site characterization tests and analyses, including the ones identified in the subject study plan, will rely heavily upon existing borehole-derived data, it would seem prudent for DOE to develop, initiate, and accomplish a program to qualify existing borehole data as soon as possible. If such a qualification process is delayed, and then later it is found that some portion of the existing borehole-derived data cannot be qualified, the redrilling of one or more boreholes, with the attendant potential for negative impacts on site characterization and licensing schedules, may be necessary.

After completion of the Phase I Review, based on the relationship of a given study plan to key site-specific issues or NRC open items, or its reliance on unique, state-of-the-art test or analysis methods, certain study plans are selected to receive a second level of review, called a Detailed Technical Review. The NRC staff considers the subject study plan a likely candidate for a Detailed Technical Review. However, until the eleven procedures mentioned earlier in this letter are completed and available to the NRC staff, we cannot make a final determination regarding the need for a Detailed Technical Review of this study plan.

Sincerely,

Joseph J. Holonich, Director
Repository Licensing and Quality
Assurance Project Directorate
Division of High-Level Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As Stated

cc: R. Loux, State of Nevada
C. Gertz, DOE/NV
S. Bradhurst, Nye County, NV
M. Baughman, Lincoln County, NV
D. Bechtel, Clark County, NV
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P. Niedzielski-Eichner, Nye County, NV
C. Thistlethwaite, Inyo County, CA
V. Poe, Mineral County, NV
F. Sperry, White Pine County, NV

References for Study Plan 8.3.1.5.1.4 Requested by NRC

- Miotke, Franz-Dieter, 1974, Carbon dioxide and the soil atmosphere: Abhandlungen Zur Karstund HohlenKunde, Series A, v. 9, pp. 1-49.

- Papadakis, J., 1965, Potential evapotranspiration: Buenos Aires, Argentina, 54 pp.

- Taylor, E.M., 1986, Impact of time and climate on Quaternary soils in the Yucca Mountain area of the Nevada Test Site: M.S. Thesis, University of Colorado, Boulder, Colorado, 217 pp.

ENCLOSURE 2

COMMENT 1

"... for a number of tests (e.g. Airborne Dust, p. 3-3), 'No explicit requirements for tolerance, accuracy, or precision have been identified...' Either these requirements should be specified in the study plan or a definitive statement as to why they are not required should be provided. The missing information should be provided to NRC as soon as possible either in a revised study plan or in a letter."

RESPONSE

Please note that the word "specified" is used in the study plan and not "identified." Specified levels of tolerance, accuracy, and precision are not contained in the Site Characterization Plan for any of the 24 tests described in the study plan. These variables are discussed in the study plan when appropriate references are available. Also, these variables are routinely discussed in the technical procedures (study plan Tables 3-1, 3-2, and 3-3) for the techniques to be employed in the study plan.

COMMENT 2

"... Eleven of the 28 technical procedures needed to support the activities in this study plan remain to be developed. ... we request that DOE provide us with a schedule for the development of those procedures and that DOE notify us when the procedures are available for review."

RESPONSE

The DOE does not maintain a schedule as to availability of these procedures, and only requires that technical procedures be in place prior to beginning work. Verification that technical procedures are available takes place during the preparation of job packages under Yucca Mountain Site Characterization Project Office (YMPO) Administrative Procedure (AP)-5.21Q (Field Work Activation). If it was NRC's intent to request specific technical procedures, DOE asks that requests for specific procedures be made through the on-site representative (OR). YMPO can then furnish them to the OR for disposition.

COMMENT 3

"The use of yet-to-be-qualified existing borehole data has been identified as part of this study plan (Activity 8.3.1.5.1.4.2 - Surficial Deposits Mapping of the Yucca Mountain Area). DOE indicates (Section 3.2.3.3, p. 3-17) that such data "will be qualified as appropriate." Inasmuch as many site characterization tests and analyses including the ones identified on the subject study plan, will rely heavily upon existing borehole-derived data, it would seem prudent for DOE to develop, initiate, and accomplish a program to qualify existing borehole data as soon as possible."

RESPONSE

The reference in the study plan to use of existing data, "...lithologic logs of previously drilled shallow boreholes...", does beg the question regarding DOE's plans for data qualification. Please refer to a recent letter from the DOE on this subject (Ltr. Roberts to Holonich, dtd., 9/3/92). In general, existing data are not intended to be the sole evidence used as the basis for interpretations bearing on the spatial and temporal relations of surface deposits. The lithologic descriptions and thickness measurements obtained in previously drilled shallow boreholes represent valuable information that can be used to supplement the data base expected from drilling new boreholes.

rec'd with letter dtd 9/16/92

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

REFERENCES FOR STUDY PLAN 8.3.1.5.1.4

102.8

Enclosure 2

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8.3.1.5.1.4

United States Department of the Interior

GEOLOGICAL SURVEY
BOX 25046 M.S. 425
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:

1-330512

WBS#: 1.2.3.1
QA : Info Copy
August 3, 1992

J. Russell Dyer
Yucca Mountain Site Characterization
Project Office
U. S. Department of Energy
P. O. Box 98608
Las Vegas, NV 89193-8608

Subject: NRC request for not-readily-available-references cited in Study Plan 8.3.1.5.1.4, Analysis of the paleoenvironmental history of the Yucca Mountain region

In further response to your letter of June 19, 1992, please find enclosed copies of the three not-readily-available-references as requested by NRC staff in their Phase I review of subject study plan. I am sorry for the delay in providing them.

Larry R. Hayes
Technical Project Officer

WRK/LRH/pnb
NRCSPREQ.RK

Dyer - w/o
Crawleff
Gertz
Johnson } w/o

8/10/92

#210-A

POTENTIAL EVAPOTRANSPIRATION

SOME CONSIDERATIONS ON PENMAN METHOD
A SIMPLER AND MORE ACCURATE FORMULA
"STOMATIC" EVAPORIMETER

by
J. PAPADAKIS
A.I.Gx.

U.S. GEOLOGICAL SURVEY
LIBRARY
MAR 14 1967
DENVER

EDITED BY THE AUTHOR
(Av. Cordoba 4564, *BUENOS AIRES*, Argentina)
1965

OCT 6 1967

SUMMARY

Penman formula is based on the controversial Bowen equation, and on the assumption that just above the evaporating surface air is saturated with vapour.

In the case of leaves evaporation takes place within the leaf, and the intracellular spaces near the stomata are certainly saturated with vapour. But these spaces are separated from the atmosphere by a perforated cuticle, which opposes so great a resistance to vapour diffusion, that leaves evaporate, per unit surface, 6 times less than a free water surface. Moreover plants have marvellous adaptations that ensure leaf movement with the lighter breeze; leaves move continuously, and vapour cannot accumulate on their surface. Due to the resistance opposed by the perforated cuticle, and to leaf movement, air at leaf surface is far from being saturated. This fact invalidates Penman formula.

Moreover the following facts should be taken in consideration:

a) Due to their continuous movement, leaves act as sling thermometers; sensible heat transfer to or from the air is very easy; and leaf temperature does not differ appreciably from air temperature.

b) Near the ground, in the "poorly ventilated" layer, vapour pressure and temperature may differ substantially from those registered in the meteorological shelter. But this layer ends at 30 cm, seldom extends to 60 cm. The great majority of leaves transpire in the "well ventilated" layer, in which midday vapour pressure and temperature differ from those registered in the meteoroligical shelter by only 1°C and 1mb, approximately. Vapour evacuation is so rapid from this layer than the daily range of vapour pressure seldom exceeds 1mb. Due to wind, temperature and vapour pressure in this layer are uniform, varying very slowly over a hundred of kilometers or so; they do not depend on local energy balance. Irrigation of extensive areas in the desert has not appreciably changed their temperature and vapour pressure.

c) Due to leaf movement and advection, leaves cannot be appreciably heated by radiation, above the regional temperature of the hour, and they cannot be cooled below it by transpiration. The effect of radiation is indirect by increasing the temperature of the whole region. But this temperature enters in the "aerodynamic" term of Penman formula; and the "energetic" term should be suppressed.

d) Due to leaf movement and the rapidity with which vapour is evacuated, the effect of wind on transpiration is negligible, if any; and wind function in the "aerodynamic" term of Penman formula should be replaced by a constant.

We arrive so at the conclusion, that Penman formula should be reduced to saturation deficit, multiplied by a constant. And this is the formula some years ago proposed by the author. Although simple, it is more accurate and integrates better all factors. Saturation deficit is computed on the basis of maximum temperature.

The forementioned considerations are supported by abundant experimental evidence. It has been proved experimentally, that in presence of wind, radiation does not increase transpiration; and with strong radiation, wind reduces transpiration. Penman method underestimates evapotranspiration and evaporation of dry climates; it overestimates that of spring, and underestimates that of autumn; it overestimates that of windy days; if Penman assumptions were valid, leaf temperatures would be incredibly low in dry climates, and incredibly high in humid climates. On the contrary, author's formula fits better the facts in all cases.

Other questions, as the "oasis" effect; the concept of p. evapotranspiration and its measurement; the influence of leaf area, growth rhythm and rain-watering pattern, on p. evapotranspiration; the influence of temperature, drought and day length on p. evapotranspiration/evaporation ratio; the use of p. evapotranspiration in climatology and irrigation; the reasons why Penman formula gives unsatisfactory results even in computing evaporation; evaporimeters; and further research are discussed; a "stomatic" evaporimeter is proposed.

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1. INTRODUCTION. THEORETICAL BASIS OF PENMAN FORMULA. DIFFUSION RESISTANCE WITHIN THE LEAVES. VAPOUR PRESSURE AT LEAF SURFACE.

1.1. Potential evapotranspiration is very important in irrigation, climatology, vegetation and crops ecology, hydrology and pedology. Irrigation covers the difference between potential evapotranspiration and rainfall. In climatology, we cannot tell how moist or dry a place or a season is, if we know only rainfall; we must compare rainfall to p.evapotranspiration. The geographic distribution of vegetation types and crops depends greatly on the balance between available water and p.evapotranspiration. Runoff, percolation and soil leaching depend greatly on the same balance.

One of the best known methods to compute p.evapotranspiration, is that of Penman. But it is little used in irrigation and climatology. And in the few cases it has been used, the results have been disappointing. The purpose of this paper is to discuss this method, both theoretically and experimentally, try to find the cause of these poor results, and see if another method might give a better answer to this important and urgent problem. We shall also discuss other aspects of evapotranspiration and propose a "stomatic" evaporimeter, which may help to study these questions.

1.2. Penman formula is based on the following considerations:

Evaporation from a free water surface is function of surface saturation deficit and wind:

$$E_o = f(u)\ (e_s - e_a) \qquad (1)$$

E_o is evaporation

$f(u)$ is a function of wind speed (u)

e_s is saturation vapour pressure at surface temperature (T_s)

e_a is mean vapour pressure of the atmosphere

If surface temperature (T_s) were equal to air temperature (T_a), evaporation would be function of air saturation deficit ($e_a - e_a$):

this hypothetical evaporation is termed by Penman "drying power of the air" (E_a):

$$E_a = f(u)\ (e_a - e_d) \qquad (2)$$

E_a is the "drying power of the air"

e_a is saturation vapour pressure at air temperature (T_a)

By dividing (1) by (2) we obtain:

$$E_o/E_a = (e_s - e_d) / (e_a - e_d) \qquad (3)$$

This equation shows that the ratio of evaporation to the "drying power of the air" is equal to that of two saturation deficits, one computed on the basis of surface temperature and the other on the basis of air temperature.

Since the difference $T_s - T_a$ is seldom considerable, equation (3) provides a sound basis to compute evaporation. But Penman resorts to a very controversial formula, that of Bowen:

$$Q/E_o = k\ (T_s - T_a) / (e_s - e_a) \qquad (4)$$

Q is the amount of heat transfered to or from the air

T_s is surface temperature

T_a is air temperature

k is the ratio of sensible heat transfer to vapour (latent heat) transfer; it is assumed constant by Bowen, but that is denied by many authors.

Bowen formula refers, with different constants, to two processes: a) vapour diffusion from a free water surface to the air covering it (limit layer); and b) turbulent transfer from an air layer to another.

Concerning the first process, we should remember, that Bowen formula has been prepared for a free water surface. If we apply it to the leaf, we should take in consideration, that because of leaf movement and position, sensible heat transfer to or from the air, is many times more rapid in this case; on the other hand, because of the resistance opposed by the perforated cuticle to vapour diffusion, evaporation per unit surface, is several times slower. Therefore k is many times greater.

Concerning the second process (turbulent transfer), to apply Bowen formula, we need know temperature and vapour pressure at the lower layer (around leaves). In this case T_s and T_a are temperatures at two levels, and e_s and e_a vapour pressures at two levels.

Penman cannot apply Bowen formula to the first process (diffusion through stomata), because we ignore k; we ignore also H the radiation received by the leaf, which is not horizontal and is often shaded. Moreover such application could only give transpiration per unit leaf area.

That is why Penman applies Bowen formula to the second process (turbulent transfer). But since we dont know temperature and vapour pressure at the lower level (around leaves) he assumes that air is saturated at this level (temperature T_s and vapour pressure e_s). And this assumption permits him to solve the equations and obtain his formula.

The trouble is that at leaf surface air is far from being saturated. In the case of leaves, evaporation takes place in the substomatal spaces, and there air is certainly saturated. But these spaces are separated from the air by a perforated cuticle, that opposes so great a resistance to vapour diffusion, that well provided with water leaves evaporate, per unit surface, 6 times less than a free water surface (Kiesselbach 1916). As we shall show in paragraph 5.4, vapour pressure at this level differs little from that registered in the meteorological shelter.

This fact invalidates Penman formula. But we shall discuss with more details this question in paragraphs 3.6, 5.3 and 5.4.

1.3. Let us now discuss two crucial questions: the resistance opposed to vapour diffusion by the perforated cuticle; and vapour pressure at leaf surface.

In this respect we should remember, that total stomatal surface is usually below half percent of leaf surface (see Parcevaux 1964). It is true, that evaporation through a perforated membrane is many times higher that corresponding to total surface of its openings. That is why leaves do not evaporate two hundred times less than an equal water surface; they evaporate 6 times less, or something like that, when stomata are fully open. But a 6 times reduction means a great resistance. Air may be saturated on a motionless free water surface; it cannot be saturated on a surface that transpires 6 times less and moves continuously.

The fact that leaves transpire several times less than a free water surface is khown, not only by the forementioned experiment, but also by the fact, that p. evapotranspiration seldom exceeds evaporation, although leaf index often exceeds 3, and consequently leaf surface is more than 6 times greater than land area.

It may be argued that the difference between leaves and a free water surface is due to the fact, that leaves receive also several times less radiation. But radiation acts by increasing leaf temperature. It cannot be argued, that leaf temperature is lower than water temperature and that the difference is sufficient to reduce 6 times saturation deficit; then leaf temperature would be near to dew point, and that cannot be.

Moreover the relation between evaporation through a perforated membrane and that from a free surface, depends on the rapidity with which the vapour produced is evacuated. If such evacuation is difficult and vapour accumulates, the bottleneck of the whole process is in this evacuation, and it does not matter how much resistance the perforated membrane opposes to vapour diffusion. But if the membrane is moving continuously, as is the case of leaves, and vapour cannot accumulate, the bottleneck is in membrane resistance.

All measurements of vapour pressure in the air surrounding leaves show, that it is far from being saturated; the difference from that registered in the meteorological shelter is only 1 mb approximately. On the contrary within leaves air is saturated. Since saturated and dry air are separated by a perforated membrane, the total openings of which are only half percent of its total surface, it is likely, that this membrane is the cause of the difference, and that vapour pressure changes sharply at this level.

Moreover turbulent transfer of vapour begins at some distance from leaf surface. And at such a distance there is abundant evidence that air is not saturated (see paragraph 5.1).

The "stomatic" evaporimeter (see paragraph 21.3) provides the possibility to test our assumptions. It is possible to construct apparatus with very small openings and a total openings surface two hundred times smaller than that of the membrane, moved by wind, etc., and use them in open air.

2. PENMAN FORMULA HAS BEEN PREPARED FOR A FREE WATER SURFACE AND EXTENDED TO A SHORT GRASS SWARD. PECULIARITIES OF THESE EV. SURFACES.

2.1. Penman formula has been prepared for a free water surface. In a free water surface the percentage of heat that is loosed or gained by sensible heat transfer is little; radiation is chiefly used in evaporation. Water temperature depends on the balance between radiation and evaporation; when radiation is strong, but for aerodynamic reasons (saturation deficit, wind) evaporation is slow, water temperature rises and evaporation increases, until an equilibrium is attained; when radiation is low but for aerodynamic reasons evaporation is rapid, water temperature comes down and evaporation decreases, until a new equilibrium is attained. Therefore evaporation greatly depends on radiation.

In a free water surface, evaporation per unit area is rapid and wind speed near the surface is low; as a consequence a layer of humid air is formed; and vapour evacuation from this layer is facilitated by the temperature gradient produced by radiation, and wind. That is why evaporation depends also on wind speed, although less than on radiation.

2.2. Penman defines potential evapotranspiration as the amount of water vaporized by a short green crop, covering entirely ground, of uniform height, and never short of water, a short dense grass sward for instance. In such a crop wind penetrates with difficulty between transpiring leaves, sensible heat transfer to or from the air is difficult, and a layer of humid air can be formed between leaves. Such crops present some analogies with a free water surface.

When grass is recently cut, water consumption is chiefly by soil; but a moist soil surface presents also many analogies with a free water surface.

3. VAPOUR AND HEAT TRANSFER BETWEEN LEAVES AND AIR. LEAF MOVEMENT AND TEMPERATURE. APPLICABILITY OF BOWEN AND PENMAN FORMULAS.

3.1. In transpiration we may distinguish two stages:

a) Vapour and heat transfer between leaves and the air-layer, in which they are transpiring

b) Vapour and heat transfer between this layer and the atmosphere above it.

Let us consider in this chapter, the first stage. The second will be treated in chapter 5.

3.2. Never short of water crops and vegetation are tall, and their leaves move continuously; the lighter breeze puts them in movement.

Until recently (Papadakis 1952), leaf movement had received little attention. But it is a universal phenomenon. All plants, that grow in sunshine, have marvellous adaptations that ensure leaf movement with the lighter breeze. It is in this way that plants avoid overheating by radiation. Transpiration cannot help them, because exactly at midday, when radiation is maximum, stomata usually close and transpiration virtually ceases. Overheating (burning) is avoided by leaf movement, which facilitates heat evacuation to air.

It is only when air is completely still, that leaf temperature increases above that of the air, and leaves may be burnt. Farmers

know well that. It is the "serre" (greenhouse) effect, because it is often observed in greenhouses, where air is still and leaves immobile.

It is to be noted, that in plants that grow in high mountains and need to be heated by radiation, because air has freezing temperatures, growth is usually compact (cushion plants), air penetrates with difficulty between leaves, and leaves are almost immobile. Many shade plants lack adaptations that ensure leaf movement. Cactus stems are immobile, but they are vertical and receive little radiation per unit green area, at midday. In short, there is abundant evidence, that leaf movement permits plants to avoid overheating by radiation.

3.3. Due to their movement, leaves work as sling thermometers, and their temperature is practically equal to that of the surrounding them air (Papadakis 1952). It is only when air is completely still that leaf temperature may be well above or well below that of the air.

Unfortunately there are very few data on leaf temperature, and few of them are reliable. *When measuring leaf temperature*, attention should be paid, not to interfere with leaf movement; wind velocity and water availability should be mentioned. Unfortunately such precautions seldom are taken.

3.4. Another effect of leaf movement is that a layer of humid air cannot be formed on leaf surface (Papadakis 1952). The lighter breeze is sufficient to put leaves in movement and impede the formation of such a layer; more wind cannot do more. That is why the influence of wind on transpiration is negligible, if any.

Moreover as we have said in paragraph 3.3, transpiration per *unit surface is approximately 6 times less than from a free water* surface. Therefore the volume of vapour to eliminate is also much less.

3.5. Kiesselbach (1916) has shown, that well provided with water maize leaves transpire three times less water, than an equal area of water. Since leaf surface is double, the ratio becomes 6:1. These figures show the resistance opposed to vapour diffusion by the perforated cuticle. Because of this resistance, vapour pressure drops abruptly from the intracellular spaces near the stomata, where air is saturated, to the air, just out of the stomata. And this fact invalidates Penman formula, which is based on the assumption, that turbulent transfer of vapour and heat begin from an air layer saturated with vapour (see also paragraph 1.3).

3.6. Let us now discuss the applicability of Bowen and Penman formulas to the leaf.

Sensible heat transfer between an evaporating surface and air depends on temperature difference:

$$Q = k_h \ (T_s - T_a) \qquad (5a)$$

Q is the heat transfered

k_h is sensible heat transfer per unit of temperature difference; it depends on how easily such transfer takes place.

On the other hands evaporation depends on saturation deficit:

$$E_v = k_e \ (e_s - e_a) \qquad (5b)$$

k_e is evaporation per unit saturation deficit (surface s.d.); it depends on how easily evaporation takes place.

By dividing (5a) by (5b) we have:

$$Q/E_v = (k_h/k_e) \ (T_s - T_a) / (e_s - e_a) \qquad (6)$$

This is Bowen equation, but the constant is replaced by k_h/k_e to point out its real meaning.

Let us now consider a surface which receives all the energy consumed in evaporation from the air (the case of psychrometer). In this case:

$$E_v = -Q$$

and $$(e_s - e_a) = (k_h/k_e) \ (T_s - T_a)$$

The case of leaves is similar to that of the psychrometer, but here

$$E_v = H - Q \qquad (7)$$

By solving (3), (6) and (7), we obtain

$$E_v = [\Delta H + (k_h/k_e) E_a] / \Delta + (k_h/k_e) \qquad (8)$$

This is Penman equation, but γ is replaced by (k_h/k_e), to point out its real meaning. We shall add that H is net radiation per unit leaf surface. In a "never short of water" crop, leaf area is usually 2½ times land area; leaf surface 5 times land area; and since soil also evaporates, the evaporating surface is 6 times greater than in *the case of a free water surface. So H is approximately 6 times* smaller than in Penman formula. E_v also is 6 times smaller, because well provided with water leaves evaporate, usually, per unit surface, 6 times less than free water.

In the case of leaves k_h (sensible heat transfer) is several times more rapid than in that of a free water surface; k_e (evapora-

tion) is, approximately, 6 times slower; so that k_h/k_e is at least 20 times greater than γ. When in Penman formula we replace γ by a figure 20 or more times greater, H by a figure 6 times smaller, and E_a by a figure 6 times smaller, the "energetic" term becomes negligible, and the equation is reduced to the "aerodynamic" term, that is to saturation deficit, since the influence of wind is negligible.

So that transpiration is practically independent of radiation, and depends on saturation deficit of the surrounding the leaves air.

Naturally upper leaves receive more radiation, probably 3 times less than a free water surface (they have a double surface and they are not continuously horizontal). But upper leaves are also more exposed to wind; sensible heat transfer (k_h) and consequently k_h/k_e, which replaces γ in Penman formula, is greater. So that the "energetic" term is negligible, in this case too, and transpiration depends on saturation deficit of the surrounding the leaves air.

4. IT HAS BEEN SHOWN EXPERIMENTALLY, THAT IN PRESENCE OF WIND, TRANSPIRATION DOES NOT INCREASE WITH RADIATION. AND WITH STRONG RADIATION, WIND REDUCES TRANSPIRATION, INSTEAD OF INCREASING IT.

4.1. The fact that transpiration does not increase with radiation or wind has been proved experimentally. In the wind tunnel of Earhart Plant Research Laboratory of California, Soriano (1953) studied the influence of wind on transpiration, at two levels of illumination. The results given by Nicotiana glauca, the leaves of which are comparable, in mobility, to those of usual crops, may be summarized as follows:

Illumination	400fc	1000fc
	Transpiration (g/h/m²)	
Still air	23.0	53.0
Gentle breeze (14 km/h)	41.9	36.0
Still air	24.4	52.5
Fresh breeze (33.5 km/h)	44.9	42.2

With still air an increase of radiation of 108% resulted in an increase of transpiration of 126%; on the contrary with gentle or fresh breeze an insignificant reduction is observed; wind temperature was in all cases 23°C. At the lower level of radiation, gentle breeze compared to still air increased transpiration by 83%; but a further increase of wind velocity, from 14 to 33.5 km/h, had not appreciable effect; at the higher level of radiation, wind reduced transpiration, instead of increasing it, as it is pretended.

The results illustrate the magnitude of sensible heat transfer between leaves and air. When air is completely still, leaves do not move, sensible heat transfer is slow, they are heated by radiation, and transpiration increases lineally with it. But with the lighter breeze, leaves move, sensible heat transfer to air is rapid, they cannot be heated by radiation, and transpiration does not increase with radiation. For the same reason a layer of moister air cannot be formed on leaf surface, and the influence of wind is insignificant. But compared to completely still air, a gentle breeze reduces transpiration, by impeding leaf heating.

4.2. The experiment of Soriano is corroborated by that of Holmes et al. (1960); they studied soil evaporation in wind tunnels, with two levels of radiation and four wind velocities; the results, evaporation in mm per day, may be summarized as follows: we mention only those obtained with untilled soil.

Wind velocity	0 m/h	1.5 m/h	2.5 m/h	7.5 m/h
Without radiation	1.7	2.7	3.9	5.2
With radiation	15.0	7.9	8.0	6.2

In absence of radiation wind increased evaporation, perhaps by impeding soil cooling and the formation of a layer of moister air on its surface; but in presence of radiation, wind reduced evaporation, by impeding soil heating Radiation increased 9 times evaporation when air was still; but with a gentle breeze, 7.5 m/h, such increase was only 19%. Even in the case of soil, in which sensible heat transfer to or from the air is much more difficult than in the case of leaves, the magnitude of such transfer is considerable, and invalidates prevailing ideas concerning the influence of radiation and wind.

5. VAPOUR AND HEAT TRANSFER FROM THE AIR-LAYER, IN WHICH LEAVES TRANSPIRE, TO THE ATMOSPHERE ABOVE IT. THE "POORLY VENTILATED" AND "WELL VENTILATED" LAYERS. THE DAILY RANGE OF VAPOUR PRESSURE SHOWS, THAT VAPOUR NEVER ACCUMULATES. APPLICABILITY OF PENMAN FORMULA TO EVAPOTRANSPIRATION.

5.1. Let us now consider the second stage of vapour and heat transfer in transpiration, that between the air-layer in which leaves transpire, and the atmosphere above it.

Within a tall crop or vegetation, we may distinguish two air layers: a "poorly ventilated," at soil surface, it is usually less than

30 cm high, and seldom reaches 60 centimeters; and a "well ventilated," in which practically all leaves transpire. In the "poorly ventilated" layer midday temperature and vapour pressure vary considerably with height and depend greatly on local conditions (soil shading and moisture). But in the "well ventilated" layer vertical gradients of temperature and humidity seldom exceed 1°C and 1mb per meter respectively; midday temperature and vapour pressure are practically equal to those registered in an opening, or a nearby standard meteorological shelter. Micrometeorological research by Ramdas (1958) and Geiger (1959) clearly show that; unfortunately so important researches are very scarse in world literature. But de shall bring some examples in paragraph 5.4.

5.2. Universal experience shows that, except for arrival of a humid air mass, vapour mixing ratio does not increase in midday. Microclimatic observations (Geiger 1959, Ramdas 1961) show that it happens the same in the "well ventilated" layer of tall crops. Although in many cases, more than 5 millimeters of water are evapotranspired in 1 day, and such vapour would be sufficient to increase vapour pressure of an air column of 6 kilometers by 1mb, the increase seldom exceeds this figure. Even in the "poorly ventilated" layer vapour accumulation is very limited, and the layer is far from being saturated (except when the atmosphere also approaches saturation).

5.3. Let us now discuss the applicability of Penman formula to vapour and heat transfer between the air layer in which leaves transpire, and the atmosphere above it.

Bowen formula may be applicable to this case:

$$Q/E_v = k\ (e_{d'} - e_d) / (T_{v'} - T_v) \qquad (9)$$

$e_{d'}$ is vapour pressure in the air layer, in which leaves transpire

$T_{v'}$ is air temperature in the same layer

k is a coefficient, that in our opinion varies from case to case (instability, etc.)

Penman formula is based on the assumption that k is equal to γ the psychrometer constant, and $e_{d'}$ is equal to e_v; Penman assumes that turbulent transfer begins with an air layer that has a temperature equal to that of the evaporating surface, and is saturated with vapour at this temperature. That may be true in the case of a free water surface. But in the case of transpiration, evaporation takes place within the leaf. In the intracellular spaces near to the stomata air is certainly saturated with vapour. But these spaces are separated from the surrounding the leaves air by a perforated cuticle, which opposes so great a resistance to vapour

diffusion, that leaf transpiration, per unit surface, is 6 times lower than from free water (see paragraph 3.5). Moreover, due to leaf movement vapour cannot accumulate on leaf surface. And vapour evacuation is so rapid, that the diurnal range of vapour pressure seldom exceeds 1mb (see paragraph 5.2). So that vapour pressure drops abrubtly from saturation in the intracellular spaces within the leaf, to a figure very close to that registered in the meteorological shelter, just out of the stomata. See also paragraph 1.3.

This fact invalidates completely Penman formula, which is based on the assumption, that turbulent transfer begins with saturation.

Universal experience shows, that in the air surrounding the upper leaves of a vegetation, vapour pressure and temperature seldom differ from those 1m upward, by more than 1mb and 1°C respectively. And with such gradients an amount of vapour equivalent to net radiation is often evacuated. When gradients are so little, a small variation of one or another is sufficient to make evaporation 2 or more times greater or smaller than energy budget. So that turbulent transfer is always sufficient to evacuate whatever amount of vapour goes out of stomata; it is always sufficient to evacuate whatever excess to radiation, and to provide whatever amount of energy required for transpiration. The bottleneck of transpiration is in vapour diffusion through stomata. Energy is not the limiting factor of evapotranspiration, and the energetic approach cannot help to solve the problem of computing potential evapotranspiration (see also paragraph 3.6).

5.4. The question of midday temperature and vapour pressure, in the air-layer in which leaves transpire, deserves more discussion.

Ramdas (1961) reports the following figures, registered in midday:

Height (cm)	Open	Sugar-cane	Sorgho	Cotton	Tobacco
		A. Temperatures (C)			
1	33.6	24.9	31.2	32.6	34.6
30	30.4	25.9	30.3	30.5	31.2
60	30.0	26.4	30.1	30.1	30.6
180	28.6	27.4	29.1	28.9	29.0
		B. Vapour Pressure (mb)			
1	12.0	18.2	13.5	12.8	13.2
30	11.1	15.2	12.4	11.6	11.5
60	10.8	14.4	12.0	11.5	10.2
180	10.7	13.2	11.9	10.9	10.9
		C. Saturation Deficit (mb)			
1	40.0	13.3	31.9	36.4	41.8
30	32.3	18.2	30.8	32.1	33.9
60	31.6	20.0	30.7	31.2	33.7
180	28.4	23.3	28.4	28.9	29.2

D. Relative Humidity (%)

Height (cm)	Open	Sugar cane	Sorgho	Cotton	Tobacco
1	23	58	30	26	24
30	26	45	29	47	25
60	25	42	29	27	25
180	27	36	30	27	27

As the figures show relative humidity was in all cases below 45% at 30 cm or higher; in some cases it was as low as 25%. Since leaves move continuously, this is also the relative humidity at leaf surface. This fact invalidates Penman formula, which is based on the assumption that at evaporating surface level air is saturated with vapour (it is the assumption that permitted Penman to establish his equation).

Concerning temperature, vapour pressure and saturation deficit, at 30 cm or higher, Ramdas figures show, that they are practically the same as in the open, for the three crops, sorgho, cotton and tobacco.

The only exception is sugar cane. Here a temperature inversion is observed; temperature at 1 cm from the ground, is 3.7°C lower than in the open at 180 cm; and there is a gradual increase of temperature with height. But even in this crop, between 60 and 180 cm, where leaves transpire, air temperature differs from that of the air by only 1.7°C; and the difference with the temperature registered in the meteorological shelter would be still less, since the shelter is placed over grass. So that even in the case of sugar cane leaf temperature is practically equal to that registered in the meteorological shelter.

The only reason for which Penman formula has been devised, is that leaf is exposed to radiation, cooled by transpiration, and its temperature may differ from that of the air: were T_l (leaf temperature) equal to T_a (air temperature), E_p (evaporation) would be equal to E_a (the evaporating power of the air), and the "energetic" term of Penman formula would be useless; p. evapotranspiration would be obtained by multiplying E_a by a coefficient, to take account of SD.

It is evident a priori, and it is shown by sugar cane figures, that leaf temperature is lower than that of the air when actual evapotranspiration exceeds momentaneous net energy. But this dependence on radiation is little; and it is observed when saturation deficit is very high, as in this case. This is probably one of the causes the relation between transpiration and evaporation is not linear (see chapter 12). By computing saturation deficit on the basis of maximum temperature, we take account of the fact that the relation between evaporation and evapotranspiration is not linear (see paragraph 17.6).

Ramdas (1961) gives also the following figures concerning wind speed within crops:

Wind Speed

(in percent of that at 180 cm from ground surface, where it was 4.85 m/h.)

Height (cm)	Sorgho	Open	Elephant foot	Sugar cane
1	49	16	26	8
30	60	16	27	9
60	62	15	37	8
180	100	26	64	12
Height of the crop (cm)		180	90	

As the figures show, crops reduce wind speed considerably, not only within the crop, but above its top (elephant foot). The reduction is especially important in the case of crops with rigid stems (sorgho, sugar cane); and it depends also naturally on crop height and density. In the case of sugar cane wind speed, even at 180cm from ground surface was only 12% of that registered at the same height at the open, and this fact explains some accumulation of vapour observed in this crop, which in addition was irrigated.

Ramdas figures show, that in the case of irrigated crops, tall, dense, with rigid stems, and when saturation deficit is very high (30 mb in this experiment), some accumulation of vapour takes place. This fact explains, why p. evapotranspiration does not increase linearly with leaf area. When leaf area index (leaf area/land area) increases beyond a certain limit, the lower leaves and soil are subjected to a lower saturation deficit, and their contribution to total evapotranspiration is low (see chapter 12).

The reader will encounter in Ramdas and his collaborators book and papers many other observations concerning temperature, vapour pressure, etc. within crops. Ramdas determined also evaporation with crops. But the Piche evaporimeter he used is affected by radiation and shading. It would be interesting to repeat such experiments with the "stomatic" evaporimeter (see paragraph 21.3)

6. THE "OASIS" EFFECT.

6.1. In paragraphs 3.6, 5.3 and 5.5 we have said, that leaves obtain easily from the air, the balance of energy they require for transpiration, when the drying power of the air is high, and net energy not sufficient. Such energy comes from surrounding areas, in which evapotranspiration is low, because of water shortness, and radiation is chiefly consumed to heat the air.

The fact is not denied by Penman assumptions. For instance *in Baghdad (Wallen et al. 1962), in July, H (for evapotranspiration)* is 4.8 mm/day; but E_T is 9.1 mm, almost double; and in fact it is still higher (14.1 mm, see paragraph 18.3); so that the contribution of advection is very important.

However there is a tendency to consider the oasis effect as an exception, a little complication, that does not invalidate balances that ignore it; and it may be eliminated by a border of less than 1 kilometer. In our opinion the "oasis effect" is omni-present, it forms part of the climatic context, it cannot be ignored in balances, and invalidates those in which it is not taken in consideration.

6.2. Universal experience shows, that except for climatic barriers, or differences in altitude, midday temperature and vapour pressure vary very little and very gradually over distances of a hundred of kilometers or more. The uniformizing agent is certainly wind, which with a speed of 3 meters per second covers 259 kilometers in 24 hours. It takes heat from drier areas, and transports it to those better provided with water.

It is to be noted that very often continuous areas, with a radius of several kilometers, have been irrigated in the desert, and such irrigation has not changed appreciably their midday temperature and *vapour pressure, at the height of the "well ventilated" layer;* differences, if any, are of the order of 1°C or 1 mb respectively; pratically they do not modify saturation deficit. This fact shows clearly, *the effect of wind in uniformizing temperatures and vapour pressure* over great distances. It shows also that midday temperature and vapour pressure — and consequently evapotranspiration — in a finite "never short of water" area, *do not depend on local balance;* they are determined by water availability 100 kilometers away; Bouchet (1964) points out this fact.

So that in a finite area — its radius may be several kilometers — when evapotranspiration is high, but radiation is not sufficient to maintain its rate, air and leaf temperature do not come down; evapotranspiration rate is maintained with energy provided by wind. And when in such a finite area, evapotranspiration is low, and there is a surplus of radiation energy, air and leaf temperature do not rise, and evapotranspiration continues at the same rate, excess energy being taken out by wind.

Therefore it is meaningless to consider the finite area as separated from the rest of the earth and estimate its energy balance

We should dress the balance of the whole region on the basis of radiation, water availability, etc.; determine in this way temperature and vapour pressure in the whole region; and on this basis determine evapotranspiration of the finite "never short" of water area.

But such a balance has never been done as far as I know. Moreover, from a practical point of view it is not necessary, because temperature and vapour pressure, at this height, are known from direct observation.

6.3. Universal experience shows that temperature and vapour pressure, at a height of 2 meters, depend greatly on air masses. A change of air mass causes a rapid and very pronounced change of temperature and/or vapour pressure. Each air mass has its own temperature and mixing ratio, and when it passes over warmer or colder, moister or drier areas, *the change is slow and gradual.* This fact shows the importance of air masses is determining temperature and absolute humidity, at this eight. Since leaves transpire in *this layer, and their temperature is practically that of the air,* we cannot ignore this influence in balances. A sea breeze, by bringing cool-humid air, reduces evapotranspiration; and a hot dry catabatic *wind has the opposite effect.*

7. AN EASY METHOD TO TEST PENMAN FORMULA

7.1. Formula (3) provides the possibility to test Penman method. According to it any difference between computed evaporation (E_o) and "drying power of the air" (E_a) should be justified by a corresponding difference between water surface temperature and air temperature. Formula (3) may be written:

$$E_o = E_a \, [1 + (e_s - e_a) / (e_s - e_d)] \qquad (10)$$

Knowing E_o, E_a, T_a and e_d, we may determine T_s; and computed T_s may be compared with *measured* T_s. *We shall give some examples.*

In Baghdad, Iraq (Wallen 1962), in July, Penman E_o is 11.6mm per day; Penman E_a 31.8 mm; T_a 35.0°C; e_d 11.7 mb. T_s should be 22.9°C. It is impossible for water surface temperature (average of 24 hours) to be so low; minimum temperature is 25.6°C.

In Baghdad, Iraq (Wallen 1962), in September, Penman E_o is 7.9 mm; Penman E_a 19.6; e_d 11.5 mb; T_a 30.7°C. T_s should be 24.7°C. It is impossible for water surface to be so cool. Minimum temperature is 21.8°C.

7.2. The test can be also applied to computed evapotranspiration (E_T); in this case the drying power of the air (E_a) should be adjusted for surface conductance and day length, by dividing it by $(\Delta/\gamma + 1)/(\Delta/\gamma + 1/SD)$. We shall give a few examples.

In Baghdad, in July (see Wallen et al. 1962) Penman E_T is 9.1 mm: adjusted E_a 30.3 mm; e_d 11.7 mb; T_a 35.0°C. T_s should be 21.2°C. It is impossible for leaves to be so cool; *minimum temperature* is 25.6°C.

In Baghdad, September (Wallen et al. 1962), Penman E_T is 6 mm.; adjusted E_a 18.5 mm; e_d 11.5 mb; T_a 30.7°C. T_s should be 19.1°C. It is impossible for leaves to be so cool; minimum temperature is 21.8.

7.3. What is the reason of such discrepancies between Penman assumptions and facts? Sensible heat transfer between the evaporating surface and air is far more easier than it is assumed by Penman formula. When saturation deficit is low leaves evacuate easily excess radiation to the air; evapotranspiration is lower than Penman E_T, and leaf temperature is also lower. When saturation deficit is very high and radiation is not sufficient to provide the energy required for the corresponding evapotranspiration, leaves obtain easily from the air the balance, with a very small temperature gradient; evapotranspiration is much higher than Penman E_T and leaf temperature is also much higher than that computed on the basis of Penman formula.

Usually, even in very dry climates, hourly net radiation is sufficient for p. evapotranspiration, and leaf temperature is approximately equal to that of the air. In night leaves are a little cooler than air, and obtain heat from it. So that, although p. evapotranspiration may exceed net radiation on a 24 hours basis, such excess disappears, or becomes insignificant, on a day-hours basis. In the desert it happens frequently to have an excess of p. evapotranspiration on net radiation, even when day hours are considered; the balance is provided by air, but a very small gradient is sufficient; leaves are cooler than air (in areas well provided by water), but the difference is little, increasing in night.

The fact that Penman formula overestimates the p. evapotranspiration of humid climates, and underestimates that of dry ones, has been proved experimentally (see paragraphs 14.1-14.5). Data on leaf temperature are scarse; but leaf temperatures, computed according to Penman assumptions, are so high in humid climates, and so low in dry climates, that they are highly unlikely or impossible.

8. SOIL EVAPORATION. THE CASE OF SHORT-OPEN CROPS AND VEGETATION.

8.1. In the preceding paragraphs we said nothing about soil evaporation. This is because when a crop shades completely soil, its evaporation is only a small part of the whole evapotranspiration.

When soil surface is moist and exposed to direct sunshine, its evaporation depends certainly on radiation; a layer of humid air can be formed on soil surface, and wind may have some effect on evaporation. But such cases are exceptional.

Usually soil is either shaded, or dry, or both. When soil is shaded and moist, the case of p. evapotranspiration, H (net radiation) is small, and evaporation depends on the drying power of the air; in this case wind may be important.

When soil is dry and exposed to sunshine, evaporation depends on the rapidity with which soil moisture is renewed; E_a is small; consequently soil temperature depends greatly on H; wind increases k and consequently reduces soil temperature and evaporation (see paragraph 4.2).

When soil is shaded and dry, H and E_a are both small, evaporation is little, soil temperature differs little from that of the air, $(T_s - T_a)$ is small.

So that although evaporation of a moist soil exposed to direct sunshine depends greatly on radiation, in the case of p. evapotranspiration (shaded more or less humid soil) it depends chiefly on saturation deficit.

8.2. Soil evaporation depends greatly on rain or watering pattern. Frequent rains or waterings maintain soil continuously moist and increase soil evaporation. On the contrary when rains or waterings are distanciated, and soil surface is dry the greater part of the time between them, soil evaporation is reduced.

8.3. Many crops and vegetation types do not cover completely the soil. In this case the "poorly ventilated" air-layer is very short; and although the crop may be short, the great majority of its leaves transpire in the "well ventilated" layer. Therefore leaf temperature is practically equal to that registered in a nearby standard meteorological shelter, and it is the same for vapour pressure in the surrounding the leaves air. That is why, in this case also, transpiration depends on saturation deficit, and it is not affected appreciably by radiation and wind.

8.4. When the crop is short of water, evapotranspiration depends naturally on water availability. But, although H (net radiation) is high, and E_a small, k is so high that the difference in temperature between leaves and air is small. But when leaves are rigid (cactus and other succulents, etc.) leaf temperatures are high.

9. LEAF AREA AND EVAPOTRANSPIRATION.

9.1. A free water surface is equal to its horizontal projection; that is why evaporating surface and land area are equal. But in evapotranspiration, total leaf plus soil surface are several times greater than land area. However, even when leaves are well provided with water, they transpire, approximately, 6 times less than an equal free water surface; and by shading, reducing wind speed, and increasing vapour pressure (see paragraph 5.4), they reduce soil evaporation. That is why, as a result of a compensation, evapotranspiration seldom is higher than evaporation; but that is not a rule without exceptions. The evapotranspiration/evaporation varies from case to case.

When soil surface is moist, an increase in leaf area is more or less compensated by a reduction in soil evaporation, and evapotranspiration does not depend greatly on leaf area.

But when soil surface is dry, and vegetation consumes water stored in the soil, such compensation does not exist, and evapotranspiration is almost lineally related to leaf area, allowance made for its evaporating capacity.

Usually soil is neither continuously moist, neither continuously dry; so that evapotranspiration depends on leaf area, but the relation is not lineal. There is abundant evidence of that.

9.2. Pruitt (1960), in the giant lysimeter of Davis (California), observed that cutting the grass did not affect appreciably daily evapotranspiration. Soil was maintained moist; moreover we are in the case of a short crop.

In irrigated crops, soil surface is moist for some time after each irrigation, then dries till to the following one. So that leaf area (crop cover) has considerable influence. Grassi (1964) carried out a very extensive study of water consumption in western United States. The ratio evapotranspiration/pan evaporation, adjusted for temperature, varies from 0.121 for 0 crop cover, to 0.712 for 50%, to 1.007 for 100%. Fig. 1 shows the ratio evapotranspiration/incident radiation (equivalent evaporation); the influence of plant cover is evident. Annual crops have low evapotranspiration, during their early growth, because leaf area is limited.

9.3. In the Mediterranean grapes and olives grow and produce their fruits during the summer, which is practically rainless, very hot and dry; the water stored in soil at the end of spring does not exceed certainly 100 millimeters; this is possible because leaf area, and yield, per unit land area, are very small. In Argentina and United States, where these crops are grown with irrigation, leaf area and yields are several times greater, evapotranspiration is greater, and these crops wilt, when not irrigated.

10. INFLUENCE OF GROWTH RHYTHM. ITS EFFECTS HAVE BEEN OFTEN ATTRIBUTED TO RADIATION.

10.1. Transpiration per unit leaf area varies considerably, according to the capacity of leaves to transpire. Such capacity decreases with age; senile leaves transpire very little, while their shade reduces soil evaporation. Fig. 1 from Grassi (1964) illustrates this influence; according to Grassi, the ratio evapotranspiration/pan evaporation decreases from 1.000 when an annual crop has completed two thirds of its vegetative cycle, to 0.799 at the end of this cycle.

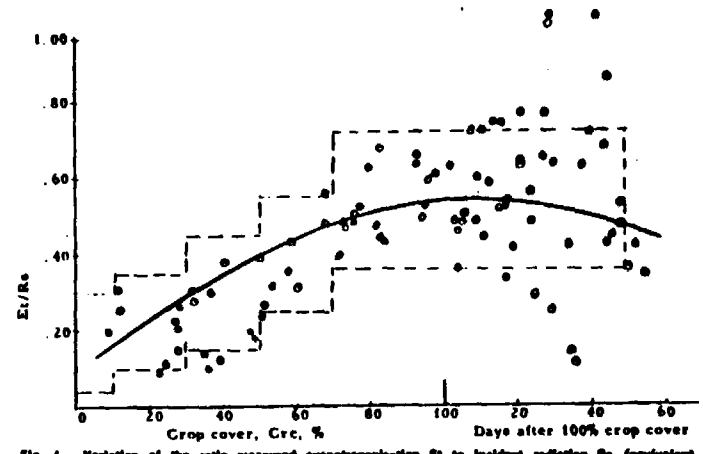

Fig. 1 - Variation of the ratio measured evapotranspiration Et to incident radiation Ro (equivalent evaporation) with ground cover and maturity for potatoes. From Grassi (1964).

10.2. The high evapotranspiration of many crops in spring compared to autumn, or in June compared to July-August, is often attributed to differences in radiation; temperatures are equally favourable, but radiation is higher in spring. But usually it is a question of vegetative stage.

For instance, in the experiment of Stranberry et al. (1955) with alfalfa, alfalfa produced 2 times more hay in June than in September; that explains why June evapotranspiration has been 37% greater than in September, although the difference in saturation deficit has been only 12%.

In the experiment of Pruitt (1960) grass evapotranspiration/pan evaporation ratio decreased from 0.80 in June-August to 0.57 in October-December; this fact shows clearly, that the cause is not radiation, but a certain dormancy of grass in autumn.

Penman has found that grass evapotranspiration/evaporation ratio decreases from 0.80 in May-August to 0.60 in November-February; that also is due to a certain dormancy of grass in winter; leaves are not fully "green".

With many crops, for instance citrus, cotton, evapotranspiration per unit saturation deficit, is higher in late summer or early autumn, than in spring, or early summer.

11. WHEN SATURATION DEFICIT IS VERY HIGH, THE MAJORITY OF CROPS ARE "SHORT OF WATER," EVEN WHEN SOIL IS MOIST.

11.1. There is abundant evidence that when saturation deficit is very high, for instance higher than 40 mb, plants cannot absorb and transport to the leaves all the water they require, stomata close, and evapotranspiration is reduced, even when soil is well provided with water. Only few crops, flooded rice for instance, probably sugar cane, continue to transpire normally under such conditions. That is why it is very difficult to measure potential evapotranspiration under such conditions; crops are seldom given all the water they need; irrigations should be given every day, or twice each day.

12. POTENTIAL EVAPOTRANSPIRATION/EVAPORATION RATIO. INFLUENCE OF TEMPERATURE, DROUGHT AND DAY LENGHT.

12.1. According to Penman, albedo is considerably greater in the case of a green crop (25% instead of a few percent). Moreover surface conductance (SD) is lower than unity, the figure for evapo-

ration. That is why evapotranspiration should always be lower than evaporation. But it is not so. As we have said in certain cases evapotranspiration exceeds evaporation, and the fact is easy to explain (see paragraph 9.1).

12.2. In Penman formula the importance of the "energetic" term decreases as climate becomes drier. Since the importance of this term, because of albedo, is lower in evapotranspiration than in evaporation, p. evapotranspiration/evaporation ratio increases, as climate becomes drier.

On the other hand the importance of the difference between 1 and SD decreases, as temperature increases; so that p. evapotranspiration/evaporation ratio increases as temperature increases.

We may conclude that according to Penman, p. evapotranspiration/evaporation ratio increases as evaporation increases.

12.2. But Grassi (1964) carried out a very extensive study of p. evapotranspiration in western United States and found, that p. evapotranspiration/evaporation ratio decreases with temperature; the figures are:

10°C	1.20
20°C	1.00
30°C	0.80

Long ago Prescott (1946-9) found in Australia, that ET is equal to $E^{0.75}$; therefore evapotranspiration/evaporation ratio decreases as evaporation increases.

12.3. It may be a part of the decrease found by Grassi and Prescott is due to the fact that plants cannot absorb and transport to the leaves all the water they need, when evaporation is very high (see paragraph 11.1). But in any case I dont think evapotranspiration/evaporation ratio increases with temperature and drought. Grassi and Prescott findings are, partly or totally, right.

12.4. Concerning day lenght, according to Penman formula, evapotranspiration/evaporation ratio should increase with day lenght. Grassi studied this factor, but he does not include it in any of his formulas. In my opinion the influence of day lenght is negligible, if any. Penman found a lower evapotranspiration/evaporation ratio in winter than in summer, and Pruitt found the same, not because winter is colder and days shorter, but because they worked with grass, and grass is dormant in winter.

13. THE CONCEPT OF POTENTIAL EVAPOTRANSPIRATION. ITS MEASUREMENT.

13.1. Potential evapotranspiration has been introduced in climatology by Thornthwaite, as a parameter to compare with rainfall, and tell how humid or dry a climate or a season is. Another reason for its introduction is the necessity to forecast how much water is necessary in irrigation. And to dress water balances in irrigation, agronomy, hydrology, pedology, etc.

That is why potential evapotranspiration might be termed "water need," and this is the term formerly used by some authors (Papadakis 1948, 1952). It may be defined as the amount of water evapotranspired by an area, covered by dense vegetation, when growth is not considerably limited by water shortages, and more water cannot increase growth by more than 10% for instance. In general this is the water irrigated crops require. And this is the water evapotranspired by a dense vegetation that does not suffer water shortages. Because even in this case, there are transitory shortages and areas less densely covered by vegetation, which evapotranspirate less.

13.2. Since p. evapotranspiration is a parameter to characterize the climate of a region, it corresponds to an area, that is in all respects similar to the rest of the region, but is not short of water. That is why Thornthwaite proposed to measure p. evapotranspiration, by a tank, in which plants are grown, and is maintained well provided with water.

But the results given by these tanks have been disappointing. Evapotranspiration varied enormously from tank to tank; moreover it was often considerably greater than that forecasted by Thornthwaite formula.

Many authors attributed all that to the "oasis effect"; tanks were too small. And they recommended to place them in a field, that has the same vegetative cover.

But the only effect of the border is to modify wind speed, and to a less extent, air temperature and vapour pressure in the "poorly ventilated" layer near the ground. Its effect on air temperature and vapour pressure of the "well ventilated" layer, in which leaves of tall crops transpire, is negligible, if any; they are governed by conditions a hundred of kilometers around.

13.3. The great differences in evapotranspiration between lysimeters are easy to explain, since transpiration depends on leaf area and leaf area varies considerably according to crop, date of sowing, soil

fertility, etc. Moreover transpiration depends on growth rhythm: grass is more or less dormant in winter; alfalfa grows more intensely in spring than in autumn; in annual crops evapotranspiration is low at the beginning and end of their vegetative cycle (see fig. 1); deciduous plants transpire very little in winter, etc.

13.4. Penman defines p. evapotranspiration as that of a short green crop completely shading the ground of uniform height and never short of water. But such definition is too limitative. The great majority of crops and vegetation are tall; and it is the same for irrigated crops. The difference is important, because short dense crops transpire in the "poorly ventilated" layer and their transpiration depends, a little, on radiation and wind; while tall crops leaves transpire in the "well ventilated" layer and their transpiration does not depend on these factors. Potential evapotranspiration is a parameter to tell how humid or dry a season or a climate is; it is essential for a parameter to be representative; and a short crop of uniform height is not representative. This fact invalidates, to a certain extent, Penman definition.

The same may be said for evapotranspirometers in which a short grass sward grows. They are less variable, but they are not representative. Moreover when recently cut, they do not shade entirely ground.

13.5. Evapotranspiration varies considerably according to rainfall pattern. By sprinkling frequently at day time, we may increase it to unexpected figures; as we have said (paragraph 3.5) a well provided with water leaf transpires 3 times less than an equal free water area; but when leaf is covered with water, it evaporates as a free water surface. On the other hand when water is given by sub-irrigation and soil is continuously dry, evapotranspiration is reduced considerably. So that maximum possible evapotranspiration is not a definite quantity that may be used as parameter.

13.6. All definitions of p. evapotranspiration contain the clause "never short of water," or other equivalent. But such clause can be interpreted in different ways. It may mean that the area receives so much water that its evapotranspiration cannot be increased by giving more water. Or it may mean, that the area receives just the water that is necessary to ensure maximum plant growth.

Although not explicit in this respect, Penman definition and formula seem to have the first meaning (maximum possible evapotranspiration). It is evident that p. evapotranspiration according to Penman definition is higher than according to my definition (see paragraph 13.1 and Papadaiks 1961). In may opinion my definition fits better the purposes for which the concept of p. evapotranspiration has been introduced in science. We define p. evapotranspiration as corresponding to 90% of maximum growth, because at 100% the curve is horizontal.

It is to be noted that water consumption for highest grain or fruit yield is usually lower than that corresponding to maximum growth; that is why it is usually unnecessary to give more water than that corresponding to our definition of p. evapotranspiration.

13.7. In spite of their defects evapotranspirometers are very useful. They need adequate interpretation of the results and many repetitions with different crops, dates of sowing, etc.

A better method of measuring p. evapotranspiration is that of irrigation experiments. But irrigations should be sufficiently frequent, and sprinkler irrigation used to imitate the rainfall pattern of humid climates and seasons. In humid climates it is difficult to measure the water lost by drainage. Naturally, in this case also interpretation should be cautious.

13.8. Actual evapotranspiration may be measured by registering soil moisture at frequent intervals and adequate depths. Actually we have apparatus (Bouyoucos gypsum blocks, etc.), that permit such determinations with minimum effort and soil disturbance.

Such determinations should be done under various vegetation and cropping conditions. They serve not only to study the climate of a region, but also vegetation, crops, tillage operations, cropping systems, hydrologic questions, etc.

One of the main tasks of agrometeorologic and agronomic stations and services should be to register soil moisture in a great variety of crops, vegetation types, etc. It is a pity that such studies are still so scarse in world literature. Efforts, money and time is spent in other research far less important and this fundamental problem is neglected. Registering soil moisture can solve a lot of climatological, vegetational, geographic, hydrologic, pedologic and agronomic problems.

14. PENMAN FORMULA UNDERESTIMATES THE EVAPORATION AND P. EVAPOTRANSPIRATION OF DRY CLIMATES AND SEASONS.

14.1. Potential evapotranspiration is the amount of water evaporated and transpirated by a "finite" area, similar in all respects to the rest of the region, but "never short of water." Penman computes the energy balance and evapotranspiration of this finite area, as if were separated from the rest of the earth.

That may be possible, when the surroundings, are also "never short of water," till to a distance of a hundred of kilometers — the distance at which wind uniformizes midday temperature and vapour pressure in the "well ventilated" layer. But it is not possible, when the surroundings are much drier than the finite "never short of water" area. In this case p. evapotranspiration is underestimated, by ignoring the surroundings.

Afortunately Penman includes, in the "aerodynamic" term of his formula, saturation deficit; moreover there is high correlation between saturation deficit and radiation, so that radiation is fonction of saturation deficit. But that is not enough. Penman formula underestimates evapotranspiration when weather is dry; this is always observed; we shall bring a few examples.

14.2. Jackson (1960) in Alice Spring, in the Australian desert, determined water consumption of an extensive field of alfalfa. Such consumption is 72% higher than Penman E_T; and pan evaporation is 50% higher than Penman E_o. The figures are (inches):

Months	J	F.	M	A	M	J	J	A	S	O.	N	D	An.
Alfalfa cons.	10.2	9.4	8.7	7.2	5.6	4.5	4.6	5.6	7.2	8.4	9.4	9.9	90.7
Pan evap.	12.3	10.7	10.0	7.2	5.0	3.5	3.8	5.0	7.3	9.6	10.7	12.0	97.1
Penman E_o	8.8	7.5	6.6	4.4	3.0	2.0	2.1	3.2	4.8	6.4	7.6	8.4	64.7
Penman E_T	7.2	6.3	5.1	3.4	2.1	1.4	1.5	2.3	3.7	5.0	6.3	6.9	51.2

Pan evaporation and Penman E_o are given by Houman (1958); Penman E_T has been computed from E_o using the following coefficients: May-Aug. 0.71; Sept.-Oct. and March-Apr. 0.77; Nov.-Febr. 0.83.

The consumption measured by Jackson is the usual figure for analogous climates. Stranberry et al. (1955) obtained the following figures in Yuma, Arizona, U.S.

Months	J	F	M	A.	M.	J.	J.	A.	S.	O.	N.	D.	An.
Alfalfa consum.	1.2	3.0	6.9	10.5	12.3	12.6	12.0	10.5	9.0	6.9	4.2	2.4	91.5

In general in the desert alfalfa consumption is of the order of 100 inches annually.

14.3. Wallen (1962) gives the following figures, in millimeters, for Damascus in the fringe of the Syrian desert:

Months	J	F	M	A	M.	J	J	A	S	O	N	D	An
Pan evap.	47	88	130	202	260	372	448	426	285	194	102	52	2606
Penman E_T	30	42	90	129	167	200	223	195	159	108	55	37	1435
E_T/pan ev.	0.64	0.48	0.77	0.64	0.64	0.54	0.50	0.46	0.56	0.56	0.54	0.71	0.55

The difference between pan evaporation and Penman E_T is too great to be attributed to the size of the pan. The ratio is very low 0.55; in July-Aug. it is only 0.46.

14.4. Houman (1958) in Australia compared pan evaporation with Penman E_o: the ratios E_o/pan evaporation are:

Months	J	F.	M.	A.	M.	J.	J	A.	S	O	N	D.	An.
Melbourne	0.98	1.00	0.95	0.84	0.65	0.53	0.77	1.00	1.18	1.12	1.05	1.05	0.98
Griffith	0.80	0.95	0.87	0.78	0.78	0.54	0.71	0.88	0.81	1.02	0.96	0.86	0.87
Alice Springs	0.70	0.71	0.66	0.61	0.60	0.56	0.57	0.62	0.66	0.67	0.71	0.70	0.65

Melbourne is less dry than Griffith; and Griffith is less dry than Alice Springs; Penman E_o/pan evaporation ratio decreases from 0.98 for Melbourne to 0.87 for Griffith, and 0.65 for Alice Springs. It is evident that the ratio decreases as climate becomes drier; Penman formula underestimates the evaporation of dry climates.

14.5. In Navrongo, Ghana, there are many dams, of many hectares each one. Their evaporation during the dry season is approximately one foot. Penman E_o is less than 8 inches.

15. PENMAN FORMULA OVERESTIMATES THE INFLUENCE OF RADIATION. THAT IS WHY SPRING EVAPOTRANSPIRATION IS OVERESTIMATED, AND THAT OF AUTUMN UNDERESTIMATED.

15.1. As we have said radiation acts on transpiration indirectly by determining leaf temperature. But in the case of tall crops leaf temperature is practically equal to that registered in a nearby standard meteorological shelter. This temperature enters in the "aerodynamic term" of Penman formula. Therefore the inclusion of an "energetic term" is not justified, and does not increase accuracy.

Afortunately radiation, more especially incoming radiation, is highly correlated with saturation deficit. Sunny days, sunny seasons, sunny climates have high saturation deficits. This fact compensates, to a great extent, the error introducted by the "energetic term." But in many cases such compensation is not sufficient. We shall give some examples.

15.2. Pruitt (1960) gives the evaporation of a U.S.W.B. evaporation pan and Penman E_o (computed evaporation)) for 6 months in Davis (California). The ratios E_o/pan evaporation are:

	J	J	A.	S	O.	N.	D	J D
E_o/pan ev.	0.86	0.87	0.88	0.72	0.69	0.65	0.54	0.79

The ratio decreases considerably and regularly from June-July to December. This fact shows that Penman formula everestimates the influence of radiation on evaporation; the low E_o of autumn-winter months is chiefly due to the "energetic term."

15.3. Pruitt (1960) gives, day by day, the evaporation of the giant lysimeter in which a short grass sward is grown, pan evaporation and incoming radiation. By taking pairs of days following one another — to eliminate the influence of growth rhythm — we have the following figures:

	High radiation	Low radiation
Incoming radiation	0.291 inch.	0.216 inch.
Max. temp. °C	24.0 °C	22.4 °C
Midday sat. def.	21.9 mb	17.9 mb
Grass evapotransp.	0.169 inch.	0.127 inch.
Pan evap.	0.252 inch.	0.178 inch.
Ratio evapotr./pan ev.	0.835	0.895

An increase of radiation by 39% increased evaporation by 42%. But the increase of grass evaporation was only 32%; and the ratio ET/EV decreased from 0.895 with low radiation to 0.835 with high radiation; that shows that evaporation is more affected by radiation than evapotranspiration. Since midday saturation deficit increased in the same time by 22%, 22% of the increase may be attributed to it; so that the influence of radiation alone amounts to 1.32/1.22, that is 8%; grass is a short crop; with a tall crop the difference would be still less, if any.

15.4. Wallen gives for Damascus, Syria, Penman E_T (computed evapotranspiration), measured evaporation, and their ratios. Here are the figures:

Months	J	F	M.	A	M.	J.	J.	A.	S.	O.	N.	D.	An.
E_T/pan ev.	0.64	0.48	0.77	0.64	0.64	0.54	0.50	0.46	0.56	0.56	0.54	0.71	0.55

The ratio decreases from 0.68 in March-May, to 0.55 for Sept.-Nov. It is clear than Penman formula underestimates autumn evapotranspiration, because of the "energetic term."

15.5. Plant growth is usually more intense in spring than in autumn, especially with grass, alfalfa, etc. This difference masks often the fact that Penman formula overestimates spring evapotranspiration and underestimates that of autumn. But other crops, for instance cotton, show well the fact; and pan evaporation also.

15.6. Saturation deficit is better correlated with incoming radiation than with net radiation. That is why the replacement of net radiation by incoming radiation does not reduce the accuracy of the formula. The fact has been observed by many authors. It is illustrated by the following figures from Pruitt (1960); inches:

Months	J	J	A	S	O	N	D
Pan evap	0.37	0.36	0.30	0.26	0.24	0.12	0.06
Penman E_{ll}	0.32	0.31	0.26	0.19	0.17	0.08	0.05
Incoming rad	0.49	0.47	0.42	0.30	0.26	0.19	0.14
E_{ll}/pan evap	0.87	0.86	0.88	0.72	0.69	0.65	0.54
Pan ev/In rad	0.76	0.75	0.71	0.86	0.94	0.64	0.62

Correlation of pan evaporation with incoming radiation is slightly better than with E_{ll}. The inclusion of so many factors (albedo, back radiation, slope of saturation vapour pressure, wind, etc.) has not increased accuracy; incoming radiation gives so good results as the complicated formula.

Grassi (1964) has carried out an extensive study of evapotranspiration on the basis of irrigation in western United States. The influence of incoming radiation and temperature is great But that of the diurnal range of temperature is usually insignificant, or slightly positive. That means that when nights are cold (high outcoming radiation) evapotranspiration is at least as high as when they are warmer; therefore there is no reason to substract back radiation; it is a useless complication.

16 PENMAN METHOD OVERESTIMATES THE INFLUENCE OF WIND. FIGURES GIVEN FOR WINDY DAYS ARE TOO HIGH.

16.1. Because of leaf movement a layer of humid air cannot be formed on leaf surface; a light breeze is sufficient to impede such formation, and more wind cannot do more. Sometimes wind, by cooling leaves reduces transpiration, when radiation is strong. This is illustrated by the experiment of Soriano (see paragraph 4.1), where wind reduced transpiration, instead of increasing it; and it is confirmed by the experiment of Holmes et al. (1960) on soil evaporation (see paragraph 4.2).

16.2. Wind increases evaporation; but its influence on evapotranspiration, even that of a short grass sward, is very little. This fact is illustrated by the work of Pruitt in California (1960 fig. 13). The following figures are illustrative; they have been obtained by comparing subsequent days with high and low wind.

	Windy days	Normal days
Wind (miles day)	409	124
Grass evapotranspiration (inch.)	0.192	0.132
Penman E_{ll} (inches)	0.289	0.124
Penman E_{ll}/grass evapotransp	1.50	1.06
Pan evaporation (inches)	0.488	0.187
Grass evapotr./pan evap.	0.39	0.71

An increase in wind velocity of 230% increased pan evaporation by 161%; but the influence on grass evaporation has been only 45%. Penman formula greatly overestimates grass evapotranspiration in windy days; E_{ll}/grass evapotranspiration ratio increased from 1.06 in normal days to 1.50 in windy days.

16.3. It is to be noted that Grassi (1964) studied the influence of different factors on the evapotranspiration of irrigated crops in western United States; and he did not find correlation with wind velocity.

16.4. Even in the case of evaporation, the relation with wind velocity cannot be linear, as assumed in Penman formula; there should be a wind speed that is sufficient to impede the formation of a humid layer on water surface, and more wind cannot do more.

Moreover leaves produce, approximately, 6 times less vapour per unit time than an equal free water surface; their lenght according to wind direction is considerably smaller; for all these reasons it is much easier for wind to evacuate vapour in the case of leaves than in that of a free water surface; and we cannot admit that the same formula is applicable to evaporation and evapotranspiration.

17. A SIMPLER AND MORE ACCURATE FORMULA.

17.1. When temperature of the evaporating surface is known, evaporation can be computed, with considerable accuracy with Dalton formula, which may be written as follows:

$$E = k_e \, (e_s - e_a) \qquad (11)$$

E is evaporation

e_s is saturation vapour pressure at surface temperature

e_r is vapour pressure in the surrounding the surface air

k is the rate of evaporation per unit area and time per unity of difference $e - e_d$; it includes the effect of wind, which is not linear, and in the case of leaves negligigle.

17.2. As we have said in paragraphs 3.2 and 3.3 leaves move continuously, they may be compared to sling thermometers, and their temperature is approximately equal to that of the air layer, within which they are moving. Because of the uniformizing effect of wind, this temperature is approximately equal to that registered in a nearby standard meteorological shelter. For the same reasons a layer of humid air cannot be formed on leaf surface; and vapour pressure around leaves is approximately equal to that registered in a nearby standard meteorological shelter (see paragraph 5.4). So that $e_r - e_d$ may be replaced by the saturation deficit registered in the meteorological shelter.

To the same conclusion we arrive, on the basis of Penman formula. Given that sensible heat transfer is very easy, while vapour production is slow, k in formula (3) is 20 at least times greater than in the case of evaporation. If we replace γ by a figure 20 times greater, in Penman formula, the "energetic term" becomes negligible (see paragraphs 3.5 and 5.3).

It is true, that when vegetation is tall and dense, the lower leaves, and soil, are subjected to a saturation deficit appreciably lower, than that registered in the meteorological shelter. This is one of the causes, the relation between p. evapotranspiration and leaf area is not linear (see chapter 9). This fact is taken in account, when adjusting water need for leaf area (see chapter 20).

17.3. An argument against the use of saturation deficit is that evapotranspiration increases vapour pressure and reduces saturation deficit. In a humid region, where evapotranspiration is high, saturation deficit is low; and in the desert where evapotranspiration is insignificant, saturation deficit is high.

But such argument is due to a confusion between actual and potential evapotranspiration. Actual evapotranspiration depends usually on available water, i.e. rainfall; and railfall is usually higher where and when saturation deficit is low. But potential evapotranspiration depends on saturation deficit and it is usually high where and when rainfall is low.

Potential evapotranspiration is an index of the amount of water a vegetated area would evapotranspire, were it provided with plenty

of water. But what really this area evapotranspires depends on the amount of water that is available (in general rainfall); and rainfall is usually negatively correlated with saturation deficit.

17.4. Saturation deficit is long ago used; Klesselbach (1916) has shown that transpiration per unit leaf area is a linear function of saturation deficit.

But at the beginning (Meyer 1926, Jenny 1941) annual rainfall was divided by annual saturation deficit. The method was naturally too crude and could not give accurate results; the seasonal distribution of the ratio was not taken in consideration.

Later the method has been refined by Prescott (1948-9) and Papadakis (1948, 1951, 1952). Monthly saturation deficit is multiplied by a constant, that gives monthly water need; and on this basis a water balance is dressed, like that proposed by Thornthwaite.

17.5. Until recently saturation deficit was computed on the basis of mean (average of 24 hours) temperature. This is illogical, since transpiration ceases in night, and the greater part of evapotranspiration takes place in a few hours in midday. However even with this imperfection saturation deficit gives better results than Penman method. For instance (Papadakis 1960) the annual p. evapotranspiration of London is 497 mm (19.6 inch.); that of Sacramento, California 1,300 mm (51.2 inch.); and that of Alice Springs, Australia 2,760 mm (108.5 inch.); such figures fit satisfactorily the facts.

But recently a modification has been introduced in saturation deficit methods. Haude (1954) has proposed to compute saturation deficit on the basis of 14 hour (2 pm) temperature. And Papadakis (1957, 1961) replaced mean temperature by maximum temperature. The formula is:

$$E = 5.625\ (e_{ma} - e_d) \qquad (12)$$

E monthly p. evapotranspiration in millimeters

e_{ma} saturation vapour pressure of average daily maximum temperature of the month considered in millibars

e_d average vapour pressure of the month in millibars.

When vapour pressure is given in millimeters or inches the constant 5.625 becomes 7.5; and E is given in millimeters or inches.

17.6. It is to be noted that Pruitt (1960) has found experimentally in the giant evapotranspirometer of Davis, that 60% of daily evapotranspiration takes place in 6 midday hours (11-16); Omar (1964) in Egypt found that 69% takes place between 10 and 15.

It is interesting that the replacement of mean temperature by maximum temperature has the effect of increasing winter evapotranspiration and decreasing that of summer; it increases the ratio p. evapotranspiration/evaporation when evaporation is low, and reduces it when evaporation is high; so that it fits the relations between p. evapotranspiration and evaporation found independently by Prescott and Grassi (see paragraph 12.2).

We shall add that Emberger (1955) is long ago using the difference between maximum and minimum temperature ($M^{\circ}-m^{\circ}$) as a parameter to tell how much a climate is dry.

17.7. It is to be noted that formula (12) integrates radiation, advection and air dryness. When the average of 10 or more days is considered, dew point is equal, or lower, than minimum temperature; so that $e_{min}-e_d$ is fonction of the diurnal range of temperature; the diurnal range of temperature is produced by radiation, more especially incoming radiation, and may be taken as an index of it.

The index is adjusted for advection, because when a cool wind blows and takes out energy, maximum temperature and e_{max} is reduced; and when a hot wind provides energy maximum temperature rises.

Finally $e_{min}-e_d$ is adjusted also for air dryness, because when the air is dry, dew point is lower than minimum temperature.

17.8. The constant of formula (12) has been determined in the following way. From agricultural and vegetation geography we know that in certain points of the world, rainfall is sufficient to maintain a mesophytic vegetation, crops do not suffer from drought, but there is not an appreciable excess of rainfall. In these points, according to many authors, annual rainfall in millimeters or inches is approximately 240 times the saturation deficit computed on the basis of mean temperature; when mean temperature is replaced by maximum temperature the relation becomes 90 : 1, in order to have, as a general average, the same figures; expressed in millibars this ratio becomes 67.5 : 1; and the corresponding monthly figure is 5.625. Many thousands of checks have shown, that when monthly rainfall is equal to 5.625 times ($e_{min}-e_d$), it is sufficient to ensure maximum crop yields

and a mesophytic vegetation; when such ratio falls below half that amount, and there is not water stored in the soil from previous rains, growth is virtually checked, except when vegetation has a very little leaf area per unit land area and it is highly drought resistant. Moreover the same tests show, that when rainfall in millimeters is greater than 5.625 times $e_{min}-e_d$, there is storage of water in the soil. Naturally such figures are only approximative; we cannot pretend great accuracy in determining such figures, given that evapotranspiration depends on vegetative cover, vegetative cycle, rainfall pattern, etc.

The constant of formula (12) replaces f (u) in the "aerodynamic" term of Penman. Since the influence of wind is negligible if any, we should replace f (u) by a constant, which corresponds to a "normal" wind speed. A speed of 100 miles/day may be considered as "normal." With such a speed Penman f (u) is equal to 0.52. Penman computes saturation deficit on the basis of mean temperature; as we have said, 240 mm of so computed saturation deficit, correspond to 90 mm computed on the basis of maximum temperature; so that 0.52 should be replaced by 0.195; the corresponding monthly figure is 5.85, a figure almost equal to 5.625.

It is interesting that Rohver (1931), cited by Bernard (1956) determined also f (u), in Fort Collins, Colorado, U.S.; for a wind of 100 miles/day its value is 0.51; that corresponds to 5.737, a figure almost equal to 0.5625.

Bernard and Frere (1956), in Yangambi, Congo, determined also f (u); for a wind of 100 miles/day their figure is 0.392; that corresponds to 4.41; this figure differs substancially from 5.625; however the figures of p. evapotranspiration, computed with formula (12) for Congo (Papadakis 1961) are not too high.

In our "Climatic Tables for the World" (Papadakis 1961), we give the p. evapotranspiration, month by month, of 2,400 stations; we have classified on this basis, all these months, into humid, intermediate and dry, and such classification fits well what is known from crop and vegetation geography.

17.9. Another advantage of formula (12) is its simplicity. All synoptical and climatologic stations register maximum temperature and vapour pressure; when vapour pressure is not known, it may be computed on the basis of relative humidity, or minimum temperature; as we have said dew point is always equal, or slightly lower, than minimum temperature and the difference follows a certain pattern; moreover e_{max} is usually so great in comparison to e_d, that a

small error in computing e_d can not affect greatly E. Calculation is very simple; with the aid of a chart (abaque) it may be done in a few seconds.

18. COMPARISON OF FORMULA (12) WITH THAT OF PENMAN, ON THE BASIS OF MEASURED P. EVAPOTRANSPIRATION AND EVAPORATION.

18.1. As we have said in the preceding paragraphs, formula (12), although simpler, integrates better the climatic factors that govern p. evapotranspiration. But theoretical considerations cannot replace experimental tests. We shall compare in this paragraphs the two formulas on the basis of measured p. evapotranspiration or evaporation.

When comparing the formulas we should remember (see paragraph 13.6), that formula (12) gives the water required for 90% of maximum growth, while Penman definition of p. evapotranspiration seems to correspond to maximum possible evapotranspiration; so that Penman formula should always give higher figures.

18.2. Jackson (1960) in Alice Springs, Australia, determined the water consumption of an extensive field of alfalfa. Figures in inches.

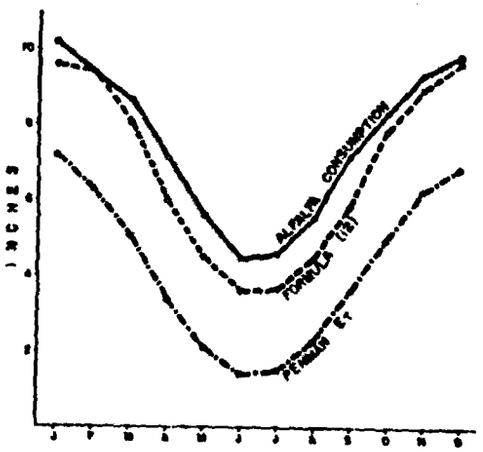

Fig. 2 - Comparison of alfalfa consumption in the field experiment of Jackson (1960) with Penman E_T, and that computed with formula (12).

Months	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	An.
Alfalfa cons.	10.2	9.4	8.7	7.2	5.6	4.5	4.6	5.6	7.2	8.4	9.4	9.9	90.7
Pan evap.	12.3	10.7	10.0	7.2	5.0	3.5	3.6	5.0	7.3	9.6	10.7	12.0	97.1
Penman E_u	8.6	7.6	6.6	4.4	3.0	2.0	2.1	3.2	4.8	6.4	7.6	8.4	64.7
Penman E_T	7.2	6.3	5.1	3.4	2.1	1.4	1.5	2.3	3.7	5.0	6.3	6.9	51.2
Formula (12)	9.6	8.4	8.1	6.0	4.5	3.6	3.7	4.5	5.9	7.9	9.0	9.7	81.9
Thornthwaite	6.9	5.7	4.8	2.7	1.4	0.9	0.7	0.9	2.2	4.1	5.7	6.7	42.6

It is evident that formula (12) approaches better alfalfa consumption and pan evaporation. Moreover Penman formula underestimates winter evaporation; E_u/pan evaporation ratio is only 0.59 in winter.

The figures given by Jackson are not excessive. A similar experiment on extense areas in Yuma, Arizona, United States, by Stranberry et al. (1955) gave the following figures:

Months	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	An.
Alfalfa cons.	1.2	3.0	6.9	10.5	12.3	12.6	12.0	10.5	9.8	8.9	4.2	2.6	91.5
Formula (12)	3.6	4.4	5.6	7.6	9.5	12.7	13.8	12.8	11.3	7.5	4.9	3.7	97.4
Thornthwaite	0.6	1.9	2.2	3.1	5.5	7.4	8.4	7.9	6.4	3.4	1.4	0.6	47.9

Here also the agreement between formula (12) and alfalfa consumption is good. The consumption in Yuma is practically the same as in Alice Springs. In general, in the hot deserts, alfalfa evapotranspirates approximately 100 inches, while Penman E_T is only 50-60 inches.

18.3. Wellen et al. (1962) give pan evaporation and Penman E_T for Damascus, Syria. Figures in millimeters:

Months	J.	F.	M.	A.	M.	J.	J.	A.	S.	O.	N.	D.	An.
Pan evap.	47	68	130	202	260	372	448	426	285	194	102	52	2606
Penman E_T	36	42	90	129	167	200	223	195	159	106	55	37	1433
Formula (12)	34	50	68	113	167	232	266	279	212	146	75	38	1682
Penman E_T/pan ev.	0.84	0.49	0.77	0.64	0.64	0.54	0.50	0.46	0.56	0.56	0.54	0.71	0.55
Formula (12)/pan ev.	0.72	0.67	0.52	0.56	0.64	0.62	0.60	0.62	0.74	0.75	0.73	0.73	0.65

It is evident that formula (12) approaches better measured evaporation. Penman formula greatly underestimates p. evapotranspiration, more especially in August, when maximum temperature is high but radiation not so strong. Penman formula overestimates spring p. evapotranspiration and underestimates that of summer and autumn; with formula (12) the ratio to pan evaporation varies less from season to season.

Wallen gives also Penman E_T for other places of the Near East; the figures (millimeters) are:

Months	J	F	M	A	M	J	J	A	S	O	N	D	An
Irbid (Jordan)													
Penman E_T	40	56	80	111	161	186	198	182	135	108	80	50	1364
Formula (12)	40	48	51	75	120	155	165	175	139	114	60	39	1181
Aleppo (Syria)													
Penman E_T	14	28	65	108	146	204	238	220	158	90	27	14	1312
Formula (12)	28	44	52	93	152	216	250	261	204	153	66	31	1550
Teheran (Persia)													
Penman E_T	20	37	74	111	161	213	230	210	135	96	48	24	1353
Formula (12)	33	42	62	98	163	223	270	266	216	127	64	37	1595
Rutba (Iraq)													
Penman E_T	34	56	93	147	190	222	254	220	171	127	69	36	1719
Formula (12)	51	69	96	142	204	270	326	340	273	192	90	57	2112
Baghdad (Iraq)													
Penman E_T	34	53	105	156	210	264	282	248	186	133	66	37	1774
Formula (12)	57	78	107	161	272	379	436	443	358	242	110	64	2707

At Irbid, where climate is less dry, Penman formula gives slightly higher figures than formula (12). In Aleppo and Teheran, where climate is drier, it happens the contrary; the difference is great in winter, because Penman formula underestimates winter p. evapotranspiration. In Rutba and Baghdad, where climate is desertic, Penman formula gives much lower figures than formula (12). In all cases Penman formula has a tendency to give high figures in spring and too low in autumn.

Concerning Iraq, Boumans (1963) found experimentally, that Penman formula underestimates p. evapotranspiration and evaporation, especially in summer and autumn; it is exactly the months in which Penman E_T is lower than that computed with formula (12); it happens always the same; Penman formula, by overestimating the importance of radiation, underestimates the evapotranspiration of summer and autumn, when the ratio radiation/temperature is lower.

18.4. Houman (1958) gives Penman E_0 for Melbourne, Griffith and Alice Springs (Australia). From Penman E_0 we computed E_T. Figures in inches.

Months	J	F	M	A	M	J	J	A	S	O	N	D	An
Melbourne													
Penman E_T	5.1	4.0	2.9	1.5	0.7	0.4	0.6	1.0	2.0	2.9	3.8	4.6	29.7
Formula (12)	4.2	4.4	3.8	2.6	1.8	1.3	1.4	1.7	2.2	2.8	3.3	3.9	33.4
Pan evapor	6.5	5.1	4.2	2.5	1.6	1.2	1.2	1.6	2.4	3.5	4.6	5.8	40.2

Months	J	F	M	A	M	J	J	A	S	O	N	D	An
Griffith													
Penman E_T	6.8	5.7	4.1	2.3	1.2	0.7	0.9	1.5	2.7	4.2	5.7	6.9	42.7
Formula (12)	7.2	7.0	5.6	3.5	2.5	1.7	1.6	2.0	3.0	4.0	5.4	6.4	49.9
Pan evapor.	10.5	7.4	6.4	4.1	2.5	1.8	1.8	2.5	4.0	5.6	7.2	10.0	63.8
Alice Springs													
Penman E_T	7.2	6.3	5.1	3.4	2.1	1.4	1.5	2.8	3.7	5.0	6.3	6.9	51.2
Formula (12)	9.6	9.4	8.1	6.0	4.5	3.6	3.7	4.5	5.9	7.9	9.0	9.7	81.9
Pan evapor.	12.3	10.7	10.0	7.2	5.0	3.5	3.8	5.0	7.3	9.6	10.7	12.0	97.1

In all cases formula (12) is in better agreement with evaporation. Evapotranspiration/evaporation ratio, according to formula (12), is 0.83 in Melbourne, 0.78 in Griffith, and 0.84 in Alice Springs. On the contrary, with Penman formula such ratios are too low and decrease as climate becomes drier; the figures are 0.71, 0.67 and 0.53 respectively. This is because Penman formula underestimates evaporation of these dry places. In all cases winter evaporation and evapotranspiration is underestimated by Penman formula (see figures of June-August).

18.5. For London Penman (1954) gives the following figures — in all cases those of formula (12) have been computed by us. We add rainfall. Figures in inches.

Months	A.	M	J.	J.	A.	S.	Sum.
Penman E_T	2.6	3.4	4.0	3.9	3.4	1.7	18.4
Formula (12)	1.6	2.1	2.8	3.1	3.0	2.2	14.8
Rainfall	1.8	1.8	1.6	2.0	2.2	1.8	11.2

Penman figures are 24% higher than those obtained by formula (12). The difference is due to a difference in the concept of p. evapotranspiration. For Penman E_T seems to be the maximum evapotranspiration that can be obtained, by giving more and more water; for us it is the amount that is sufficient to obtain 90% of maximum growth.

It is to be noted that Penman questions "are any of these values too big?," and recommends to give 3 inches less water (rainfall + irrigation); 3 inches is approximately the difference between 18.4 and 14.8. Penman says that these 3 inches may be taken from soil reserves; but I doubt if, when irrigations are given as scheduled, soil is drier at the end of September than at the end of March.

Abundant evidence shows that crops do not require 18.4 inches in summer to give 90% of maximum growth. Normal April-September rainfall is 11.2 inches; and in spite of that non-irrigated potato, beet, clovers, grass, all summer crops little resistant to drought, give very high yields almost the highest in the world.

Naturally 50% of the years rainfall is lower than normal and crops suffer from drought; moreover many soils have not sufficient water holding capacity to provide the difference of 3.6 inches (14.8-11.2) from their reserves, without causing drought stress; finally in some years total summer rainfall may be normal, but it is badly distributed. For all these reason many years, 5-6 in ten, are rather dry in London, and some irrigation is welcome. But to say, that irrigation is needed more than 9 years in ten, is an exaggeration.

If the water needed to obtain 90% of maximum growth from April to September in London were 18.4 inches, July and August would be so dry, 5 years in ten, that growth would stop, potato and beet would be a failure, and clover and grass would dry out.

It is to be noted, that according to Kendrew (1961) April-September evaporation in Camden Square, London, amounts to 13.5 inches. This figure is slightly lower than the 14.8 cumputed by formula (12); and p. evapotranspiration is usually lower than evaporation. So that I dont think formula (12) underestimates London p. evapotranspiration. It is rather Penman formula that overestimates it. But it may be a difference of concept.

18.6. The figures given in the preceding paragraphs show that Penman formula in humid climates as that of London give the maximum possible evapotranspiration, which is considerably higher than the water needed by crops and vegetation, and the parameter wanted to tell how much is humid or dry a climate or season. In dry climates the same formula gives much less than the fore-mentioned need. So that the figures given are not comparable and cannot be used in climatology, or to schedule irrigation. On the contrary formula (12) gives comparable results, which represent water need of crops and irrigation.

Moreover Penman formula underestimates winter and autumn p. evapotranspiration, and overestimates that of non-dry springs. Formula (12) has not such defects.

18.7. From the figures given in this chapter and in paragraphs 14.2 and 14.4 it is evident, that Penman formula gives unsatisfactory results, even in the case of evaporation from a free water surface.

It seems that even in this case, heat transfer is easier than assumed by Bowen formula; the bottleneck of evaporation is more in water vaporization, and less in the elimination by turbulence of the vapour produced. As a consequence the influence of radiation and of wind is not so great.

It may be that Bowen formula is an acceptable approximation, on an hourly basis; but it becomes wrong, when the hourly values are replaced, by one computed on the basis of mean temperature; the variation of $T_s - T_a$ and $e_s - e_d$ during the 24 hours are too great to permit such a simplification.

18.8. Moreover we should remember that the equations, on which Penman formula is based are mere approximations. That is why it is dangerous to combine, solve them, and prepare in this way new equations. Even if Bowen formula were satisfactory, the results might be disappointing. We shall give an example.

In soil science the sum of absorbed cations, including H, is equal to cation absorbing capacity. We could then determine Ca, Mg, K and cation exchange capacity, and by difference obtain Na. But the methods of analysis, more especially that of cation exchange capacity, are only approximative — although more accurate than Bowen formula —. If we do so we may obtain negative values of Na, which is a non-sense, even in a natric soil; and high values in a soil containing negligible amounts of absorbed Na.

Approximate equations may be used, with caution, to have a picture of the problem for which they have been devised. But it is dangerous to combine, solve them, and produce new formulas. The most we can obtain in this way is suggestions. In any case such formulas cannot be considered as valid a priori. They need to be tested.

19. USE OF POTENTIAL EVAPOTRANSPIRATION IN CLIMATOLOGY.

19.1. Potential evapotranspiration has been introduced in science by Thornthwaite as a parameter to compare with rainfall and tell how humid or dry a climate, a season, or a period is. .

When studying climates it is essential to dress a water balance, which shows the annual march of water availability. Potential evapotranspiration permits to dress such a balance, according to the scheme given by Thornthwaite (1948). For climatic studies it is satisfactory to assume, that the water that may be stored in the soil is 100 mm. Naturally that does not mean that when this water is exhausted plants die; many plants have the capacity to reduce their transpiration, and their growth, as soil becomes drier, and there is always some available water for them in the soil; leaf area is in these cases small and soil area per unit leaf area very great.

19.2. In climatic studies it is essential to determine the humid and dry seasons. But the criteria used are often arbitrary. Potential evapotranspiration permits to do that more accurately. Months in which rainfall exceeds p. evapotranspiration are considered humid; and those in which rainfall plus the water stored in the soil from previous rains covers less than half of p. evapotranspiration dry; the remainder are intermediate (Papadakis 1952). Seasons may be presented by a formula for instance 7-9/11-5; that means that the humid season begins with July and terminates with September, both July and September being included; the dry season begins with November and terminates with May, both November and May being included; October and June are intermediate.

19.3. The difference rainfall minus p. evapotranspiration during the humid season is also an important climatic parameter; it is termed Ln (leaching rainfall, Papadakis 1952). The higher is Ln the more reliable is the humid season. It is also very useful in vegetation geography, pedology and hydrology.

19.4. The difference p. evapotranspiration minus rainfall during the non-humid season is also an important climatic parameter, termed S (drought stress, Papadakis 1963).

When the humid or dry season are split into two or more parts, Ln and S are computed on the basis of the continuous series of months, that gives the higher algebraic sum.

19.5. It is evident that a method that gives good results under humid conditions, but fails under dry ones, cannot be used in climatology, because it does not permit comparisons; for the same reasons methods that include coefficients, which vary from case to case and are fixed more or less arbitrarily, are inconvenient. Universality is an essential characteristic of whatever method of computing p. evapotranspiration to be used in climatology.

The constant 5.625 of formula (12) does not vary from month to month or from climate to climate, the method is equally adapted to all climates, and these are great advantages.

20. USE OF POTENTIAL EVAPOTRANSPIRATION IN IRRIGATION.

20.1. For irrigation purposes the figures given by formula (12) should be considered as integrating only the climatic factors. They need to be adjusted for differences in kind of crop, leaf area, growth rhythm, and watering pattern.

20.2. The majority of crops give their higher yields, with an amount of rainfall equal to p. evapotranspiration computed with formula (12), and more water does not increase appreciably yields. But in forage crops, more water increases yield, although, usually, such increase is neither economical, nor practical (too frequent irrigations). Some vegetables give their best quality and quantity, when grown in a humid atmosphere and frequent sprinkling is useful; that increases considerably water consumption. Rice is grown in flooded land and its consumption exceeds that computed by formula (12).

On the other hand many crops do not fructify well, when shaded Leaf area is maintained small; and their evapotranspiration is therefore low.

Grassi (1964) gives the following crop factors:

Annual crops		Orchard crops	
Alfalfa	1.088	Apples + cover crop	1.268
Beans	0.963	Dates + cover crop	1.068
Corn	1.003	Dates + grapefruit	0.987
Cotton	1.082	Grapes	0.608
Oats	0.890	Grapefruit	0.620
Potatoes	1.017	Lemon	0.521
Sorghum grain	1.162	Oranges	0.513
Sugar beets	1.004		
Winter wheat	1.100		

The small factor of some of these crops is due to the fact that plants are distanciated. We shall add, that in some crops, for instance alfalfa, sorghum grain, cotton, we may give less water; yield is lower but the crop is not a failure. While in others, for instance potatoes, sugar beet, corn, a reduction of water during the critical period, which coincides with that of maximum need, may conduce to a failure. Grapes can be grown with less water, giving lower yields; but in the case of citrus the amount corresponding to the factor should be given. Although these factors have been prepared for other formula, they may be used as coefficients by which the figures given by formula (12) are to be multiplied.

20.3. Concerning crop cover Grassi (1964) gives the following values:

Cover	% value	Cover	value
0 %	0.113	60 %	0.767
10 %	0.247	70 %	0.840
20 %	0.371	80 %	0.904
30 %	0.485	90 %	0.957
40 %	0.589	100 %	1.000
50 %	0.683		

20.4. In an annual crop leaf area is very small at the beginning; then increases gradually; at the end of the vegetative cycle, leaf area may be great, but leaves do not transpire actively. Therefore evapotranspiration is low at the beginning, then increases, reaches a maximum, and decreases again before harvest. This fact has been observed by many authors. Grassi (1964) gives the following values. The time from sowing to ripening is taken as equal to 100.

Vegetative cycle	value	Vegetative cycle	value
0	0 090	60	0 991
10	0 343	70	0 998
20	0 555	80	0 963
30	0 726	90	0 887
40	0 855	100	0 770
50	0 944		

20.5 Water need depends also on frequency and method of irrigation. When waterings are frequent, and soil is maintained constantly humid, soil evaporation is higher than in the opposite case. On the contrary when waterings are distanciated soil pF increases, plants close their stomata during certain hours in midday and transpiration is reduced.

When furrow irrigation is used, soil between rows is not moistened and soil evaporation is reduced. The reduction is still greater with subirrigation.

In desertic climates, soil dries very rapidly after irrigation and that reduces soil evaporation. Moreover waterings are never as frequent as they should be, crops suffer a certain drought stress, more or less intense, and that reduces considerably water consumption; but for the same reason crops very sensitive to drought are difficult to grow, even with irrigation.

20.6 The fore-mentioned agronomic factors and considerations are to be used cautiously. For instance the low water need of young crops is due to their small leaf area; we cannot apply in the same case a reduction for crop cover and another for vegetative cycle. The low crop factor of some crops is due to their small leaf area. Sometimes at sowing soil should be maintained moist to facilitate germination, and that results in considerable soil evaporation; in a humid climate, even with distanciated waterings, soil is continuously moist and evaporates actively.

21. EVAPORIMETERS. THE "STOMATIC" EVAPORIMETER.

21.1. The usual concept of evaporimeters is that they should permit to compute evaporation of a big water surface, a lake for instance. And given that they are small, and the elimination of water vapour from their surface is easier, a more or less arbitrary coefficient is applied.

But the difference between a lake and a small evaporimeter is not only that. Lake evaporation depends greatly on water depth and topographic situation. The greater is its depth, the lower is its surface temperature in midday, and the lower is its evaporation in 24 hours. Although a deep lake is warmer in night, night evaporation is not important, and cannot compensate the lower day evaporation. Topographic situation is very important, because it affects local atmospheric circulation. Moreover there is a lag of lake evaporation on that of evaporimeters. For all these reasons it is not justified to calibrate the evaporimeters, on the basis of lake evaporation.

21.2. When an evaporimeter is placed at ground level, it is encountered in the "poorly ventilated" layer, and its evaporation depends on local conditions; it is little representative, and figures vary considerably from one to another. It may be preferable to place its surface at a level exceeding 60 cm, and in a non-sheltered point.

But in this way the evaporimeter is exposed to lateral radiation; and to avoid that, walls and bottom should be white and made of a thermically isolating material. Water depth should be also small. An evaporimeter of this type is very sensitive to radiation and little to wind.

21.3. Piche evaporimeters, placed within a standard meteorological shelter are not affected by radiation and wind, and are useful to compute p. evapotranspiration (Bouchet 1964, Reiss 1964). Their defect is that the evaporating surface is cooled by evaporation.

An evaporimeter that has not such defect is the "stomatic evaporimeter." It consists of a metallic box, a few centimeters in diameter, with a perforated cover (see Fig. 3); the openings one millimeter in diameter are distanciated, their total surface being only 4% of the total area of the evaporimeter. Within the box we place blotting paper or other absorbing material glued to the bottom; it is more convenient that water; the distance from blotting paper to the cover is only 1 or a few millimeters; the evaporimeter is hanging from the side, or resting or long legs, so that air circulates easily on its surface and bottom. Because of that, the high thermi-

cal conductivity of its bottom and the high ratio bottom/total surface of the openings, water temperature is practically equal to that of the air, a layer of humid air is not formed on its surface, and *evaporation does not depend on radiation or wind.*

The evaporimeter is placed in the meteorological shelter. It may be used outside, to study evaporation at different levels within crops, etc.; in this case it is hanging from the side, in order to reduce the radiation received, and facilitate its movement by wind; it imitates leaf movement. *Naturally the blotting paper should be*

Fig. 3 - "Stomatic" evaporimeter. PERF. COV., perforated cover; BL. P., blotting paper or other absorbing material glued to the bottom; CH., chain to hang the apparatus. The box is metallic, conducting well heat and reflecting radiation. When the apparatus is used in open air, rain entrance should be avoided by making the openings smaller, and covering the cover with a water repellent cloth. The evaporimeter is calibrated by placing it in a practically dark wide chamber, at 25°C and 17mb vapour pressure; to such conditions corresponds a daily evaporation of 8.25mm; if chamber temperature and vapour pressure differ a little from these figures, we add half millimeter for each millibar of saturation deficit; temperature and vapour pressure should be maintained as constant as possible; during calibration a gentle ventilation is necessary, to avoid cooling.

maintained continuously well impregnated with water. A surface with great albedo is an advantage.

The "stomatic" evaporimeter is weighted; as it is small, a precision balance is required, if observations are to be done frequently. *Combined with a registering balance it permits to register evaporation.*

The "stomatic" evaporimeter is very useful in climatology, microclimatology, and irrigation; in the last case observations may be done at long intervals, and the balance may be less precise.

22. A CURIOUS FACT. FURTHER RESEARCH.

22.1. Dalton formula is very old. Saturation deficit has long ago been used by Meyer (1926), Jenny (1941), Prescott (1948-9), Papadakis (1948) with satisfactory results.

However Thornthwaite proposed, in 1948, a method based on temperature and day lenght, and ignoring air humidity. It was evident, *a priori*, that such a method cannot work; air humidity is very important; day lenght does not affect appreciably evapotranspiration. It was easy to see that with this method, dry climates as that of Rio Cuarto, Argentina, appear as having a better water balance than more humid climates, as that of Paris, France (Papadakis 1962). However this method has been adopted by many scientists, who found it satisfactory.

It is true that irrigation men in Western United States never used it, and prefered that of Blaney Criddle, which as a local method, works satisfactorily. It is also true that Thornthwaite climatic classification had not a great acceptance among geographers, who continued to use, or returned rapidly, to Koeppen classification. But Thornthwaite method has been in vogue during many years, and it is only recently that is has been abandoned.

22.2. In the meantime appeared Penman method, which gives better results, because radiation is highly correlated with saturation deficit; moreover saturation deficit enters in the "aerodynamic term."

It was known a priori, that wind *uniformizes midday temperature* and vapour pressure over distances of a hundred of kilometers, taking heat from dry areas and transporting it to those "not short of water"; consequently we cannot estimate the energy balance of a finite never short of water area, as if it were separated from the rest of the earth. A simple test would show, that the figures Penman method gives for the desert are far below pan evaporation, irrigation needs, etc. However this method has been widely adopted. It is only now that some meteorologists become aware of its defects.

It is true that very few irrigation men use it; and it is practically *unknown among geographers.*

22.3. What is the cause of these curious facts? Meteorology is the science of the atmosphere. But until recently meteorologists had not the possibility to study it, except near soil surface. Recent technic progress permitted them to study the atmosphere at considerable distances from soil surface. They rushed in this study, and the achievements have been marvellous.

But because of this rush, many meteorologists have forgotten, that meteorology is a science of the earth, a geographic science;

and climatology has been abandoned. Many meteorologists doubt now if climatology is a science; they confound it with climatography a mere description of climate. A proof of this abandonment is that after Koeppen, any progress in climatology has been done by vegetationists, agronomists, etc.; the contribution of meteorologists to climatic classification is very little.

Having abandoned climatology, meteorologists could not test Thornthwaite and Penman formulas.

22.4. Another reason is the great scientific prestige of Thornthwaite and Penman. The contribution of these two scientists to meteorology in general, and agricultural meteorology in particular, is outstanding. We owe them many of the most important recent achievements.

Unfortunately many scientists adopt a method, not because they have examined it thoroughly and have been convinced; but because of the prestige of the scientist, who proposes it. And this is what happened.

22.5. Some scientists are so convinced by Penman formula, that when all the evaporimeters, irrigation experiments, etc. of a vast continent, give results which show clearly, that the formula does not work, they conclude that it is the evaporimeters, experiments, etc., that are wrong; and they often recommend, to stop any direct measurement of evaporation and evapotranspiration, and use the money in radiation studies.

In my opinion the experimental study of evaporation and evapotranspiration should be intensified. We need numerous observations on leaf temperature, without interfering with their movement, and registering in the same time wind velocity and air temperature in a nearby standard meteorological shelter; we need numerous observations concerning air temperatures at different levels within crops, and vegetation types; we need numerous observations on evaporation at different levels within crops and vegetation types, using for instance the "stomatic" evaporimeter we are proposing. Moreover evaporimeters and evapotranspirometers should be used in all meteorologic stations; irrigation experiments should be multiplied; and last but most important, actual evapotranspiration should be registered, in various vegetation types and crops, under various cropping methods, using apparatus registering soil moisture as those of Bouyoucos (1961). Theory is necessary; science is theory; but theories should be tested.

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E. Taylor

IMPACT OF TIME AND CLIMATE ON QUATERNARY SOILS IN THE YUCCA MOUNTAIN AREA OF THE NEVADA TEST SITE

by

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To the GRADUATE SCHOOL OF THE UNIVERSITY OF COLORADO:

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The final copy of this thesis has been examined by the undersigned, and we find that both the content and the form meet acceptable presentation standards of scholarly work in the above discipline.

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May 28 1986

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Impact of time and climate on Quaternary soils in the Yucca Mountain area of the Nevada Test Site

Thesis directed by Professor Peter W. Birkeland

The influences of time and climate were studied on a Quaternary chronosequence in the Yucca Mountain area of the Nevada Test Site. The soils are formed in alluvium derived from ash-flow tuffs and eolian dust. Both secondary $CaCO_3$ and opaline SiO_2 appear initially as coatings on the underside of clasts and over time form indurated horizons. The maximum amounts of $CaCO_3$, opaline SiO_2, and usually clay occur in the same horizon. In these horizons, opaline SiO_2 is more abundant than $CaCO_3$ and clay. There is little change in the soil-clay mineralogy over time. Vesicular A (Av) horizons have not formed on Holocene deposits, but are common on Pleistocene deposits.

Regression statistics suggest that quantified field properties and secondary clay, silt, $CaCO_3$, and opaline SiO_2 accumulate at a logarithmic rate. However, owing to the effects of erosion, and eolian additions, these secondary properties may be better expressed by linear rates. It is likely that erosion results in long-term accumulation rates less than the measured accumulation rates. Average accumulation rates are higher for the Holocene soils. This relationship suggests that the translocation of eolian material was not limited by Holocene precipitation.

The modern climate and two climatic models of the last glacial maximum were used to generate soil water balances and to calculate evapotranspiration. These calculations suggest that translocation of dissolved and solid material in Holocene soils can be attributed chiefly to high-precipitation storm events.

There are several different trends in $CaCO_3$ accumulation in the Holocene soils, and in older soils that have experienced at least one major climatic change. These trends suggest that changes in temperature and (or) seasonality of the precipitation dominated the climatic change associated with the Holocene-Pleistocene boundary. Comparison of actual Holocene soil $CaCO_3$ profiles with those generated by a computer suggest that this climatic change was gradual.

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CHAPTER I

INTRODUCTION AND METHOD OF STUDY

Introduction

Statement of Problem

A high-level nuclear waste site has been proposed for Yucca Mountain on the Nevada Test Site (NTS) (Fig. 1). This waste is the by-product of commercial enterprises and nuclear weapons production. Estimates vary from 1,000 to 100,000 yrs for the duration that this material remains hazardous (Winograd, 1981). To assure prolonged integrity of any nuclear-waste repository, long-term environmental stability of that site needs to be considered, as well as the impact of future climatic change.

This study addresses the problem of characterizing past climatic variability near the proposed nuclear-waste repository site at Yucca Mountain. Climatic changes are considered to be caused by variation in net global solar-energy input, a consequence of the precession of Earth's orbit and the obliquity and eccentricity of its axial position (Imbrie and Imbrie, 1980). Major global climatic change occurs at regular frequencies of 10,000 to 100,000 yrs (Shackleton and Opdyke, 1973). The Holocene Epoch is the most recent in a long series of relatively brief (7,000-20,000 yrs) interglacials, that punctuate much longer (90,000-150,000 yrs)

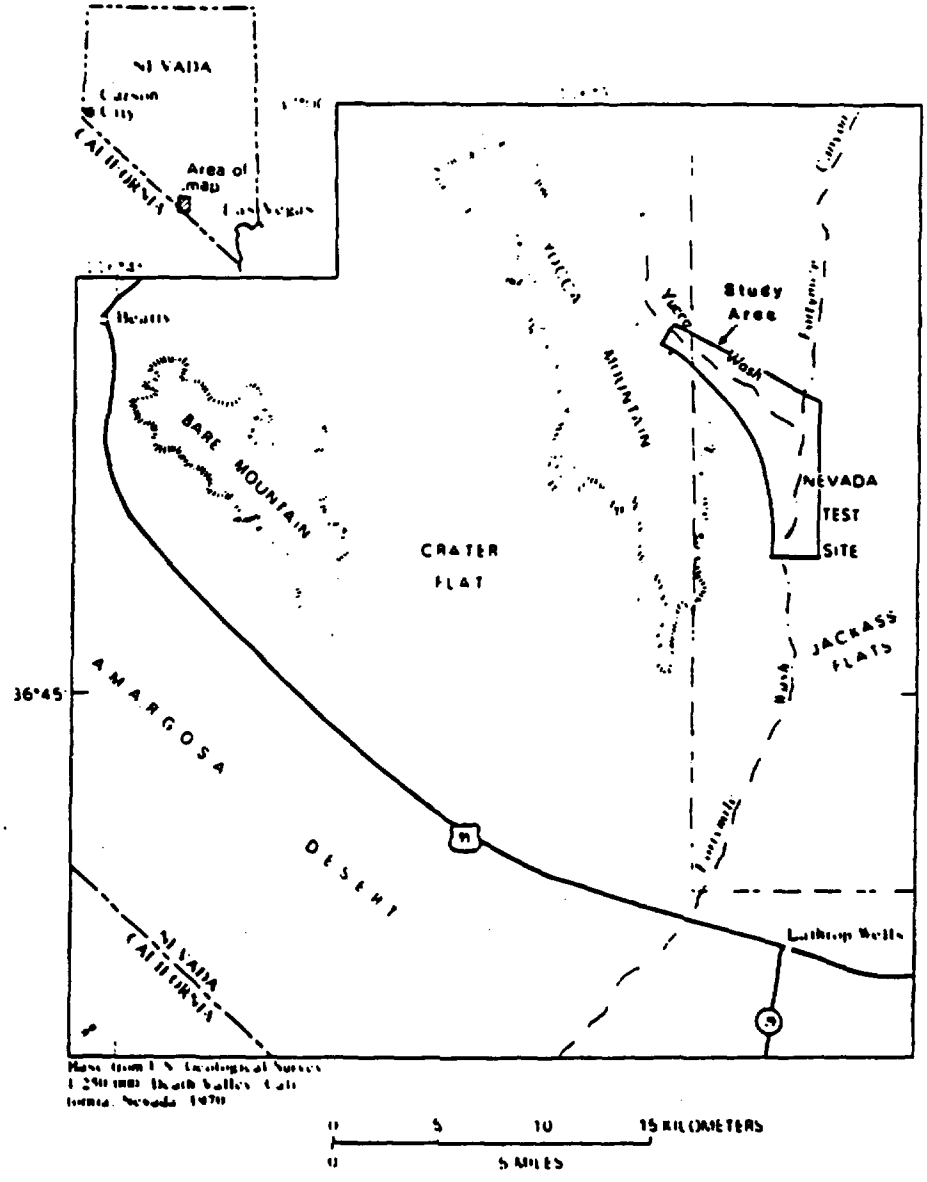


Figure 1. Location of study area.

periods of glaciations. A permanent repository for nuclear waste must be able to withstand the effects of a major climatic change. A climatic change that results in greater effective moisture may cause percolating water to move within the zone of waste material during the time that the material is still hazardous.

Objectives

The objectives of this study are twofold, (1) to document the effects of time and climate on soil developement, and (2) to use soil data to characterize long-term, past climatic variability in the study area. Paleoclimatic reconstructions span the last 2 Ma, emphasizing the last 45,000 yrs because the age control and botanical evidence is best understood during this time. This study is part of a larger study of the paleoclimate of the NTS area. For example, other workers are studying past ground water levels and rates of recharge (Winograd, 1981; Winograd and Doty, 1980), regional lake and playa chronologies (L. V. Benson, U.S. Geological Survey, oral communication, 1985), and radiocarbon-dated plant macro and microfossils from ancient packrat middens (Spaulding, 1983, R. S. Thompson, U.S. Geological Survey, oral communication). One of the assumptions common to all these studies is that past climates approximate the climates that may occur in the next 100,000 yrs.

Strategy

Soil-geomorphic research can provide data useful for interpreting relative and absolute dating of alluvial deposits, stratigraphic correlation, and paleoclimate. To apply pedologic data to this goal, I use the state-factor approach developed by Jenny (1941, 1980) which defines the independent factors of soil formation as climate, biota, parent material, relief, and time. To understand the impact of a single factor on the development of soils, all other factors must either be held constant, or any variation in one of the factors must have little impact on the single factor that is being studied. The assumption then is made that soil development is chiefly dependent on the single varying factor. In this study two factors have varied--climate and time. When all factors are held constant except time, the soil sequence is defined as a chronosequence. When all factors are held constant except climate, the soil sequence is defined as a climosequence. The study area is particularly suitable for soil-paleoclimatic interpretations because the factors can be identified, key ones can be considered constant, and all pedogenic processes occur well above the present or former ground water table.

Five groups of different aged geomorphic deposits were studied along an elevation transect of 400 m of relief, from 1082 to 1483 m (Fig. 2). Present-day annual precipitation nearly doubles along the transect. For any group of deposits of the same approximate age, one can observe or predict the depth relationships of most soil properties. Soil properties that are much deeper than anticipated suggest climatic change. These properties can be

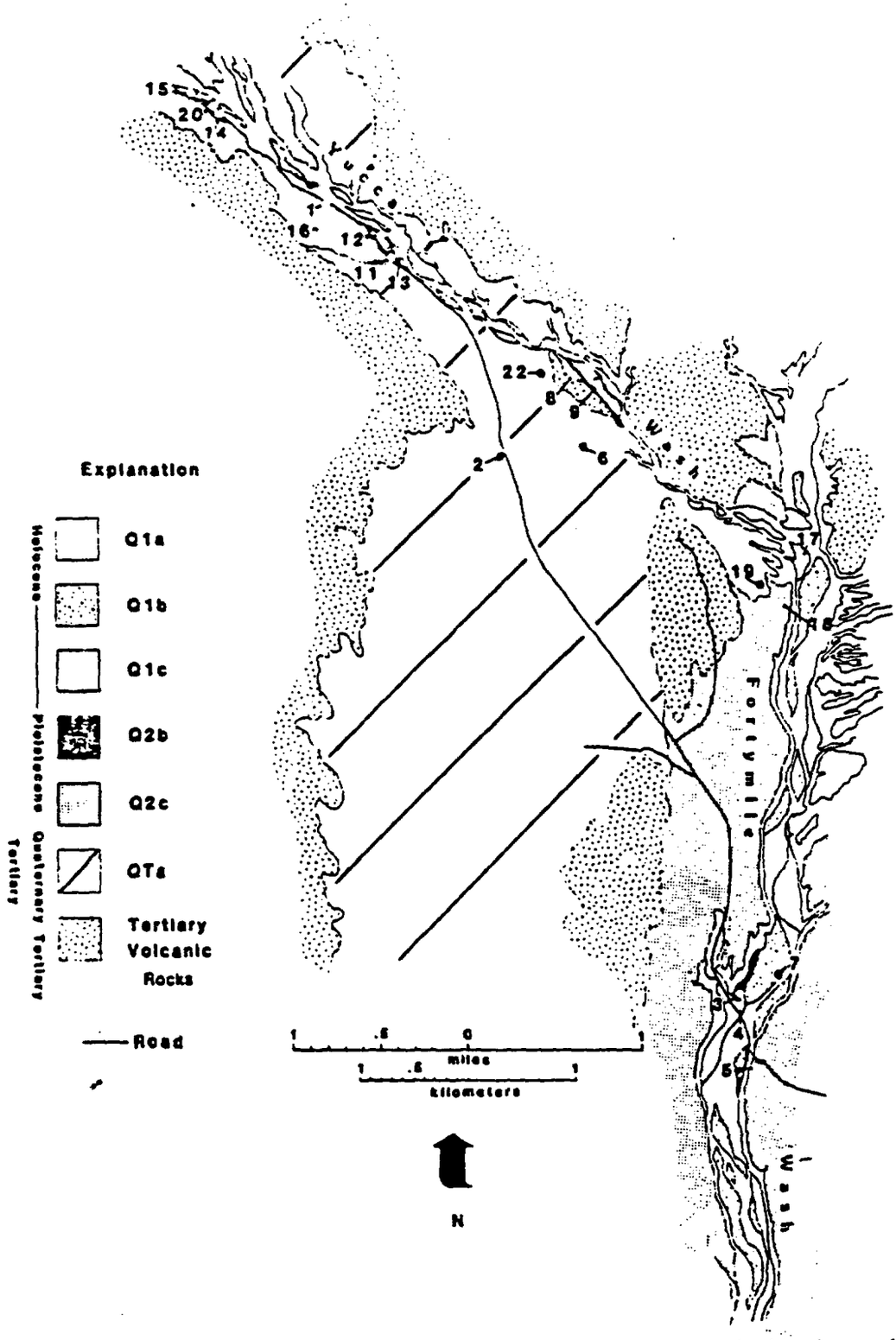


Figure 2. Map of Quaternary deposits, Tertiary bedrock, and trench locations in the study area.

compared to possible climate-models for the glacial maximums. The primary evidence and discussion for the effects of climatic change and time on soil development are based on physical and chemical soil properties.

Location of Study Area

The study area is along Yucca Wash and Fortymile Wash on the east side of Yucca Mountain near the southwest corner of NTS (Fig. 1). This area is in the Basin and Range Province of western North America (Fenneman, 1931), on the southeastern margin of the Great Basin (Morrison, 1965). With respect to the flora, the site is located on the boundary of the Mojave Desert to the south and the Great Basin Desert to the north (Cronquist and others, 1972).

The Quaternary deposits at the upper end of the elevation transect are along Yucca Wash (YW) just northeast of Yucca Mountain. The transect follows Yucca Wash southeastward to its confluence with Fortymile Wash (FW), and proceeds due south to the road crossing across Fortymile Wash. The total transect distance is just over 13 km.

Methods of Field Work and Soil Description

Locating Study Area

The selection of the study area was accomplished with the use of air photos and preliminary surficial geologic maps by D. L. Hoover (U.S. Geological Survey, written communication, 1983). The primary study site was then selected and mapped. Stratigraphic units are defined on the basis of landscape position, surface

morphology, degree of packing and sorting of desert pavement, desert varnish, and soil-profile development.

Description and Sampling

Twenty trenches were excavated by backhoe through the soil into unconsolidated soil parent material (Appendix A). Trenches were located on stable parts of terrace or fan surfaces, with the stability measured by the integrity of the pavement and the preservation of the B horizon.

Soil profiles were described according to methods and terminology outlined by the Soil Survey Staff (1951) and Birkeland (1984). I use the horizon descriptor Cuk for horizons that have all the characteristics of unconsolidated parent material with the exception of translocated $CaCO_3$. Soil texture is from laboratory particle-size data after the carbonate and silica cement were removed. Calcic horizon terminology is after Gile and others (1979 and 1981; Bachman and Machette, 1977; Machette, 1985). Greater than 0.20 percent carbonate in the <2 mm fraction is detectable in the field by 10% HCl.

Two to three kg bulk samples, and three to eight peds were collected for each horizon. Bulk samples were sieved and the gravel percent determined on a weight basis in the laboratory.

Pedogenic Silica

Silica-cemented horizons or duripans were identified in the field by first soaking air-dried samples in water, followed by soaking in 10% HCl overnight. Cementation and brittleness are preserved when the predominant cementing agent is silica. Duripans

in the study area also have a characteristic pinkish-yellow color, 7.5YR 7/4-6 (dry) and 7.5YR 5-6/6 (moist) Munsell colors, and are extremely hard when dry.

Because of the presence of silica, allophane was suspected. Allophane is a noncrystalline-clay weathering product of volcanic glass and associated with duripan formation. A field test (Fieldes and Perrott, 1966) that determines the presence of amorphous allophane by measuring the change in pH with the addition of NaF, was unsuccessful. A simple, laboratory method, independent of pH (Wada and Kakuto, 1985) was not much more successful. Thirty to 50 mg of air-dried soil (<2mm) is placed on a white spot plate, and 0.4 ml of 0.02% toluidine blue solution is added. If the color of the supernatant remains blue after 15 seconds, it suggests the presence of allophane and imogolite. A larger sample, 50-100 mg, is used for coarse-textured soil. The samples frequently remained blue in horizons that contained opaline SiO_2 cement as well as the eolian vesicular A horizons.

Index of Soil Development

Soil field properties were quantified according to Harden (1982), and Harden and Taylor (1983) (Appendix B). The soil development indices were programmed and calculated with the "LOTUS 1-2-3" spreadsheet on an IBM-PC computer (Nelson and Taylor, 1985a and 1985b).

Micromorphology

Oriented samples of soil peds and gravel were collected. Samples were stained with blue epoxy so that amorphous material could be more easily recognized. Thin sections were cut perpendicular to the soil surface.

Statistical Methods

Statistical techniques used in this study include (1) descriptive statistics that characterize the sample population, (2) bivariate regression and correlation (r^2) analysis of individual properties with time or climate as the dependent variable, and (3) multiple and stepwise regression analyses to test possible predictive models of groups of soil properties with a single soil property as the dependent variable (Till, 1974; Davis, 1983).

The null hypothesis (H_o) for regression analysis is to test whether there is a significant relationship between time or climate, and the independent soil properties. H_o = no association. When $F_{calculated} > F_{critical}$ or $t_{calculated} > t_{critical}$, at the 5% significance level, H_o is rejected and the conclusion is made that there is a significant relationship. Significance is the level of probability that the described relationship between properties could occur randomly. Thus at 5% there is a 1:20 chance that the relationship is random. The standard error is a measure of the accuracy of prediction. It is an estimate of the standard error of the residuals, or the estimate of the standard error between measured and predicted values of the dependent variable about the

due to sampling variability in the slope of the regression, is used to generate the 95% confidence intervals. Residual analysis was used to check multiple regression assumptions. All statistics were done on an IBM-PC computer with the "STATPRO" statistical package.

CHAPTER II

ENVIRONMENTAL SETTING, PAST AND PRESENT

Geologic Setting and Chronology

Yucca Wash originates in an area composed exclusively of Tertiary volcanic rocks (Christiansen and Lipman, 1965; Lipman and McKay, 1965). The alluvium in Yucca Wash is derived from these welded and nonwelded ash-flow tuffs. The alluvium in Fortymile Wash is also derived from similar siliceous volcanic rocks with a small component of basalt. Carbonate and opaline SiO_2-rich eolian dust have been added to these alluvial deposits over time.

Quaternary Stratigraphy

The Quaternary stratigraphic nomenclature used on NTS (Table 1) was modified from that initially described by Bull (1974; Ku and others, 1979; McFadden, 1982) in the Vidal Junction area, California, about 320 km south of NTS. Deposits at Vidal Junction were differentiated mainly on the basis of soil properties. However, the identification of units at NTS is based primarily on geomorphic features, and to a lesser extent on soil properties (Hoover and others, 1981; Swadley, 1983). The main features include preservation of bar-and-swale topography, elevation above modern washes, packing and sorting of desert pavement, desert varnish, and the presence or absence, and thickness of the vesicular A horizon.

Table 1. Quaternary stratigraphy of the Yucca Mountain area, NTS. Modified from Hoover and others (1981; Szabo and others, 1981; and Swadley and Hoover, 1983); soil properties are those of this study. Textures are for the <2 mm fraction and pertain to all soil horizons. Pleistocene deposits have age estimates based on U-Trend dating. Some of the age estimates may be minimum ages. See Appendix G for information on the origin of assigned ages. Units can be combined (e.g. Qla/Qlb) in areas where they cannot be differentiated at a given map scale and (or) where a unit is mantled by a thin, patchy unit.

Stratigraphic Units: Unit Designation	Estimated Age	Key Properties and Diagnostic Criteria for Recognition
Latest Holocene		
Qla	historic	Fluvial gravel and finer grained over bank deposits on and adjacent to the floors of active washes. No pedogenic alteration. Typically <2 m thick.
Late Holocene		
Qlb	<140 yrs < 3ka	Fluvial gravel, sheetwash, or debris flows on steep slopes. Fluvial deposits form a terrace 0.5-2 m above active channels; bar-and-swale topography preserved. Thought to date from major episode of arroyo incision considered to have taken place 140 yrs ago (Bryan, 1925). No desert pavement has developed. Soils have a thin A; Cox, Cuk and (or) Cu; stage I $CaCO_3$ (commonly contains reworked gravel with stage II $CaCO_3$ coats); texture S, LS or SL. Usually <2 m thick.
Qle		Eolian sand in active modern dunes in areas away from mountain fronts. No pedogenic alteration; texture S or LS. Locally as much as 50 m thick; typically <10 m thick.

Table 1 continued. Quaternary stratigraphy of the Yucca Mountain Area, NTS.

Stratigraphic Units: Unit Designation	Estimated Age	Key Properties and Diagnostic Criteria for Recognition
Qls	3.3-7 ka	Slope wash or sand sheets. composed primarily of reworked eolian sand and <25 percent gravel; deposited as much as 10 km from mountain fronts. Commonly dissected near active channels. Soils and pavement are similar to those of unit Qlc, except texture is most commonly S. Usually <2 m thick.
Middle to Early Holocene or Late Pleistocene		
Qlc	~10 ka 3-20	Primarily terraces formed in fluvial gravel; may include fans, colluvium, or sheetwash. Fluvial deposits form a terrace 1-2 m above active channels. Lacks bar-and-swale topography. Incipient desert pavement development and little or no varnish development. Soils have an A; 10YR Bw, Bkj, Btj and (or) Bqj; stage I-II $CaCO_3$ and (or) stage I SiO_2; texture S, LS, or SL. Commonly <2 m thick.
Late Pleistocene		
Q2a	30-47 ka	Mostly sandy slope wash derived in part from eolian sediment. Commonly contains <25 percent gravel. Typically caps older deposits and is locally covered by Holocene deposits. Usually lacks topographic expression. Soils have an Av; Bt and (or) Bk; stage I $CaCO_3$; texture SL, L, or C. Usually <1.5 m thick.

Table 1 continued. Quaternary stratigraphy of the Yucca Mountain Area, NTS.

Stratigraphic Units: Unit Designation	Estimated Age	Key Properties and Diagnostic Criteria for Recognition
Middle Pleistocene		
Q2b	145-160 ka 140-160	Fluvial gravel that forms strath terraces, or debris flow fans. Fluvial deposits form a terrace 5-12 m above active channels. Typically very poorly sorted with large boulders up to 1 m in diameter; commonly contains fluvial sedimentary features. Desert pavement is well sorted, tightly packed and darkly varnished. Soils have an Av; 10YR to 7.5YR Bw, Bt, Bqm, and (or) Bk; stage I-II $CaCO_3$ and (or) stage II-III SiO_2; texture S, LS or SL. Commonly <2 m thick.
Q2c	270-430 ka 300-400	Fluvial gravel or debris flows on steep slopes. Fluvial deposits form a terrace 10-21 m above active channels. Desert pavement is well sorted, tightly packed with continuous varnish. Soils have an Av; 7.5YR. Bt, Bqm, B/K and (or) Kqm; stage III-IV $CaCO_3$ (K horizon <1 m thick) and (or) stage III SiO_2; texture S to L. Usually <65 m thick.
Q2e	<738 ka	Eolian sand in inactive dunes and sand ramps at and adjacent to hill and mountain fronts. Desert pavement is well sorted, tightly packed, and darkly varnish. Soils have an Av; Bk, Bkq, B/K and (or) K; stage III-IV $CaCO_3$ and (or) stage III-IV SiO_2; texture LS, SL, or L. Usually <20 m thick.

Table 1 continued. Quaternary stratigraphy of the Yucca Mountain Area, NTS.

Stratigraphic Units: Unit Designation	Estimated Age	Key Properties and Diagnostic Criteria for Recognition
Q2s	<738 ka	Slope wash or sand sheets (tabular bodies of sandy slopewash) down slope from sand ramps. Generally lacks desert pavement. Soils have an Av; Bk, Bkq, B/K and (or) K; stage III-IV $CaCO_3$ and (or) stage III-IV SiO_2; texture LS, SL or L. Usually <2 m thick.
Early Pleistocene		
QTa	1.1-2.0 my > 1 my	Alluvial fans; usually extremely eroded and overlain by a veneer or mantle of younger deposits. Commonly deposits are adjacent to hills and mountain fronts, 20-30 m above active channels. Lacks depositional form; erosional modification results in ballena or accordant, rounded ridges. Large boulders up to 1 m in diameter may be scattered on the surface. Desert pavement is well-sorted, tightly packed and has continuous dark varnish; commonly contains opaline SiO_2 platelets from the underlying soil. Soils have an A or Av; 7.5YR Bt, Bqm, B/K, Kqm, and (or) Kmq; stage III-IV $CaCO_3$ (K horizon >1 m thick) and stage III-IV SiO_2. Commonly <20 m thick.

The assigned ages for these mapping units are based almost exclusively upon U-trend analyses on soil samples (Rosholt, 1980) (Appendix G).

Several depositional facies are recognized on these deposits. Fluvial deposits are poorly to moderately well sorted and poorly to well bedded; gravel clasts are angular to subrounded. Debris flows are poorly sorted, and poorly stratified to massive. Clasts are matrix supported and are angular to subrounded. Eolian sand and loess are moderately to well sorted sorted, respectively. Sheetwash is moderately well sorted and may have thin bedding.

Features of desert pavement help distinguish some units. Pavement packing tends to change from none to dense with time, sorting increases from poor to well, and varnish changes from none to dull black to shiny purplish-black. Desert pavement features are a useful relative age indicator because they clearly change with time. However, thin layers of eolian and sheetwashed fine-grained deposits tend to blanket most gravelly deposits in the study area, and thus mask the development of desert pavements.

The expression of fluvial bar-and-swale features become more subdued with time. The obliteration of these features is due primarily to burial by eolian or sheetwash deposits, and (or) to erosion. With time, the surface becomes smoother.

Topographic form of terraces also change in a gross way. Deposits younger than QTa have a good terrace expression. However, erosional modification results in ballenas or accordant, rounded

ridges (Peterson, 1981) that are typical of the QTa unit. These topographic forms represent a distinctive late stage of piedmont dissection.

Ages of Deposits

The ages assigned to the stratigraphic units on NTS and the surrounding area are based primarily on U-trend dating of deposits exposed in trenches excavated to study Quaternary faults (Hoover and others, 1981; Szabo and others, 1981; Swadley and Hoover, 1983) (Appendix G). Other techniques used are the age of assumed channel incision, ^{14}C, and correlation to ash geochronologies. The Quaternary stratigraphy used in the Yucca Mountain area (Table 1) was a product of the above tectonic studies.

Geomorphic Setting

Terrace Formation--Tectonic vs Climatic

The Quaternary landscape in the study area was formed by three major geomorphic processes; (1) fluvial erosion and deposition, (2) eolian erosion and deposition, and (3) hillslope processes. Major influences on these processes are tectonism (basin subsidence and (or) mountain front uplift) and climate. Of most interest here are the fluvial terraces.

The terraces studied are fill terraces (Fig. 3). Although the overall fluvial activity has been one of downcutting, these were interrupted by periods of aggradation. Subsequent downcutting resulted in fill terraces.

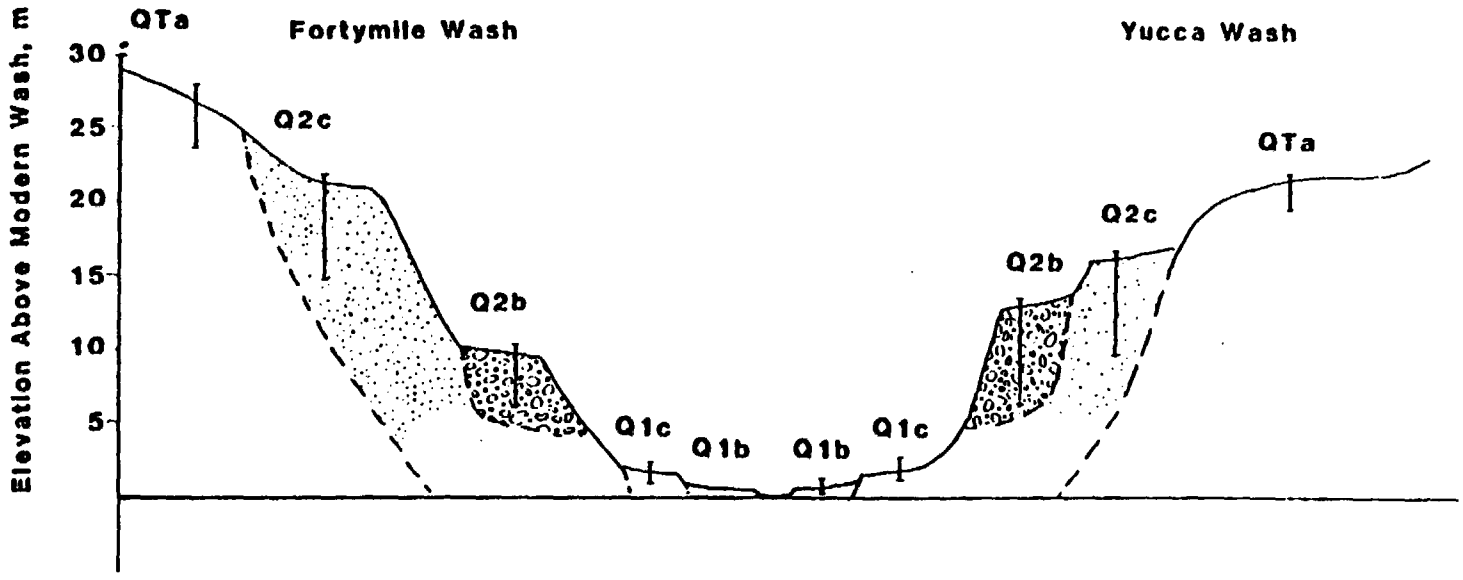


Figure 3. Generalized cross section showing the stratigraphic relationships of Quaternary fluvial deposits along Yucca Wash and Fortymile Wash. Variability in height of terrace surfaces above the modern wash is defined with the vertical bars.

The terraces do not seem to be of tectonic origin. A recent study on the west side of Yucca Mountain suggests that faulting has occurred in the Holocene (J. W. Whitney and R. R. Shroba, U.S. Geological Survey, oral communication, 1985). However there has not been any evidence for faulting of any of the Quaternary fluvial terrace deposits in the study area. In addition, longitudinal profiles of the terraces along Yucca Wash and Fortymile Wash (Fig. 4), although they diverge downstream, do not require tectonism to explain this relationship. Finally, if the terraces have been influenced by tectonic uplifts in the upper reaches of the drainages, cut terraces might be expected rather than fill terraces.

Climatic change may explain the presence of fill terraces in the area. Bull (1979) and Bull and Schick (1979) propose a model for fluvial behavior in arid areas during climatic change. If the climate changes to greater aridity and higher temperatures, the basin characteristics are such that the stream responds by aggrading. As time goes on, sediment availability decreases as erosion exposes bedrock, runoff increases, and erosion of the valley fill takes place. In general, each terrace, therefore could represent a climatic change. In this case, the formation of a terrace could be correlative with the early interglacials.

There have been few paleohydrologic models for the region that the depositional units in the study area may be correlative. Smith (1984) has proposed one for the last 3.2 my, with most of the data taken from a core in Searles Lake, California. The four most recent climatic regimes are of interest here. Regime I (0 - ~10 ka) was dry. Regime II (~10 - 130 ka) was characterized by both dry and

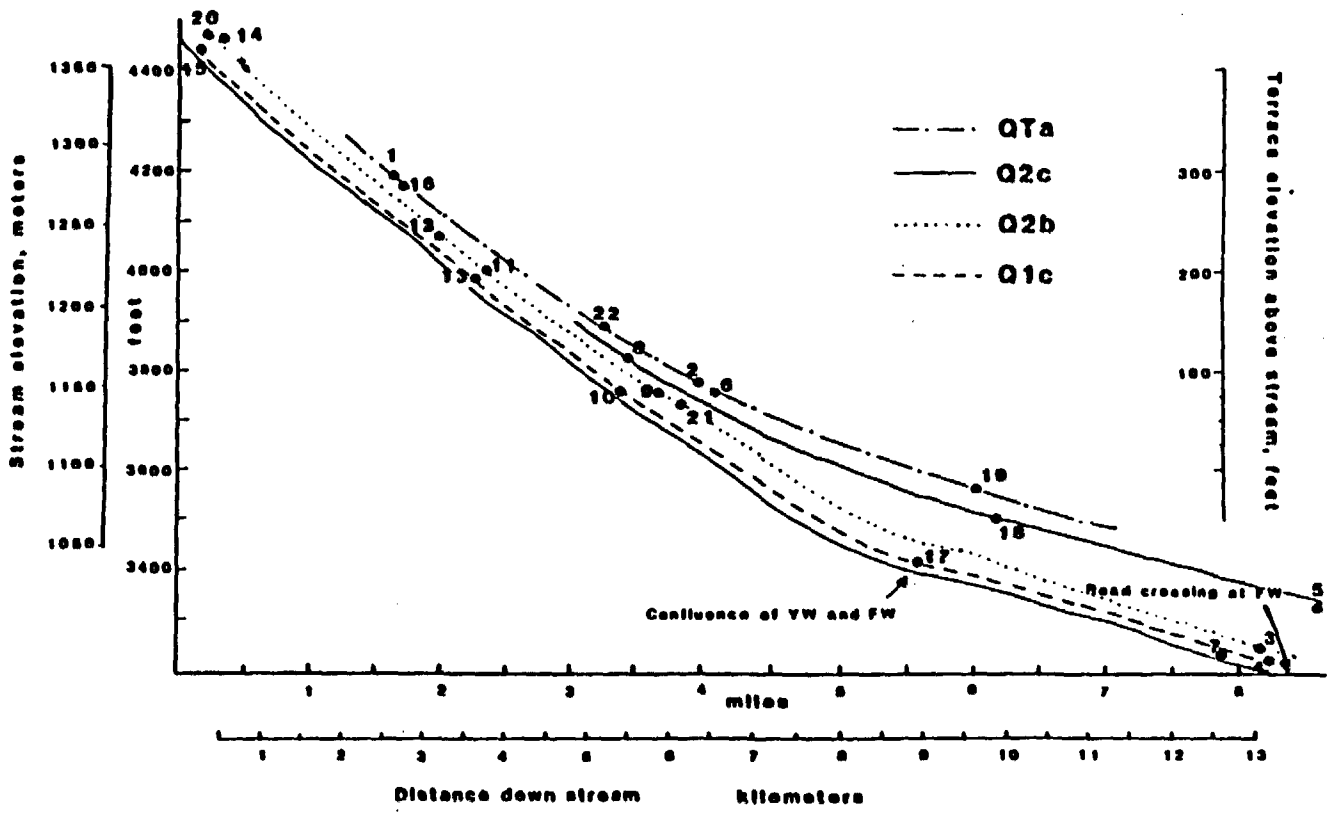


Figure 4. Profiles of terrace deposits along Yucca Wash (YW) and Fortymile Wash (FW). Locations of soil trenches are indicated by dots and numbers.

wet cycles, but long intervals of high lake levels support a relatively wet interval. Regime III (130 - ~310 ka) was similar to but drier than Regime II. Finally, Regime IV (310 - 570 ka) was a long dry period.

Correlation can be made of some of the deposits in the area with the climatic model of Smith (1984). Unit Q1c could correlate with the transition from Regime II to I, and that would follow the Bull and Schick (1979) model. Other deposits may correlate to changes from one regime to another. Unit Q2b, a strath terrace deposit inset into the older Q2c, places a minimum age on the major time of incision of Fortymile Wash. Unit Q2b could be correlated with the transition from Regime III to II at 130 ka, and likewise the stabilization of unit Q2c would be correlative with the transition from Regime IV to III at 310 ka. These latter correlations are very tentative and do not follow the Bull (1979) model. Obviously the fluvial response to climatic change is not simple, as the crossing thresholds also may from terraces (Schumm, 1977)

Ground Water Setting

Most ground water flow through the NTS area originates in volcanic highlands to the north; these include Pahute Mesa (35 km NW) and Timber Mountain (15 km N). The remainder of the ground water flow enters from the east as underflow in the regional lower carbonate aquifer (Winograd and Thordarson, 1975; Winograd and Doty, 1980). Flow directions beneath the eastern part of NTS are to the south and west from the highlands, until the water surfaces at the

extensive network of active springs at Ash Meadows in the Amargosa Desert (45 km SE). Evidence exists for somewhat greater spring activity during the last glacial maximum. Fossil tufa deposits occur as high as 40 m above present ground water level in this area (Winograd and Doty, 1980). All pedogenic processes in the Yucca Mountain area are well above the ground water table of the area which is from 490 to 610 m below the surface today.

Modern Climate

Southern Nevada is arid to semiarid. Because average annual precipitation in much of this area is less than 150 mm and there is greater than 10% perennial plant cover, it is actually a semiarid desert. Beatty, Nevada is only 24 km due west of the study area. It is at the same elevation as the lowest soil-trench elevation in the study transect (1083 m), and is at the same latitude (37°54'N) (Fig. 1) It is used here as an estimate of the climate of the lower end of the study area. The mean annual precipitation (MAP) at Beatty is 117 mm, and the mean annual temperature (MAT) is 15.3°C (Table 2). At the upper end of the transect, which lies 400 m above the lower end, precipitation is assumed to increase by 70% to about 200 mm. This assumption is based on (1) vegetation change, (2) precipitation data from stations in southern and south-central Nevada that are at similar elevations and latitudes, and (3) Quiring's (1983) regression equation relating MAP and elevation on NTS:

$$y = 1.36x - 0.51 \qquad \text{Equation (2.1)}$$

where y = MAP in inches and x = elevation in feet.

HOLOCENE (PRESENT) CLIMATE

Month	Temperature(°C) Mean Monthly avg. 1/	max	min	Precipitation (cm) low	high	Pan Evap. (cm) 2/	ET_p (cm) T 3/	B & C 4/	P 5/
J	4.8	12.4	-2.9	1.80	3.07	5.53	0.71	1.58	5.39
F	6.6	14.6	-1.3	1.78	3.02	7.54	1.17	2.36	6.23
M	9.8	18.7	1.1	1.27	2.16	14.44	2.74	2.83	8.42
A	14.2	23.3	5.0	1.27	2.16	15.14	5.35	4.89	11.18
M	18.4	28.1	8.8	0.84	1.43	26.52	9.06	10.19	15.01
J	23.3	33.5	13.1	0.31	0.52	29.52	13.42	14.72	20.62
J	27.1	37.5	16.7	0.46	0.78	31.64	17.45	16.13	25.61
A	25.9	36.2	15.5	0.51	0.86	27.07	15.17	14.76	23.90
S	22.2	32.5	11.9	0.46	0.78	20.63	10.39	12.17	19.68
O	15.8	25.2	6.4	0.76	1.30	13.34	5.62	8.52	12.62
N	9.7	18.5	0.8	0.91	1.55	6.53	2.22	3.11	8.35
D	5.7	13.5	-2.2	1.32	2.25	5.38	0.91	2.39	5.79
avg or sum	15.3	24.5	6.1	11.68	19.86	163.86 6/ (203.28)	84.21	93.65	162.80

CLIMATE DURING GLACIAL MAXIMUM - Spaulding model

J	-2.2	5.5	-2.9	2.44	4.14	4.98	0.00	0.00	2.32
F	-0.4	7.6	-1.3	2.40	4.08	6.79	0.00	0.00	2.76
M	2.8	11.7	1.1	1.72	2.92	13.00	1.28	0.29	4.02
A	7.2	16.3	5.0	1.72	2.92	13.63	3.73	1.10	5.52
M	11.4	21.1	8.8	1.13	1.92	23.87	6.73	3.22	7.70
J	16.3	26.5	13.1	0.15	0.26	26.57	9.92	5.85	10.99
J	20.1	30.5	16.7	0.23	0.39	28.48	12.58	7.23	13.87
A	18.9	29.2	15.5	0.25	0.43	24.36	11.03	6.39	12.88
S	15.2	25.5	11.9	0.23	0.39	18.57	7.71	4.63	10.51
O	8.8	18.2	6.4	1.03	1.75	12.01	4.07	2.24	6.35
N	2.7	11.5	0.8	1.23	2.10	5.88	1.02	0.30	4.00
D	-1.3	6.5	-2.2	1.78	3.31	4.84	0.00	0.00	2.53
avg or sum	8.3	17.5	6.1	14.31	24.32	147.47 (182.96)	58.07	31.25	83.45

CLIMATE DURING GLACIAL MAXIMUM - Mifflin and Wheat model

J	-0.2	7.5	-2.9	3.03	5.15	4.48	0.00	0.00	3.07
F	1.6	9.6	-1.3	2.99	5.08	6.11	0.40	0.16	3.61
M	4.8	13.7	1.1	2.13	3.63	11.70	1.82	0.50	5.11
A	9.2	18.3	5.0	2.13	3.63	12.27	4.22	1.40	6.92
M	13.4	23.1	8.8	1.41	2.39	21.48	7.33	3.78	9.52
J	18.3	28.5	13.1	0.51	0.87	23.91	10.70	6.56	13.40
J	22.1	32.5	16.7	0.77	1.31	25.63	13.62	7.95	16.82
A	20.9	31.2	15.5	0.85	1.45	21.92	11.93	7.06	15.65
S	17.2	27.5	11.9	0.77	1.31	16.71	8.33	5.24	12.81
O	10.8	20.2	6.4	1.28	2.18	10.81	4.51	2.75	7.91
N	4.7	13.5	0.8	1.54	2.61	5.29	1.47	0.53	5.07
D	0.7	8.5	-2.2	2.22	3.77	4.36	0.15	0.07	3.33
avg or sum	10.3	19.5	6.1	19.63	33.37	132.73 (164.67)	64.48	35.96	103.22

In addition to the orographic influence on precipitation, two basic storm types exist in the area. The two storm types result in precipitation derived from (1) winter cyclonic activity, and (2) intense summer convection (Houghton and others, 1975). As will be shown later, the seasonality of precipitation will influence some of the soil property vs depth relationships.

No long term temperature data exist for the Yucca Mountain area. D. L. Hoover (U.S. Geological Survey, written communication, 1984) however estimates that there is a 3°C difference in MAT in the 400 m elevation change. He bases this on the relationship that,

$$x = 7.48 - 0.004081y \text{ for MAT} \qquad \textbf{Equation (2.2)}$$

where x = MAT in °F and y = elevation in feet.

Paleoclimate in the NTS Region

A large number of data sources exist to reconstruct the paleoclimate in the American Southwest. There are two sources of paleoclimatic information of particular interest in the study area, packrat middens and suggested climates responsible for pluvial lakes.

Packrat Midden Evidence

Paleoenvironmental data from analyses of plant microfossils remains in packrat (*Neotoma sp.*) middens provide perhaps the most detailed information concerning the timing and nature of climatic changes on the NTS during the late Quaternary (Van Devender and Spaulding, 1979; Spaulding, 1983). Plants sensitive to frigid temperatures and those restricted to moist habitats are missing in

the plant microfossil record from 45-10 ka (Spaulding, 1983). Juniper and pinyon pine and Joshua tree were present at lower altitudes in the NTS area. These data suggest milder, wetter winters and cooler, drier summers relative to the present during the last glacial maximum (18 ka). Following the last glacial maximum Spaulding (1983) infers a warming trend from 16-10 ka. After 11-10 ka, the conditions like the present prevailed and juniper and pinyon pine woodland are not present. Elements of desert scrub were present by 15 ka at elevations as high as 990 m Spaulding (1982). The vegetation change was transitional, implying a transitional climatic change from late Pleistocene to Holocene.

Based on evidence from packrat middens, climatic conditions in the Yucca Mountain area during the glacial maximum (18 ka), compared to the present climate, probably had (1) a MAT decrease of 6-7°C, (2) drier summers with a temperature decrease of 7-8°C, and (3) winter precipitation up to 70% greater than present. In all the following discussions this climatic change is referred to as the Spaulding climatic model for the glacial maximum (Table 2).

Pluvial Lake Evidence

The pluvial lake chronologies in the southwestern United States suggest that the effective moisture of the late glacial and early Holocene was much greater than the effective moisture in the modern climate. High lake stands are recorded at 14-11 ka in lakes in both glacial and nonglaciated drainages (Morrison, 1965; Benson, 1978; Lajoie and Robinson, 1982; Wells and others, 1984). The disappearance of juniper and pinyon pine woodland at 11-10 ka is

coincident with the lowering of Lake Mojave from a high stand between 15.5 and 10.5 ka (Wells and others, 1984).

Although the effective moisture was greater, there is little evidence in the northern Mojave Desert for increased annual precipitation during the late Wisconsin (18 ka). Present day playas contained ephemeral lakes or marshes during the full-glacial north of latitude 36° N (Mifflin and Wheat, 1976). Mifflin and Wheat (1976) propose that the MAT was 5°C lower, the MAP 69% greater, and the evaporation 10% less than today. This is referred to in the following discussions as the Mifflin and Wheat glacial maximum climatic model (Table 2).

The reduction of full-glacial summer precipitation in the NTS area, relative to that of today, can be attributed to the dependence of summer precipitation on oceanic air from the Gulf of Mexico. Global cooling weakened these subtropical high-pressure systems and restricted the influence of the oceanic air to very southern regions (Houghton and Sakamoto, 1975). Summer precipitation also depends upon local convective uplift which is lacking if summer temperature is low.

Summary of the Glacial Climate Models

In the southern Basin and Range and northern Mojave desert regions, the onset of the last major glacial climate began about 45 ka. The late Wisconsin began about 24 ka, based on dates from Searles Lake (Smith, 1979), and the pollen and lake record from Lake Lahontan (Mehringer, 1967; Benson, 1978), and at 18 ka is thought to have been a full glacial in the western United States (CLIMAP,

1976). The period from 25 to 11 ka was the maximum development of alpine glaciers, intermittent filling of playa lakes, and expansion of upland vegetation. Physical evidence for paleoclimatic and paleoenvironmental reconstructions for the last glacial vary from a 2-3°C temperature decrease and a 100% increase in precipitation, to a 7-11°C temperature decrease and less precipitation than today (Spaulding and others, 1983; Thompson, 1984). At about 11 ka, there was a significant decrease in the pluvial lake levels, and changes in the vegetation, that mark the end of the late Wisconsin in the southwest (Van Devender and Spaulding, 1979) Transitional plant communities persisted until the early Holocene (7.8 ka) (Spaulding and others, 1983).

CHAPTER III

MAJOR PEDOLOGICAL CHANGES WITH TIME

Morphology

Soils that are formed in alluvium, colluvium and eolian sand of Holocene to early Pleistocene or latest Pliocene(?) age near Yucca Mountain are characterized by distinctive trends in the accumulation of secondary clay, $CaCO_3$, and opaline SiO_2 that correspond with the ages of the surficial deposits.

Pedogenic Opaline Silica

Cementation by pedogenic opaline SiO_2 is common in the study area. Accumulation of opaline SiO_2 is common in parent materials containing readily weatherable glass from pyroclastic rock or volcanic ash, such as those in the study area. Eolian influx of readily soluble silica-rich dust is also a likely source. Glass tends to weather rapidly and if it is of mafic composition, rich in bases, weathering can liberate silica at a rapid rate. The glass alters to amorphous SiO_2 or semi-crystalline allophane, imogolite and opaline SiO_2 (Bleeke and Parfitt, 1984).

In general, two terms are used for silica-cemented layers: (1) duripan, specifically for pedogenic accumulations (Soil Survey Staff, 1975), and (2) silcrete for geologic-pedologic occurrences (Summerfield, 1983; Nettleton and Peterson, 1983). Both terms are

applied to an indurated product of surficial and (or) near-surface silicification, formed by the cementation and (or) replacement of bedrock, unconsolidated sediments, or soil. The silicification is produced by low temperature physio-chemical processes. Silcretes are not exclusively the product of pedogenic weathering. A few grade laterally into petrocalcic horizons (Summerfield, 1983). Silcrete has an arbitrary lower limit of 85% opaline SiO_2 by weight (Summerfield, 1983), so it would be a very unusual pedogenic horizon. Silcretes are not present in the study area. Duripans have no limit on the content of opaline SiO_2, they vary in the degree of cementation by SiO_2 and commonly contain accessory cements, chiefly $CaCO_3$.

Because silica accumulation produces a unique morphology that varies with age, stages of development here have been defined (Table 3). On the basis of horizon morphology, those with stages III-IV morphology would qualify as duripans of the Soil Conservation Service (Soil Survey Staff, 1975, p. 41).

Table 3. General characteristics of pedogenic opaline silica stages.

Stage I	White, yellow, or pinkish scale-like coatings <2 mm thick on the undersides of gravel clasts. Found in soils on Q1c deposits, may occur at depths on older deposits.
Stage II	Stalactitic or pendant features 2-4 mm long extending downward from a coat on the undersides of gravel clasts. Found in soils on Q2b deposits, may occur at depths on older deposits.
Stage III	Opaline SiO_2 cemented horizon, extremely hard when dry. Peds do not slake in water or a weak solution of HCl. The color is a 7.5YR, probably due to clay particles in the silica cement. Found in soils on Q2b, Q2c and QTa deposits, and maximum accumulations tend to form in horizons of maximum $CaCO_3$ accumulation. Frequently in the field stage III appears to be forming above the maximum accumulation of $CaCO_3$ because the whiteness of the $CaCO_3$ masks the precipitated opaline SiO_2.
Stage IV	Stage III morphology with laminar, indurated opaline SiO_2 platelets, 4-10 mm thick, in the upper part. Maximum $CaCO_3$ accumulation is below maximum opaline SiO_2 induration. Commonly calcareous ooids are precipitated above platelets. Found in soils on Q2c (infrequently and thin) and QTa deposits.

Carbonate and Opaline Silica

At the NTS, soils accumulate secondary $CaCO_3$ and opaline SiO_2 in distinctive trends with increasing ages of the surficial deposits. Soils formed in gravelly alluvium less than 3(?) ka (Q1b) contain little or no secondary $CaCO_3$ or opaline SiO_2. Soils formed in gravelly alluvium 3-20(?) ka (Q1c) and sandy colluvium about 30-40 ka (Q2a) commonly have a Bk horizon about 20-50 cm thick that has thin, discontinuous coatings of $CaCO_3$ (stage I) and (or) opaline SiO_2 scales and pendants on the undersides of stones (stage I-II). Soils formed in gravelly alluvium about 140-160 ka (Q2b) may have a

opaline SiO_2-cemented Btqm horizon (duripan, stage III) about 50 cm thick that overlies or engulfs a $CaCO_3$-enriched Bk/K (stage II-III) horizon about 50-70 cm thick. The secondary opaline SiO_2 in the duripan typically occurs as finely disseminated matrix cement and as coatings and pendants on stones. The secondary $CaCO_3$ in the underlying Bk/K horizon typically occurs as coatings on stones and as bridges between some of the stones in the Bk-layers, and as coatings and finely disseminated matrix cement in the $CaCO_3$-indurated K-lenses. Soils formed in gravelly alluvium about 300-400 ka (Q2c) commonly have a opaline SiO_2-indurated Kqm horizon (stage III) about 50 cm thick that overlies a Bk/K horizon (stage II-III) about 40-50 cm thick. The oldest alluvium, which is >1 Ma (QTa), has soils with a Kqm horizon more than 100 cm thick. Commonly, the upper part of the Kqm horizon consists of platelets, 0.5-1 cm thick, cemented by laminar opaline SiO_2 (stage IV), and it may be overlain by layers of $CaCO_3$ ooids as much as 10 cm thick (stage III).

Carbonate is primarily derived from airborne dust and the opaline SiO_2 from in-place weathering of the parent material, although the addition of silica-rich dust may also be a likely source.

The $CaCO_3$ morphology in the NTS area differs from that described by Gile and others for the Las Cruces area, New Mexico, although both areas have similar climates, soil parent materials, and accumulation rates of modern airborne dust (Gile and others, 1979). In addition, secondary $CaCO_3$ is less abundant in the NTS area than in deposits of similar age in the Las Cruces area. These differences in the amount of secondary $CaCO_3$ may result from

differences in the seasonality of precipitation and the amount of secondary opaline SiO_2. Unlike the Las Cruces area, most precipitation in the NTS area occurs during the cool, winter months at soil moisture temperatures that result in $CaCO_3$ being more soluble (Table 2). Infiltrating soil moisture tends to translocate $CaCO_3$ to the base of the wetting zone, where it forms lenses rather than discrete K horizons as in the Las Cruces area. Thin-section studies of soils in the NTS area indicate that opaline SiO_2 has replaced $CaCO_3$ in some of the older soils. This relationship suggests that opaline SiO_2 accumulation in the NTS soils is favored over that of $CaCO_3$.

Vesicular A Horizons

Well developed vesicular A horizons (Av) have not formed on the coarse gravelly Holocene deposits (Qlc) in the Yucca Mountain area. On the Pleistocene deposits the Av's are typically between 5 and 10 cm thick and there is no relationship between the thickness of the Av horizon and the age of the underlying deposit. Eolian silts and fine sands appear to accumulate only on deposits that have been previously plugged by the addition of fine material into the coarse alluvium. Although McFadden and others (1984) have described the ubiquitous nature of Av's in the Mojave desert on Holocene deposits and volcanic flows, it appears in this area that due to the coarseness of most of the young deposits, available eolian fines are either translocated deeper into the deposit or lost by wind erosion. It is also possible that the eolian material that forms Av horizons has been less abundant during the Holocene, although this

contradicts many of the current ideas on sediment availability associated with the Holocene-Peistocene climatic change (Bull, 1979).

Profile Index Values

Field properties of soils (Appendix A) can be quantified by assigning points for developmental increases in soil properties in comparison to those of the parent material (Harden, 1982; Harden and Taylor, 1983) (Appendix B). Ten field properties are quantified and normalized for each horizon, including two properties that reflect $CaCO_3$ buildup in soils formed in arid environments. The ten properties are rubification (increasing (redder) color hue and (or) chroma), melanization (decreasing (darkening) color value), color paling (decreasing (yellower) color hue and (or) chroma), color lightening (increasing (whitening) color value), total texture (includes texture and wet consistence), clay films, structure, dry consistence, moist consistence, and pH. Unlike the Harden (1982) definition, values for pH were quantified based on the absolute difference in comparison to the parent material. Wet consistence was usually not available in the study area, and therefore was not included in the index calculations.

Soil profile indices were initially calculated two different ways; using all soil properties and (1) rubification and melanization, or (2) color paling and lightening properties. Both ways to calculate the soil profile index include eight properties. I have called the first way to calculate the profile index value rub-mel, and the second pale-light. Rub-mel was developed for a

xeric soil moisture regime, and pale-light for an arid soil moisture regime. According to Harden and Taylor (1983) complete profiles are calculated using either one of the two methods, not combinations for a given profile. Profile indices are calculated using either rubification and melanization, (rub-mel) or color paling and color lightening (pale-light).

Parent material values used to calculate the indices vary with the kind of material. For alluvium they are 10YR 6/2 (dry) and 10YR 4/2 (moist), sand, loose, and non-sticky and non-plastic. In contrast, for the eolian and reworked gravels the values are 10YR 6/3 (dry) and 10YR 4/3 (moist), sandy loam, soft, and non-sticky and non-plastic.

Of the ten possible independent properties all were significant with log age at the 5% level, except melanization (r^2=0.01) and color paling (r^2=0.01) (N=20, r^2 critical=0.18) (Fig. 5). The properties most significant in the profile index calculation have the highest r^2 values. They are dry consistence (r^2=0.48), color lightening (r^2=0.45), rubification (r^2=0.40), and structure (r^2=0.37), and are referred to as the four best properties (Fig. 5). The profile index values using the four best properties did not improve the relationship between soil development and time over that using all eight properties with the highest r^2 values (Fig. 6).

Significant trends are apparent when profile index values (Appendix B) are plotted as a function of age (Fig. 6). Profile index values have been calculated using rub-mel and pale-light soil properties (Fig. 6). It makes no difference in the index values vs

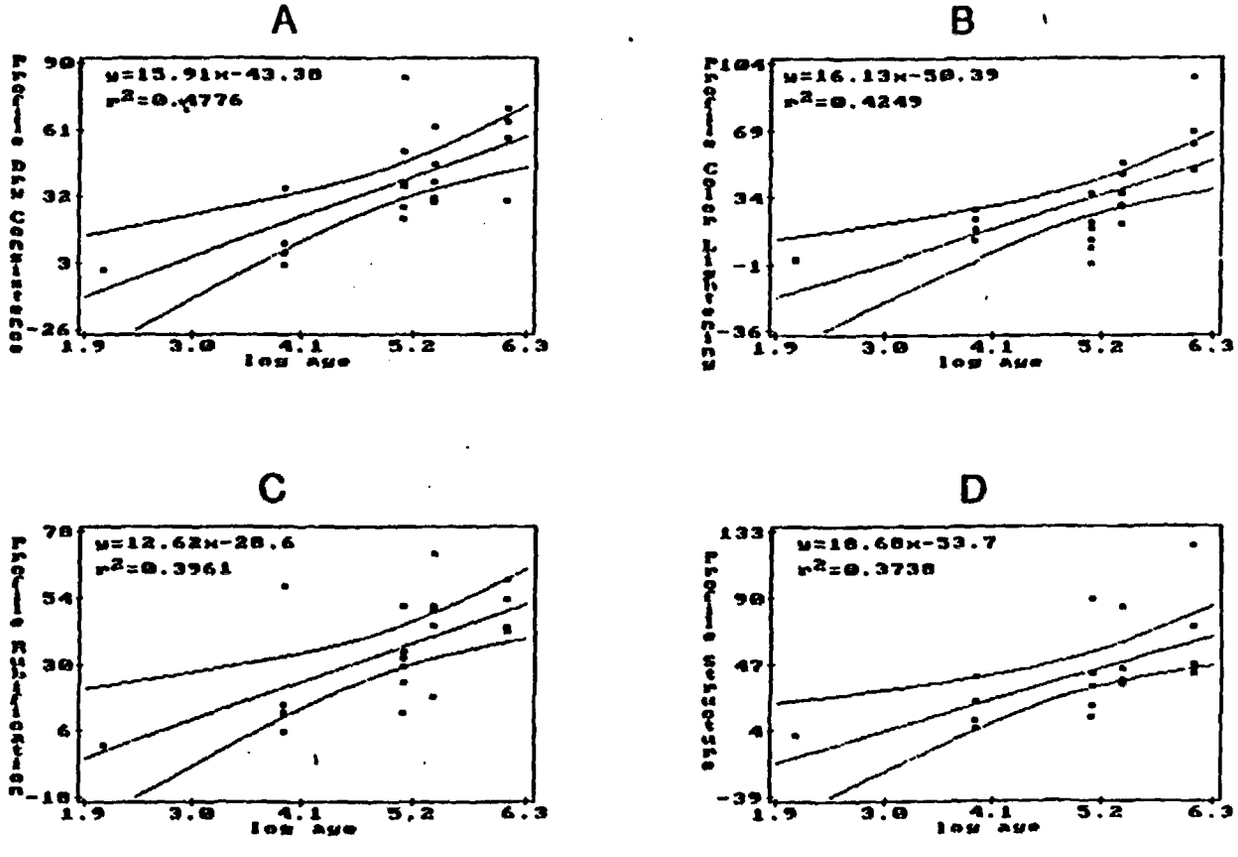


Figure 5. Bivariate regression analyses of significant property profile index values vs time. 95% confidence interval surrounds regression line. (A) dry consistence, (B) color lightening, (C) rubification, (D) structure, (E) texture, (F) clay films.

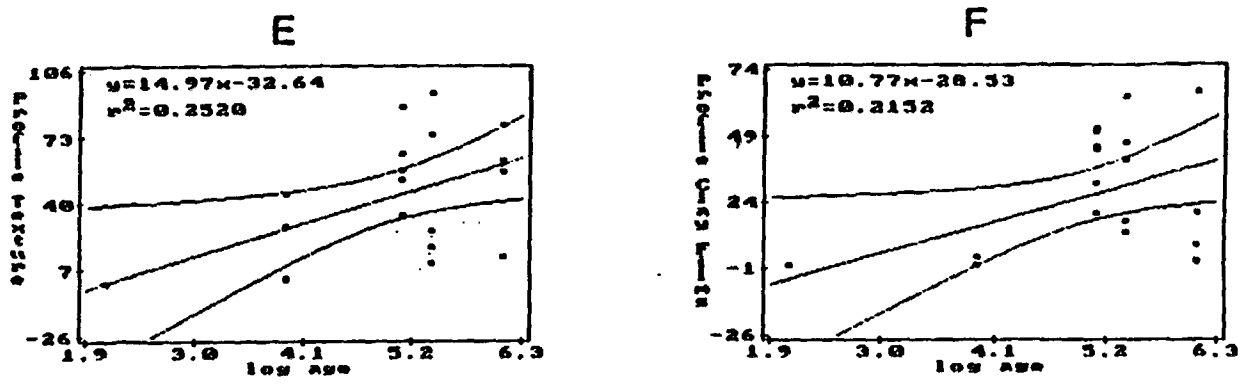


Figure 5 continued. Bivariate regression analyses of significant property profile index values vs time. 95% confidence interval surrounds regression line. (A) dry consistence, (B) color lightening, (C) rubification, (D) structure, (E) texture, (F) clay films.

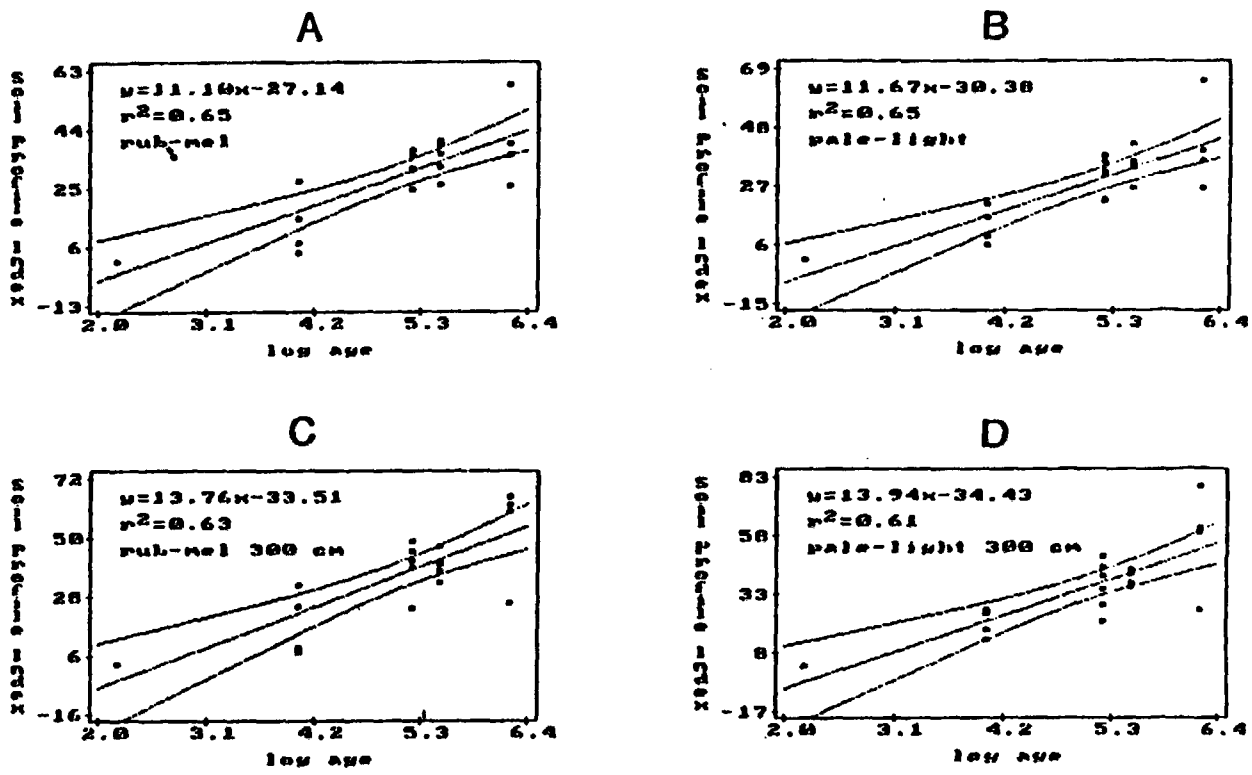


Figure 6. Bivariate regression analyses of soil profile index values vs time. 95% confidence interval limits are above and below the regression line. (A) Rub-mel, all soil properties including rubification and melanization. (B) Pale-light, all soil properties including color lightening and color paling. (C and D) Soil properties for rub-mel and pale-light climatic regime are quantified to an arbitrary maximum depth of 300 cm. (E) Rub-light, all soil properties including rubification and color lightening. (F) Best four properties are dry consistence, color lightening, rubification, and structure.

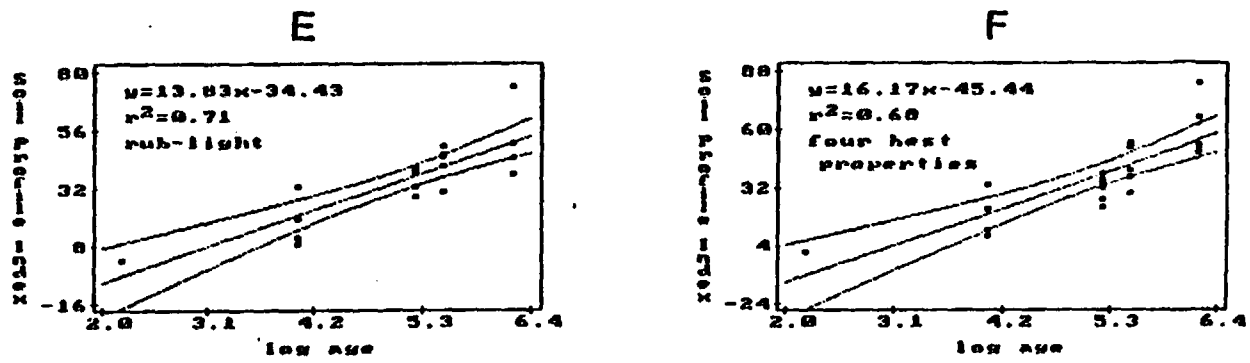


Figure 6 continued. Bivariate regression analyses of soil profile index values vs time. 95% confidence interval limits are above and below the regression line. (A) Rub-mel, all soil properties including rubification and melanization. (B) Pale-light, all soil properties including color lightening and color paling. (C and D) Soil properties for rub-mel and pale-light climatic regime are quantified to an arbitrary maximum depth of 300 cm. (E) Rub-light, all soil properties including rubification and color lightening. (F) Best four properties are dry consistence, color lightening, rubification, and structure.

time if the rub-mel (r^2=0.65) or pale-light (r^2=0.65) properties are for the measured profile thickness, or are for an arbitrary depth of 300 cm for the rub-mel (r^2=0.63) or pale-light (r^2=0.61) properties (Fig. 5).

Because melanization and color paling did not have significant correlations with time, the profile index was calculated using rubification and color lightening. When all soil properties are included with rubification and color lightening the profile index value is called rub-light. The rub-light profile index values vs time increases the r^2 value to 0.71 (Fig. 6).

The increase in the individual profile property values with time (Fig. 5) can be explained by aridic climatic pedogenesis models. Rubification increases both because of the increasing redness of Bt horizons and the accumulation of opaline SiO_2, as the latter results in colors redder than the parent material. Lightening increase with time because A horizons do not get darker, and $CaCO_3$ and opaline SiO_2 accumulating horizons are lighter than the parent material. Dry consistence gets harder over time as clay and cementing agents accumulate and indurate horizons. Structure changes from unconsolidated parent material. Texture, wet consistence, and clay films represent pedogenic accumulations of clay.

There may be a subtle influence of local climate on profile index values. Unit Q1c shows little change with elevation, but weak trends are discernable for units Q2b, Q2c, and QTa with the increase in QTa being much greater than that of the younger units when only the four best properties are used (Fig. 7).

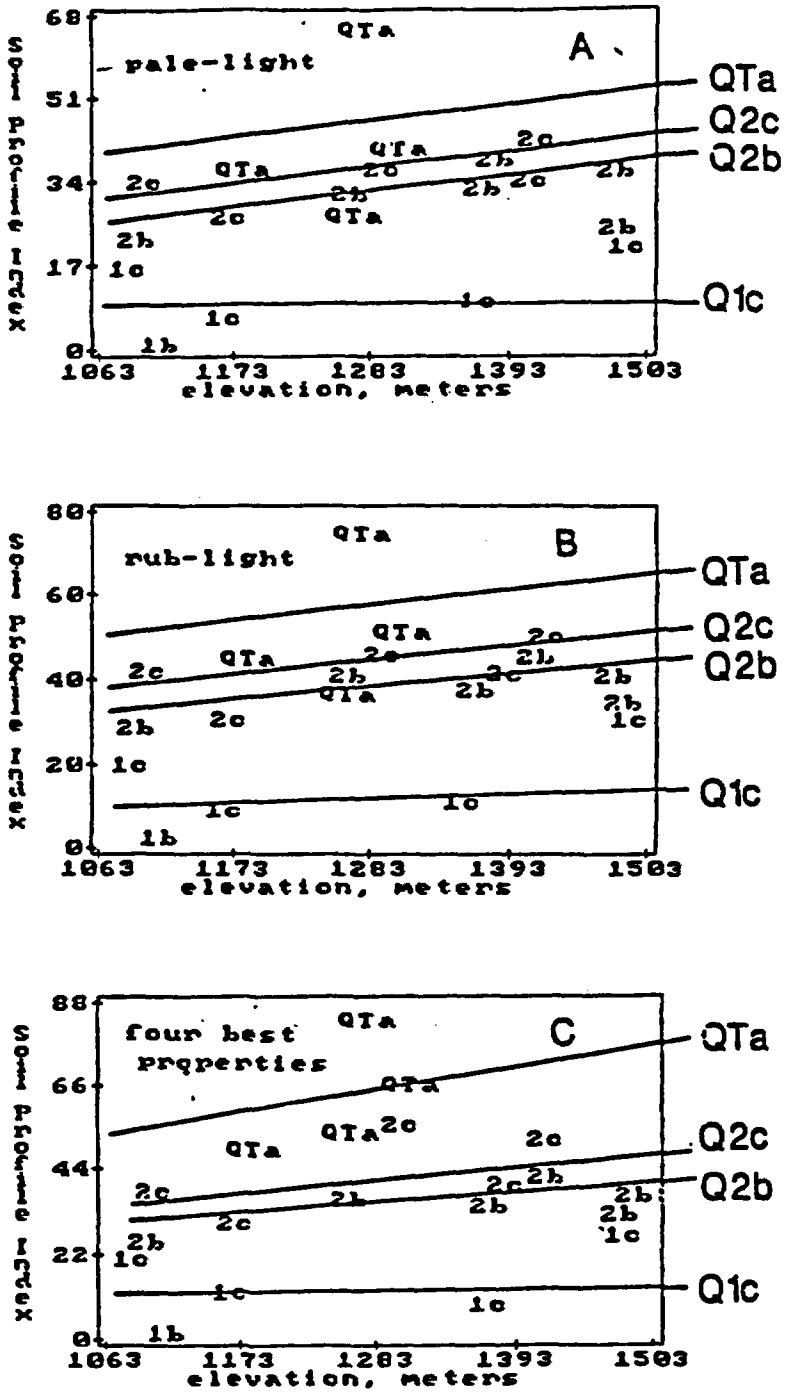


Figure 7. Soil index values vs elevation. The index value plots between the number and letter of each stratigraphic unit. (A) Pale-light field properties including color paling and color lightening. (B) Rub-light properties including rubification and color lightening. (C) Index calculated using four best properties: dry consistence, rubification, color lightening, and structure.

Profile index values for the study area are comparable to index values from the Las Cruces, New Mexico soil chronosequence (Harden and Taylor, 1983) (Table 4). Comparative index values are best when they are based on the four best properties. The older soils in the Las Cruces area have greater values probably because $CaCO_3$ accumulation is greater at Las Cruces than at NTS.

Table 4. Comparison of soil profile index values for the study area and Las Cruces, New Mexico.

AGE			INDEX VALUES				
			This Study		Las Cruces	Four Best Properties	
This Study	Las Cruces						
log Age	Age		Pale-light[1]	Rub-light[2]	Pale-light[1]	This Study[3]	Las Cruces[4]
2.18	150 yrs	--	<5	<5		<5	
4.00	10 ka	4-20 ka	6-21	9-32	5-41	9-33	4-35
5.18	150 ka	120 ka	23-38	29-41	22-26	23-39	24-31
5.48	300 ka	290 ka	26-42	31-49	1-56	30-54	29-95
6.18	1.5 my	>500 ka	27-64	38-74	>43	49-83	>110

[1] all properties ten including color paling and color lightening
[2] all properties ten including rubification and color lightening
[3] dry consistence, structure, color lightening, rubification
[4] dry consistence, structure, color lightening, color paling

Accumulations of Carbonate, Clay, Silt, and Opaline Silica

The influence of age and climate on soils can be evaluated based on trends in the accumulation of pedogenic $CaCO_3$, clay, silt, and opaline SiO_2 (Gile and others, 1979 and 1981; McFadden, 1982; Machette, 1985). The amounts of these pedogenic constituents can be determined by deducing the initial amount in the soil parent material from that in the present soil.

Method to Calculate Rates of Accumulation

Trends in soil constituents are best when expressed on a mass basis. Secondary accumulation of all constituents can be computed in gm in a vertical column of $1cm^2$ area for the <2mm fraction, for each horizon according to equation 3.1.

Equation (3.1)

$$P = ([(\%P)(BD)_{present} - (\%P)(BD)_{PM}]thickness)(\%<2mm)$$

where P = pedogenic property, BD = bulk density, and PM = parent material.

The profile sum is calculated by summing the horizon values through the profile (Fig. 8), and rates of accumulation are computed by dividing the estimated age into the average profile sum for a unit (Fig. 9). Predicted profile sums are the average $gm/cm^2/10^3$ yr rate for a given unit converted to a yearly number, and multiplied by the soil age (Appendix H). Predicted profile sums are used to check the age assignment on a given unit.

Rates of Accumulation of $CaCO_3$, Clay, Silt, and Opaline SiO_2

Profile sums suggest that $CaCO_3$, clay, silt, and opaline SiO_2 accumulated at a logarithmic rate (Fig. 8). All r^2 values were highest when the log age regression model was used (Table 5). However, these logarithmic rates may be a function of the erosion and soil loss on the older surfaces, and the complete volume of these constituents may not be measured. The long term rates in fact, for properties dependent primarily on eolian additions is probably better expressed as a linear rate.

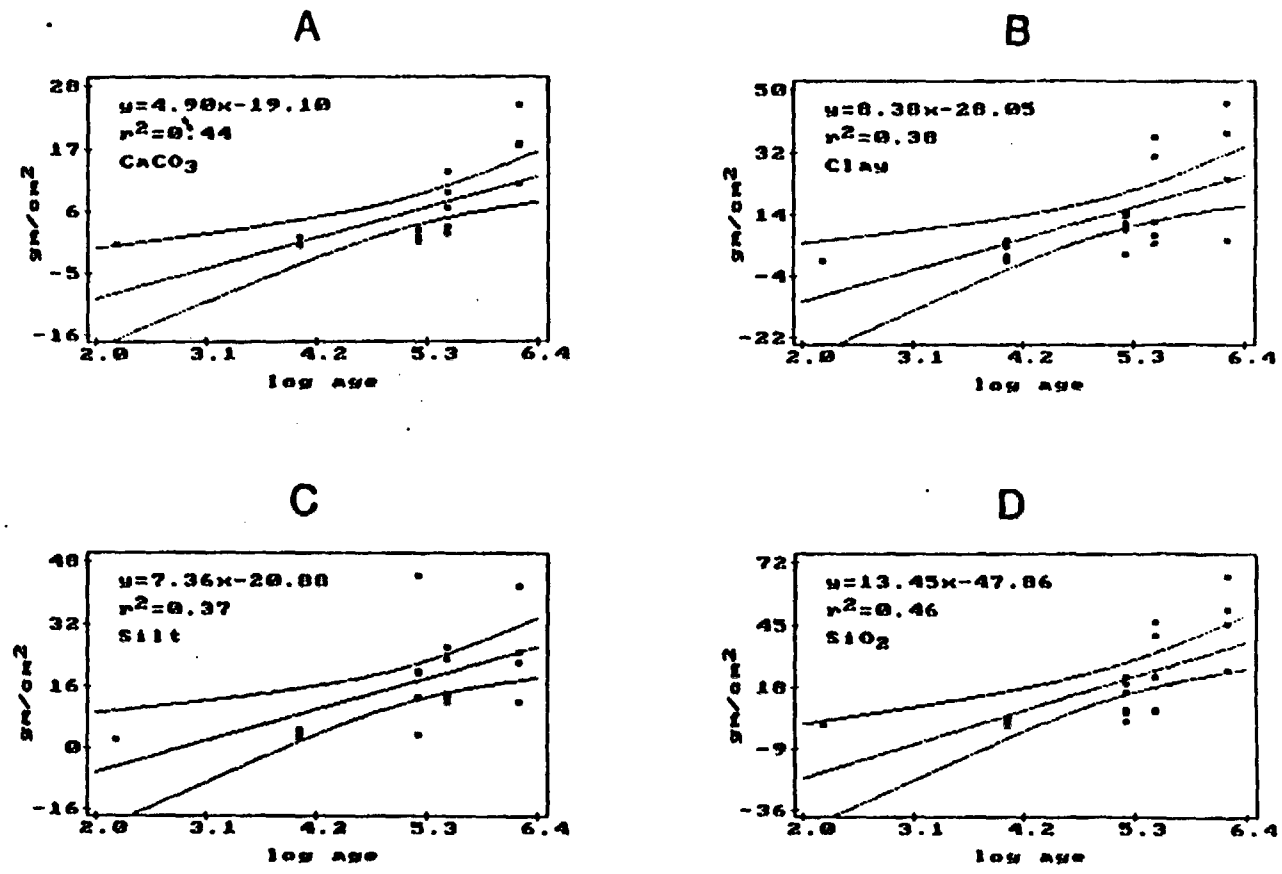


Figure 8. Profile sum of horizon weights vs age for pedogenic $CaCO_3$ (A), clay (B), silt (C), and opaline SiO_2 (D) on soils developed on stratigraphic units Q1c ($10^{4.0}$), Q2b ($10^{5.18}$), Q2c ($10^{5.48}$), and QTa ($10^{6.18}$).

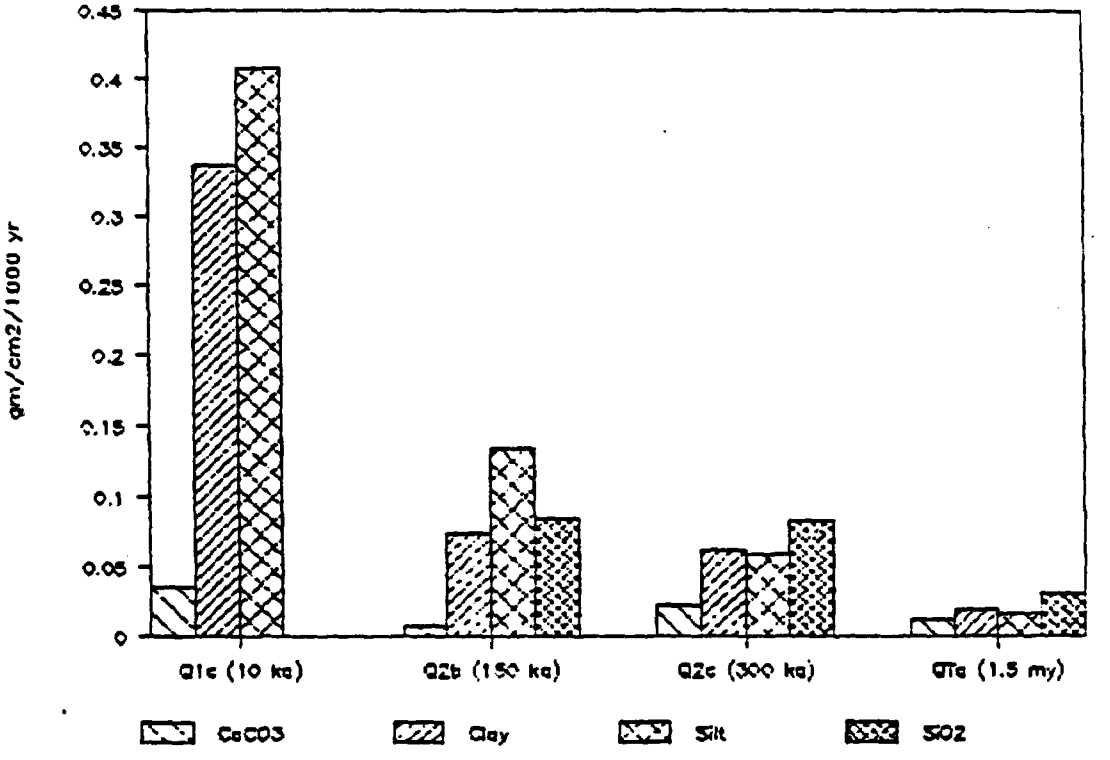


Figure 9. Average rates of accumulation of pedogenic $CaCO_3$, clay, silt, and opaline SiO_2 (profile sums divided by age) based on profile weight sums, on soils developed on stratigraphic units Q1c, Q2b, Q2c and QTa.

Table 5. Correlation coefficients (r^2) for $CaCO_3$, clay, silt, and opaline SiO_2 profile sums vs. linear age and log age. Critical value for r^2 at a 5% probability level is 0.42, and at 1% is 0.54.

	linear age	log age
$CaCO_3$	0.39	0.44
Clay	0.12	0.38
Silt	0.02	0.37
SiO_2	0.23	0.46

Holocene to late Pleistocene soils (Qlc) accumulate $CaCO_3$, clay, and silt at a higher average rate than the older soils. For example, $CaCO_3$ accumulation decreases from an average rate of 0.04 $gm/cm^2/10^3yr$ during the Holocene to 0.01-0.03 $gm/cm^2/10^3yr$ in the older soils (Fig. 9). Clay and silt accumulation rates on the Qlc deposits are considerably higher than on the older deposits. Deposits Q2b and Q2c are the best estimates of long term average rates of accumulation of $CaCO_3$, clay, silt, and opaline SiO_2. The gently rolling topography of QTa is less stable than the younger deposits. The low rates for all four properties on QTa are a result of the erosion which has formed the ballena topography. The loss of soil results in calculated low accumulation rates (Appendix J).

There are several sources for the $CaCO_3$, clay, silt, and opaline SiO_2 accumulations in soils. One source is due to weathering and (or) translocation of a constituent in place. Pedogenic opaline SiO_2 forms this way as may some clays. A second source is atmospheric additions, either as ions in solution (in the case of Ca^{++}) or as solid dust particles (clay, silt, and some $CaCO_3$) (Gile and others, 1979).

A generalized model for $CaCO_3$, clay, silt, and opaline SiO_2 accumulation rates is that the rates vary with climate. During interglacials (7,000-20,000 yrs duration) rates are rapid because increased aridity, decreased vegetation cover, and exposed playa surfaces, all contribute to increased airborne transport. Greater areas are exposed and wind has better access to it, resulting in greater accumulation rates. In contrast increased vegetation and more effective precipitation of glacial climates (100,000-150,000 yrs duration) could result in comparatively slow rates of accumulation. Yet another factor is having sufficient precipitation to move atmospheric materials into the soil. For example, accumulation rates of pedogenic $CaCO_3$ in the Mojave Desert during the Holocene are characterized by Machette (1985) as climate or precipitation-limited, suggesting that soils may be accumulating material slower now than in the late Pleistocene because of the lack of sufficient precipitation to move material into the soil via soil-water movement. Therefore during glacial climates there is less available eolian material, but greater precipitation to translocate the material, and during interglacial climates insufficient precipitation to translocate the available eolian dust. Accumulation rates could be the same in both climates, or different.

Carbonate rates of accumulation in the study area are extremely low compared to rates calculated by Machette (1985) for the Vidal Junction area, which has a climate similar to that of the study area. The rates also vary with age of stratigraphic unit in the study area (Fig. 9). However, if the Qlc soils actually range in age for 5 to 40 ka, then these reputed Holocene rates may be too

high. If an age of 5,000 yrs is assumed, the rate for $CaCO_3$ accumulation would be 0.08 $gm/cm^2/10^3$ yr, and if an age of 40,000 yrs is assumed, the rate would decrease to 0.01 $gm/cm^2/10^3$ yr. Both rates fall within the range of long term rates. In either case, the decrease in precipitation associated with the climatic change at the Holocene-Pleistocene boundary was not enough to significantly decrease the already extremely low rate of $CaCO_3$ influx. In fact, similar rates of carbonate accumulation during the Holocene and pre-Holocene may suggest that the climatic change was the result of decreased temperatures and not precipitation.

Rates of accumulation of clay and silt respond the same way as $CaCO_3$ to changes in age assessment on the Qlc deposit. If Qlc is estimated to be between 5-40 ka, the rates still remain higher than the long term rates calculated on the older deposits (Fig. 9). For clay the range of accumulations rates is between 0.7-0.09 $gm/cm^2/10^3$ yr, and for silt between 0.8-0.1 $gm/cm^2/10^3$ yr on the Qlc deposit. The long term rate for clay is 0.08-0.07 $gm/cm^2/10^3$ yr, and for silt 0.13-0.06 $gm/cm^2/10^3$ yr. This suggests that precipitation since the stabilization of Qlc is not a limiting factor, and that clay and silt are not being accumulated slower during the Holocene than during glacial climates. This supports the $CaCO_3$ accumulation data that the climatic change was not enough to significantly decrease rates of accumulation.

Rates of accumulation of opaline SiO_2 remain relatively constant over time at about 0.08 $gm/cm^2/10^3$ yr. There is little or no opaline SiO_2 to be measured for the Qlc deposits.

Machette (1985) proposes that it is reasonable to use average profile $CaCO_3$ content of relic soils between about 100,000 and 150,000 yrs old to estimate the ages of still older calcic soils in the same chronosequence. Soils in this age range have experienced a number on glacial-interglacial climatic cycles. Age estimates of soils younger than 100,000 yrs may also be made, but they may be less precise. In this study, no unit for any property consistently best estimated the age.

In the study area a number of different rates for a given property were used to calculate an estimated profile sum (Appendix J). The difference between the estimated sum and the actual profile sum was calculated. The amount of time to account for the difference was then computed. For example, for deposit Q2c the average profile sum is 6.80 gm/cm^2, but the estimated profile sum is 3.0 gm/cm^2 (0.01 $gm/cm^2/10^3$ yr, the long term rate, X 300,000 yrs). At a rate of 0.01 $gm/cm^2/10^3$ yr it would take 380,000 yrs to accumulate the difference (6.80-3.0=3.80 gm/cm^2). This discrepancy is either (1) an age error of 100%, (2) accumulation rates are off by one half for that age range, this may be accounted for by erosion on deposits that the long term rates are calculated from or (3) represents additions of about two times the potential $CaCO_3$ on the Q2c deposits used in this example.

Depth Functions of Significant Soil Properties

Soil properties that commonly exhibit change with time and (or) climate include clay, $CaCO_3$, and opaline SiO_2. Most of these properties are also strongly influenced by vertical position in the

soil profile, as illustrated for some properties of soils in the Yucca Mountain area (Figs. 10-13).

Soils exhibit increases in clay, $CaCO_3$, and opaline SiO_2 over time. Pedogenic change can be better examined by converting these properties to horizon weights. Pedogenic clay clearly increases with time, although $CaCO_3$ and opaline SiO_2 have higher correlation coefficients with the age of the deposit (Table 6). With the exception of soils formed on deposits of Q2c age, clay, $CaCO_3$, and opaline SiO_2 maximums occur in the same horizon (Figs. 10-13). On Q2c deposits the maximum occurrence of pedogenic clay is immediately above the maximum occurrence of pedogenic $CaCO_3$ and opaline SiO_2. In nearly all soils formed in all deposits, the maximum $CaCO_3$ and opaline SiO_2 occur in the same horizon, and there is more opaline SiO_2 than $CaCO_3$.

Table 6. Correlation coefficients (r^2) for linear age, log age, $CaCO_3$, clay, and opaline SiO_2 for A, B and K, and C horizons, and all horizons combined. No significant opaline SiO_2 was measured on A and C horizons. Critical values for r^2 at the 5% probability level are 0.35 for A horizons, 0.18 for B and K horizons combined, 0.37 for C horizons, and 0.14 for all horizons combined.

	A C	B & K all	A C	B & K all	A C	B & K all	A C	B & K all
	linear age		log age		$CaCO_3$		Clay	
$CaCO_3$	.55	.49	.43	.42				
	.58	.43	.42	.26				
Clay	.21	.44	.18	.42	.40	.55		
	.11	.37	.49	.34	.30	.58		
Opaline SiO_2	-	.52	-	.47	-	.75	-	.85
	-	-	-	-	-	-	-	-

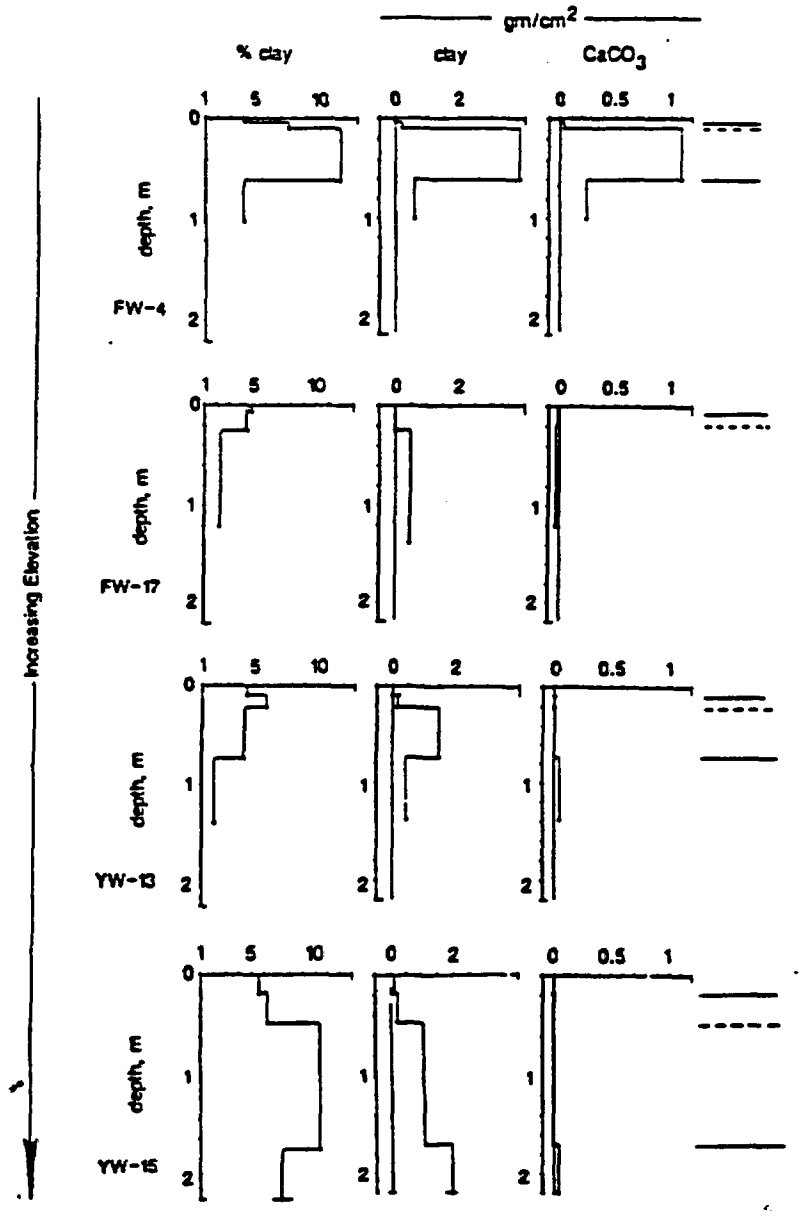


Figure 10. Depth plots of pedogenic clay, $CaCO_3$, and opaline SiO_2 in soils developed on unit Qlc. Lines on the far right represent major horizon and depositional boundaries: solid lines are for A-B or K-C horizons, dashed lines are for depositional boundaries.

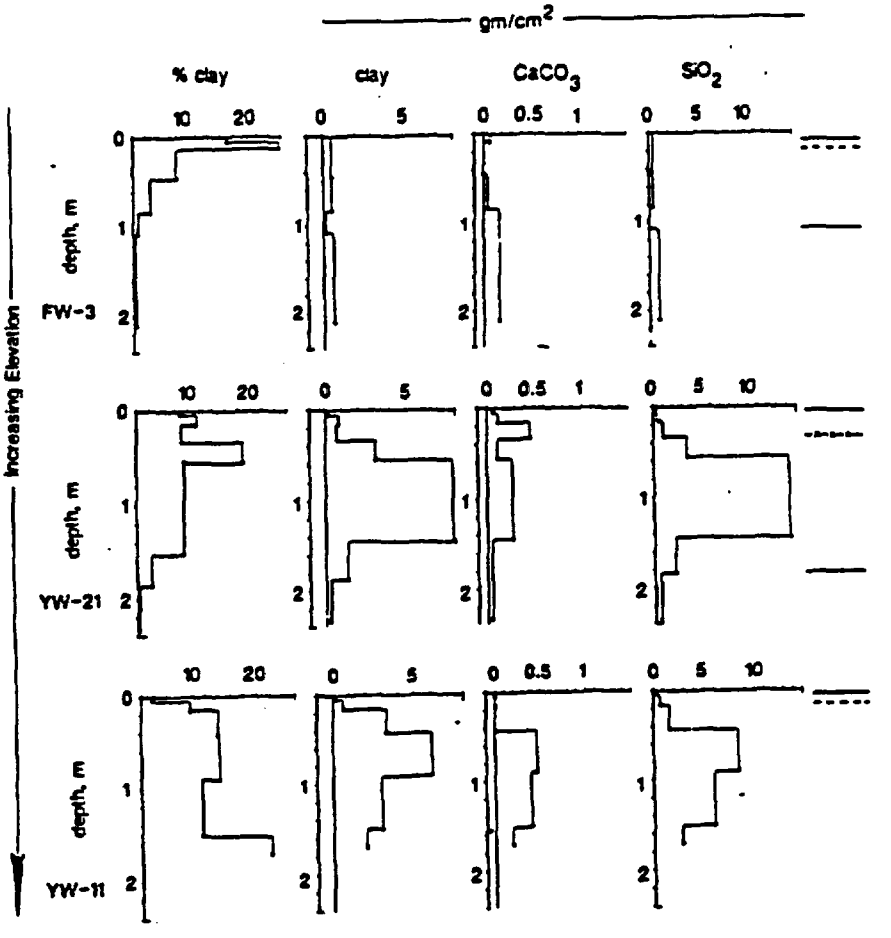


Figure 11. Depth plots of pedogenic clay, $CaCO_3$, and opaline SiO_2 in soils developed on unit Q2b. Lines on the far right represent major horizon and depositional boundaries: solid lines are for A-B or K-C horizons, dashed lines are for depositional boundaries, and dashed lines with x's are for buried soils.

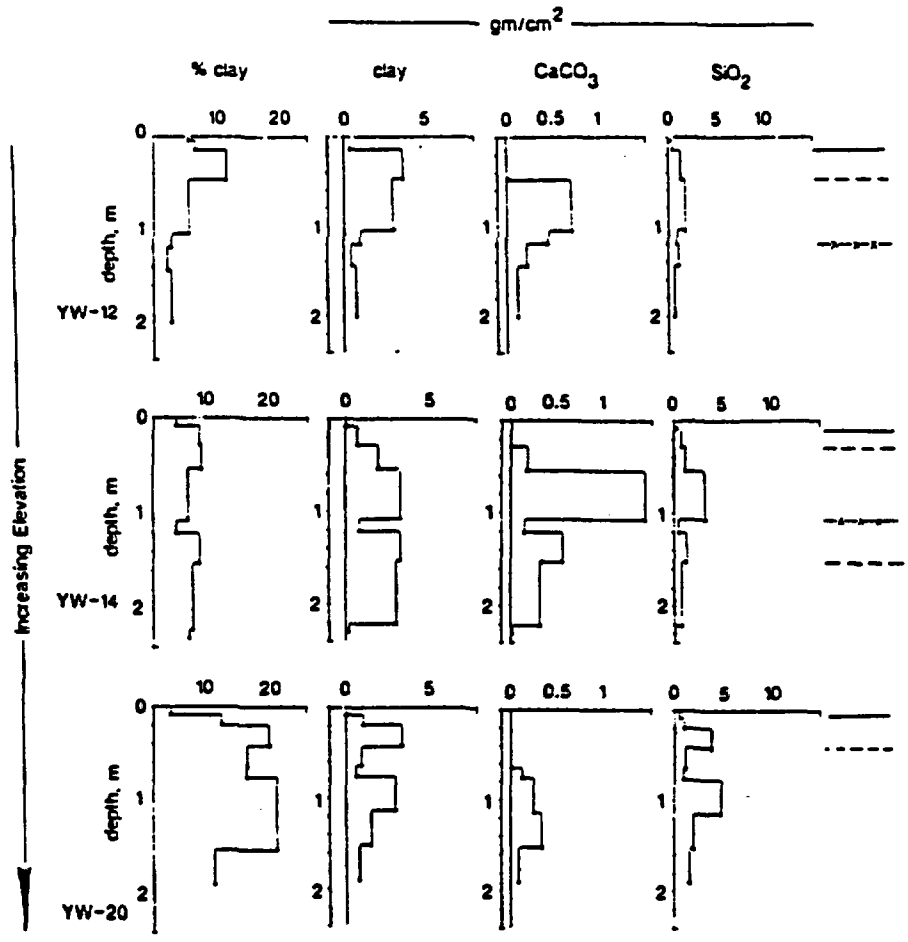


Figure 11 continued. Depth plots of pedogenic clay, $CaCO_3$, and opaline SiO_2 in soils developed on unit Q2b. Lines on the far right represent major horizon and depositional boundaries: solid lines are for A-B or K-C horizons, dashed lines are for depositional boundaries, and dashed lines with x's are for buried soils.

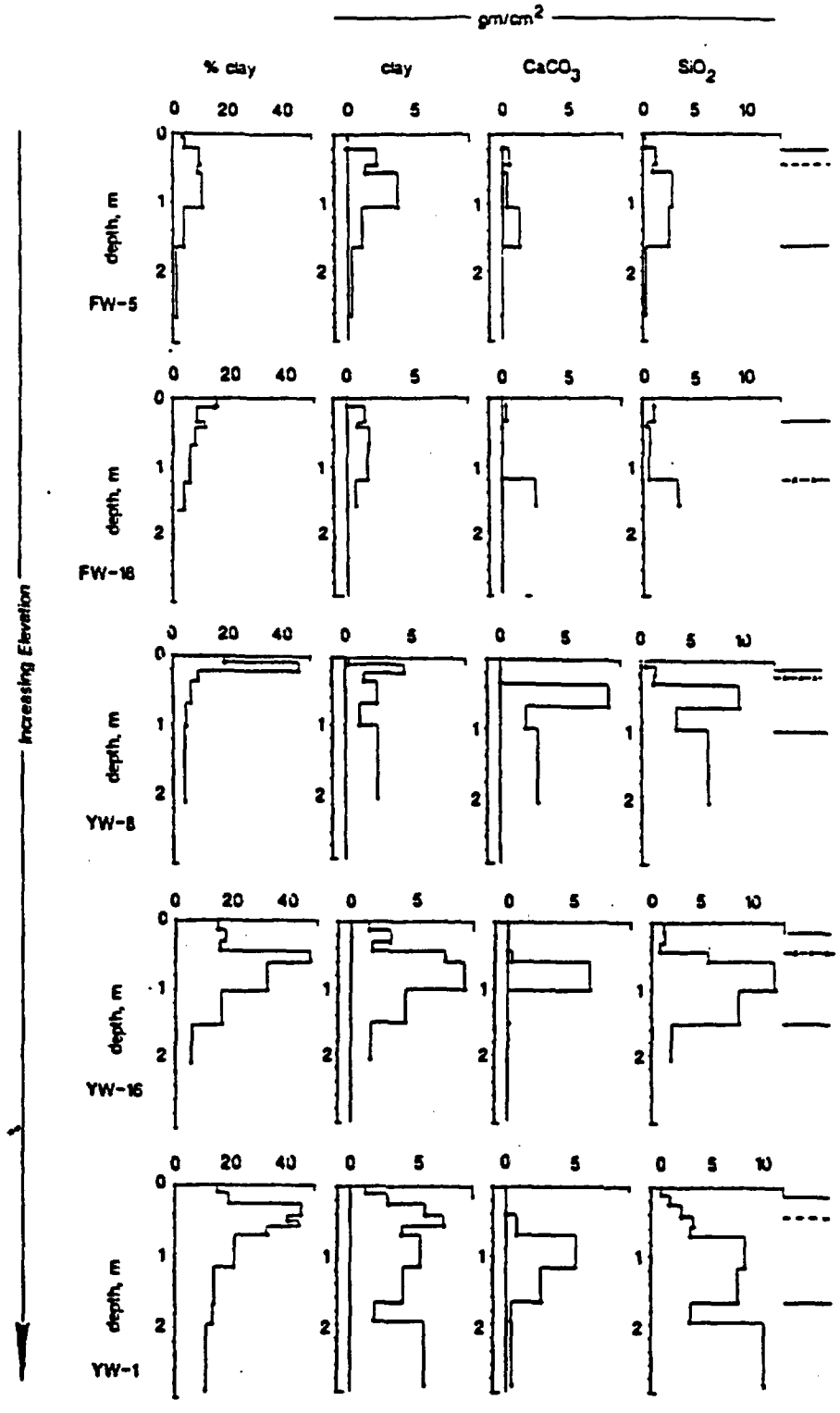


Figure 12. Depth plots of pedogenic clay, $CaCO_3$, and opaline SiO_2 in soils developed on unit Q2c. Lines on the far right represent major horizon and depositional boundaries: solid lines are for A-B or K-C horizons, dashed lines are for depositional boundaries, and dashed lines with x's are for buried soils.

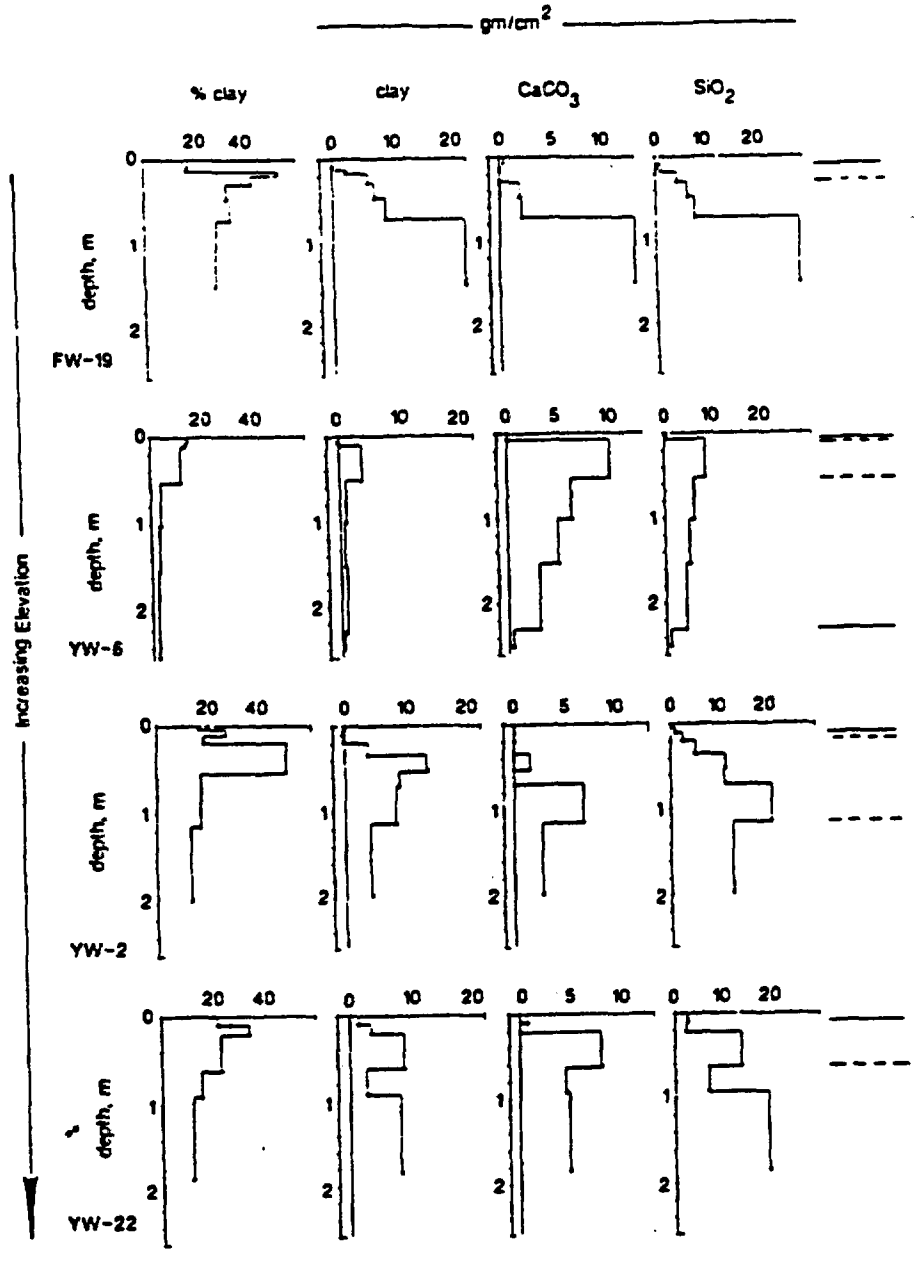


Figure 13. Depth plots of pedogenic clay, $CaCO_3$, and opaline SiO_2 in soils developed on unit QTa. Lines on the far right represent major horizon and depositional boundaries: solid lines are for A-B or K-C horizons, dashed lines are for depositional boundaries, and dashed lines with x's are for buried soils.

Primary and Secondary Minerals Identified by X-ray Diffraction

Quartz, feldspars (primarily plagioclase and orthoclase), and dolomite are the dominant minerals in the parent material sand and silt fraction, and they also appear in the clay fraction. Quartz is the dominant peak in most X-ray diffraction (XRD) traces. The following clays were identified in the soils: tobermorite, weathered mica, a mixed layer group of minerals, and kaolinite (Table 7). There is also XRD evidence for amorphous silica.

Tobermorite [$Ca_5(Si_6O_{18}H_2)\cdot 4H_2O$] is a hydrated calcium silicate found in cement, and rarely occurs in nature (Taylor, 1950; Heller and Taylor, 1951). It has a 2:1 layer structure similar to that of vermiculite (Megaw and Kelsey, 1956; Hamid, 1980), with minor variations in structure due to the chemical composition. Tobermorite displays a sharp peak at 11.6Å when untreated, which shifts to 10.4Å when glycolated (Fig 14). Although it is always reported to shift to 9.35Å when heated to 300°C and collapse at 800°C (Taylor, 1959), in these and other soil samples (Reheis, 1984) it is completely destroyed by heat treatment, and when pedogenic opaline SiO_2 is chemically removed (Appendix D). It has cation-exchange and selectivity properties intermediate between those of clay minerals and zeolites (Komarneni and Roy, 1983). Wollastonite is the stable phase resulting from the destruction of tobermorite at 800°C.

Tobermorite is usually found in zones of intense hydrothermal alteration (Heddle, 1880; McConnell, 1954; Harvey and

Table 7. Clay Minerals Identified and their Diagnostic Features

Clay Mineral	TREATMENT						Probable Source
	Air Dry	I 1/	Glycolated	300°C	500°C	Silica Removed	
Tobermorite	11.3-11.4 2/ (002)	s	10.6	d 3/	d	d	parent material and pedogenic
Weathered Mica	10.2-10.3 (001)	m-w, b	nc 4/	nc	nc	nc	pedogenic
Mixed Layer	10.5-12.0 (001)	b	nc	nc	peak intensifies (s)	nc	pedogenic
Kaolinite	7.1-7.3 (001)	s-w, b	nc	nc	d	nc	parent material

1/ Intensity of Peak: s, strong or sharp spike; m, moderate spike; w, weak spike; b, broad or spread out.

2/ All values are in Å.

3/ d, peak disappeared

4/ nc, no change in peak intensity or width.

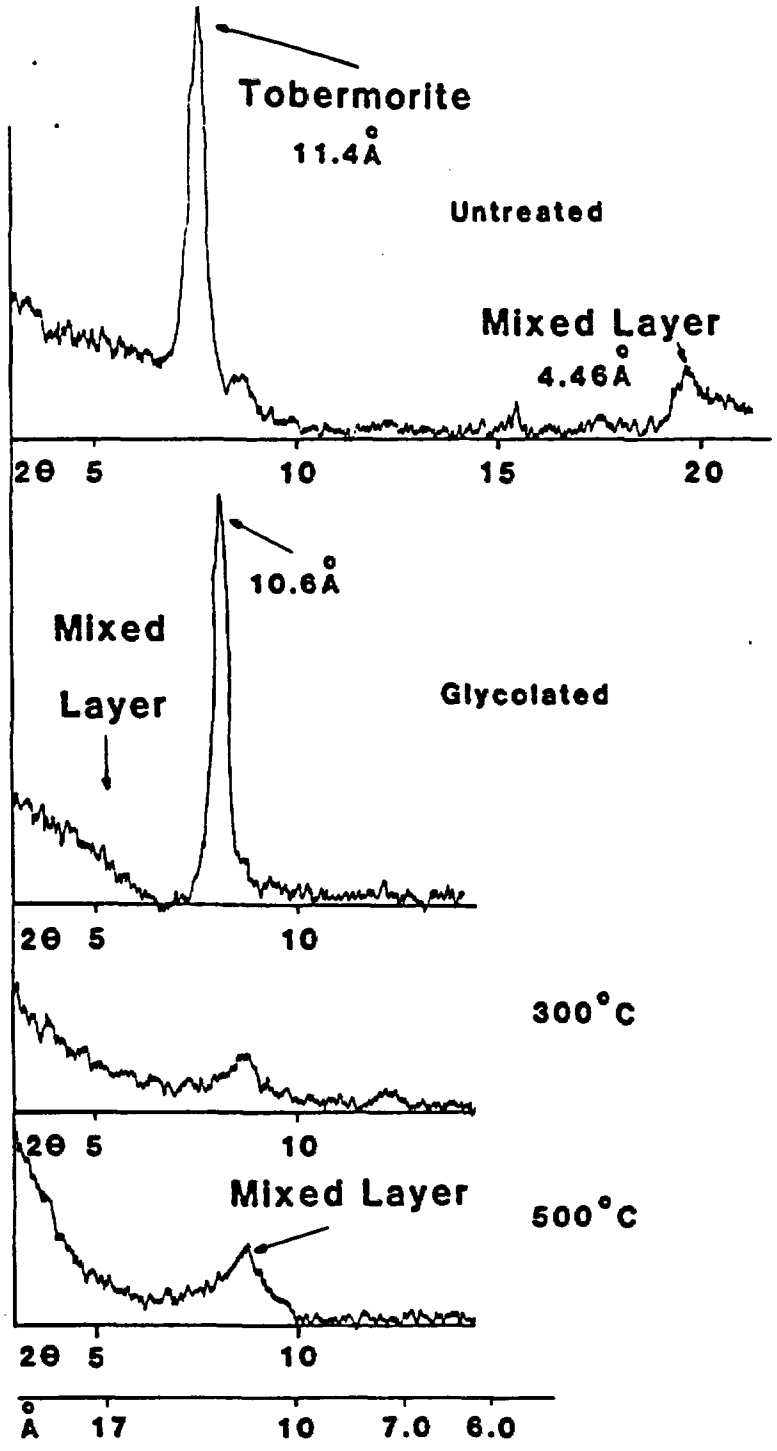


Figure 14. Representative XRD traces of tobermorite and mixed-layer clays: untreated, glycolated, and heated traces.

Beck, 1960; Gross and others, 1967: Webb, A. B., 1971; Kusachi and others, 1984). It has also been reported in contact metamorphic limestones (Eakle, 1917). In some cases it is completely replaced by calcite. In all cases tobermorite is of secondary origin. Reheis (1984) reported the presence of tobermorite in Montana soils, that it was pedogenic in origin, and that the amount increased with age.

Tobermorite with an 11Å primary peak has been synthesized hydrothermally and at low temperatures from many different starting materials such as mixtures of lime or portland cement with either quartz or amorphous silica (Heller and Taylor, 1951; Mitsuda, 1970; Snell, 1975; Mitsuda and Taylor, 1978; Komarneni and Roy, 1983).

It is difficult to know whether the source of the tobermorite is from the parent material (Harvey and Beck, 1960), or formed in place. In the soils studied, tobermorite tends to be most abundant in two places: (1) at the surface where eolian materials are abundant, and (2) at depth in horizons with the greatest amount of secondary opaline SiO_2 and $CaCO_3$ in older soils developed on deposits Q2c and QTa. The origin of tobermorite at the surface seems to be from the eolian materials, but that at depth could be pedogenic and formed in place.

Weathered mica has a poorly defined broad peak (10.0 Å) and is not effected by glycolation or heat treatment (Appendix D). Upon heat treatment the peak intensifies.

Mixed-layer illite-montmorillonite clays are recognized by distinct shoulders on diffraction peaks at about 10.5 or 12 Å, suggesting incipient, poorly developed intergrades of layer-lattice

clays (Vanden Heuvel, 1966). The intensity and consistency of the high order (004) 4.5Å peak, and low-2θ angle background levels, reflects random interstratification common in a weathering environment (Jones, 1983). Because of the complete collapse of smectitic layers at 500°, this treatment produces a sharp, well-defined peak at 10.2Å that is the mixed layer clay minerals (Figs. 14). These mixed-layer clay minerals are common in volcanic parent materials in southwestern Nevada (Jones, 1983).

Kaolinite (7.2 Å) in the study area is poorly crystalline, with a low height to width ratio (Appendix D). Because the same peak appears in most samples including unweathered alluvium, it is likely that it is derived from the parent material.

Palygorskite (10.7Å and 5.4Å) and sepiolite (12.3Å and 2.68Å) were never identified even though they are abundant in calcic soils in the southwestern U.S. (Vanden Heuvel, 1966; Gardner, 1972; Bachman and Machette, 1977; Hay and Higgins, 1980; Jones, 1983). Most of the above workers attribute the formation of palygorskite and sepiolite to the alteration of detrital mixed-layer illite-montmorillonite. The one speculation that can be made for the absence of these Mg-rich silicate clay minerals is that Ca-rich silicates (tobermorite) may form preferentially in this environment.

Amorphous silica can be identified on the XRD traces (Table 8, Figure 15). Jones and Segnit (1971, 1972) have subdivided opaline SiO_2 (poorly crystalline naturally occurring hydrous silica with >1% water) into three classes based on XRD and the amount of disorder of crystal stacking. In order of increasing amorphous

Table 8. X-ray Diffraction Classification of Opaline Silica (Jones and Segnit, 1971).

Classification	Temperature of Formation	Environment of Formation	Source in Soil Environment	XRD Peaks (Å)
Opal-C	high	lava flows.	parent material	4.0, 2.5, and 2.8
Opal-CT (most common)	low	silica associated with secondary clays, biogenic skeletons, volcanic ash, and infrequently gem-quality opal.	primarily pedogenic	4.3, 4.1, 3.9, and 2.5 definition and spacing is variable based on order, water content, and age.
Opal-A	low	gem-quality opal, biogenic skeletons, material and volcanic ash, silica gels, and some silica associated with clays.	parent material ane pedogenic	diffuse peak centered at 4.1

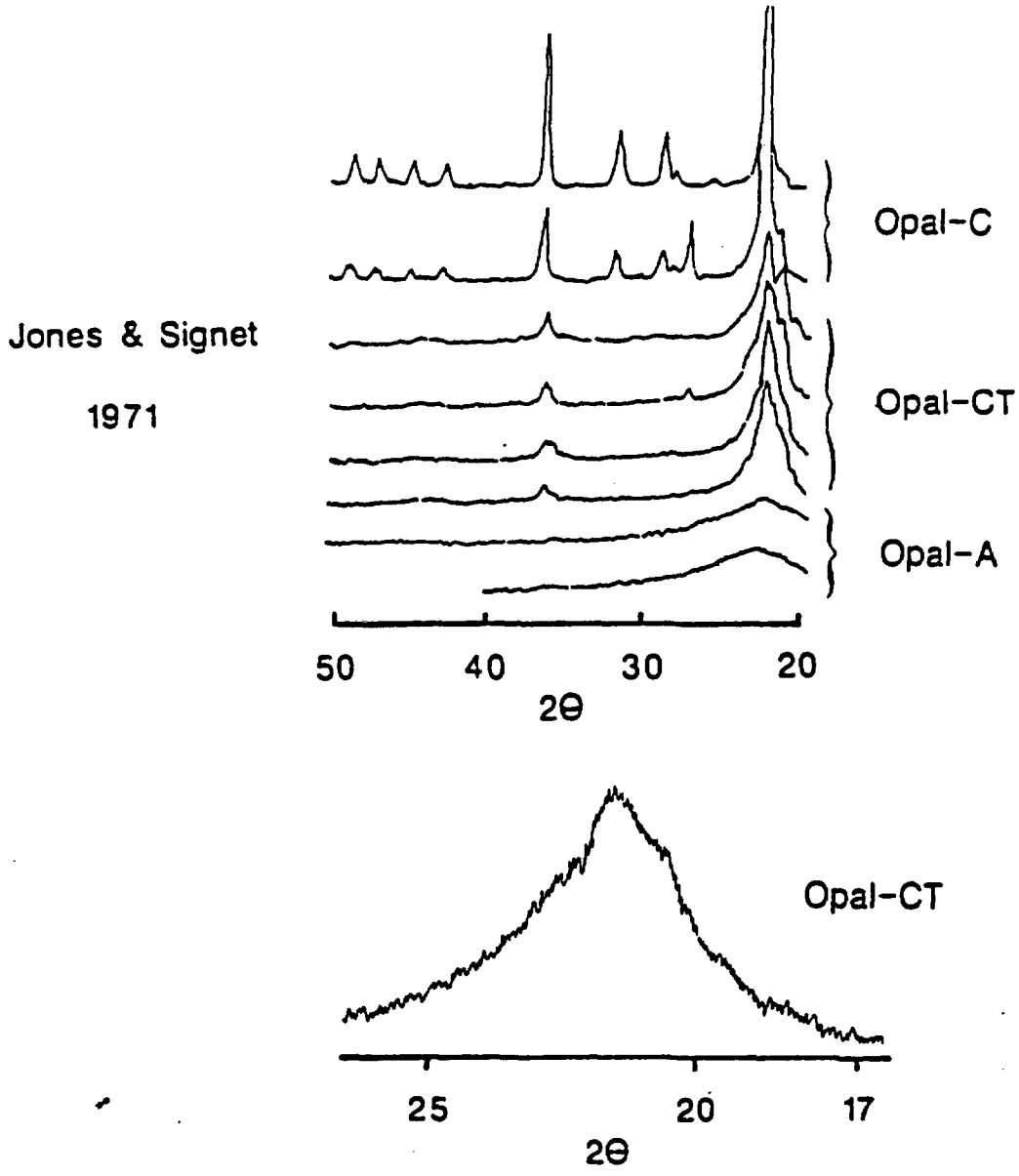


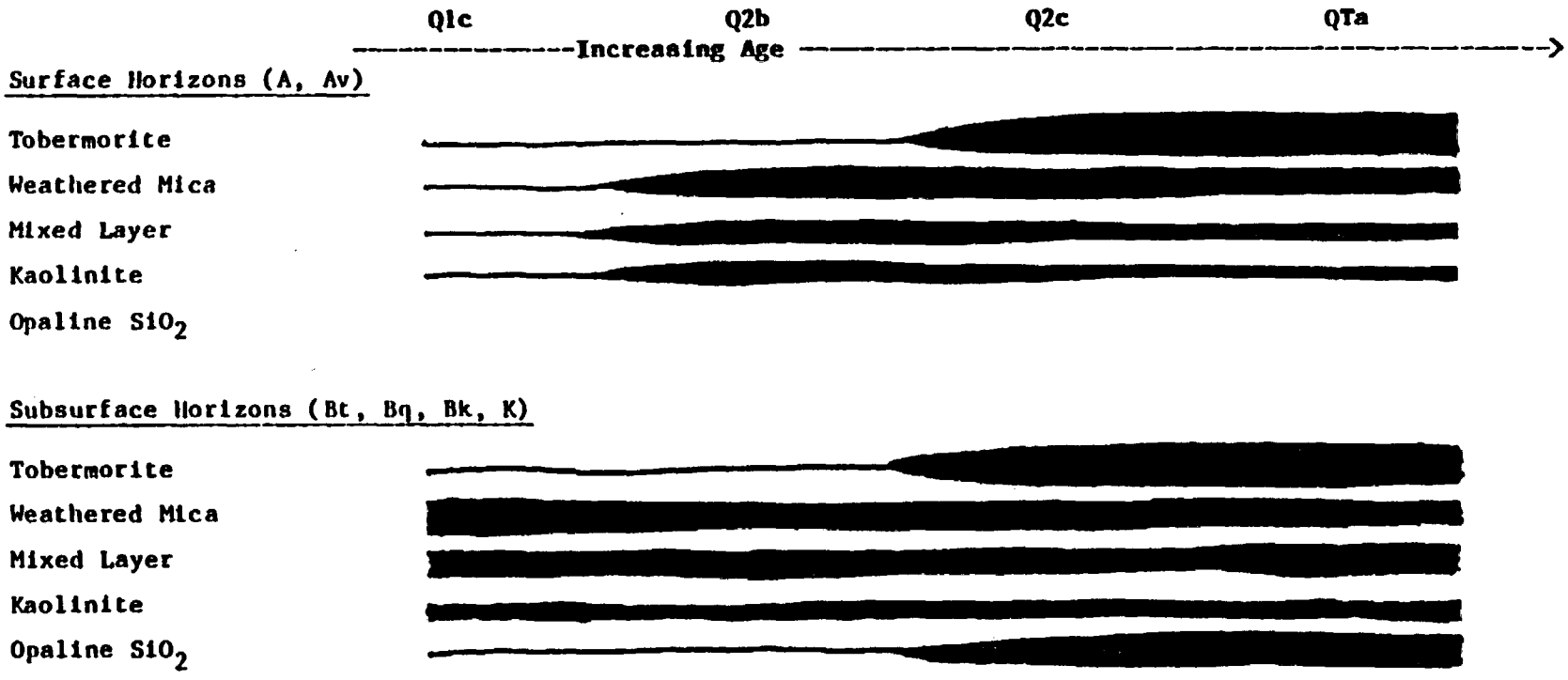
Figure 15. Representative XRD trace of Opal-CT vs the three opal classes of Jones and Signet (1971).

state they are Opal-C, Opal-CT, and Opal-A. Each is associated with a unique environment of formation (Jones and Segnit, 1971).

Diffractograms of several of the mixed-layer illite-smectite-dominated soils do have broad, but sharply spiked peaks centered between 4.1-4.3Å, suggesting the presence of Opal-CT (Figure 15). Peaks are not effected by heat treatment, but are absent after pedogenic silica is removed.

The clay mineralogy and relative abundance is strongly related to the climate, but also changes with the time and with depth in the profile (Birkeland, 1974 and 1984). Time-related changes in clay mineralogy are related to the stability of the various clays in the local soil environment, however Birkeland (1974 and 1984) believed that the clay minerals of soils developed in low-clay parent material change little with time. The uniformity of the clay minerals present in the study area suggest the latter, that there has been little change in either environment or in the mineralogy over time. However, the relative abundances have increased (Fig. 16).

Figure 16. Relative abudance of clay minerals on the soils formed on deposits Q1c, Q2b, Q2c, and QTa. Width of bars equals approximate abundance.



CHAPTER IV

USING SOIL DATA TO ASSESS PALEOCLIMATE

Soil Water Balance and Leaching Index

The relationship between soils and climate can be approximated by evaluating soil water balance and leaching indices (Arkley, 1963, 1967). If the available water-holding capacity (AWC) of a soil is known, the amount of water that will potentially percolate through each soil horizon or depth increment can be calculated. Sometimes the word recharge is used by pedologists instead of percolation, but to clearly distinguish between the hydrologic application of recharge, I use percolation. Knowing the frequency of wettings per year, and assuming (a) that downward movement of water takes place only when field capacity for that part of the soil has been reached, and (b) that moisture is removed from the soil by evapotranspiration until the permanent wilting point is reached, one can construct curves depicting water movement (Arkley, 1963; Birkeland, 1984). In order to forecast soil water movement it is necessary to know the precipitation (P) and approximate potential evapotranspiration (ET_p). ET_p is the amount of water lost by evaporation and vegetative transpiration as long as sufficient soil moisture is available (Thornthwaite, 1948).

Water balance calculations predict the status of soil moisture on a mean annual basis. Critical to this study are those months when water is stored in various depths in the soil at moisture values above permanent wilting point; this happens when P is greater than ET_p. This water is available for plant growth, weathering reactions, and if the water is moving, it can translocate dissolved or solid material within the soil. In contrast, water is lost from the soil system when $P<ET_p$ until the soil reaches water contents approaching permanent wilting point. One of the key elements to this approach is to get an accurate measurement of ET_p

Seven methods of calculating ET_p show a wide range of values (Table 9). All are based on empirical formulas. Of the Penman (1956) and Ritchie (1982, Williams, 1984) methods to calculate ET_p, the latter is recommended by the Soil Conservation Service; these were estimated from data in similar climatic regions, because of the lack of necessary data. The methods were selected because they compare favorably with lysimeter measurements in arid regions (Stanhill, 1961; Omar, 1968; McGuinness and Bordne, 1972; Farnsworth and others, 1982).

Pan evaporation data for the growing season only (Apr-Oct) from Pahrump, Nevada, about 30 km south of Yucca Mountain, are used here as a reasonable approximation of ET_p. Pan evaporation data come closest to the lysimeter-derived measurements of 150-200 cm from similar arid regions. Nevada currently has only four stations that measure pan evaporation, and Pahrump (203 cm/yr) is the nearest such station to NTS. Longer term pan evaporation records exist for Boulder City, adjacent to Lake Mead, but because of its proximity to

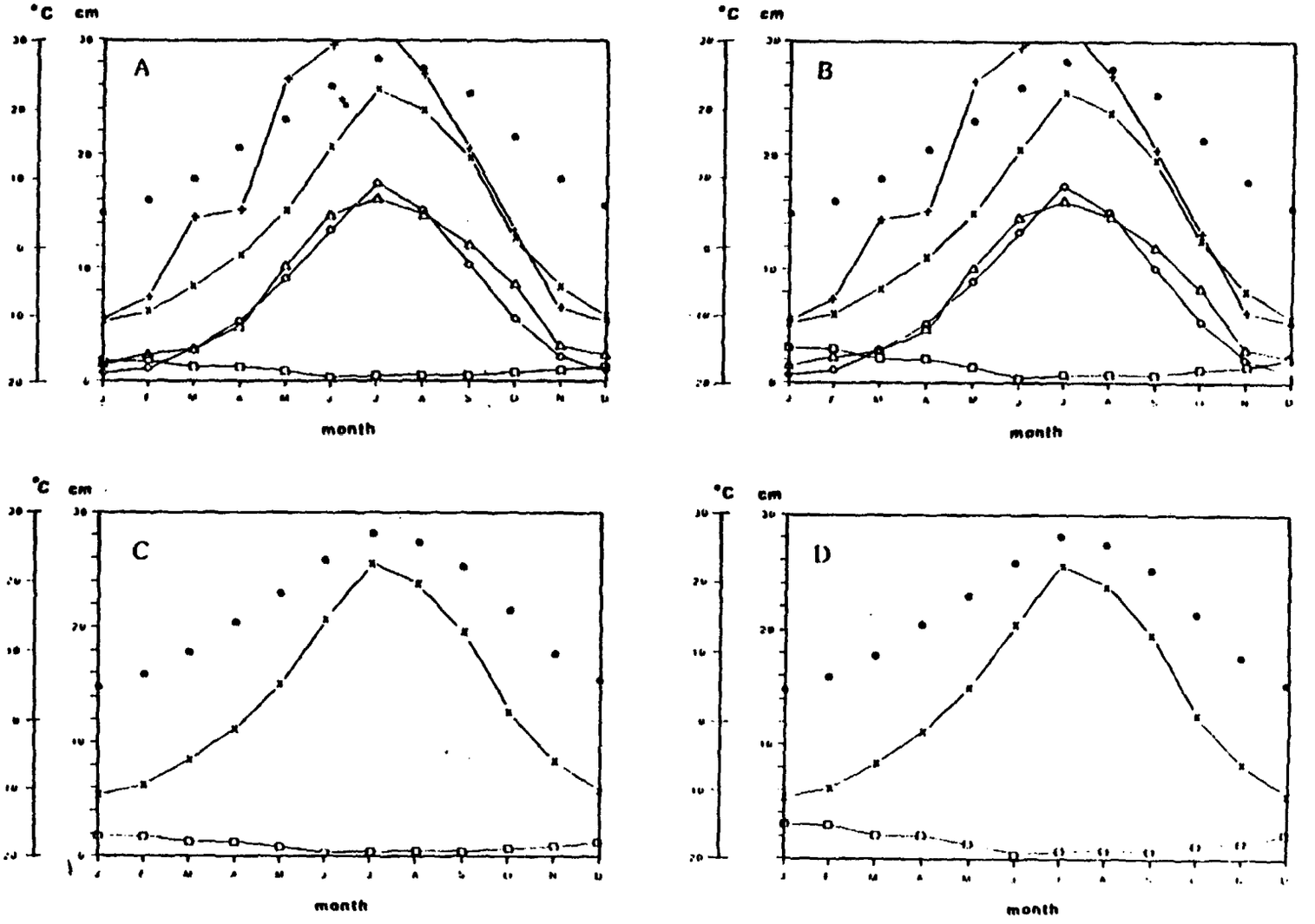
Table 9. Comparison of methods to calculate potential evapotranspiration using Beatty, Nevada weather information (Table 2).

Method and Calculated Annual ET_p Variables	Limitations
1) Thornthwaite (1948) - 84 cm latitude mean monthly temperature (T) day length factor	Underestimates in an arid environment by as much as 150%.
2) Blaney & Criddle (1962) - 94 cm latitude mean monthly T % daytime hours vegetation consumptive use coefficient	Underestimates in an arid environment, and vegetation factor must estimated for nonirrigated soil.
3) Penman (1956) - ~100 cm mean monthly T mean monthly min T daily solar radiation wind movement (mi/day)	Limited number of solar radiation stations, and a large amount of error in wind movement data due to variability in height of monitoring stations.
4) Ritchie (1972), Williams (1984) - ~100 cm mean monthly maximum and and minimum T daily solar radiation and albedo soil cover and biomass indices	Same as Penman, and data are not available for most areas
5) Kohler, Nordenson and Fox (1955) - 127 cm mean monthly T mean water surface T wind movement (mi/day) pan evaporation	Data are not always available.
6) Pan Evaporation for the growing season only (Apr-Oct) - 164 cm cm of water loss	Data are sparse, may overestimate amount due to the influence of wind, and assumes no ET during cold months.
7) Papadakis (1965) - 163 cm saturation vapor pressure and dew point that can be derived respectively from the mean monthly maximum and minimum T	May overestimate amount

the lake, the pan evaporation values are extremely high compared to lysimeter-derived measurements from areas similar to NTS. The average monthly long term values for pan evaporation from Pahrump was summed for the growing season only, April to October (164 cm), because it is assumed that little or no evapotranspiration occurs during the winter months. The Papadakis method for estimating ET_p is used in this study because it best approximated the pan evaporation data summed for the growing season only from Pahrump.

Water budget plots for several different climatic models for the study area indicate significant soil-moisture differences between glacial and interglacial climates. The data for Beatty (Table 2) is used to approximate the Holocene climate (Fig. 17) and two different models for climates during the last glacial maximum are presented (Figs. 18 and 19). The climatic models for the glacial maximum are (1) Spaulding's (1983 and 1985) with a decrease in MAT of 7°C, an increase MAP of 35%, and a decrease in summer precipitation of 50% and (2), Mifflin and Wheats' (1976) with a decrease in MAT of 5°C, an increase of MAP of 68% and, a decrease in evaporation of 10% (Table 2). These three climatic conditions were evaluated at the low end of the elevation transect, and again at the high end where the modern climate has 70% greater MAP than at the low end of the elevation transect (Quiring, 1983).

When the Papadakis method is used to estimate ET_p, the Holocene climate (Beatty) shows that $ET_p > P$ and no soil water percolation occurs in the soil when monthly climate data are used (Fig. 17). Translocation of dissolved and solid material within the soil can be attributed to periodic high-precipitation storm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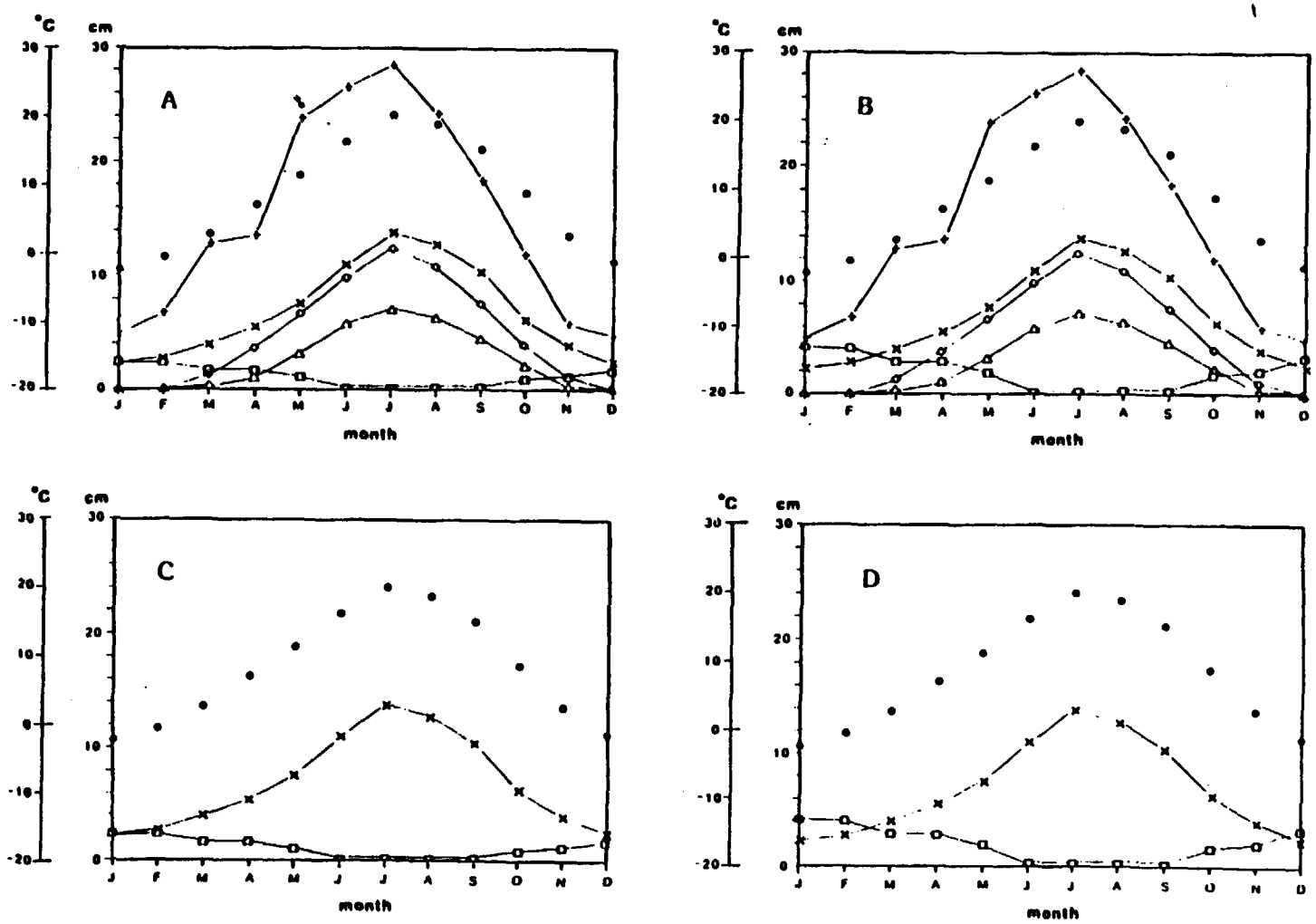
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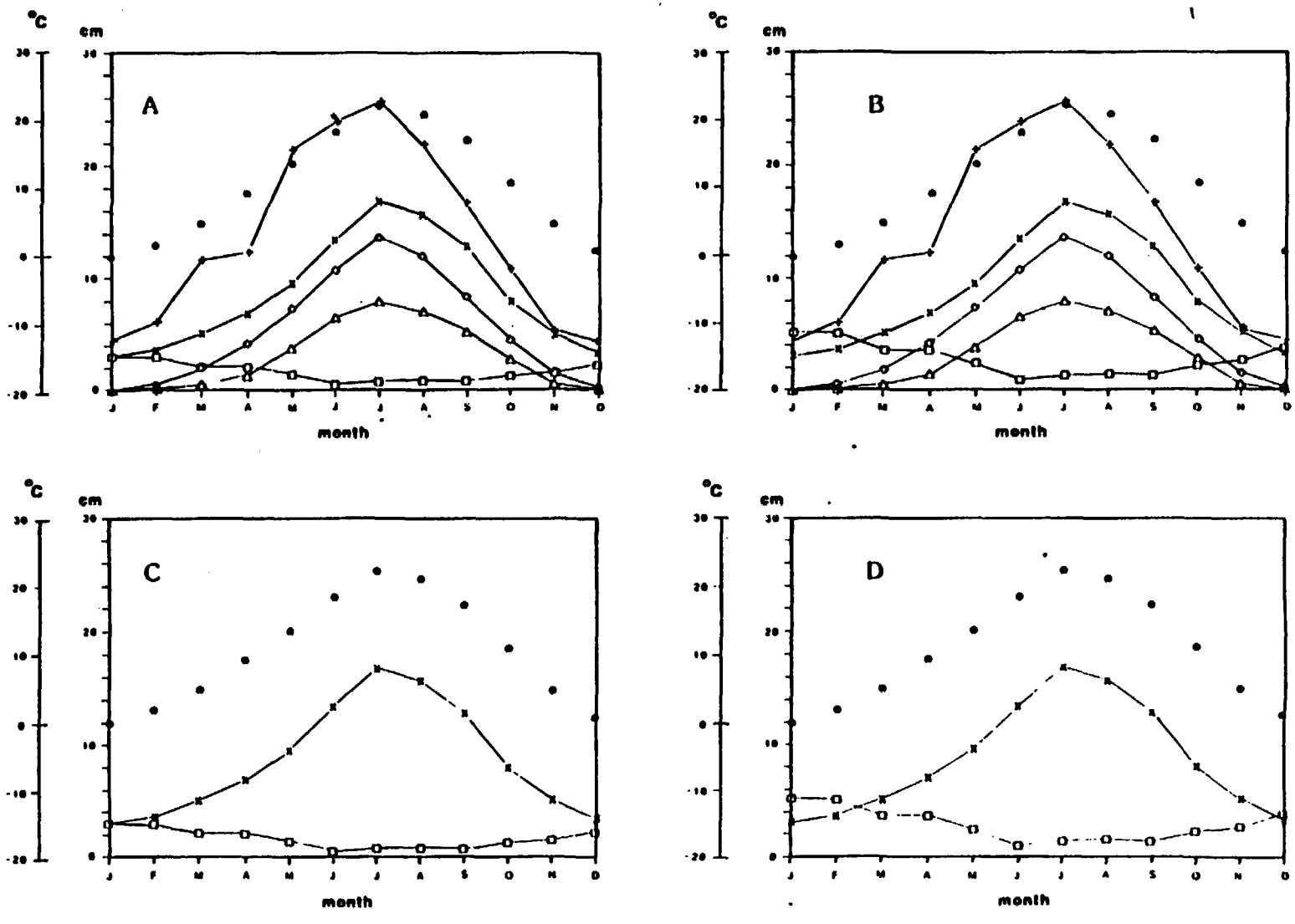
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events. This is true for both ends of the elevation transect. In contrast, if the Thornthwaite or Blaney-Criddle methods of calculating ET_p had been used, soil water percolation would have been predicted during one or more winter months (Fig. 17).

The two glacial climatic models give very similar water balance plots (Figs. 18 and 19). Soil water balance calculations of the glacial maximum climate using the Papadakis method of calculating ET_p predict that soil water percolation can occur only at the upper end of the elevation transect during January and February (Figs. 18 and 19). It is concluded that translocation could occur during these months in addition to both winter and summer high precipitation storm events. The other models for calculating ET_p predict even longer periods of soil water percolation as well as greater amounts.

Both soil water balance calculations of the glacial maximum predict soil water percolation during the cooler winter months at the upper end of the elevation transect, and not at the lower end. On similar aged deposits there should be a response to the increased available moisture on the dissolved and solid material that is translocated in the soils.

Carbonate Translocation

When moisture is available for translocation, soluble salts and $CaCO_3$ move downward and precipitate out at a depth approximated by the wetting front (Arkley, 1963; McFadden and Tinsley, 1985). The percentage of $CaCO_3$ decreases with elevation in the Holocene soils (Qlc, Fig. 20), thus following the suggested difference in

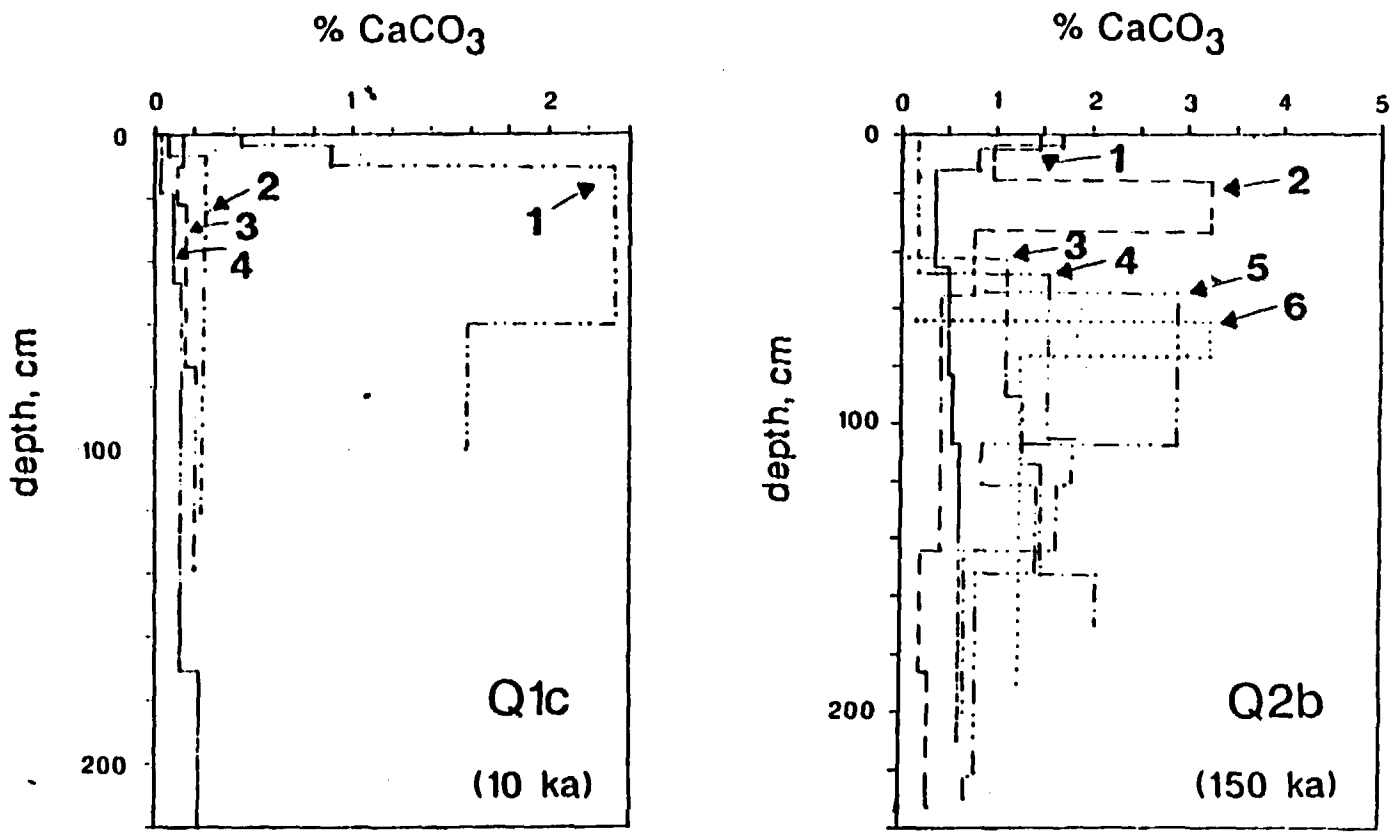

Figure 20. Percent $CaCO_3$ vs depth for soils formed on deposits Q1c (A) and Q2b (B). Numbers 1 to 6 are in order of lowest to highest soil profile elevation up the transect.

leaching with elevation. The Q1c soil at the lowest elevation in the transect has over 2% $CaCO_3$ accumulation at 9-60 cm, whereas at greater elevations on the transect, the $CaCO_3$ accumulation is much less (<0.3%). In addition the upper depths of maximum $CaCO_3$ for each profile is deeper with higher elevation, therefore with increasing precipitation the $CaCO_3$ decreases in amount and depth of maximum accumulation. The increase in frequency and amount of precipitation in the modern climate, up the transect, is sufficient to translocate the $CaCO_3$.

If the climate in the past has been similar to the Holocene, $CaCO_3$ accumulation should occur at similar depths along the transect in the older soils. Significant variations in the $CaCO_3$ depths observed in older soils should reflect differences in amounts of effective moisture.

The $CaCO_3$ in the soils formed on Q2b deposits does not have the predicted response. Generally $CaCO_3$ increases rather than decreases in amount, and increases to depth of maximum accumulation with increasing elevation (Fig. 20). The $CaCO_3$ in soils formed on Q2c deposits has a similar response with some reversals, however the two highest soils are nearly at the same elevation (Fig. 21). Although, generally the soils at lower elevations have far less $CaCO_3$ (1-2%) than the soils at higher elevations (18-23%), and the depth to maximum accumulation increases with elevation. The soils formed on QTa deposits do not show an obvious trends with increasing elevation (precipitation) (Fig. 21). Irrespective of elevation, detectable $CaCO_3$ first occurs at a depth of 10 to 30 cm. This could be due to the influence of a greater number of climatic changes, and

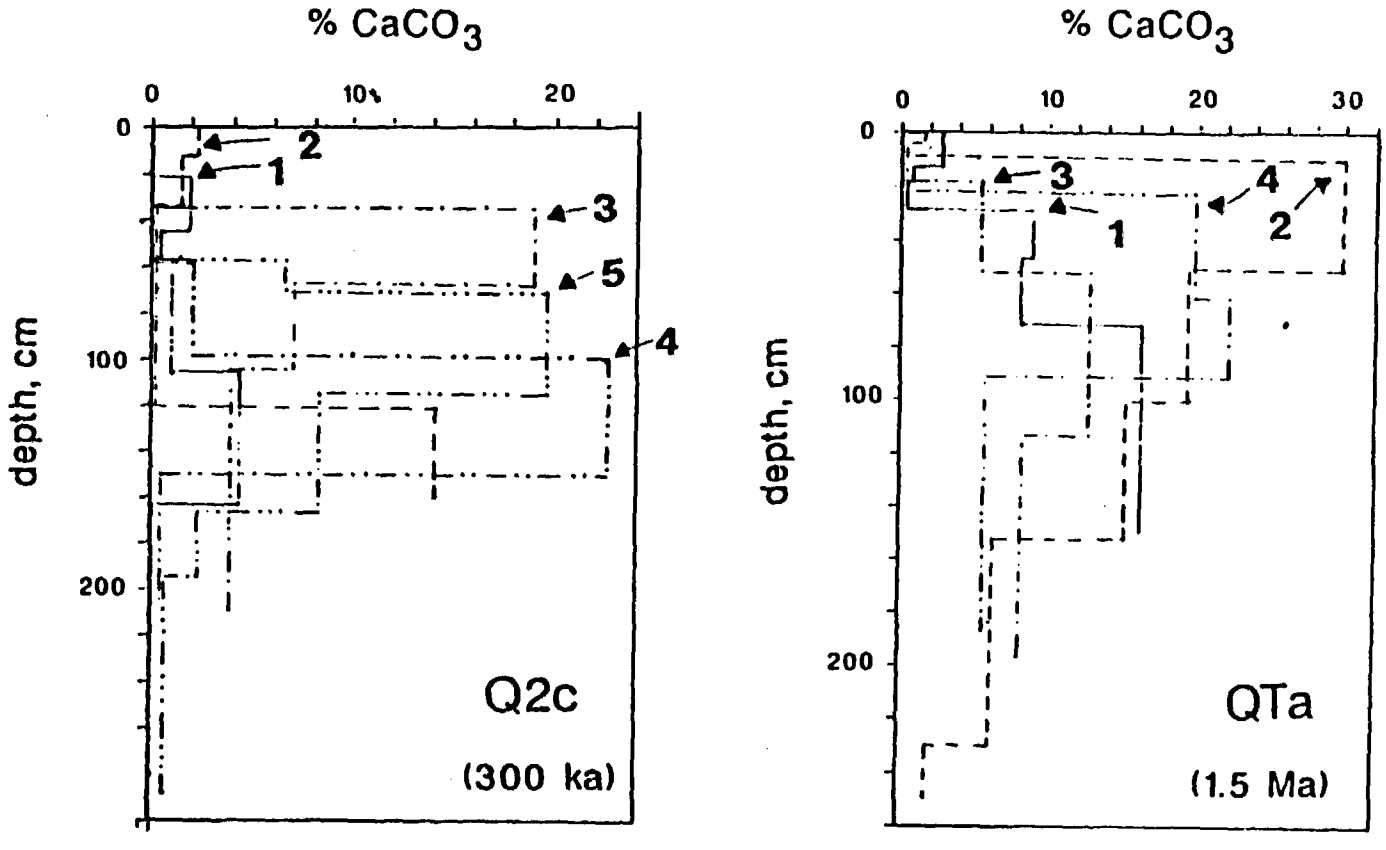

Figure 21. Percent $CaCO_3$ vs depth for soils formed on deposits Q2c (A) and QTa (B). Numbers 1 to 5 are in order of lowest to highest soil profile elevation up the transect.

the unknown amount of irregular erosion on the QTa deposits. Soils of extreme age tend to reflect the leaching of occasional wet years much more than do the younger soils.

During the modern climate storm events tend to flush the soil system and translocate any available $CaCO_3$ (Fig. 20). In comparison, soils that have been exposed to one or more glacial events are "more efficient" at accumulating $CaCO_3$. This accumulation effect could be due to two climatic influences. First, based on the soil water budgets during the glacial maximum (Figs. 18 and 19) predictable soil water percolation occurs using monthly climate data at the upper end of the transect. The constant wetting and drying may be more efficient at precipitating $CaCO_3$. Secondly, effective precipitation could have actually been less in the past than during the Holocene and as a result moisture was not available to translocate soluble $CaCO_3$ deeper. In this case the regional climatic change associated with the Holocene-Pleistocene boundary would not be associated with changes in precipitation, but primarily changes in temperature. Without changing the amount of precipitation during the glacial maximum, $CaCO_3$ can be translocated deeper by simply increasing the temperature of available moisture and thus the solubility of $CaCO_3$. This temperature increase of the available moisture may represent increased precipitation during the warmer summer months.

Some soil profiles have a bimodal distribution of $CaCO_3$ in the pre-Holocene soils (Figs. 20 and 21). The bimodal nature of soil can be explained by climatic change, much the way McFadden (1982) did. The deeper accumulation represent periods of greater

leaching. In contrast, the shallower accumulation is similar enough to that of the Qlc soils to suggest an origin during the Holocene.

Computer Generated Model for Carbonate Translocation

Computer models can be generated to approximate $CaCO_3$ distribution in the soils of NTS. Basically they follow those of McFadden and Tinsley (1985). Climate can be related directly to the change in soil moisture throughout the year. The calculation of soil water movement (Arkley 1963, 1967) is based on the concept that the net excess of P over ET_p for those months in which $P>ET_p$ represents the total moisture available to wet the soil, but this is surely a simplification of natural conditions. This value, defined as the leaching index, may be calculated two different ways. In one method the excess of P over ET_p during the months in which $P>ET_p$ is summed. In the other method the average P for the wettest month is used if the maximum P for a given month is greater than the summed difference of $P>ET_p$. For arid and semiarid regions the second method gives a higher leaching index than does the first method. Both the Spaulding and Mifflin and Wheat climatic models along the Fortymile Wash and Yucca Wash transect have a leaching index less than the average January precipitation, and thus the second method is appropriate. The latter value is used in the computer model.

The computer-generated compartment model for $CaCO_3$ translocation generates "synthetic" distributions showing the translocation of $CaCO_3$ as a function of soil depth, time, and climate (Mayer and others, 1985). Different scenarios can be simulated, including abrupt or gradual changes in climate. The

variables utilized in the model are the leaching index value, calcic-dust influx, parent material $CaCO_3$ content, and partial pressure of soil (PCO_2), texture, initial water content, and soil temperature (Appendix I).

Various parameters were used in the model. Fresh alluvium is the parent material. The following parameters were used: a $CaCO_3$ dust flux of $0.1 gm/cm^2/10^3 yrs$, no parent material carbonate, the PCO_2 at the surface of $10^{-3.5}$, increasing to $10^{-2.5}$ at the maximum rooting depth, and decreasing with depth to $10^{-3.4}$, a sand texture, an initial moisture content of 0.02% with a permanent wilting point of 0.018%, and a soil temperature at the surface of 16.5 ^{o}C which levels off to 19.3 ^{o}C at 50 cm. (Appendix I). The calculated precipitation for the two extremes along the transect were used for the Holocene climate, and the glacial maximum climate used is the model proposed by Spaulding (Table 2). The program was run for 30,000 yrs of glacial climate, followed by 10,000 yrs of Holocene climate. Two climatic scenarios were considered for the Pleistocene-Holocene climatic change, abrupt and gradual (Fig. 10).

The abrupt climatic change model predicts a bimodal $CaCO_3$ distribution, whereas the gradual climatic change model does not (Fig. 22). The $CaCO_3$ translocation modeled is compared to data from soils on Q2b deposits because they have experienced at least one glacial climate. At the low end of the transect there is a bimodal distribution of $CaCO_3$, in contrast at higher elevations the distribution is gradual (Fig. 20). So which climatic model is most closely predicting the expected distribution: the abrupt model for the lower elevations and the trend climatic model for the higher

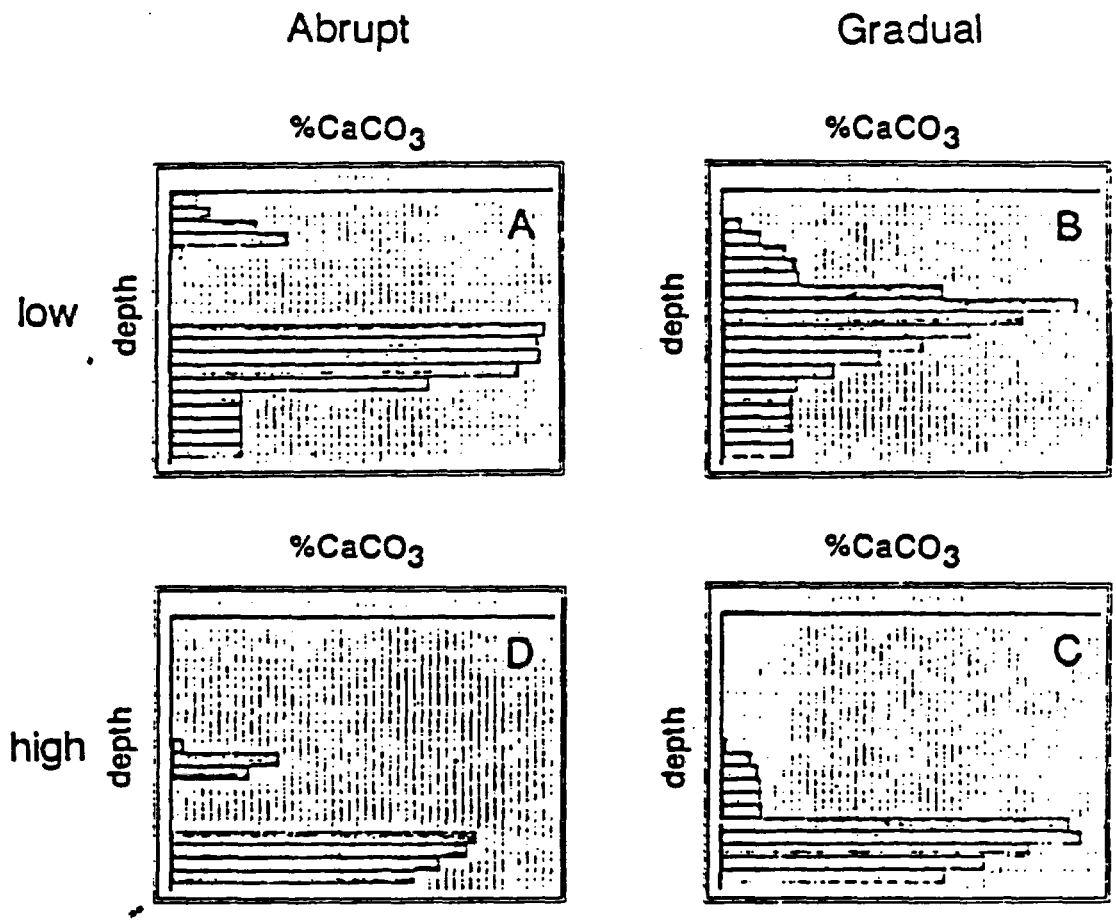

Figure 22. Modeled $CaCO_3$ accumulation for 30,000 yrs of glacial climate with either an abrupt (A and C) or gradual (B and D) change to the Holocene for 10,000 yrs for the low (A and B) and high (C and D) ends of the elevation transect.

elevations? Based on the $CaCO_3$ translocation on Qlc (Fig. 8A), $CaCO_3$ is not being moved out of the soil at lower elevations. The bimodal distribution in the lower soils is considered to be a function of the Holocene climate, and the best long term prediction is that climatic change is gradual, not abrupt.

Pedogenic Silica Morphology as a Climatic Indicator

Duripans are silica-cemented pedogenic horizons which form whenever silica is released by mineral weathering and not subsequently combined with secondary clay minerals or leached from the soil profile.

The chemistry and morphology of duripans are different in areas of arid and subhumid climates (Summerfield, 1983; Chadwick, 1985). In subhumid climates duripans contain Fe and Al as accessory cements along with oriented clays and high concentrations of resistant TiO_2 compared to more soluble cations. They also have prismatic structure. Colloform features and glaebules dominate the micromorphology of subhumid duripans (Brewer, 1964). The matrix silica is well crystallized quartz rather than opaline silica.

The micromorphology of arid-soil silica concentrations are characterized by length-slow chalcedony in vughs or voids. The secondary fill is microquartz and megaquartz. These void fills are diagnostic of silicification at a high a pH (Folk and Pittman, 1971). Some argue the formation of silica in arid climates is related to the replacement of carbonates (West, 1973; Jacka, 1974; Milner, 1976). Glaebules of clay are absent or inherited. The primary fabric is floating, and the secondary fabric is grain and

(or) matrix supported (Brewer, 1964). Opaline silica is the primary matrix component. The structure associated with the maximum duripan development is massive to platy.

Silica cemented horizons in the study area have no characteristics associated with duripans formed in subhumid climates. There is a lack of evidence for deep weathering in the profile. $CaCO_3$ is the accessory cement with little or no secondary clay accumulation. In the absence of effective precipitation or drainage to remove newly dissolved silica, it is precipitated elsewhere within the calcrete horizon, or $CaCO_3$ preferentially precipitates after opaline silica bonds adjacent soil grains without necessarily plugging intervening pore spaces (Chadwick, 1985). The complimentary solubility relationship with respect to pH between calcite and quartz is a highly alkaline environment (>pH 9). This suggests that localized zones could develop across a pH gradient in which calcite and silica were simultaneously precipitating. This kind of model implies contemporaneous calcrete and duripan development as a function of local variations in pH related to topography and soil-moisture conditions.

CHAPTER V

SUMMARY, CONCLUSIONS, AND FUTURE STUDIES

A high level nuclear waste site has been proposed in the Yucca Mountain area of the Nevada Test Site. A permanent repository for nuclear waste must be able to withstand the effects of a major climatic change. A climatic change that results in greater effective moisture may cause percolating water to move within the zone of waste material during the time that the material is still hazardous. The objectives of this study are to document the effects of time and climate on the soil development and to used soil data to characterize long-term past climatic variability.

Five groups of different-aged deposits were studied along an elevation transect of 400 m, from 1082 to 1483 m (Fig. 2). Present day annual precipitation nearly doubles along the transect from 120 to 200 mm (Table 2).

No definitive evidence exists regarding any climatic or tectonic influences on the formation of the terraces in the study area. The terraces studied are fill terraces (Fig. 3), and are not likely to be of tectonic origin. Although longitudinal profiles of the terraces diverge downstream (Fig. 4), tectonics are not required to explain this relationship. Climatic change may account for the formation of the terraces.

Soils that formed in alluvium and eolian fines of Holocene to early Pleistocene or latest Pliocene (?) age near Yucca Mountain are characterized by distinctive trends in the accumulation of secondary clay, $CaCO_3$, and opaline SiO_2 that correspond with the ages of the surficial deposits. Both $CaCO_3$ and opaline SiO_2 appear initially as coatings on the underside of clasts and over time form cemented and indurated horizons (Table 3). There is no macro- or micromorphological evidence that suggests that the silica cementation occurred under climatic conditions cooler and (or) wetter than those of the present climate. Vesicular A (Av) horizons have not formed on the coarse, gravelly Holocene deposits in the Yucca Mountain area. On the older deposits where Av horizons have formed, there is no relationship between the thickness of the Av horizon and age of the underlying deposit. The Av horizons are consistently between 5 and 10 cm thick.

Quantified field properties, by the Harden method, vs log age of the deposit are are all significant at the 5% level except melanization and color paling (Fig. 5). The profile indices also clearly slow a relationship with log age of the deposit (Fig. 6). When the four properties with the highest r^2 values vs log age are combined and compared to the same field properties on similar-aged deposits from the Las Cruces, New Mexico area, the index values are very similar in the two areas on similar aged deposits. This suggests that compared to an area with independently-dated deposits the age assignments for the deposits in the Yucca Mountain area, based on field properties, are not unreasonable (Table 4).

The accumulation of secondary $CaCO_3$, clay, silt, and opaline SiO_2 is determined on a horizon basis by deducing the initial amount assumed to have been in the soil parent material from that in the present soil horizon. Profile sums of horizon weights of these components suggest that $CaCO_3$, clay, silt, and opaline SiO_2 accumulate at a logarithmic rate (Table 5). However, these rates may be a primarily a function of the erosion and of secondary material loss from the older soils, and the volumes determined for these constituents may only be minimum values. The long term rates for properties dependent primarily on eolian additions is probably better expressed by linear rate.

Holocene to late Pleistocene age soils (Qlc) have accumulated $CaCO_3$, clay, silt, and opaline SiO_2 at a higher average rate than the older soils (Fig. 9). Accumulation rates are dependent upon the availability of eolian material on the soil surface and sufficient precipitation to move the material into the soil. Increased rates of accumulation of $CaCO_3$, clay, silt, and opaline SiO_2 during the Holocene can be attributed to several possible climatic scenarios associated with the Holocene-Pleistocene climate change. The accumulation rates suggest that precipitation since the stabilization of Qlc has not been a limiting factor, and that climatic change was not sufficient to significantly decrease rates of accumulation. This suggests that the climatic change was the result of decreases in temperature rather than precipitation.

No one long term rate of accumulation approximates the actual profile sum for $CaCO_3$, clay, silt, or opaline SiO_2 for a given aged deposit. The predicted profile sums using rates from

deposits that are known to have experienced at least one cycle of climatic change tend to underestimate the actual profile sums. These discrepancies is estimating the actual age are either (1) age errors on the deposits, (2) long term accumulation rates are off for that age range, this may be accounted for by erosion on the deposits that the long term rates are calculated from, or (3) represent much greater additions or $CaCO_3$, clay, silt, or opaline SiO_2 than the potential rates of accumulation predicts.

Soil properties that commonly exhibit changes with time and (or) climate include clay, $CaCO_3$, and opaline SiO_2. Most of these properties are strongly influenced by vertical position in the soil profile. With the exception of soils formed on deposits of Q2c age, clay, $CaCO_3$, and opaline SiO_2 maximums occur in the same horizon. On Q2c deposits the maximum amount of pedogenic clay is in a zone immediately above the zone with the maximum amount of pedogenic $CaCO_3$ and opaline SiO_2. In nearly all of the soils in this study, the maximum amounts of $CaCO_3$ and opaline SiO_2 occur in the same horizon, and in these horizons opaline SiO_2 is more abundant than $CaCO_3$.

The mineralogy and relative abundance of soil-clay minerals are strongly related to the climate, but they also changes with the time and with depth in the profile. The pedogenic clays in the Yucca Mountain soils have developed in very low-clay parent materials. There has been little change in the soil-clay mineralogy over time, in spite of climatic changes that have occurred since the stabilization of these deposits and initiation of soil development (Fig. 16).

The relationship between soils and climate can be approximated by evaluating soil water balance and leaching indices. Two climatic models of the glacial climate, one based on packrat midden evidence and a second on pluvial lake chronologies, were used along with modern climate data from Beatty, Nevada to calculate the soil water balance (Figs. 17-19). The Papadakis method of calculating potential evapotranspiration was used in this study (Table 9). The Holocene soil water balance calculations suggest that no soil water will percolate to depths using climatic data on a mean monthly basis. Translocation of dissolved and solid material within the soil can be attributed to periodic high-precipitation storm events. Both models of the glacial-maximum climate predict that at the high end of the elevation transect soil water percolation will occur during the cooler winter months, as well as during high-precipitation storm events.

When moisture is available for translocation, soluble salts and $CaCO_3$ move downward in solution and precipitate at depths approximated by the estimated depth of the wetting front. Depth plots of percent $CaCO_3$ for soils formed in Q1c-aged deposits suggest that near the upper end of the transect the modern-climatic soil moisture conditions are sufficient to translocate the available $CaCO_3$ (Fig. 20). Carbonate accumulates near the surface on the Q1c-aged deposits at the low end of the elevation transect, but appears to be translocated to greater depths, below the base of the soil, at higher elevations where precipitation is greater.

With increasing elevation, soils on the Q2b deposits that have experienced at least one climatic change have different $CaCO_3$

depth plots than the Q1c deposits (Fig. 20). Generally with increasing elevation and precipitation in the Q2b soils, $CaCO_3$ increases rather than decreases in amount, and increases in amount to the depth of maximum $CaCO_3$ accumulation with increasing elevation and precipitation (Fig. 20). The older soils tend to reflect the effects of leaching during occasional wetter years much more than do the younger soils. As a result, the older soils do not show trends in the accumulation of $CaCO_3$ with elevation (Fig. 21).

The different trends in accumulation in $CaCO_3$ on the Q1c and Q2b soils could be due primarily to two climatic influences: (1) additional moisture during a glacial maximum as determined from the water balance calculations, and (2) the likely changes in the effective precipitation during a glacial maximum. With only modest increases in the precipitation, the depth to which $CaCO_3$ would be translocated and deposited in a soil would be greatly increased. Without change in precipitation, $CaCO_3$ can be translocated deeper by merely increasing the temperature of the soil water and thus increasing the solubility of $CaCO_3$. This temperature increase of available moisture may represent increased precipitation during the warmer summer months during a glacial maximum.

A computer model was used to generate an approximate vertical $CaCO_3$ distribution in the soils in the Yucca Mountain area. Parameters used to generate the model describe the physical characteristics of the deposit, $CaCO_3$ influx rates, and climate. The model was run using the Spaulding (1985) glacial-maximum climate model for 30,000 yrs followed by 10,000 yrs of the modern climate (Fig. 22). This climatic change was generated both abruptly and

gradually. By comparing the computer-generated model to field data for the depths and distributions of $CaCO_3$, the model-generated data suggest that the climatic change at the Holocene-Pleistocene boundary was gradual.

Several future studies of the soils in the Yucca Mountain area have been planned in order to expand and clarify the findings of this study. They include the following: (1) soil thin-section analyses and total chemistry in order to help determine the genesis of the silica-cemented horizons; (2) a relative dating study of the degree of preservation of bar-and-swale topography, degree of rounding and size of surface boulders, and degree or sorting and packing of desert pavements; (3) evapotranspiration measurements with weighing lysimeters and evaporative pans with the Water Resources Division of the U.S. Geological Survey; (4) stable oxygen and carbon isotopes in the pedogenic silica and opal phytoliths for paleoclimatic indicators; (5) the relative abundance and distribution of tobermorite (?) and its relationship to mixed layer clays, palygorskite and sepiolite; (6) a more refined and complete morphostratigraphic stratigraphy for the deposits in the NTS area.

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APPENDICES

Appendix A. Soil field descriptions for the Yucca Wash and Fortymile Wash area, Nevada Test Site.

Map Unit, elev (m) (m >stream)	Sample number	Horizon	Basal depth cm	Lower boundary	Color dry	Color moist	Texture 1/	% gravel	Structure	pH	Consistence Dry	Consistence Moist	Consistence Wet	$CaCO_3$	Clay Films	SiO_2	Parent Material
Q1b	FW-2	Ak	1.5	--	10YR7/2	10YR4/2	S	18	1 vt pl	7.75	so	so,po		0	0	0	eolian & overbank
		Cox	18	--	10YR6.5/2	10YR3/3	S	12	m	7.80	lo	so,po		0	0	0	eolian & overbank
1030 (0.6)		2Ckox	100+	--			S	63	sg	8.15	lo	so,po		weak 1 disc	0	0	fluvial gravel
Q1c	FW-4	Ak	3	so	10YR6/3	10YR4/3	LS	5	1 c pl 2° 2 f abk	7.30	so	so,vps		0, c in places		0	overbank fines mixed w/ gravel component
1006 (1.2)		Bcj	9	sw	10YR7/2.5	10YR5/4	LS	7	1 m pl 2° 2 f-m abk-sbk	7.35	sh	so,po		1, cw	3 m br	0	"
	2/	2Bck	60	gl	10YR7/3	10YR5/4	SL	28	3 co-vco abk	7.60	sh	so,po		cv 1+-	0	0	fluvial gravel
		2Cuk	100+	--	10YR6.5/3	10YR5/4	LS	67	sg	7.80	lo	so,po		1+	0	0	fluvial gravel
Q1c	FW-17	A	6	cl	10YR6/3	10YR4/3	LS	40	1 c pl 2° 1 m-c abk	7.50	so	so,po		0	0	0	pebbly overbank sand
1079 (1.8)		Buk	24	cw	10YR7/3	10YR4.5/3	LS	40	m in places 2° 1 m-c abk	8.00	so	so,po		0	0	0	pebbly overbank sand
		2Cuk	120+	--	10YR7/3	10YR5/3	S	75	sg	8.10	lo	so,po		o	0	0	fluvial gravel
Q1c	FW-13	A	9	cw	10YR5/2	10YR3/2	LS	53	3m gr, 2° sg	6.80	so	so,po		0	0	0	pebbly overbank sand
		Bw	21	cw	10YR6/2	10YR4/2	SL	33	1 f-m abk 2° sg	7.10	so	so,po		0	0	0	pebbly overbank sand
1266 (0.9)		2Bqj	73	sw	10YR6/3	10YR4.5/3	S	48	sg	7.40	so	so,po		0	0	1	fluvial gravel
		2Ckqm	138+	--	10YR6/1	10YR5/2	S	67	sg	7.60	lo	so,po		1+, cw	0	1-	fluvial gravel
Q1c	FW-15	A	18		10YR5/2	10YR4/2	LS	55	2 m gr	7.20	so	so,po		0	0	0	fluvial gravel
		Bw	46 (46-108 & 108-170)		10YR6/3	10YR3.5/3	LS	62	2 m gr	7.30	so-sh	so-sp, po		0	0	0	fluvial gravel
1378 (1.2)		2Bqk	170		7.5YR6.5/4	7.5YR4/4	SL	78	sg	7.60	sh	so,po		1+, cw	0	1+	fluvial gravel
		2Cuk	220+	--	7.5YR6.5/4	7.5YR5/4	LS	63	sg	7.95	so	so,po		lenses 1	0	0	fluvial gravel
Q2b	FW-3 2/ 3/	Avk	5	so	10YR7/2.5	10YR4/3	L	10	2 c pl 2° 2 co abk	7.75	so-sh	so,po		c-co in places	0	0	eolian and sheetwash
1012 (4.6)		Bck	12	sw	10YR7/3	10YR4/3.5	L	33	2 m-co abk	7.65	sh	s,p		c 1	1 mk pf & po	0	eolian and sheetwash
	3/	2Bck	45	cw	7.5YR6/4	7.5YR4/4	SL	82	sg 2° 1 m abk	7.65	sh	s,p		1	1 m po & br	1	fluvial gravel
		2Bqmk1	83	cw	7.5-10YR7/5 7.5YR5/5	7.5-10YR5/6 7.5YR4/4 (grav)	LS	81	m	7.60	h	so,po in veins		c, 1+	3m gr	11	fluvial gravel
	3/ 4a/	2Bqmk2	107	gw	10YR7/4	7.5YR5/6	S	83	m	7.60	h	so,po		1,pods of 11	1-2 m gr	11 ~1cm thick on bottom of clasts	fluvial gravel
	4b/	2Ckqm	210+	--	10YR5/2	10YR3/2	S	80	sg	7.90	lo	so,po		1	0	1	fluvial gravel

Map Unit, elev (m) (m >stream)	Sample number	Horizon	Basal depth cm	Lower boundary	Color dry	Color moist	Texture 1/	% gravel	Structure	pH	Consistence Dry	Consistence Moist	Consistence Wet	$CaCO_3$	Clay Films	SiO_2	Parent Material
Qlc and Q2b over Q2c	TW-21	Avk	4	as	10YR7/3	10YR4/3	SL+	19	3 co abk	8.00	so-sh	so,p	ev		2 m po	0	eolian, sheetwash and gravel
		Btjk	15	aw	10YR6/3	10YR4/3	SL+	17	2 t pl 2° 1 f abk	7.50	sh	so,po	ev		3 mk br	0	
1173 (12.8)		Bk	33	dt	10YR6.5/3	10YR4/3	SL	47	sg	7.45	so	so,po	11 on diss		0	0	channel gravel
		2Btqkb1	55	ct	10YR5.5/3	10YR3.5/3	SL	54	2 m abk	7.50	h	so,po	1,matrix 0		3 m gr & br	111	channel gravel
		2Btqmkb1	144	as	10YR6/4	10YR4/4	SL	59	m	8.10	sh	so,po-po	lenses 111, none in places		1 m gr	111	channel gravel
		3Bqmkb2	186	cw	7.5YR-10YR 7/4	7.5YR-10YR 4/4	LS	48	m	7.35	sh	so,po	1,matrix 0		1 m gr	111	fluvial gravel
	4b/	3Ckqmb2	233+	--			S	79	sg	7.30	sh-so	so,po	0		0	1	fluvial gravel
Q2b	TW-11	Av	4	as	10YR6/3	10YR4/3	LS	40	3 m pl 2° 2 m abk	7.00	so	so,ps	0		0	0	sheetwash & eolian
1274 (7.3)		Bt1	15	as	10YR6/3	10YR4/3	SL	27	1 m abk	7.20	so	so,ps	0		0	0	sheetwash & eolian
		2Bt2	42	aw	10YR6/4	10YR4/4	SL	39	2 m abk	7.05	h	so,ps	0		1 m gr	0	sheetwash & eolian
		2Btqmk	90	cb	10YR6.5/4 10YR8/2	10YR4/4 10YR6/4 (pf)	SL	48	m in place 2° 2 f-m abk	7.90	sh	s,po	1+,gr pf matrix 0		2 m br & po	11 & 111	channel gravel
		2Bkq	150	at-b	10YR7/4	10YR5/4	SL	75	m-sg	7.95	lo	so,po	11		1 m br	1	channel gravel
	4a/	2Kqmk	170+	--	10YR8/2 10YR7/3	10YR6/4 10YR5/6 (SiO_2)	SL	73	m	8.00	sh	so,po	111		0	0	debris flow
Qlc over Q2b	TW-12	Av1	4	as	10YR6/3	10YR3.5/3	SL	35	1-2 vt-t pl	7.20	so	so,ps	0		0	0	sheetwash & eolian
		Av2	14	cw	10YR6/3	10YR4/3	SL	25	1-2 t pl 2° 2 co abk	7.80	so	so,ps	0		0	0	sheetwash & eolian
1283 (6.1)		Bt	47	ct	10YR6.5/3	10YR4/3	SL	24	3 m-co abk	7.50	sh	s,ps	0		0	0	sheetwash & eolian
		2Bk1	105	gw	10YR7/2 10YR6/3	10YR4.5/3 10YR4/3	SL-	56	2 m-co abk 2° 2 f abk	7.80	sh-h	so,po	11+ pf & grav		2 m po & br	0	channel gravel
		2Bk2	120	aw	10YR6/4	10YR4/4	LS	10	sg	8.00	so	so,po	11, cw		2 m po & br	111	channel gravel
		2Bqmkb	130		10YR6/4	10YR4/4	S	66	3 m abk	7.95	sh	so,po	e-		2 m pf & gr	IV-	channel gravel
			144	cw	10YR8/2	10YR7/3	LS-		3 m abk		sh	so,po	111 in places		0	0	cemented gravel
		2Bqkb	200+	--			LS	80	sg	7.85		so,po	e diss,1		0	1	channel gravel
Qlc over Q2b(?)	TW-14	A	8	cs	10YR7/3	10YR4/3	SL	32	2 vf pl	7.15	so	so,ps	0		0		eolian & sheetwash
		Bt	28	gw	10YR6/3	10YR4/3	SL	24	1 co-vco abk	7.15	so	so-so, po	0		0		eolian & sheetwash
1369 (12.2)		2Bk	54	gw	10YR6/3	10YR4/3	SL	35	2 m abk	7.80	so	so,ps	at+ diss		0	0	colluvium
		2Bkq	107	cw	10YR7/3	10YR4.5/3	SL	42	sg	8.05	lo	so,po	ev11 diss		0	1	colluvium
		3Bkjb	121	aw	10YR5.5/3	10YR3/3.5	SL-	19	2 m abk	8.05	sh-h	so,po	so pf 1 0 in ped		2m gr	0	fluvial gravel
		3Bqmkjb	152	gw	10YR6/3	10YR3/3	SL	30	m, 2° 3 f-vf abk	8.00	sh	so,po	1, 111 in veins		1 m pf	111	fluvial gravel
		4Bqmk2b	221	cw	10YR6/3	10YR4/3	SL-	63	m-sg	8.00	vh	so,po	so 1		1 m pf & gr	111	fluvial gravel
		4Bkjb	230+	--	7.5YR5/4	7.5YR4/4	SL-LS	80	sg	8.50	lo	so,po	1 diss		2 mk pf	1	fluvial gravel

Map Unit, elev (m) (m >stream)	Sample number	Horizon	Basal depth cm	Lower boundary	Color dry	Color moist	Texture 1/	% gravel	Structure	pH	Consistence Dry	Consistence Moist	Consistence Wet	$CaCO_3$	Clay Films	SiO_2	Parent Material
Q2b(?)	YW-20	Av	8	co	10YR6/3	10YR3/4	SL	38	1 m-co abk	6.90	sh	so,po		0	0	0	sheetwash & eolian
		Bt1	19	co	10YR	10YR4/3.5	SL	24	3 co-vco abk	6.90	sh	so,po		0	3 mk po	0	sheetwash & eolian
1373		Bt2	42	gw	10YR6/4	7.5YR4/4	L	39	2 m-co abk	6.75	sh fr	so,po		0	0	1	sheetwash & eolian
(10.7)		2Bq	64	gw	7.5YR5/4	7.5YR4/4	SL	84	1-2 m abk	7.30	sh	so,po		0	2 m br	1	fluvial gravel
		2Bqk1	76	sh	7.5YR5/4	7.5YR6/4	SL	84	1-2 m abk	7.80	sh	so,po		1+ - II	1 m gr	I-III	fluvial gravel
		2Bqk2-1	114		7.5YR5/4	7.5YR4/4	SL	68	m-sg	7.95		so,po		disc	2 m br	III	bedded fluvial
		2Bqk2-2	152		7.5YR6/4	7.5YR4/4	SCL-	89		8.00				II	0	I-II	gravel
		2Bqk2-3	190+		7.5YR6/4	7.5YR4/4	SL	89		8.00				I, disc	0	II	
Q1c over Q2c	YW-5 3/	A	5	as	7.5YR7/3	7.5YR4/3	S	25	1 vt pl 2° vf-f abk	7.55	so	so,po		0	0	0	sheetwash
		AB	20	aw	10YR6/3	10YR3/3	S	9	1 m abk	7.30	so-sh	so,po		0	1 m gr	0	sheetwash
1021		Btk	45	aw-b	10-7.5YR7/2	10YR4/3	SL	14	m, 2° lco abk	7.45	sh	so,po		II-ev cw	1 m gr	I	sheetwash
(13.4)		2Btkb	56	as-d	7.5YR5.5/4	7.5YR4/4	SL	18	3 m abk	7.55	h	so,po		0	2 mk-k pf & po	I	fluvial gravel
		2Btqmkb	106	cw	7.5YR6/4	7.5YR5/6	SL	60	m	7.50	vh	so,po		II pf	2 mk br	III	fluvial gravel
		2Kqb	164	aw	7.5YR7/4	7.5YR5/6	S	71	m, 2° 2m abk	7.60	vh (co)	so,po		lenses	3 m br	I+	fluvial gravel
					7.5YR8/2	7.5YR7/4 ($CaCO_3$)					sh (SiO_2)			of III	5-7 cm thick		
		2Cqn	263+		10YR6/1	10YR4/2	S	72	sg	7.50	lo	so,po		0 & lenses of I	0	II	fluvial gravel
Q2c over QTa	YW-18	Avk	11	as	10YR7/3	10YR6.5/3	L	13	3 co abk . 2° 1 co-vc pl	8.10	sh	so,po		e disc		0	sheetwash & eolian
		Ak	33	co	10YR7/3	10YR4.5/3	SL	24	sg	8.00	lo	so,vpo		ev disc	0	0	sheetwash & eolian
1085		Btkj	40	cw	10YR6/4	10YR4/4	SL	30	2 m-co pl 2° 1 f abk			so,po		e disc	2 mk po	0	sheetwash & eolian
(21.3)		2Btqkj1	66	cw	7.5-10YR6/4	7.5YR4/4	SL-	53	1 co pl 2° 3 vc abk	7.55	h	so,po		I pf	2 k po & br,	I-II It pf	fluvial gravel
		2Btqkj2	120	aw	10YR6/3	10YR4/4	LS	72	m	7.25	h	so,po		II+ lenses	2 k br	II	fluvial gravel
	4a/	3Kb	160+	--	white 5/	10YR8/4	S	76	m	7.20	sh			III	0	0	fluvial gravel
Q2a over Q2c	YW-8	Av	11	cw	10YR6/3	10YR4/3	L	13	3 co abk	7.40	sh fr	so,p		0	3 k po 3 m br	0	eolian & sheetwash
		Bt1	21	cw	7.5YR6/4	5YR4/6	C	13	2 f pr 2° 2 f abk	7.30	so	vs,vp		0	4 k pf	0	eolian & reworked gravel
1198		2Bt2b	35	cw	7.5YR7/6	7.5YR5/6	SL	27	3 m-co abk	7.45	vh	so,po		0	pods of 4 k pf	0	fluvial gravel
(18.0)		2Kqmb	68	as	7.5YR7/6	7.5YR6/6	LS	18	2 co-vco abk 3 vco pl in places	7.90	vh	so,po		II-III	1 mk br & gr	III	fluvial gravel
		2Kb	100	cl	10YR8/2 ($CaCO_3$)	7.5YR7.5/6	S	52	1 f pl 3 f-co abk	8.15	h	so,po		III in lenses	0	0	fluvial gravel
		2Cwkb	210+	--	10YR7/3	10YR4/3	S	62	sg	7.75	lo	so,po		II	0	0	fluvial gravel

Map Unit, elev (m) (m >stream)	Sample number	Horizon	Basal depth cm	Lower boundary	Color dry	Color moist	Texture 1/	% gravel	Structure	pH	Consistence Dry	Consistence Moist	Consistence Wet	$CaCO_3$	Clay Films	SiO_2	Parent Material
Q2a over YN-16 Q2c		Av	13	as	10YR5/3	10YR3/3	SL		1 m abk	7.05	lo	s,p	0		1m grápo	0	eolian
		Bt1	30	aw	10YR5.5/4	10YR4/4	L		1 m abk	7.55	so	s,p	0		1m gr	0	eolian
		Bt2	43	aw	7.5-10YR5/4	7.5-10YR4/4	SL		2 vco abk to abk	7.60	so	s,p	0		3m gr	0	eolian
1311 (10.7)		2Btqkb	58	al	7.5YR7/5	7.5YR5/6	SL	44	1 c pl 2° 2 m abk	7.70		s,pa	II		3 ok pf	III	fluvial gravel
		2Kqk	100	cw	7.5YR8/2 white 6/	7.5YR7/7 ($CaCO_3$)	LS	57	m	7.90	sh	so,po	III+	0		IV	fluvial gravel
		2Bqmkb	150	cw	7.5-10YR6/4	7.5YR4/4	LS	70	m 2° 2 f abk	7.65	h-vh	so,po	lenses III	0		III	fluvial gravel
		2Ckqmb	207+	--	10YR6/4 white 6/	10YR3.5/4 ($CaCO_3$)	S	71	sg	7.90	lo-sh	so,po	lenses III	0		II	fluvial gravel
Q1c over YN-1W Q2c		A	10	co	10YR6/3	10YR4/2	SL	27	1 m-c abk 2° sg	7.25	so	so,po			1 m gr		eolian & sheetwash
		Bt	25	c-aw	10YR5.5/3	10YR4/3	SL+	15	1 m abk 2° 2 f-m abk	7.20	so	so,po			0		eolian & sheetwash
1317 (12.5)	2/	2Btqkj1b	42	as	7.5YR5/4	10YR4/3	C-	47	2 co abk	7.30	sh fi	s,p			2m-k pf	II	eolian & fluvial gravel
		2Btqkj2b	56	cw	7.5YR5/4	7.5YR4/4	C-	30	2 co abk	7.48	sh vfi	s,p			2 k pf	II	eolian & fluvial gravel
		3Kb	78+	cw	7.5YR6/4	7.5YR5/4	C-	46	1 c pl	7.70	h vfi	s,po	III-IV-	0			eolian & fluvial gravel
Q1c over YN-1E Q2c		Spoil	30														
		2Btkjqb	50		7.5YR6/6	7.5YR5/4	C-	32	1-2 m abk	7.60	h vfr	s,p	0		0	II	colluvium
		2Btqmkb	56	aw	7.5YR7/4-5	7.5YR4/4	C-	38	1-2 m pl 2° 1 m abk	8.10	v-sh fi	so,po	0		0	IV	colluvium
(con't 1W)	4a/	3Kqm1b	78	cw	10YR8/2	10YR7/2	SCL+	50	2 vc pl	8.15	sh fr	po,po	IV-		0	IV	debris flow
1317		4Kqm2b	115	cw			SCL	61	m	8.40	vh fr	so,po	III-IV-		0	III	debris flow
(12.5)		5Bkb	167	dw	7.5YR7/6		SL	66	sg	8.10			lenses IV-	0			fluvial gravel
		5Cmkb	195	dw	7.5YR7/4	7.5YR5/4	SL	70	sg	8.40	lo lo	so,po	dfus	0			fluvial gravel
		5Cmb	290+	--	7.5YR7/4 7.5YR6/2-3	7.5YR5/4	LS+	67	sg	8.40	lo lo	so,po	dfus	0			fluvial gravel
QTa	YN-19	Avk1	4	as	10YR7/2	10YR3.5/3	L		3 m-co abk	8.45	so fr	so,po	so	0		0	sheetwash
		Avk2	9	aw	10YR	10YR4/3	SL	5	3 co abk	8.45	h	s,po	so	1 m po		0	sheetwash
1093		Bk	13	aw	7.5YR7/4	7.5YR5/4	L	13	1 m abk	8.15	so	s,po	sv cw	0		0	sheetwash
(28.0)		Btk	17	as	7.5YR6.5/4	7.5YR4/4	L	3	1 f-vf abk 1 f pl	7.80		so,po	0	0		0	sheetwash
		Btqmkj	29	cw	7.5YR6.5/4	7.5YR5/5	L	11	3 m pl	7.70	sh	so,po	II on pf	3 m br		III+	fluvial gravel
	4a/	2Kqd1	47	cw	10YR8/2 7.5YR7/4	7.5YR7/3 7.5YR5/6	L L		3 vc pl 2° 3 c abk	7.30	sh	so,po	III	3-4k pf		III	fluvial gravel debris flow?
	4a/	2Kqm2	72	cw	10YR8/3	7.5YR7/6	L	34	m 2° 2 f-vf abk & vf pl	7.40	vh	so,po	III	0		III	fluvial gravel
	4a/	2Kqm3	150+	--	10YR7/4	10YR5/6	SL	40	m	7.60	vh	so,po	III	0		III	fluvial gravel

Map Unit, elev (m) (m >stream)	Sample number	Horizon	Basal depth cm	Lower boundary	Color dry	Color moist	Texture 1/	% gravel	Structure	pH	Consistence Dry	Consistence Moist	Consistence Wet	$CaCO_3$	Clay Films	SiO_2	Parent Material
QTa	YW-6 5/	Avk	6	cs		10YR4/3	L	24	3 vcs abk	7.70	fr	ss,ps	s dlss	0	0		eolian & sheetwash
		Btk	10	as		7.5YR5/6	L	14	2 m abk	7.60	fr	s,p	s dlss	2 m pf	0		eolian & sheetwash
1170	4a/	2Kmq	52	as	7.5YR7/6	7.5YR6/6	SL		3 vcs pl	7.75		ss,ps	IV	0	IV		fluvial gravel
(19.8)					7.5YR8/2	white 6/ (CaCO3)											
		3Kqm	101	gw	7.5YR7/4 white 6/ (CaCO3)	7.5YR5/6	S	59	m	7.80	sh	ss,ps	III lenses	0	II		fluvial gravel
		3Kqy	153	gw	10YR8/2	10YR6/3	S	67	sg	7.60	ss	ss,ps	II with lenses of III	0	II		fluvial gravel
		3Bkq	230	--	7.5YR7/4	10YR4/3	S	63	sg	7.60	lo	ss,ps	I	0	II		fluvial gravel
		3Ckqm	250+				S	41		7.70							
QTa	YW-2W	Avk	3	as	10YR7/3	10YR4/3	L	6	3 cs abk	7.95	sh	ss,p	sv	0	0		eolian & sheetwash
		Ak	10	cw	10YR7/4	10YR3.5/3	L	9	1 m abk-sg	7.95	ss	ss,p	s	0	0		eolian & sheetwash
1180		Bty	19	sf	10YR5.5/3	10YR3/4	L	12	2 vf abk-sg	7.60	ss	s,p	s	0	0		eolian & sheetwash
(21.3)	3/ 4a/	2Btqmky	34	ci	10YR7/4 7.5YR6/6 (SiO2)	10YR3/3 7.5YR4/4	L-	23	3 cs pl	7.50	sh		1-2 mm lenses II on pf top	2 m gr & br	III		fluvial gravel
		2Btqmy	70+	--	7.5YR5.5/6	7.5YR4/4	L-	33	2 cs pl 2° f-m abk	7.50	sh	ss,ps-ps	lenses on pf top	4 m pf	III		fluvial gravel
QTa	YW-2E	Spoil	4														
		Btk	19		7.5YR6/4	7.5YR4/4	CL	13	2 m-cs abk	8.20	ss	ss,p	sv	2 m gr			eolian & sheetwash
1180	3/ 4a/	2Ktqm	52		7.5YR8/6 (internal peds)	7.5YR7/6	C	39	3 vcs pl	8.20	sh	ss,ps	III-IV coats peds	1 m gr 2 ok pf	IV		fluvial gravel
(21.3)					10YR8/4 pf white 6/	10YR7/6 (CaCO3)											
		2Kqm	114		white 6/ (CaCO3)		SCL-	48	2 vcs pl	8.00	h-sh	ss,ps	IV in places	1 m gr & br	IV		fluvial gravel (debris flow?)
		3Kq	197+	--	10YR8/2	10YR6/3	SL	76	m	7.55	ss	ss,ps	III, veiny on pebbles				fluvial gravel
QTa	YW-22	Avk	10	aw	10YR7/3	10YR5/3	CL	5	2 vcs abk 2° 1 m-cs pl	8.50	ss-sh	s,ps	s	1 m ps	0		eolian & sheetwash
1209		Btk	21	aw	7.5YR5.5/6	7.5YR4/4	CL+	20	2 f-m abk	8.00	ss	s,p	s	2mk br&gr	0		eolian & reworked gravel
(19.2)	4a/	Kqm	62	as	7.5YR8/4	7.5YR7/6	SCL	42	2 vc pl & m	7.90	sh	ss,ps	IV	0	IV		eolian & reworked gravel
		2Kmq	92	cw	10YR8/1 white 6/ (CaCO3)	7.5YR6.5/6	SL	54	m	7.65	sh	ss,ps	III	0	IIII		fluvial gravel
		2Bkqm	184+	--	7.5YR7/4	7.5YR5/4	SL	52	1 m abk	7.65	h	ss,ps	II	0	II		fluvial gravel

Key to Appendix A *

Horizon Boundary

Distinctness		Topography	
va	very abrupt	s	smooth
a	abrupt	w	wavy
c	clear	i	irregular
g	gradual	b	broken
d	diffuse		

Soil Texture

co	coarse	S	sand	SCL	sandy clay loam
f	fine	LS	loamy sand	CL	clay loam
vf	very fine	SL	sandy loam	SiCL	silty clay loam
		L	loam	SC	sandy clay
		SiL	silt loam	C	clay
		Si	silt	SiC	silty clay

Soil Structure

Grade		Size		Type	
m	massive	vf	very fine (v thin)	gr	granular
sg	single grained	f	fine (thin)	pl	platey
1	weak	m	medium	pr	prismatic
2	moderate	co	coarse (thick)	cpr	columnar
3	strong	vco	very coarse (v thick)	abk	angular blocky
				sbk	subangular blocky

If two structures - listed as primary and secondary (2°)

Soil Consistence

Dry		Moist		Wet	
lo	loose	lo	loose	so,po	non-sticky or plastic
so	soft	vfr	very friable	ss,ps	slightly sticky or plastic
sh	slightly hard	fr	friable	s,p	sticky or plastic
h	hard	fi	firm	vs,vp	very sticky or plastic
vh	very hard	vfi	very firm		
eh	ex hard	efi	extremely firm		

Clay Films

Frequency		Thickness		Morphology	
vf	very few	n	thin	pf	ped face coating
1	few	mk	moderately thick	br	bridging grains
2	common	k	thick	po	pore linings
3	many			gr	gravel coats

$CaCO_3$

Effervescence on matrix

0 - none in matrix.
diss - disseminated, discontinuous.
e - slightly, bubbles are readily observed.
es - strongly, bubbles form a low foam.
ev - violently, thick foam "jumps" up.

Key to Appendix A (continued)

* For more information, see Soil Survey Staff 1951 and 1975

1/ Texture is based on lab analyses

2/ Sampled for phytolith and pollen analyses

3/ Sampled for U-trend dating

4a/ Soil ped thin section

4b/ Rock thin section

5/ Sampled for ^{36}Cl analyses

6/ White carbonate is whiter than 10YR8/0

Appendix B. Soil Profile Index Values

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		RUBIFICATION (maximum=100) Color #1	Color #2	Normalized property	x thickness	Profile property	Weighted mean
FWA-1				0.00	0.00	0.00	0.00		
FWA-2				0.00	0.00	0.00	0.00		
FWA-3				0.00	0.00	0.00	0.00		
FWA-4				0.00	0.00	0.00	0.00		
IWA-1				0.00	0.00	0.00	0.00		
IWA-2				0.00	0.00	0.00	0.00		
7.01	A	0	1.5	0.00	0.00	0.00	0.00	0.87	0.01
7.02	Cox	2	18	10.00	0.00	0.05	0.87		
7.03	2Cvcx	18	100	0.00	0.00	0.00	0.00		
4.01	A	0	7	20.00	0.00	0.11	0.32	15.47	0.15
4.02	Bk1	7	9	25.00	0.00	0.13	0.79		
4.03	2Bk2	9	60	30.00	0.00	0.16	8.05		
4.04	2Ckn	60	100	30.00	0.00	0.16	6.32		
17.01	A	0	6	20.00	0.00	0.11	0.63	12.63	0.11
17.02	Bw	6	24	20.00	0.00	0.11	1.89		
17.03	2Ckn	24	120	20.00	0.00	0.11	10.11		
13.01	A	0	9	0.00	0.00	0.00	0.00	5.47	0.04
13.02	Bw	9	21	0.00	0.00	0.00	0.00		
13.03	2Bqj	21	73	20.00	0.00	0.11	5.47		
13.04	2Ckqn	73	138	0.00	0.00	0.00	0.00		
15.01	A	0	18	0.00	0.00	0.00	0.00	57.89	0.26
15.02	Bw	18	46	20.00	0.00	0.11	2.95		
15.03	2Bqj	46	170	60.00	0.00	0.32	39.16		
15.05	2Ckn	170	220	60.00	0.00	0.32	15.79		
3.01	Av	0	5	0.00	0.00	0.00	0.00	34.45	0.16
3.02	Avkj	5	12	5.00	0.00	0.03	0.18		
3.03	2Btxj	12	45	60.00	0.00	0.32	10.42		
3.04	2Btjqmk1	45	83	80.00	70.00	0.39	15.00		
3.05	2Btjqmk2	83	107	70.00	0.00	0.37	8.84		
3.06	2Cvqn	107	210	0.00	0.00	0.00	0.00		
21.01	Av	0	4	0.00	0.00	0.00	0.00	32.11	0.14
21.02	Bw	4	15	0.00	0.00	0.00	0.00		
21.03	Bk	15	33	0.00	0.00	0.00	0.00		
21.04	2Btjqkjb1	33	55	20.00	0.00	0.11	2.32		
21.05	2Btjqmkb1	55	144	40.00	0.00	0.21	18.74		
21.06	3Bqmkb2	144	186	50.00	0.00	0.26	11.05		
21.07	3Ckqn	186	222	999.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)	RUBIFICATION (maximum=100) Color #1	Color #2	Normalized property	% thickness	Profile property	Weighted mean
11.01	Av	0 4	0.00	0.00	0.00	0.00	29.58	0.17
11.02	A	4 15	0.00	0.00	0.00	0.00		
11.03	2Bt1	15 42	40.00	0.00	0.21	5.68		
11.04	2Btcak	42 90	40.00	20.00	0.16	7.58		
11.05	2Bk2	90 150	40.00	0.00	0.21	12.63		
11.06	3Btqak3	150 170	20.00	50.00	0.18	3.68		
12.01	Av1	0 4	0.00	0.00	0.00	0.00	12.16	0.06
12.02	Av2	4 14	0.00	0.00	0.00	0.00		
12.03	Bt	14 47	0.00	0.00	0.00	0.00		
12.04	2Bk1	47 105	10.00	20.00	0.08	4.58		
12.05	2Bk2	105 120	40.00	0.00	0.21	3.16		
12.06	2Btqak2	120 144	60.00	10.00	0.18	4.42		
12.07	2Ck2	144 200	999.00	0.00	0.00	0.00		
14.01	A	0 8	0.00	0.00	0.00	0.00	23.53	0.10
14.02	Bw	8 28	0.00	0.00	0.00	0.00		
14.03	2Bk	28 54	20.00	0.00	0.11	2.74		
14.04	2Btjvc	54 107	20.00	0.00	0.11	5.58		
14.05	3Bkjc	107 121	25.00	0.00	0.13	1.84		
14.06	3Bqmv1b	121 152	20.00	0.00	0.11	3.36		
14.07	4Bqmv2c	152 221	20.00	0.00	0.11	7.26		
14.08	4Brjc	221 230	60.00	0.00	0.32	2.84		
20.01	Av1	0 8	10.00	0.00	0.05	0.42	51.08	0.27
20.02	Av2	8 19	5.00	0.00	0.03	0.25		
20.03	Bw	19 42	30.00	0.00	0.16	3.63		
20.04	2Btjq	42 64	60.00	0.00	0.32	6.95		
20.05	2Btjqv1	64 76	60.00	0.00	0.32	3.79		
20.06	2Btjqk2-1	76 114	60.00	0.00	0.32	12.00		
20.07	2Btjqk2-2	114 152	60.00	0.00	0.32	12.00		
20.08	2Btjqk2-3	152 190	60.00	0.00	0.32	12.00		
5.01	A	0 5	20.00	0.00	0.11	0.53	44.03	0.17
5.02	Bw	5 20	0.00	0.00	0.00	0.00		
5.03	Bk	20 45	5.00	0.00	0.03	0.66		
5.04	2Btc	45 56	60.00	0.00	0.32	3.47		
5.05	2Btqak	56 106	80.00	0.00	0.42	21.05		
5.06	2Ktcc	106 164	80.00	40.00	0.32	18.32		
5.07	2Cqm	164 267	0.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		RUBIFICATION (maximum=100) Color #1	Color #2	Normalized property	x thickness	Profile property	weighted mean
18.01	Av	0	11	0.00	0.00	0.00	0.00	18.21	0.11
18.02	A	11	33	0.00	0.00	0.00	0.00		
18.03	Bt	33	49	20.00	0.00	0.11	0.74		
18.04	2Btqk1	49	66	55.00	0.00	0.29	7.57		
18.05	2Btqk	66	120	40.00	30.00	0.18	9.93		
18.06	3Kc	120	160	999.00	0.00	0.00	0.00		
8.01	Av	0	9	0.00	0.00	0.00	0.00	50.85	0.24
8.02	Bt1	9	21	70.00	0.00	0.37	4.43		
8.03	2Bt2	21	35	100.00	0.00	0.53	7.37		
8.04	2kqm	35	68	110.00	0.00	0.58	19.11		
8.05	2k	68	100	50.00	0.00	0.26	8.43		
8.05	2Ck	100	210	20.00	0.00	0.11	11.58		
16.01	Av	0	13	0.00	0.00	0.00	0.00	70.00	5.83
16.02	Bw	13	30	20.00	0.00	0.11	1.79		
16.03	Bt	30	43	30.00	0.00	0.16	2.05		
16.04	2Btqk	43	58	90.00	0.00	0.47	7.11		
16.05	2kq	58	100	70.00	0.00	0.37	15.47		
16.06	2Bqm (nc)	100	150	60.00	0.00	0.32	15.79		
16.07	2Bqm	100	150	60.00	0.00	0.32	15.79		
16.08	2Ckqm	150	207	40.00	0.00	0.21	12.00		
1.01	A	0	10	0.00	0.00	0.00	0.00	49.28	0.17
1.02	Bt	10	25	0.00	0.00	0.00	0.00		
1.03	2Btqm1	25	42	40.00	0.00	0.21	3.58		
1.04	2Btqm2	42	56	60.00	0.00	0.32	4.42		
1.08	3kqm1	56	70	0.00	0.00	0.00	0.00		
1.09	4kqm2	70	115	999.00	0.00	0.00	0.00		
1.10	5Bk	115	167	50.00	0.00	0.26	13.68		
1.11	5Ck	167	195	60.00	0.00	0.32	8.84		
1.12	6Cr	195	290	60.00	15.00	0.20	18.75		
19.01	Av1	0	4	0.00	0.00	0.00	0.00	43.37	0.00
	Av2	4	9	0.00	0.00	0.00	0.00		
19.03	Bk	9	13	40.00	0.00	0.21	0.84		
19.04	Bw	13	17	40.00	[illegible]	0.21	0.84		
19.05	Btqm	17	29	70.00	0.00	0.37	4.42		
19.06	2ktqm	29	47	20.00	80.00	0.26	4.74		
19.07	2kqm1	47	72	60.00	0.00	0.32	7.89		
19.08	2kqm2	72	150	60.00	0.00	0.32	24.63		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		RUBIFICATION (maximum=100) Color #1	Color #2	Normalized property	X thickness	Profile property	Weighted mean
6.01	Av	0	6	0.00	0.00	0.00	0.00	53.42	0.00
6.02	Bt	6	10	80.00	0.00	0.42	1.68		
6.03	2Bqg	10	52	100.00	10.00	0.29	12.16		
6.04	3Bwg	52	101	80.00	0.00	0.42	20.67		
6.05	3Kg	101	153	10.00	0.00	0.05	2.74		
6.06	3Cksg	153	230	40.00	0.00	0.21	16.21		
6.07	3Cksgr	230	300	999.00	0.00	0.00	0.00		
2.01	Av	0	3	0.00	0.00	0.00	0.00	41.87	0.21
2.02	A	3	10	10.00	0.00	0.05	0.37		
2.03	Bv	10	19	10.00	0.00	0.05	0.47		
2.04	2Bqgsy	19	34	30.00	80.00	0.29	4.34		
2.05	2Btqgsy	34	70	80.00	0.00	0.42	15.16		
2.07	Ktqg	19	52	100.00	60.00	0.42	13.89		
2.08	Kg	52	114	10.00	0.00	0.05	3.26		
2.09	2k	114	197	10.00	0.00	0.05	4.37		
22.01	Av	0	10	0.00	0.00	0.00	0.00	60.42	0.33
22.02	Bw	10	21	80.00	0.00	0.42	4.63		
22.03	K	21	62	80.00	0.00	0.42	17.26		
22.04	Kg	62	92	60.00	0.00	0.32	9.47		
22.05	Bkqg	92	184	60.00	0.00	0.32	29.05		

SOIL PROFILE INDEX VALUES

Sample	horizon	Depth (cm)		MELANIZATION (maximum=85) Color #1	Color #2	Normalized property	x thickness	Profile property	weighted mean
FWA-1				0.00	0.00	0.00	0.00		
FWA-2				0.00	0.00	0.00	0.00		
FWA-3				0.00	0.00	0.00	0.00		
FWA-4				0.00	0.00	0.00	0.00		
YWA-1				0.00	0.00	0.00	0.00		
YWA-2				0.00	0.00	0.00	0.00		
7.01	A	0	1.5	0.00	0.00	0.00	0.00	1.94	0.02
7.02	Cox	2	18	10.00	0.00	0.12	1.94		
7.03	2Ckox	18	100	0.00	0.00	0.00	0.00		
4.01	A	0	3	0.00	0.00	0.00	0.00	0.00	0.00
4.02	Bk1	3	9	0.00	0.00	0.00	0.00		
4.03	2Bk2	9	60	0.00	0.00	0.00	0.00		
4.04	2Ckn	60	100	0.00	0.00	0.00	0.00		
17.01	A	0	6	0.00	0.00	0.00	0.00	0.00	0.00
17.02	Bw	6	24	0.00	0.00	0.00	0.00		
17.03	2Ckn	24	120	0.00	0.00	0.00	0.00		
13.01	A	0	9	20.00	0.00	0.24	2.12	2.12	0.02
13.02	Bw	9	21	0.00	0.00	0.00	0.00		
13.03	2Bqj	21	73	0.00	0.00	0.00	0.00		
13.04	2Ckqn	73	138	0.00	0.00	0.00	0.00		
15.01	A	0	18	10.00	0.00	0.12	2.12	3.76	0.02
15.02	Bw	18	46	5.00	0.00	0.06	1.65		
15.03	2Bqk	46	170	0.00	0.00	0.00	0.00		
15.05	2Ckn	170	220	0.00	0.00	0.00	0.00		
3.01	Ahv	0	5	0.00	0.00	0.00	0.00	0.00	0.00
3.02	Avkj	5	12	0.00	0.00	0.00	0.00		
3.03	2Btrj	12	45	0.00	0.00	0.00	0.00		
3.04	2Btjqkb1	45	83	0.00	-10.00	0.00	0.00		
3.05	2Btjqkb2	83	107	0.00	0.00	0.00	0.00		
3.06	2Ckqn	107	210	0.00	0.00	0.00	0.00		
21.01	Av	0	4	0.00	0.00	0.00	0.00	2.59	0.01
21.02	Bw	4	15	0.00	0.00	0.00	0.00		
21.03	Bt	15	33	0.00	0.00	0.00	0.00		
21.04	2Btjqkjb1	33	55	10.00	0.00	0.12	2.59		
21.05	2Btjqkb1	55	144	0.00	0.00	0.00	0.00		
21.06	3Bqmkb2	144	186	0.00	0.00	0.00	0.00		
21.07	3Ckqn	186	233	0.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		MELANIZATION (maximum=85) Color #1	Color #2	Normalized property	x thickness	Profile property	Weighted mean
11.01	Av	0	4	0.00	0.00	0.00	0.00	0.00	0.00
11.02	B	4	15	0.00	0.00	0.00	0.00		
11.03	2Bt1	15	42	0.00	0.00	0.00	0.00		
11.04	2Btqk1	42	90	0.00	0.00	0.00	0.00		
11.05	2Bkq	90	150	0.00	0.00	0.00	0.00		
11.06	3Kqmkb	150	170	0.00	0.00	0.00	0.00		
12.01	Av1	0	4	5.00	0.00	0.06	0.24	0.24	0.00
12.02	Av2	4	14	0.00	0.00	0.00	0.00		
12.03	Bt	14	47	0.00	0.00	0.00	0.00		
12.04	2Bk1	47	105	0.00	0.00	0.00	0.00		
12.05	2Bk2	105	120	0.00	0.00	0.00	0.00		
12.06	2Btqmk2	120	144	0.00	0.00	0.00	0.00		
12.07	3qkb	144	200	0.00	0.00	0.00	0.00		
14.01	A	0	5	0.00	0.00	0.00	0.00	0.00	0.00
14.02	Bw	5	28	0.00	0.00	0.00	0.00		
14.03	2Bk	28	54	0.00	0.00	0.00	0.00		
14.04	2Btjkq	54	107	0.00	0.00	0.00	0.00		
14.05	3Bkjb	107	121	0.00	0.00	0.00	0.00		
14.06	3Bqmk1b	121	152	0.00	0.00	0.00	0.00		
14.07	4Bqmk2b	152	221	0.00	0.00	0.00	0.00		
14.08	4Bkjb	221	230	0.00	0.00	0.00	0.00		
20.01	Av1	0	8	10.00	0.00	0.12	0.94	4.94	0.03
20.02	Av2	8	19	0.00	0.00	0.00	0.00		
20.03	Bw	19	42	0.00	0.00	0.00	0.00		
20.04	2Btjq	42	64	10.00	0.00	0.12	2.59		
20.05	2Btjqk1	64	76	10.00	0.00	0.12	1.41		
20.06	2Btjqk2-1	76	114	0.00	0.00	0.00	0.00		
20.07	2Btjqk2-2	114	152	0.00	0.00	0.00	0.00		
20.08	2Btjqk2-3	152	190	0.00	0.00	0.00	0.00		
5.01	A	0	5	0.00	0.00	0.00	0.00	2.41	0.01
5.02	Bw	5	20	10.00	0.00	0.12	1.76		
5.03	Bk	20	45	0.00	0.00	0.00	0.00		
5.04	2Btb	45	56	5.00	0.00	0.06	0.65		
5.05	2Btqmkb	56	106	0.00	0.00	0.00	0.00		
5.06	2Btqb	106	164	0.00	0.00	0.00	0.00		
5.07	2Cqm	164	263	0.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		MELANIZATION (maximum=85) Color #1	Color #2	Normalized property	x thickness	Profile property	Weighted mean
18.01	Av	0	11	0.00	0.00	0.00	0.00	0.00	0.00
18.02	A	11	33	0.00	0.00	0.00	0.00		
18.03	Bt	33	40	0.00	0.00	0.00	0.00		
18.04	2Btqb1	40	66	0.00	0.00	0.00	0.00		
18.05	2Btqb	66	120	0.00	0.00	0.00	0.00		
18.06	3Kb	120	160	0.00	0.00	0.00	0.00		
8.01	Av	0	9	0.00	0.00	0.00	0.00	3.82	0.01
8.02	Bt1	9	21	20.00	0.00	0.24	2.82		
8.03	2Bt2	21	35	0.00	0.00	0.00	0.00		
8.04	2Kqm	35	68	0.00	0.00	0.00	0.00		
8.05	2K	68	100	0.00	0.00	0.00	0.00		
8.05	2Ck	100	210	0.00	0.00	0.00	0.00		
16.01	Av	0	13	20.00	0.00	0.24	3.06	5.59	0.47
16.02	Bw	13	30	5.00	0.00	0.06	1.00		
16.03	Bt	30	43	10.00	0.00	0.12	1.53		
16.04	2Btqx	43	58	0.00	0.00	0.00	0.00		
16.05	2Kq	58	100	0.00	0.00	0.00	0.00		
16.06	2Bqm (nc)	100	150	0.00	0.00	0.00	0.00		
16.07	2Bqm	100	150	0.00	0.00	0.00	0.00		
16.08	2Ckqm	150	207	0.00	0.00	0.00	0.00		
1.01	A	0	10	0.00	0.00	0.00	0.00	4.33	0.02
1.02	Bt	10	25	5.00	0.00	0.06	0.88		
1.03	2Btqb1	25	42	10.00	0.00	0.12	2.00		
1.04	2Btqb2	42	56	10.00	0.00	0.12	1.65		
1.08	3Kqmb1	56	70	0.00	0.00	0.00	0.00		
1.09	4Kqmb2	70	115	0.00	0.00	0.00	0.00		
1.10	5Bk	115	167	0.00	0.00	0.00	0.00		
1.11	5Cnk	167	195	0.00	0.00	0.00	0.00		
1.12	5Cn	195	290	0.00	0.00	0.00	0.00		
19.01	Av1	0	4	5.00	0.00	0.06	0.24	0.24	0.00
	Av2	4	9	0.00	0.00	0.00	0.00		
19.03	Bk	9	13	0.00	0.00	0.00	0.00		
19.04	Bw	13	17	0.00	0.00	0.00	0.00		
19.05	Btqa	17	29	0.00	0.00	0.00	0.00		
19.06	2Ktqa	29	47	0.00	0.00	0.00	0.00		
19.07	2Kqa1	47	72	0.00	0.00	0.00	0.00		
19.08	2Kqa2	72	159	0.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		MELANIZATION (maximum=85) Color #1	Color #2	Normalized property	% thickness	Profile property	Weighted mean
6.01	Av	0	6	10.00	0.00	0.12	0.71	0.71	0.00
6.02	Bt	6	10	0.00	0.00	0.00	0.00		
6.03	2kqm	10	52	0.00	-40.00	0.00	0.00		
6.04	3kmq	52	101	0.00	0.00	0.00	0.00		
6.05	3kq	101	152	0.00	0.00	0.00	0.00		
6.06	3Ckq	152	230	0.00	0.00	0.00	0.00		
6.07	3Ckq+	230	300	0.00	0.00	0.00	0.00		
2.01	Av	0	3	0.00	0.00	0.00	0.00	5.88	0.03
2.02	A	3	10	5.00	0.00	0.06	0.41		
2.03	By	10	19	15.00	0.00	0.18	1.59		
2.04	2Bqmxy	19	34	10.00	0.00	0.12	1.76		
2.05	2Btqmv	34	70	5.00	0.00	0.06	2.12		
2.07	Ktqm	19	52	0.00	0.00	0.00	0.00		
2.08	Kq	52	114	0.00	0.00	0.00	0.00		
2.09	2K	114	197	0.00	0.00	0.00	0.00		
22.01	Av	0	10	0.00	0.00	0.00	0.00	0.65	0.00
22.02	Bw	10	21	5.00	0.00	0.06	0.65		
22.03	K	21	62	0.00	0.00	0.00	0.00		
22.04	Km	62	92	0.00	0.00	0.00	0.00		
22.05	Bkqm	92	184	0.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)	COLOR-FALLING (maximum=99) Color #1	Color #2	Normalized property	x thickness	Profile property	Weighted mean
FWA-1			0.00	0.00	0.00	0.00		
FWA-2			0.00	0.00	0.00	0.00		
FWA-3			0.00	0.00	0.00	0.00		
FWA-4			0.00	0.00	0.00	0.00		
YWA-1			0.00	0.00	0.00	0.00		
YWA-2			0.00	0.00	0.00	0.00		
7.01	A	0 1.5	0.00	0.00	0.00	0.00	0.00	0.00
7.02	Cca	2 18	0.00	0.00	0.00	0.00		
7.03	2Ckcr	18 100	0.00	0.00	0.00	0.00		
4.01	A	0 3	0.00	0.00	0.00	0.00	0.00	0.00
4.02	Bk1	3 9	0.00	0.00	0.00	0.00		
4.03	2Bk2	9 60	0.00	0.00	0.00	0.00		
4.04	2Ckn	60 100	0.00	0.00	0.00	0.00		
17.01	A	0 6	0.00	0.00	0.00	0.00	0.00	0.00
17.02	Bw	6 24	0.00	0.00	0.00	0.00		
17.03	2Ckn	24 120	0.00	0.00	0.00	0.00		
13.01	A	0 9	0.00	0.00	0.00	0.00	10.83	0.06
13.02	Bw	9 21	0.00	0.00	0.00	0.00		
13.03	2Bqj	21 73	0.00	0.00	0.00	0.00		
13.04	2Ckqn	73 138	10.00	0.00	0.17	10.83		
15.01	A	0 18	0.00	0.00	0.00	0.00	0.00	0.00
15.02	Bw	18 46	0.00	0.00	0.00	0.00		
15.03	2Bqk	46 170	0.00	0.00	0.00	0.00		
15.05	2Ckn	170 220	0.00	0.00	0.00	0.00		
3.01	Av	0 5	5.00	0.00	0.08	0.42	0.42	0.00
3.02	Avkj	5 13	0.00	0.00	0.00	0.00		
3.03	2Btkj	13 45	0.00	0.00	0.00	0.00		
3.04	2Btjqak1	45 83	0.00	0.00	0.00	0.00		
3.05	2Btjqak2	83 107	0.00	0.00	0.00	0.00		
3.06	2Ckqn	107 210	0.00	0.00	0.00	0.00		
21.01	Av	0 4	0.00	0.00	0.00	0.00	0.00	0.00
21.02	Bw	4 15	0.00	0.00	0.00	0.00		
21.03	Bk	15 33	0.00	0.00	0.00	0.00		
21.04	2Btjqkjb1	33 55	0.00	0.00	0.00	0.00		
21.05	2Btjqakb1	55 144	0.00	0.00	0.00	0.00		
21.06	3Bqakb2	144 186	0.00	0.00	0.00	0.00		
21.07	3Ckqn	186 233	999.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)	COLOR-PALING (maximum=60) Color #1	Color #2	Normalized property	% thickness	Profile property	Weighted mean
11.01	A	0 4	0.00	0.00	0.00	0.00	0.00	0.00
11.02	A	4 15	0.00	0.00	0.00	0.00		
11.03	2Btj	15 42	0.00	0.00	0.00	0.00		
11.04	2Btqgv	42 90	0.00	0.00	0.00	0.00		
11.05	2Bkq	90 150	0.00	0.00	0.00	0.00		
11.06	3kqgkb	150 170	0.00	0.00	0.00	0.00		
12.01	Av1	0 4	0.00	0.00	0.00	0.00	0.00	0.00
12.02	Av2	4 14	0.00	0.00	0.00	0.00		
12.03	Bt	14 47	0.00	0.00	0.00	0.00		
12.04	2Bk1	47 105	0.00	0.00	0.00	0.00		
12.05	2Bk2	105 120	0.00	0.00	0.00	0.00		
12.06	2Btqgkb	120 144	0.00	0.00	0.00	0.00		
12.07	8qkb	144 200	999.00	0.00	0.00	0.00		
14.01	A	0 8	0.00	0.00	0.00	0.00	0.00	0.00
14.02	Bw	8 28	0.00	0.00	0.00	0.00		
14.03	2Bk	28 54	0.00	0.00	0.00	0.00		
14.04	2Btjkq	54 107	0.00	0.00	0.00	0.00		
14.05	3Bkjb	107 121	0.00	0.00	0.00	0.00		
14.06	3Bqgkjb	121 152	0.00	0.00	0.00	0.00		
14.07	4Bqgk2b	152 221	0.00	0.00	0.00	0.00		
14.08	4Bvjb	221 230	0.00	0.00	0.00	0.00		
20.01	Av1	0 8	0.00	0.00	0.00	0.00	0.00	0.00
20.02	Av2	8 19	0.00	0.00	0.00	0.00		
20.03	Bw	19 42	0.00	0.00	0.00	0.00		
20.04	2Btjq	42 64	0.00	0.00	0.00	0.00		
20.05	2Btjqk1	64 76	0.00	0.00	0.00	0.00		
20.06	2Btjqk2-1	76 114	0.00	0.00	0.00	0.00		
20.07	2Btjqk2-2	114 152	0.00	0.00	0.00	0.00		
20.08	2Btjqk2-3	152 190	0.00	0.00	0.00	0.00		
5.01	A	0 5	0.00	0.00	0.00	0.00	20.67	0.08
5.02	Bw	5 20	0.00	0.00	0.00	0.00		
5.03	Bk	20 45	10.00	0.00	0.17	4.17		
5.04	2Btb	45 56	0.00	0.00	0.00	0.00		
5.05	2Btqgkb	56 106	0.00	0.00	0.00	0.00		
5.06	2Btqg	106 164	0.00	0.00	0.00	0.00		
5.07	2Cqg	164 263	10.00	0.00	0.17	16.50		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		COLOR-FALING (maximum=60) Color #1	Color #2	Normalized property	% thickness	Profile property	Weighted mean
18.01	Av	0	11	0.00	0.00	0.00	0.00	0.00	0.00
18.02	A	11	33	0.00	0.00	0.00	0.00		
18.03	Bt	33	49	0.00	0.00	0.00	0.00		
18.04	2Btqkj	49	66	0.00	0.00	0.00	0.00		
18.05	2Btqk	66	120	0.00	0.00	0.00	0.00		
18.06	3Kc	120	160	999.00	0.00	0.00	0.00		
8.01	Av	0	9	0.00	0.00	0.00	0.00	0.00	0.00
8.02	Bt1	9	21	0.00	0.00	0.00	0.00		
8.03	2Bt2	21	35	0.00	0.00	0.00	0.00		
8.04	2kqg	35	68	0.00	0.00	0.00	0.00		
8.05	2k	68	100	0.00	0.00	0.00	0.00		
8.05	2Ck	100	210	0.00	0.00	0.00	0.00		
16.01	Av	0	13	0.00	0.00	0.00	0.00	0.00	0.00
16.02	Bw	13	30	0.00	0.00	0.00	0.00		
16.03	Bt	30	43	0.00	0.00	0.00	0.00		
16.04	2Btqk	43	58	0.00	0.00	0.00	0.00		
16.05	2kq	58	100	0.00	0.00	0.00	0.00		
16.06	2Bqg (nc)	100	150	0.00	0.00	0.00	0.00		
16.07	2Bcm	100	150	0.00	0.00	0.00	0.00		
16.08	2Ckqn	150	207	0.00	0.00	0.00	0.00		
1.01	A	0	10	10.00	0.00	0.17	1.67	36.33	0.13
1.02	Bt	10	25	0.00	0.00	0.00	0.00		
1.03	2Btqb1	25	42	0.00	0.00	0.00	0.00		
1.04	2Btqb2	42	56	0.00	0.00	0.00	0.00		
1.08	3Kqgb1	56	70	0.00	0.00	0.00	0.00		
1.09	4Kqgb2	70	115	999.00	0.00	0.00	0.00		
1.10	5Bk	115	167	40.00	0.00	0.67	34.67		
1.11	5Cnk	167	195	0.00	0.00	0.00	0.00		
1.12	5Cn	195	290	0.00	0.00	0.00	0.00		
19.01	Av1	0	4	10.00	0.00	0.17	0.67	1.50	0.00
	Av2	4	9	10.00	0.00	0.17	0.83		
19.03	Bk	9	13	0.00	0.00	0.00	0.00		
19.04	Bw	13	17	0.00	0.00	0.00	0.00		
19.05	Btqg	17	29	0.00	0.00	0.00	0.00		
19.06	2Btqg	29	47	0.00	0.00	0.00	0.00		
19.07	2kqg1	47	72	0.00	0.00	0.00	0.00		
19.08	2kqg2	72	150	0.00	0.00	0.00	0.00		

Sample	Horizon	Depth (cm)		COLOR-PALING (maximum=50) Color #1	Color #2	Normalized property	X thickness	Profile property	Weighted mean
6.01	Av	0	6	0.00	0.00	0.00	0.00	0.00	0.00
6.02	Bt	6	10	0.00	0.00	0.00	0.00		
6.03	Btqa	10	52	0.00	0.00	0.00	0.00		
6.04	Btkq	52	101	0.00	0.00	0.00	0.00		
6.05	Btq	101	152	0.00	0.00	0.00	0.00		
6.06	2Ck1	152	220	0.00	0.00	0.00	0.00		
6.07	2Ck2	220	300	999.00	0.00	0.00	0.00		
2.01	Av	0	3	0.00	0.00	0.00	0.00	0.00	0.00
2.02	A	3	10	0.00	0.00	0.00	0.00		
2.03	Bv	10	19	0.00	0.00	0.00	0.00		
2.04	2Bqmky	19	34	0.00	0.00	0.00	0.00		
2.05	2Btqmv	34	70	0.00	0.00	0.00	0.00		
2.07	Ktqm	19	52	0.00	0.00	0.00	0.00		
2.08	kq	52	114	0.00	0.00	0.00	0.00		
2.09	2k	114	157	0.00	0.00	0.00	0.00		
22.01	Av	0	10	0.00	0.00	0.00	0.00	0.00	0.00
22.02	Bw	10	21	0.00	0.00	0.00	0.00		
22.03	F	21	62	0.00	0.00	0.00	0.00		
22.04	km	62	92	0.00	0.00	0.00	0.00		
22.05	Bkqm	92	184	0.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)	COLOR-LIGHTENING (maximum=30) Color #1	Color #2	Normalized property	x thickness	Profile property	Weighted mean CC
FWH-1			0.00	0.00	0.00	0.00		
FWH-2			0.00	0.00	0.00	0.00		
FWH-3			0.00	0.00	0.00	0.00		
FWH-4			0.00	0.00	0.00	0.00		
YWH-1			0.00	0.00	0.00	0.00		
YWH-2			0.00	0.00	0.00	0.00		
7.01	A	0 1.5	10.00	0.00	0.13	0.19	1.22	0.01
7.02	Cox	2 18	5.00	0.00	0.06	1.03		
7.03	2Ckox	18 100	0.00	0.00	0.00	0.00		
4.01	A	0 3	0.00	0.00	0.00	0.00	21.75	0.22
4.02	Bk1	3 9	20.00	0.00	0.25	1.50		
4.03	2Bk2	9 60	20.00	0.00	0.25	12.75		
4.04	2Ckn	60 100	15.00	0.00	0.19	7.50		
17.01	A	0 6	0.00	0.00	0.00	0.00	27.38	0.22
17.02	Bw	6 24	15.00	0.00	0.19	3.38		
17.03	2Ckn	24 129	20.00	0.00	0.25	24.00		
13.01	A	0 9	0.00	0.00	0.00	0.00	11.38	0.05
13.02	Bw	9 21	0.00	0.00	0.00	0.00		
13.03	2Bqj	21 73	5.00	0.00	0.06	3.25		
13.04	2Ckqn	73 138	10.00	0.00	0.13	8.13		
15.01	A	0 18	0.00	0.00	0.00	0.00	17.13	0.05
15.02	Bw	18 46	0.00	0.00	0.00	0.00		
15.03	2Bqx	46 170	5.00	0.00	0.06	7.75		
15.05	2Ckn	170 220	15.00	0.00	0.19	9.38		
3.01	Av	0 5	10.00	0.00	0.13	0.63	17.00	0.05
3.02	Avkj	5 12	10.00	0.00	0.13	0.88		
3.03	2Btkj	12 45	0.00	0.00	0.00	0.00		
3.04	2Btjqkb1	45 83	20.00	0.00	0.25	9.50		
3.05	2Btjqmb2	83 107	20.00	0.00	0.25	6.00		
3.06	2Ckqn	107 210	0.00	0.00	0.00	0.00		
21.01	Av	0 4	10.00	0.00	0.13	0.50	6.88	0.03
21.02	Bw	4 15	0.00	0.00	0.00	0.00		
21.03	Bt	15 33	5.00	0.00	0.06	1.13		
21.04	2Btjqkjb1	33 55	0.00	0.00	0.00	0.00		
21.05	2Btjqmkb1	55 144	0.00	0.00	0.00	0.00		
21.06	3Bqmkb2	144 186	10.00	0.00	0.13	5.25		
21.07	3Ckqn	186 233	999.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		COLOR-LIGHTENING (maximum=80) Color #1	Color #2	Normalized property	X thickness	Profile property	Weighted mean cc
11.01	Av	0	4	0.00	0.00	0.00	0.00	3c.00	0.21
11.02	A	4	15	0.00	0.00	0.00	0.00		
11.03	2Bt;	15	42	0.00	0.00	0.00	0.00		
11.04	2Btqmx	42	90	5.00	40.00	0.28	13.50		
11.05	2Bxc	90	150	20.00	0.00	0.25	15.00		
11.06	3kqgxt	150	170	40.00	20.00	0.38	7.50		
12.01	Av1	0	4	0.00	0.00	0.00	0.00	20.44	0.10
12.02	Av2	4	14	0.00	0.00	0.00	0.00		
12.03	Bt	14	47	5.00	0.00	0.06	2.0c		
12.04	2Bk1	47	105	15.00	0.00	0.19	10.88		
12.05	2Bk2	105	120	0.00	0.00	0.00	0.00		
12.06	2Btqmkb	120	144	0.00	50.00	0.31	7.50		
12.07	Bqkb	144	200	999.00	0.00	0.00	0.00		
14.01	A	0	8	10.00	0.00	0.13	1.00	10.94	0.05
14.02	Bw	8	28	0.00	0.00	0.00	0.00		
14.03	2Bk	28	54	0.00	0.00	0.00	0.00		
14.04	2Btjrq	54	107	15.00	0.00	0.19	9.94		
14.05	3Bkjb	107	121	0.00	0.00	0.00	0.00		
14.0c	3Bqmr1b	121	152	0.00	0.00	0.00	0.00		
14.07	4Bqmr2b	152	221	0.00	0.00	0.00	0.00		
14.08	4Bkjb	221	230	0.00	0.00	0.00	0.00		
20.01	Av1	0	8	0.00	0.00	0.00	0.00	0.00	0.00
20.02	A.2	8	19	0.00	0.00	0.00	0.00		
20.03	Bw	19	42	0.00	0.00	0.00	0.00		
20.04	2Btjq	42	64	0.00	0.00	0.00	0.00		
20.05	2Btjqk1	64	76	0.00	0.00	0.00	0.00		
20.0c	2Btjqk2-1	76	114	0.00	0.00	0.00	0.00		
20.07	2Btjqk2-2	114	152	0.00	0.00	0.00	0.00		
20.08	2Btjqk2-3	152	190	0.00	0.00	0.00	0.00		
5.01	A	0	5	10.00	0.00	0.13	0.63	35.38	0.12
5.02	Bw	5	20	0.00	0.00	0.00	0.00		
5.03	Br	20	45	10.00	0.00	0.13	3.13		
5.04	2Btb	45	5c	0.00	0.00	0.00	0.00		
5.05	2Btqmkb	5c	10c	10.00	0.00	0.13	c.25		
5.06	2Btqb	10c	1c4	20.00	50.00	0.44	25.38		
5.07	2Cqn	164	2c3	0.00	0.00	0.00	0.00		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		COLOR-LIGHTENING (maximum=50) Color #1	Color #2	Normalized property	x thickness	Profile propert.	weighted mean CC
18.01	Av	0	11	15.00	0.00	0.15	1.06	19.69	0.12
18.02	A	11	33	15.00	0.00	0.15	4.13		
18.03	Bt	33	46	0.00	0.00	0.00	0.00		
18.04	2Btqb1	46	66	0.00	0.00	0.00	0.00		
18.05	2Btqb	66	120	20.00	0.00	0.25	13.50		
18.06	3kb	120	160	999.00	0.00	0.00	0.00		
8.01	Av	0	9	0.00	0.00	0.00	0.00	51.63	0.23
8.02	Bt1	9	21	0.00	0.00	0.00	0.00		
8.03	2Bt2	21	35	20.00	0.00	0.25	3.50		
8.04	2kqm	35	68	30.00	0.00	0.38	12.38		
8.05	2k	68	100	55.00	0.00	0.69	22.00		
8.06	2Cr	100	210	10.00	0.00	0.13	13.75		
16.01	Av	0	13	0.00	0.00	0.00	0.00	30.00	2.50
16.02	Bw	13	30	0.00	0.00	0.00	0.00		
16.03	Bt	30	43	0.00	0.00	0.00	0.00		
16.04	2Btqk	43	58	20.00	0.00	0.25	3.75		
16.05	2kq	58	100	50.00	0.00	0.63	26.25		
16.06	2Bqg (nc)	100	150	0.00	0.00	0.00	0.00		
16.07	2Bqg	100	150	0.00	0.00	0.00	0.00		
16.08	2Ckqn	150	207	0.00	0.00	0.00	0.00		
1.01	A	0	10	0.00	0.00	0.00	0.00	46.00	0.16
1.02	Bt	10	25	0.00	0.00	0.00	0.00		
1.03	2Btqb1	25	42	0.00	0.00	0.00	0.00		
1.04	2Btqb2	42	56	0.00	0.00	0.00	0.00		
1.08	3kqmb1	56	70	50.00	0.00	0.63	8.75		
1.09	4kqmb2	70	115	999.00	0.00	0.00	0.00		
1.10	5Bk	115	167	10.00	0.00	0.13	6.50		
1.11	5Cnx	167	195	20.00	0.00	0.25	7.00		
1.12	5Cn	195	290	20.00	0.00	0.25	23.75		
19.01	Av1	0	4	10.00	0.00	0.13	0.50	47.63	0.00
	Av2	4	9	10.00	0.00	0.13	0.63		
19.03	Bk	9	13	20.00	0.00	0.25	1.00		
19.04	Bw	13	17	5.00	0.00	0.06	0.25		
19.05	Btqe	17	29	15.00	0.00	0.19	2.25		
19.06	2ktqm	29	47	50.00	20.00	0.44	7.88		
19.07	2kqm1	47	72	50.00	0.00	0.63	15.63		
19.08	2kqm2	72	150	20.00	0.00	0.25	19.50		

SOIL PROFILE INDEX VALUES

Sample	Horizon	Depth (cm)		COLOR-LIGHTENING (maximum=600) Color #1	Color #2	Normalized property	X thickness	Profile property	Weighted mean pr
6.01	Av	0	6	0.00	0.00	0.00	0.00	61.50	0.00
6.02	Bt	6	10	10.00	0.00	0.13	0.50		
6.03	2kqm	10	52	30.00	20.00	0.31	13.13		
6.04	3kmq	52	101	20.00	0.00	0.25	12.25		
6.05	3kq	101	153	40.00	0.00	0.50	26.00		
6.06	3Ckq	153	230	10.00	0.00	0.13	9.63		
6.07	3Ckqr	230	300	999.00	0.00	0.00	0.00		
2.01	Av	0	3	10.00	0.00	0.13	0.38	96.25	0.49
2.02	A	3	19	10.00	0.00	0.13	0.88		
2.03	By	19	19	0.00	0.00	0.00	0.00		
2.04	2Bqekv	19	34	10.00	0.00	0.13	1.88		
2.05	2Btqsv	34	70	0.00	0.00	0.00	0.00		
2.07	Ktqm	19	52	50.00	50.00	0.63	20.63		
2.08	Kq	52	114	40.00	0.00	0.50	31.00		
2.09	2k	114	197	40.00	0.00	0.50	41.50		
22.01	Av	0	10	20.00	0.00	0.25	2.50	68.00	0.37
22.02	Bw	10	21	0.00	0.00	0.00	0.00		
22.03	K	21	62	50.00	0.00	0.63	25.63		
22.04	Kp	62	92	45.00	0.00	0.56	16.88		
22.05	Bkqm	92	184	20.00	0.00	0.25	23.00		

Sample	Horizon	Depth (cm)	Total texture (maximum=90) Normalized property	X thickness	Profile property	Weighted mean pp
FWA-1			0.00	0.00		
FWA-2			0.11	0.00		
FWA-3			0.00	0.00		
FWA-4			0.00	0.00		
YWA-1			0.00	0.00		
YWA-2			0.00	0.00		
7.01	A	0 1.5	0.00	0.00	0.00	0.00
7.02	Cox	2 18	0.00	0.00		
7.03	2Ckox	18 100	0.00	0.00		
4.01	A	0 3	0.17	0.50	28.94	0.29
4.02	Bk1	3 9	0.22	1.33		
4.03	2Bk2	9 60	0.44	22.67		
4.04	2Ckn	60 100	0.11	4.44		
17.01	A	0 6	0.22	1.33	3.33	0.03
17.02	Bw	6 24	0.11	2.00		
17.03	2Ckn	24 120	0.00	0.00		
13.01	A	0 9	0.11	1.00	2.33	0.02
13.02	Bw	9 21	0.11	1.33		
13.03	2Bqj	21 73	0.00	0.00		
13.04	2Ckqn	73 138	0.00	0.00		
15.01	A	0 18	0.22	4.00	44.89	0.20
15.02	Bw	18 46	0.28	7.78		
15.03	2Bqk	46 170	0.22	27.56		
15.05	2Ckn	170 220	0.11	5.56		
3.01	Av	0 5	0.56	2.78	34.44	0.16
3.02	Avkj	5 12	0.78	5.44		
3.03	2Btkj	12 45	0.67	22.00		
3.04	2Btjqak1	45 83	0.11	4.22		
3.05	2Btjqak2	83 107	0.00	0.00		
3.06	2Ckqn	107 210	0.00	0.00		
21.01	Av	0 4	0.56	2.22	52.28	0.22
21.02	Bw	4 15	0.44	4.89		
21.03	Bk	15 33	0.33	6.00		
21.04	2Btjqkjb1	33 55	0.44	9.78		
21.05	2Btjqakb1	55 144	0.28	24.72		
21.06	3Bqakb2	144 186	0.11	4.67		
21.07	3Ckqn	186 233	0.00	0.00		

Sample	Horizon	Depth (cm)		Total texture (maximum=90) Normalized property	X thickness	Profile property	Weighted mean pp
11.01	Av	0	4	0.33	1.33	64.89	0.38
11.02	e	4	15	0.44	4.89		
11.03	2Btj	15	42	0.44	12.00		
11.04	2Btjqm	42	90	0.56	26.67		
11.05	2Bkq	90	150	0.22	13.33		
11.06	3Bqmkb	150	170	0.33	6.67		
12.01	Av1	0	4	0.33	1.33	56.67	0.25
12.02	Av2	4	14	0.33	3.33		
12.03	Bt	14	47	0.56	18.33		
12.04	2Bk1	47	105	0.44	25.78		
12.05	2Bk2	105	120	0.11	1.67		
12.06	2Btqmkb	120	144	0.00	0.00		
12.07	Bqkb	144	200	0.11	6.22		
14.01	A	0	8	0.33	2.67	88.22	0.38
14.02	Bw	8	28	0.39	7.78		
14.03	2Bt	28	54	0.44	11.56		
14.04	2Btjkq	54	107	0.44	23.56		
14.05	2Bkjb	107	121	0.22	3.11		
14.06	3Bqm'1b	121	152	0.22	6.89		
14.07	4Bqmk2b	152	221	0.44	30.67		
14.08	4Bkjt	221	230	0.22	2.00		
20.01	Av1	0	8	0.11	0.89	51.89	0.27
20.02	Av2	8	19	0.22	2.44		
20.03	Bw	19	42	0.33	7.67		
20.04	2Btjq	42	64	0.33	7.33		
20.05	2Btjqk1	64	76	0.33	4.00		
20.06	2Btjqk2-1	76	114	0.22	8.44		
20.07	2Btjqk2-2	114	152	0.33	12.67		
20.08	2Btjqk2-3	152	190	0.22	8.44		
5.01	A	0	5	-0.22	-1.11	10.33	0.04
5.02	Bw	5	20	-0.22	-3.33		
5.03	Bt	20	45	0.00	0.00		
5.04	2Btb	45	56	0.33	3.67		
5.05	2Btqmkb	56	106	0.22	11.11		
5.06	2Btqb	106	164	0.00	0.00		
5.07	2Cqn	164	200	0.00	0.00		

Sample	Horizon	Depth (cm)		Total texture (maximum=90) Normalized property	X thickness	Profile property	Weighted mean pp
18.01	Av	0	11	0.33	3.67	18.22	0.11
18.02	A	11	33	0.06	1.22		
18.03	Bt	33	49	0.22	1.56		
18.04	2Btqk1	49	66	0.22	5.78		
18.05	2Btqk	66	120	0.11	6.00		
18.06	3kb	120	150	0.00	0.00		
8.01	Av	0	9	0.44	4.00	26.33	0.17
8.02	Bt1	9	21	1.00	12.00		
8.03	2Bt2	21	35	0.22	3.11		
8.04	2kqm	35	68	0.11	3.67		
8.05	2k	68	100	0.11	3.56		
8.06	2Ck	100	210	0.00	0.00		
16.01	Av	0	13	0.33	4.33	74.89	6.24
16.02	Bw	13	30	0.33	5.67		
16.03	Bt	30	43	0.33	4.33		
16.04	2Btqk	43	58	0.89	13.33		
16.05	2kq	58	100	0.44	18.67		
16.06	2Bqm (nc)	100	150	0.22	11.11		
16.07	2Bqm	100	150	0.22	11.11		
16.08	2Ckqn	150	207	0.11	6.33		
1.01	A	0	10	0.22	2.22	95.11	0.33
1.02	Bt	10	25	0.22	3.33		
1.03	2Btqk1	25	42	1.00	17.00		
1.04	2Btqk2	42	56	1.00	14.00		
1.08	3kqmb1	56	70	0.33	4.67		
1.09	4kqmb2	70	115	0.33	15.00		
1.10	5Bk	115	167	0.22	11.56		
1.11	5Cnk	167	195	0.22	6.22		
1.12	5Cn	195	290	0.22	21.11		
19.01	Av1	0	4	0.33	1.33	61.89	0.00
	Av2	4	9	0.44	2.22		
19.03	Bk	9	13	0.33	1.33		
19.04	Bw	13	17	0.33	1.33		
19.05	Btqm	17	29	0.56	6.67		
19.06	2Ktqm	29	47	0.33	6.00		
19.07	2Kqm1	47	72	0.33	8.33		
19.08	2Kqm2	72	150	0.44	34.67		

Sample	Horizon	Depth (cm)		Total texture (maximum=90) Normalized property	X thickness	Profile property	Weighted mean cc
6.01	Av	0	6	0.33	2.00	13.56	0.01
6.02	Bt	6	10	0.56	2.22		
6.03	2Kqm	10	52	0.22	9.33		
6.04	3Kmq	52	101	0.00	0.00		
6.05	3Kq	101	153	0.00	0.00		
6.06	3Dkq	153	230	0.00	0.00		
6.07	3Dkqr	230	300	0.00	0.00		
2.01	Av	0	3	0.44	1.33	79.83	0.41
2.02	A	3	10	0.44	3.11		
2.03	Bv	10	19	0.56	5.00		
2.04	2Bqmkv	19	34	0.39	5.83		
2.05	2Btqmv	34	70	0.39	14.00		
2.07	Ktqm	19	52	0.56	18.33		
2.08	Kq	52	114	0.22	13.78		
2.09	2K	114	157	0.22	18.44		
22.01	Av	0	10	0.56	5.56	56.11	0.30
22.02	Bw	10	21	0.89	9.78		
22.03	B	21	62	0.33	13.67		
22.04	Km	62	92	0.22	6.67		
22.05	Bkqm	92	184	0.22	20.44		

Sample	Horizon	Depth (cm)		STRUCTURE (maximum=1.0) Normalized property	* thickness	Profile property	Weighted mean
FWA-1				0.00	0.00		
FWA-2				0.00	0.00		
FWA-3				0.00	0.00		
FWA-4				0.00	0.00		
YWA-1				0.00	0.00		
YWA-2				0.00	0.00		
7.01	A	0	1.5	0.25	0.38	0.38	0.00
7.02	Cox	2	18	0.00	0.00		
7.03	2Cnox	18	100	0.00	0.00		
4.01	A	0	3	0.50	1.50	38.50	0.39
4.02	Bk1	3	9	0.50	3.00		
4.03	2Bk2	9	60	0.67	34.00		
4.04	2Ckn	60	100	0.00	0.00		
17.01	A	0	6	0.42	2.50	5.50	0.05
17.02	Bw	6	24	0.17	3.00		
17.03	2Ckm	24	120	0.00	0.00		
13.01	A	0	9	0.67	6.00	10.00	0.07
13.02	Bw	9	21	0.33	4.00		
13.03	2Bqj	21	73	0.00	0.00		
13.04	2Ckqn	73	139	0.00	0.00		
15.01	A	0	18	0.50	9.00	23.00	0.10
15.02	Bw	18	46	0.50	14.00		
15.03	2Bqk	46	170	0.00	0.00		
15.05	2Ckn	170	220	0.00	0.00		
3.01	Av	0	5	0.67	3.33	12.33	0.06
3.02	AVkj	5	12	0.50	3.50		
3.03	2Btkj	12	45	0.17	5.50		
3.04	2Btjqmk1	45	83	0.00	0.00		
3.05	2Btjqmk2	83	107	0.00	0.00		
3.06	2Ckqn	107	210	0.00	0.00		
21.01	Av	0	4	0.67	2.67	20.08	0.09
21.02	Bw	4	15	0.58	6.42		
21.03	Bt	15	33	0.00	0.00		
21.04	2Btjqkjb1	33	55	0.50	11.00		
21.05	2Btjqmkb1	55	144	0.00	0.00		
21.06	3Bqmkb2	144	186	0.00	0.00		
21.07	3Ckqn	186	233	0.00	0.00		

STRUCTURE (maximum=60)

Sample	Horizon	Depth (cm)		Normalized property	x thickness	Profile property	Weighted mean
11.01	Av	0	4	0.83	3.33	32.50	0.19
11.02	A	4	15	0.33	3.67		
11.03	2Bt1	15	42	0.50	13.50		
11.04	2Btcan	42	90	0.25	12.00		
11.05	2Bvq	90	150	0.00	0.00		
11.06	3Kqmkb	150	170	0.00	0.00		
12.01	Av1	0	4	0.33	1.33	88.67	0.44
12.02	Av2	4	14	0.58	5.83		
12.03	Bt	14	47	0.67	22.00		
12.04	2Bk1	47	105	0.75	43.50		
12.05	2Bk2	105	120	0.00	0.00		
12.06	2Btqmkb	120	144	0.67	16.00		
12.07	Bqkb	144	200	0.00	0.00		
14.01	A	0	8	0.42	3.33	40.33	0.18
14.02	Bw	8	28	0.33	6.67		
14.03	2Bk	28	54	0.50	13.00		
14.04	2Btjxq	54	107	0.00	0.00		
14.05	3Bkjb	107	121	0.50	7.00		
14.06	3Bqmk1b	121	152	0.33	10.33		
14.07	4Bqmk2b	152	221	0.00	0.00		
14.08	4Bkjb	221	230	0.00	0.00		
20.01	Av1	0	8	0.33	2.67	32.83	0.17
20.02	Av2	8	19	0.67	7.33		
20.03	Bw	19	42	0.50	11.50		
20.04	2Btjq	42	64	0.33	7.33		
20.05	2Btjqk1	64	76	0.33	4.00		
20.06	2Btjqk2-1	76	114	0.00	0.00		
20.07	2Btjqk2-2	114	152	0.00	0.00		
20.08	2Btjqk2-3	152	190	0.00	0.00		
5.01	A	0	5	0.42	2.08	33.08	0.13
5.02	Bw	5	20	0.33	5.00		
5.03	Bk	20	45	0.17	4.17		
5.04	2Btb	45	56	0.67	7.33		
5.05	2Btqmkb	56	106	0.00	0.00		
5.06	2Ktqb	106	164	0.25	14.50		
5.07	2Cqn	164	203	0.00	0.00		

STRUCTURE (maximum=60)

Sample	Horizon	Depth (cm)		Normalized property	x thickness	Profile property	weighted mean
18.01	Av	0	11	0.75	8.71	34.46	0.22
18.02	A	11	33	0.00	0.00		
18.03	Bt	33	40	0.58	4.08		
18.04	2Btqk;	40	66	0.83	21.67		
18.05	2Btqk	66	120	0.00	0.00		
18.06	3Kb	120	160	0.00	0.00		
8.01	Av	0	9	0.67	6.00	82.25	0.40
8.02	Bt1	9	21	0.92	11.00		
8.03	2Bt2	21	35	0.67	9.33		
8.04	2kqm	35	68	0.92	30.25		
8.05	2k	68	100	0.83	26.67		
8.06	2Ck	100	210	0.00	0.00		
16.01	Av	0	13	0.33	4.33	43.50	3.63
16.02	Bw	13	30	0.33	5.67		
16.03	Bt	30	43	0.75	9.75		
16.04	2Btqv	43	58	0.75	11.25		
16.05	2kq	58	100	0.00	0.00		
16.06	2Bqm (nc)	100	150	0.25	12.50		
16.07	2Bqm	100	150	0.00	0.00		
16.08	2Ckqn	150	207	0.00	0.00		
1.01	A	0	10	0.33	3.33	36.92	0.13
1.02	Bt	10	25	0.58	8.75		
1.03	2Btqb1	25	42	0.50	8.50		
1.04	2Btqb2	42	56	0.50	7.00		
1.08	3kqmb1	56	70	0.67	9.33		
1.09	4Kqmb2	70	115	0.00	0.00		
1.10	5Bv	115	167	0.00	0.00		
1.11	5Cnk	167	195	0.00	0.00		
1.12	5Cn	195	290	0.00	0.00		
19.01	Av1	0	4	0.67	2.67	46.92	0.00
	Av2	4	9	0.67	3.33		
19.02	Bk	9	13	0.33	1.33		
19.04	Bw	13	17	0.58	2.33		
19.05	Btqm	17	29	0.83	10.00		
19.06	2Ktqm	29	47	1.17	21.00		
19.07	2kqm1	47	72	0.25	6.25		
19.08	2kqm2	72	150	0.00	0.00		

STRUCTURE (maximum=60)

Sample	Horizon	Depth (cm)		Normalized property	% thickness	Profile property	Weighted mean
6.01	Av	0	6	0.67	4.00	41.00	0.00
6.02	Bt	6	10	0.50	2.00		
6.03	2Btqm	10	52	0.83	35.00		
6.04	3Bkq	52	101	0.00	0.00		
6.05	3Ck	101	150	0.00	0.00		
6.06	3Ckq	150	230	0.00	0.00		
6.07	3Ckqm	230	300	0.00	0.00		
2.01	Av	0	3	0.67	2.00	123.17	0.67
2.02	A	3	10	0.33	2.33		
2.03	By	10	19	0.50	4.50		
2.04	2Bqmky	19	34	0.83	12.50		
2.05	2Btqmy	34	79	0.92	33.00		
2.07	Ktqm	19	52	0.83	27.50		
2.08	Kq	52	114	0.67	41.33		
2.09	2K	114	157	0.00	0.00		
22.01	Av	0	10	0.75	7.50	71.00	0.39
22.02	Bw	10	21	0.50	5.50		
22.03	K	21	62	0.67	27.33		
22.04	Km	62	92	0.00	0.00		
22.05	Bkqm	92	184	0.33	30.67		

Sample	Horizon	Depth (cm)	DRY CONSISTENCE (maximum=100) Normalized property	X thickness	Profile property	Weighted mean pp
FWA-1			0.00	0.00		
FWA-2			0.00	0.00		
FWA-3			0.00	0.00		
FWA-4			0.00	0.00		
YWA-1			0.00	0.00		
YWA-2			0.00	0.00		
7.01	A	0 1.5	0.10	0.15	0.15	0.00
7.02	Cox	2 18	0.00	0.00		
7.03	2Ckox	18 100	0.00	0.00		
4.01	A	0 3	0.10	0.30	11.70	0.12
4.02	Bk1	3 9	0.20	1.20		
4.03	2Bk2	9 60	0.20	10.20		
4.04	2Ckn	60 100	0.00	0.00		
17.01	A	0 6	0.10	0.60	2.40	0.02
17.02	Bw	6 24	0.10	1.80		
17.03	2Ckn	24 120	0.00	0.00		
13.01	A	0 9	0.10	0.90	7.30	0.05
13.02	Bw	9 21	0.10	1.20		
13.03	2Bqj	21 73	0.10	5.20		
13.04	2Ckqn	73 138	0.00	0.00		
15.01	A	0 18	0.10	1.80	35.80	0.16
15.02	Bw	18 46	0.15	4.20		
15.03	2Bqk	46 170	0.20	24.80		
15.05	2Ckn	170 220	0.10	5.00		
3.01	Av	0 5	0.15	0.75	27.35	0.17
3.02	Avkj	5 12	0.20	1.40		
3.03	2Btkj	12 45	0.20	6.60		
3.04	2Btjqmk1	45 83	0.30	11.40		
3.05	2Btjqmk2	83 107	0.30	7.20		
3.06	2Ckqn	107 210	0.00	0.00		
21.01	Av	0 4	0.15	0.60	83.75	0.36
21.02	Bw	4 15	0.20	2.20		
21.03	Bk	15 33	0.10	1.80		
21.04	2Btjqkjb1	33 55	0.30	6.60		
21.05	2Btjqmkb1	55 144	0.50	44.50		
21.06	3Bqmkb2	144 186	0.50	21.00		
21.07	3Ckqn	186 233	0.15	7.05		

Sample	Horizon	Depth (cm)		DRY CONSISTENCE (maximum=100) Normalized property	X thickness	Profile property	Weighted mean pp
11.01	Ak	0	4	0.10	0.40	37.60	0.22
11.02	A	4	15	0.10	1.10		
11.03	2Btj	15	42	0.30	8.10		
11.04	2Btqsk	42	90	0.50	24.00		
11.05	2Bkq	90	150	0.00	0.00		
11.06	3Kqskb	150	170	0.20	4.00		
12.01	Av1	0	4	0.10	0.40	36.00	0.18
12.02	Av2	4	14	0.10	1.00		
12.03	Bt	14	47	0.20	6.60		
12.04	2Bk1	47	105	0.25	14.50		
12.05	2Bk2	105	120	0.10	1.50		
12.06	2Btqskb	120	144	0.50	12.00		
12.07	Bqkb	144	200	0.00	0.00		
14.01	A	0	8	0.10	0.80	52.00	0.23
14.02	Bw	8	28	0.10	2.00		
14.03	2Bk	28	54	0.10	2.60		
14.04	2Btjkq	54	107	0.00	0.00		
14.05	3Bkjb	107	121	0.25	3.50		
14.06	3Bqsk1b	121	152	0.50	15.50		
14.07	4Bqsk2b	152	221	0.40	27.60		
14.08	4Bkjb	221	230	0.00	0.00		
20.01	Av1	0	8	0.10	0.80	22.40	0.12
20.02	Av2	8	19	0.10	1.10		
20.03	Bw	19	42	0.10	2.30		
20.04	2Btjq	42	64	0.20	4.40		
20.05	2Btjqk1	64	76	0.20	2.40		
20.06	2Btjqk2-1	76	114	0.10	3.80		
20.07	2Btjqk2-2	114	152	0.10	3.80		
20.08	2Btjqk2-3	152	190	0.10	3.80		
5.01	A	0	5	0.00	0.00	38.15	0.15
5.02	Bw	5	20	0.05	0.75		
5.03	Bk	20	45	0.10	2.50		
5.04	2Btb	45	56	0.30	3.30		
5.05	2Btqskb	56	106	0.40	20.00		
5.06	2Btqb	106	164	0.20	11.60		
5.07	2Cqn	164	203	0.00	0.00		

Sample	Horizon	Depth (cm)		DRY CONSISTENCE (maximum=100) Normalized property	X thickness	Profile property	Weighted mean pp
15.01	Av	0	11	0.10	1.10	45.80	0.29
15.02	A	11	33	0.00	0.00		
15.03	Bt	33	40	0.10	0.70		
15.04	2Btqk1	40	66	0.30	7.80		
15.05	2Btqk	66	120	0.30	16.20		
15.06	3kq	120	160	0.50	20.00		
8.01	Av	0	9	0.10	0.90	29.30	0.14
8.02	Bt1	9	21	0.00	0.00		
8.03	2Bt2	21	35	0.40	5.60		
8.04	2kqm	35	68	0.40	13.20		
8.05	2k	68	100	0.30	9.60		
8.06	2Ck	100	210	0.00	0.00		
16.01	Av	0	13	0.00	0.00	62.20	5.16
16.02	Bw	13	30	0.00	0.00		
16.03	Bt	30	43	0.00	0.00		
16.04	2Btqk	43	58	0.20	3.00		
16.05	2kq	58	100	0.50	21.00		
16.06	2Bqm (nc)	100	150	0.35	17.50		
16.07	2Bqm	100	150	0.30	15.00		
16.08	2Ckqm	150	207	0.10	5.70		
1.01	A	0	10	0.00	0.00	31.20	0.11
1.02	Bt	10	25	0.00	0.00		
1.03	2Btqm1	25	42	0.20	3.40		
1.04	2Btqm2	42	56	0.20	2.80		
1.05	3kqmb1	56	70	0.50	7.00		
1.06	4kqmb2	70	115	0.40	18.00		
1.10	5Bk	115	167	0.00	0.00		
1.11	5Cmk	167	195	0.00	0.00		
1.12	5Cm	195	290	0.00	0.00		
19.01	Av1	0	4	0.00	0.00	57.20	0.00
	Av2	4	9	0.20	1.00		
19.02	Bk	9	13	0.00	0.00		
19.04	Bw	13	17	0.00	0.00		
19.05	Btqm	17	29	0.50	6.00		
19.06	2ktqm	29	47	0.50	9.00		
19.07	2kqm1	47	72	0.40	10.00		
19.08	2kqm2	72	150	0.40	31.20		

Sample	Horizon	Depth (cm)		DRY CONSISTENCE (maximum=100) Normalized property	x thickness	Profile property	Weighted mean pc
6.01	Av	0	6	999.00	0.00	25.70	0.00
6.02	Bt	6	10	999.00	0.00		
6.03	Bxqm	10	52	999.00	0.00		
6.04	Bxmq	52	101	0.50	24.50		
6.05	Bkq	101	153	0.10	5.30		
6.06	BCxq	153	230	0.00	0.00		
6.07	BCkqr	230	300	0.00	0.00		
2.01	Av	0	3	0.10	0.30	70.30	0.36
2.02	A	3	10	0.00	0.00		
2.03	Bt	10	19	0.00	0.00		
2.04	2Bqmkv	19	34	0.40	6.00		
2.05	2Btqmv	34	79	0.40	14.40		
2.07	Ktqm	19	52	0.50	16.50		
2.08	Kq	52	114	0.40	24.80		
2.09	2k	114	157	0.10	8.30		
22.01	Av	0	10	0.05	0.50	64.70	0.35
22.02	Bw	10	21	0.10	1.10		
22.03	K	21	62	0.50	20.50		
22.04	Km	62	92	0.50	15.00		
22.05	Bxqm	92	184	0.30	27.60		

Sample	Horizon	Depth (cm)		MOIST CONSISTENCE (maximum=100) Normalized property	x thickness	Profile property	Weighted mean pp
FWA-1				999.00	0.00		
FWA-2				999.00	0.00		
FWA-3				999.00	0.00		
FWA-4				999.00	0.00		
YWA-1				999.00	0.00		
YWA-2				999.00	0.00		
7.01	A	0	1.5	999.00	0.00	0.00	0.00
7.02	Con	2	18	999.00	0.00		
7.03	2Ckcm	18	100	999.00	0.00		
4.01	A		3	999.00	0.00	0.00	0.00
4.02	Bk1	3	9	999.00	0.00		
4.03	2Bk2	9	60	999.00	0.00		
4.04	2Ckn	60	100	999.00	0.00		
17.01	A	0	6	999.00	0.00	0.00	0.00
17.02	Bw	6	24	999.00	0.00		
17.03	2Ckm	24	120	999.00	0.00		
13.01	A	0	9	999.00	0.00	0.00	0.00
13.02	Bw	9	21	999.00	0.00		
13.03	2Bqj	21	73	999.00	0.00		
13.04	2Ckm	73	138	999.00	0.00		
15.01	A	0	18	999.00	0.00	0.00	0.00
15.02	Bw	18	46	999.00	0.00		
15.03	2Bqk	46	170	999.00	0.00		
15.05	2Ckn	170	220	999.00	0.00		
3.01	Av	0	5	999.00	0.00	0.00	0.00
3.02	Avtj	5	12	999.00	0.00		
3.03	2Btkj	12	45	999.00	0.00		
3.04	2Btjqmk1	45	83	999.00	0.00		
3.05	2Btjqmk2	83	107	999.00	0.00		
3.06	2Ckqn	107	210	999.00	0.00		
21.01	Av	0	4	999.00	0.00	0.00	0.00
21.02	Bw	4	15	999.00	0.00		
21.03	Bk	15	33	999.00	0.00		
21.04	2Btjqkjb1	33	55	999.00	0.00		
21.05	2Btjqmkb1	55	144	999.00	0.00		
21.06	3Bqmkb2	144	186	999.00	0.00		
21.07	3Ckqn	186	233	999.00	0.00		

MOIST CONSISTENCE (maximum=100)

Sample	Horizon	Depth (cm)		Normalized property	x thickness	Profile property	weighted mean pc
11.01	Av	0	4	999.00	0.00	0.00	0.00
11.02	A	4	15	999.00	0.00		
11.03	2Btj	15	42	999.00	0.00		
11.04	2Btqgk	42	90	999.00	0.00		
11.05	2Bkq	90	150	999.00	0.00		
11.06	3Kqgkb	150	170	999.00	0.00		
12.01	Av1	0	4	999.00	0.00	0.00	0.00
12.02	Av2	4	14	999.00	0.00		
12.03	Bt	14	47	999.00	0.00		
12.04	2Bk1	47	105	999.00	0.00		
12.05	2Bk2	105	120	999.00	0.00		
12.06	2Btqgkb	120	144	999.00	0.00		
12.07	Bqkb	144	200	999.00	0.00		
14.01	A	0	8	999.00	0.00	0.00	0.00
14.02	Bw	8	28	999.00	0.00		
14.03	2Bk	28	54	999.00	0.00		
14.04	2Btjkq	54	107	999.00	0.00		
14.05	3Bkjb	107	121	999.00	0.00		
14.06	3Bqgak1b	121	152	999.00	0.00		
14.07	4Bqgk2b	152	221	999.00	0.00		
14.08	4Bkjb	221	230	999.00	0.00		
20.01	Av1	0	8	999.00	0.00	0.00	0.00
20.02	Av2	8	19	999.00	0.00		
20.03	Bw	19	42	999.00	0.00		
20.04	2Btjq	42	64	999.00	0.00		
20.05	2Btjqk1	64	76	999.00	0.00		
20.06	2Btjqk2-1	76	114	999.00	0.00		
20.07	2Btjqk2-2	114	152	999.00	0.00		
20.08	2Btjqk2-3	152	190	999.00	0.00		
5.01	A	0	5	999.00	0.00	0.00	0.00
5.02	Bw	5	20	999.00	0.00		
5.03	Bk	20	45	999.00	0.00		
5.04	2Btb	45	56	999.00	0.00		
5.05	2Btqgkb	56	106	999.00	0.00		
5.06	2Ktqb	106	164	999.00	0.00		
5.07	2Cqn	164	263	999.00	0.00		

Sample	Horizon	Depth (cm)		MOIST CONSISTENCE (maximum=100) Normalized property	x thickness	Profile property	Weighted mean pp
18.01	Av	0	11	999.00	0.00	0.00	0.00
18.02	B	11	33	999.00	0.00		
18.03	Bt	33	46	999.00	0.00		
18.04	2Btqkj	46	66	999.00	0.00		
18.05	2Btqk	66	120	999.00	0.00		
18.06	3Kq	120	160	999.00	0.00		
8.01	Av	0	9	999.00	0.00	0.00	0.00
8.02	Bt1	9	21	999.00	0.00		
8.03	2Bt2	21	35	999.00	0.00		
8.04	2kqm	35	68	999.00	0.00		
8.05	2k	68	100	999.00	0.00		
8.06	2Ck	100	210	999.00	0.00		
16.01	Av	0	13	999.00	0.00	0.00	0.00
16.02	Bw	13	30	999.00	0.00		
16.03	Bt	30	43	999.00	0.00		
16.04	2Btqk	43	58	999.00	0.00		
16.05	2kq	58	100	999.00	0.00		
16.06	2Bqm (nc)	100	150	999.00	0.00		
16.07	2Bqm	100	150	999.00	0.00		
16.08	2Ckqn	150	207	999.00	0.00		
1.01	A	0	10	999.00	0.00	11.80	0.04
1.02	Bt	10	25	999.00	0.00		
1.03	2Btqb1	25	42	999.00	0.00		
1.04	2Btqb2	42	56	999.00	0.00		
1.05	3kqmb1	56	70	0.20	2.80		
1.09	4kqmb2	70	115	0.20	9.00		
1.10	5Bk	115	167	0.00	0.00		
1.11	5Cnk	167	195	0.00	0.00		
1.12	5Cn	195	290	0.00	0.00		
19.01	Av1	0	4	999.00	0.00	0.00	0.00
	Av2	4	9	999.00	0.00		
19.02	Bk	9	13	999.00	0.00		
19.04	Bw	13	17	999.00	0.00		
19.05	Btqm	17	29	999.00	0.00		
19.06	2ktqm	29	47	999.00	0.00		
19.07	2kqm1	47	72	999.00	0.00		
19.08	2kqm2	72	150	999.00	0.00		

Sample	Horizon	Depth (cm)		MOIST CONSISTENCE (maximum=100) ------> Normalized property	% thickness	Profile property	Weighted mean pp
6.01	Av	0	6	0.20	1.20	2.00	0.00
6.02	Bt	6	10	0.20	0.80		
6.03	2Kqm	10	52	999.00	0.00		
6.04	3Kmq	52	101	999.00	0.00		
6.05	3Kq	101	153	999.00	0.00		
6.06	3Cxq	153	230	999.00	0.00		
6.07	3Cxqm	230	300	999.00	0.00		
2.01	Av	0	3	999.00	0.00	0.00	0.00
2.02	Ap	3	10	999.00	0.00		
2.03	By	10	19	999.00	0.00		
2.04	2Bqmky	19	34	999.00	0.00		
2.05	2Btqmy	34	70	999.00	0.00		
2.07	Ktqm	19	52	999.00	0.00		
2.08	Kq	52	114	999.00	0.00		
2.09	Zr	114	197	999.00	0.00		
22.01	Av	0	10	999.00	0.00	0.00	0.00
22.02	Bw	10	21	999.00	0.00		
22.03	Ak	21	62	999.00	0.00		
22.04	Km	62	92	999.00	0.00		
22.05	Bkqm	92	184	999.00	0.00		

Sample	Horizon	Depth (cm)	pH (maximum=7.5) Normalized property	X thickness	Profile property	weighted mean
FWA-1			0.04	0.00		
FWA-2			0.02	0.00		
FWA-3			0.05	0.00		
FWA-4			0.21	0.00		
YWA-1			0.06	0.00		
YWA-2			0.19	0.00		
7.01	A	0 1.5	0.06	0.09	5.70	0.05
7.02	Cox	2 18	0.05	0.75		
7.03	2Ckox	18 100	0.05	4.45		
4.01	A	0 3	0.19	0.57	5.69	0.09
4.02	Bk1	3 9	0.17	1.05		
4.03	2Bk2	9 60	0.10	5.25		
4.04	2Ckn	60 100	0.05	1.83		
17.01	A	0 6	0.13	0.79	4.83	0.04
17.02	Bw	6 24	0.01	0.21		
17.03	2Ckn	24 120	0.04	3.84		
13.01	A	0 9	0.33	2.95	20.94	0.15
13.02	Bw	9 21	0.25	2.95		
13.03	2Bqj	21 73	0.16	8.32		
13.04	2Ckqn	73 138	0.10	6.69		
15.01	A	0 18	0.22	3.91	23.86	0.11
15.02	Bw	18 46	0.19	5.28		
15.03	2Bqk	46 170	0.12	14.53		
15.05	2Ckn	170 220	0.00	0.14		
3.01	Av	0 5	0.06	0.30	11.99	0.06
3.02	Avkj	5 12	0.09	0.62		
3.03	2Btkj	12 45	0.09	2.93		
3.04	2Btjqmk1	45 83	0.10	3.91		
3.05	2Btjqmk2	83 107	0.10	2.47		
3.06	2Ckqn	107 210	0.02	1.77		
21.01	Av	0 4	0.01	0.05	26.75	0.11
21.02	Bw	4 15	0.13	1.45		
21.03	Bk	15 33	0.15	2.62		
21.04	2Btjqkjb1	33 55	0.13	2.89		
21.05	2Btjqmkb1	55 144	0.04	3.56		
21.06	3Bqmkb2	144 186	0.17	7.32		
21.07	3Ckqn	186 233	0.19	8.86		

Sample	Horizon	Depth (cm)		pH (maximum=7.5) Normalized property	x thickness	Profile property	Weighted mean
11.01	A+	0	4	0.27	1.10	11.70	0.07
11.02	A	4	15	0.22	2.39		
11.03	2Btj	15	42	0.26	7.02		
11.04	2Btqak	42	90	0.02	0.82		
11.05	2Bkq	90	150	0.00	0.17		
11.06	3Bqakb	150	170	0.01	0.22		
12.01	Av1	0	4	0.22	0.87	10.31	0.05
12.02	Av2	4	14	0.05	0.46		
12.03	Bt	14	47	0.13	4.24		
12.04	2Bk1	47	105	0.05	2.85		
12.05	2Bk2	105	120	0.01	0.17		
12.06	2Btqakb	120	144	0.00	0.07		
12.07	Bqkb	144	200	0.03	1.76		
14.01	A	0	8	0.23	1.85	11.92	0.03
14.02	Bw	8	29	0.23	4.63		
14.03	2Bk	29	54	0.05	1.19		
14.04	2Btjkq	54	107	0.03	1.36		
14.05	3Bkjb	107	121	0.03	0.36		
14.06	3Bqakjb	121	152	0.01	0.35		
14.07	4Bqakjb	152	221	0.01	0.79		
14.08	4Bkjb	221	230	0.15	1.39		
20.01	Av1	0	8	0.30	2.42	19.38	0.10
20.02	Av2	8	19	0.30	3.33		
20.03	Bw	19	42	0.35	7.95		
20.04	2Btjq	42	64	0.19	4.15		
20.05	2Btjqk1	64	76	0.05	0.55		
20.06	2Btjqk2-1	76	114	0.00	0.11		
20.07	2Btjqk2-2	114	152	0.01	0.43		
20.08	2Btjqk2-3	152	190	0.01	0.43		
5.01	A	0	5	0.12	0.59	33.07	0.13
5.02	Bw	5	20	0.19	2.83		
5.03	Bk	20	45	0.15	3.64		
5.04	2Btb	45	56	0.12	1.29		
5.05	2Btqakb	56	106	0.13	6.57		
5.06	2ktab	106	164	0.09	5.14		
5.07	2Cqn	164	263	0.13	13.01		

Sample	Horizon	Depth (cm)		pH (maximum=3.5) Normalized property	Thickness	Profile property	Weighted mean
18.01	Av	0	11	0.04	0.44	19.29	0.13
18.02	A	11	33	0.01	0.23		
18.03	Bt	33	40	0.12	0.82		
18.04	2Btqk1	40	66	0.26	5.27		
18.05	2Btqk	66	120	0.22	11.72		
18.06	3Bk	120	160	0.02	0.65		
8.01	Av	0	9	0.16	1.44	14.65	0.07
8.02	Bt1	9	21	0.19	2.26		
8.03	2Bt2	21	35	0.15	2.04		
8.04	2Bqm	35	68	0.02	0.57		
8.05	2Bk	68	100	0.05	1.74		
8.06	2Ck	100	210	0.00	0.00		
16.01	Av	0	13	0.26	3.38	14.81	1.23
16.02	Bw	13	30	0.12	1.44		
16.03	Bt	30	43	0.14	1.34		
16.04	2Btqk	43	58	0.07	1.11		
16.05	2Bkq	58	100	0.02	0.72		
16.06	2Bqm (inc)	100	150	0.09	4.43		
16.07	2Bqm	100	150	0.02	0.86		
16.08	2Ckqm	150	207	0.02	0.98		
1.01	A	0	10	0.20	2.03	34.69	0.12
1.02	Bt	10	25	0.22	3.26		
1.03	2Btqm1	25	42	0.19	3.21		
1.04	2Btqm2	42	56	0.16	2.24		
1.05	3Kqmc1	56	70	0.05	0.76		
1.09	4Kqmc2	70	115	0.13	5.66		
1.10	5Bk	115	167	0.04	2.05		
1.11	5Cnk	167	195	0.13	3.32		
1.12	5Cn	195	290	0.13	11.94		
19.01	Av1	0	4	0.14	0.56	17.97	0.00
	Av2	4	9	0.14	0.70		
19.02	Bk	9	13	0.05	0.22		
19.04	Bw	13	17	0.05	0.18		
19.05	Btqm	17	29	0.07	0.89		
19.06	2Ktqm	29	47	0.19	3.39		
19.07	2Kqm1	47	72	0.16	4.00		
19.08	2Kqm2	72	150	0.10	8.02		

pH (maximum=7.5)

Sample	Horizon	Depth (cm)		Normalized property	x thickness	Profile property	Weighted mean
2.01	Av	0	2	0.07	0.45	24.05	0.05
2.02	Bt	2	10	0.10	0.41		
2.03	Btqg	10	52	0.05	2.53		
2.04	Btqg	52	101	0.05	2.24		
2.05	Bkq	101	152	0.10	5.35		
2.06	BCkq	152	230	0.10	7.92		
2.07	BCkqr	230	300	0.07	5.20		
2.01	Av	0	3	0.00	0.01	20.32	0.10
2.02	A	3	10	0.00	0.02		
2.03	By	10	19	0.10	0.92		
2.04	2Bgqky	19	34	0.13	1.97		
2.05	2Btqgy	34	70	0.13	4.73		
2.07	Btqg	19	52	0.07	2.22		
2.08	Bq	52	114	0.01	0.71		
2.09	Ck	114	147	0.12	9.72		
22.01	Av	0	10	0.15	1.54	13.18	0.07
22.02	Bw	10	21	0.01	0.13		
22.03	B	21	62	0.02	0.70		
22.04	Bm	62	92	0.09	2.86		
22.05	Bkqm	92	184	0.09	8.15		

br, bridge; po,pore; pf,ped face; cl,clay

Sample	Horizon	Depth (cm)		br #1	br #2	po #1	po #2	pf #1	pf #2	cl #1	cl #2	Normal prop	% thick	Profile prop	weigh mean
FWA-1				0	0	0	0	0	0	0	0	0.00	0.00		
FWA-2				0	0	0	0	0	0	0	0	0.00	0.00		
FWA-3				0	0	0	0	0	0	0	0	0.00	0.00		
FWA-4				0	0	0	0	0	0	0	0	0.00	0.00		
YWA-1				0	0	0	0	0	0	0	0	0.00	0.00		
YWA-2				0	0	0	0	0	0	0	0	0.00	0.00		
7.01	A	0	1.5	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00
7.02	Cox	2	18	0	0	0	0	0	0	0	0	0.00	0.00		
7.03	2Cnox	18	100	0	0	0	0	0	0	0	0	0.00	0.00		
4.01	A	0	3	0	0	0	0	0	0	0	0	0.00	0.00	3.22	0.02
4.02	Bk1	3	9	70	0	0	0	0	0	0	0	0.54	3.23		
4.03	2Bk2	9	60	0	0	0	0	0	0	0	0	0.00	0.00		
4.04	2Ckn	60	100	0	0	0	0	0	0	0	0	0.00	0.00		
17.01	A	0	6	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.02
17.02	Bw	6	24	0	0	0	0	0	0	0	0	0.00	0.00		
17.03	2Ckn	24	120	0	0	0	0	0	0	0	0	0.00	0.00		
13.01	A	0	9	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00
13.02	Bw	9	21	0	0	0	0	0	0	0	0	0.00	0.00		
13.03	2Bqj	21	72	0	0	0	0	0	0	0	0	0.00	0.00		
13.04	2Ckqn	72	138	0	0	0	0	0	0	0	0	0.00	0.00		
15.01	A	0	18	0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00
15.02	Bw	18	46	0	0	0	0	0	0	0	0	0.00	0.00		
15.03	2Bqk	46	170	0	0	0	0	0	0	0	0	0.00	0.00		
15.05	2Ckn	170	220	0	0	0	0	0	0	0	0	0.00	0.00		
3.01	Av	0	5	0	0	0	0	0	0	0	0	0.00	0.00	50.54	0.24
3.02	Avxj	5	12	0	0	0	50	60	0	0	0	0.46	3.23		
3.03	2Btxj	12	45	0	70	60	0	0	0	0	0	0.69	22.85		
3.04	2Btjqnx1	45	83	0	0	0	0	0	0	60	0	0.46	17.54		
3.05	2Btjqnx2	83	107	0	0	0	0	0	0	45	0	0.29	6.92		
3.06	2Cxqn	107	210	0	0	0	0	0	0	0	0	0.00	0.00		
21.01	Av	0	4	0	0	50	0	0	0	0	0	0.35	1.38	20.00	0.09
21.02	Bw	4	15	80	0	0	0	0	0	0	0	0.62	6.77		
21.03	Bk	15	33	0	0	0	0	0	0	0	0	0.00	0.00		
21.04	2Btjqk;b1	33	55	70	0	0	0	0	0	0	0	0.54	11.85		
21.05	2Btjqxkb1	55	144	0	0	0	0	0	0	0	0	0.00	0.00		
21.06	3Bqxkb2	144	186	0	0	0	0	0	0	0	0	0.00	0.00		
21.07	3Ckqn	186	233	0	0	0	0	0	0	0	0	0.00	0.00		

br, bridge; pc,pore; pf,ped face; cl,clast

Sample	Horizon	Depth (cm)		br #1	br #2	pc #1	pc #2	pf #1	pf #2	cl #1	cl #2	Normal prop	λ thick	Profile prop	weight mean
		CLAY FILM INDEX													
11.01	Av	0	4	0	0	0	0	0	0	0	0	0.00	0.00	44.31	0.26
11.02	A	4	15	0	0	0	0	0	0	0	0	0.00	0.00		
11.03	2Bt1	15	42	0	0	0	0	0	0	0	0	0.00	0.00		
11.04	2Btqk1	42	90	60	0	0	50	0	0	0	0	0.54	25.35		
11.05	2Bkq	90	150	50	0	0	0	0	0	0	0	0.31	18.46		
11.06	2Kqgk2	150	170	0	0	0	0	0	0	0	0	0.00	0.00		
12.01	Av1	0	4	0	0	0	0	0	0	0	0	0.00	0.00	52.22	0.26
12.02	Av2	4	14	0	0	0	0	0	0	0	0	0.00	0.00		
12.03	Bt	14	47	0	0	0	0	0	0	0	0	0.00	0.00		
12.04	2Bk1	47	105	0	60	50	0	0	0	0	0	0.54	31.23		
12.05	2Bk2	105	120	0	60	50	0	0	0	0	0	0.54	8.05		
12.06	2Btqgkb	120	144	0	0	0	0	60	0	0	50	0.54	12.92		
12.07	3qkb	144	200	0	0	0	0	0	0	0	0	0.00	0.00		
14.01	A	0	8	0	0	0	0	0	0	0	0	0.00	0.00	45.42	0.20
14.02	Bw	8	25	0	0	0	0	0	0	0	0	0.00	0.00		
14.03	2Bw	25	54	0	0	0	0	0	0	0	0	0.00	0.00		
14.04	2Btjkq	54	107	0	0	0	0	0	0	0	0	0.00	0.00		
14.05	3Bkjb	107	121	0	0	0	0	0	0	50	0	0.35	4.85		
14.06	3Bqgkjb	121	152	0	0	0	0	50	0	0	0	0.31	9.54		
14.07	4Bqgkjb	152	221	0	0	0	0	50	0	0	40	0.38	26.54		
14.08	4Bkjb	221	270	0	0	0	0	70	0	0	0	0.50	4.50		
20.01	Av1	0	8	0	0	0	0	0	0	0	0	0.00	0.00	31.31	0.16
20.02	Av2	8	19	0	0	70	0	0	0	0	0	0.54	5.92		
20.03	Bw	19	42	0	0	0	0	0	0	0	0	0.00	0.00		
20.04	2Btjq	42	64	60	0	0	0	0	0	0	0	0.42	9.31		
20.05	2Btjqk1	64	76	0	0	0	0	0	0	0	0	0.00	0.00		
20.06	2Btjqk2-1	76	114	60	0	0	0	0	0	0	0	0.42	16.08		
20.07	2Btjqk2-2	114	152	0	0	0	0	0	0	0	0	0.00	0.00		
20.08	2Btjqk2-3	152	190	0	0	0	0	0	0	0	0	0.00	0.00		
5.01	A	0	5	0	0	0	0	0	0	0	0	0.00	0.00	63.42	0.24
5.02	Bw	5	20	0	0	0	0	0	0	0	0	0.00	0.00		
5.03	Bk	20	45	0	0	0	0	0	0	0	0	0.00	0.00		
5.04	2Btb	45	56	0	0	0	65	75	0	0	0	0.65	7.19		
5.05	2Btqgkb	56	106	70	0	0	0	0	0	0	0	0.50	25.00		
5.06	2Ktqb	106	164	70	0	0	0	0	0	0	0	0.54	31.23		
5.07	2Cqb	164	203	0	0	0	0	0	0	0	0	0.00	0.00		

br. bridge: po.pore: pf.ped face: cl.clast
CLAY FILM INDEX

Sample	Horizon	Depth (cm)	br #1	br #2	po #1	po #2	pf #1	pf #2	cl #1	cl #2	Normal prop	X thick	Profile prop	weig mean
18.01	Av	0	11	0	0	0	0	0	0	0	0.00	0.00	39.58	0.00
18.02	A	11	33	0	0	0	0	0	0	0	0.00	0.00		
18.03	Bt	33	49	0	0	60	0	0	0	0	0.42	2.96		
18.04	2Btqv1	49	66	0	0	70	0	0	0	0	0.77	20.09		
18.05	2Btqv2	66	120	0	0	0	0	50	0	0	0.31	16.62		
18.06	3Kb	120	160	0	0	0	0	0	0	0	0.00	0.00		
8.01	A.	0	9	0	70	80	0	0	0	0	0.77	6.91	46.62	0.00
8.02	Bt1	9	21	0	0	0	0	100	0	0	0.81	9.69		
8.03	2Bt2	21	35	0	0	0	0	90	0	0	0.69	9.69		
8.04	3kqm	35	65	80	0	0	0	0	0	0	0.62	20.31		
8.05	3K	65	100	0	0	0	0	0	0	0	0.00	0.00		
8.06	3Cr	100	210	0	0	0	0	0	0	0	0.00	0.00		
16.01	Ap	0	10	0	0	0	40	0	0	0	0.20	3.00	12.23	1.02
16.02	Bw	10	30	0	0	0	0	0	0	0	0.00	0.00		
16.03	Bt	30	43	0	0	0	0	0	0	0	0.00	0.00		
16.04	2Btqb	43	58	0	0	0	0	80	0	0	0.62	9.23		
16.05	2kc	58	100	0	0	0	0	0	0	0	0.00	0.00		
16.06	2Bqm (mc)	100	150	0	0	0	0	0	0	0	0.00	0.00		
16.07	3Bqm	100	150	0	0	0	0	0	0	0	0.00	0.00		
16.08	3Dkcn	150	207	0	0	0	0	0	0	0	0.00	0.00		
1.01	A	0	10	0	0	0	0	0	0	0	0.00	0.00	16.58	0.00
1.02	Bt	10	25	0	0	0	0	0	0	0	0.00	0.00		
1.03	2Btqb1	25	42	0	0	0	0	70	0	0	0.50	8.50		
1.04	2Btqb2	42	56	0	0	0	0	80	0	0	0.58	8.08		
1.05	3kqmb1	56	70	0	0	0	0	0	0	0	0.00	0.00		
1.06	4kqmb2	70	115	0	0	0	0	0	0	0	0.00	0.00		
1.10	5Bk	115	167	0	0	0	0	0	0	0	0.00	0.00		
1.11	5Dnk	167	195	0	0	0	0	0	0	0	0.00	0.00		
1.12	5Cn	195	290	0	0	0	0	0	0	0	0.00	0.00		
19.01	Av1	0	4	0	0	0	0	0	0	0	0.00	0.00	19.73	0.00
	Av2	4	9	0	0	40	0	0	0	0	0.23	1.15		
19.03	Bk	9	12	0	0	0	0	0	0	0	0.00	0.00		
19.04	Bw	12	17	0	0	0	0	0	0	0	0.00	0.00		
19.05	Btqm	17	29	70	0	0	0	0	0	0	0.54	6.46		
19.06	2ktqm	29	47	0	0	0	0	85	0	0	0.67	12.12		
19.07	2kqm1	47	72	0	0	0	0	0	0	0	0.00	0.00		
19.08	2kqm2	72	150	0	0	0	0	0	0	0	0.00	0.00		

br, bridge; po,pore; p*,pod face; cl,clast

Sample	Horizon	Depth (cm)		br #1	br #2	po #1	po #2	p* #1	p* #2	cl #1	cl #2	Normal proc	Z thick	Profile proc	Weight mean
0.01	Av	0	0	0	0	0	0	0	0	0	0	0.00	0.00	1.09	0.00
0.02	Bt	0	10	0	0	0	0	60	0	0	0	0.42	1.09		
0.03	2Bqg	10	52	0	0	0	0	0	0	0	0	0.00	0.00		
0.04	2Bmq	52	101	0	0	0	0	0	0	0	0	0.00	0.00		
0.05	2Bq	101	152	0	0	0	0	0	0	0	0	0.00	0.00		
0.06	2Cxq	152	220	0	0	0	0	0	0	0	0	0.00	0.00		
0.07	2Cxqr	220	300	0	0	0	0	0	0	0	0	0.00	0.00		
2.01	Av	0	3	0	0	0	0	0	0	0	0	0.00	0.00	65.46	0.22
2.02	A	3	10	0	0	0	0	0	0	0	0	0.00	0.00		
2.03	Bv	10	19	0	0	0	0	0	0	0	0	0.00	0.00		
2.04	2Bqmv	19	34	0	60	0	0	0	0	0	0	0.42	6.35		
2.05	2Btqm	34	70	0	0	0	0	80	0	0	0	0.65	23.54		
2.07	Kbcm	19	52	0	0	0	0	0	70	0	0	0.50	18.50		
2.08	Kq	52	114	0	50	0	0	0	0	0	0	0.31	19.08		
2.09	2K	114	197	0	0	0	0	0	0	0	0	0.00	0.00		
22.01	Av	0	10	0	0	40	0	0	0	0	0	0.22	2.21	7.81	0.04
22.02	Bw	10	21	70	0	0	0	0	0	0	0	0.50	5.50		
22.03	K	21	62	0	0	0	0	0	0	0	0	0.00	0.00		
22.04	Kq	62	92	0	0	0	0	0	0	0	0	0.00	0.00		
22.05	Bxcm	92	184	0	0	0	0	0	0	0	0	0.00	0.00		

INDEX VALUE - RUBIFICATION & MELANIZATION ---

Sample	Horizon	Depth (cm)		Horizon Index (Sum normalized prop'n prod)		% horizon thickness	Profile Index	weighted Mean
FWA-1				0.04	0.01	0.00		
FWA-2				0.17	0.02	0.00		
FWA-3				0.05	0.01	0.00		
FWA-4				0.21	0.03	0.00		
YWA-1				0.06	0.01	0.00		
YWA-2				0.19	0.03	0.00		
7.01	A	0	1.5	0.41	0.06	0.09	1.23	0.01
7.02	Bex	2	18	0.22	0.03	0.51		
7.03	2Ckex	18	100	0.05	0.01	0.64		
4.01	A	0	3	1.06	0.15	0.45	15.22	0.15
4.02	Bh1	3	9	1.77	0.25	1.51		
4.03	2Bh2	9	60	1.57	0.22	11.45		
4.04	2Ckn	60	100	0.31	0.04	1.80		
17.01	A	0	6	0.98	0.14	0.84	4.10	0.07
17.02	Bw	6	24	0.49	0.07	1.27		
17.03	2Cwn	24	120	0.13	0.02	1.99		
13.01	A	0	9	1.44	0.21	1.86	6.85	0.05
13.02	Bw	9	21	0.79	0.11	1.35		
13.03	2Bqj	21	73	0.37	0.05	2.71		
13.04	2Cwqn	73	138	0.10	0.01	0.96		
15.01	A	0	18	1.16	0.17	2.98	27.03	0.12
15.02	Bw	18	46	1.28	0.18	5.12		
15.03	2Bqk	46	170	0.86	0.12	15.15		
15.05	2Ckn	170	220	0.57	0.08	3.78		
3.01	Av	0	5	1.43	0.20	1.02	24.44	0.12
3.02	Avj	5	12	2.06	0.29	2.05		
3.03	2Btkj	12	45	2.13	0.30	10.04		
3.04	2Btjqmk1	45	83	1.37	0.20	7.44		
3.05	2Btjqmk2	83	107	1.06	0.15	3.63		
3.06	2Cxqn	107	210	0.02	0.00	0.25		
21.01	Av	0	4	1.73	0.25	0.99	34.85	0.15
21.02	Bw	4	15	1.97	0.28	3.10		
21.03	Bk	15	33	0.58	0.08	1.49		
21.04	2Btjqkjb1	33	55	2.14	0.31	6.72		
21.05	2Btjqmkb1	55	144	1.03	0.15	13.07		
21.06	3Bqmkb2	144	186	1.05	0.15	6.29		
21.07	3Cxqn	186	233	0.34	0.07	3.18		

INDEX VALUE - RUBIFICATION & MELANIZATION ---

Sample	Horizon	Depth (cm)		Horizon Index (Sum normalized prop/# prop)		% horizon thickness	Profile Index	Weighted Mean
11.01	Av	0	4	1.54	0.22	0.88	31.51	0.15
11.02	A	4	15	1.09	0.16	1.72		
11.03	2Bt1	15	42	1.71	0.24	6.61		
11.04	2Btqmx	42	90	2.02	0.29	12.84		
11.05	2Bkq	90	150	0.74	0.11	6.37		
11.06	3Kqmkb	150	170	0.72	0.10	2.08		
12.01	Av1	0	4	1.04	0.15	0.60	37.07	0.19
12.02	Av2	4	14	1.06	0.15	1.52		
12.03	Bt	14	47	1.55	0.22	7.32		
12.04	2Bk1	47	105	2.11	0.30	17.46		
12.05	2Bk2	105	120	0.97	0.14	2.09		
12.06	2Btqmxb	120	144	1.89	0.27	6.49		
12.07	Bqxb	144	200	0.14	0.02	1.60		
14.01	A	0	8	1.08	0.15	1.24	37.25	0.16
14.02	Bw	8	25	1.05	0.15	3.01		
14.03	2Bk	25	54	1.20	0.17	4.44		
14.04	2Btjxq	54	107	0.59	0.08	4.32		
14.05	2Bkjb	107	121	1.48	0.21	2.95		
14.06	3Bqmk1b	121	152	1.48	0.21	6.55		
14.07	4Bqmk2b	152	221	1.33	0.19	13.27		
14.08	4Bkjb	221	270	1.19	0.17	1.53		
20.01	Av1	0	8	1.02	0.15	1.16	30.55	0.16
20.02	Av2	8	19	1.86	0.27	2.92		
20.03	Bw	19	42	1.44	0.21	4.72		
20.04	2Btjq	42	64	1.91	0.27	6.01		
20.05	2Btjqk1	64	76	1.35	0.19	2.31		
20.06	2Btjqk2-1	76	114	1.06	0.15	5.78		
20.07	2Btjqk2-2	114	152	0.76	0.11	4.13		
20.08	2Btjqk2-3	152	190	0.65	0.09	3.52		
5.01	A	0	5	0.42	0.06	0.30	32.07	0.12
5.02	Bw	5	20	0.47	0.07	1.00		
5.03	Bk	20	45	0.44	0.06	1.57		
5.04	2Btb	45	56	2.45	0.35	3.84		
5.05	2Btqmkb	56	106	1.67	0.24	11.96		
5.06	2Btqb	106	164	1.39	0.20	11.54		
5.07	2Bqb	164	263	0.13	0.02	1.86		

INDEX VALUE - RUBIFICATION & MELANIZATION ---

Sample	Horizon	Depth (cm)		Horizon Index (Sum normalized prop/# prop)		% horizon thickness	Profile Index	weighted Mean
18.01	Av	0	11	1.27	0.19	1.44	26.25	0.16
18.02	A	11	32	0.07	0.01	0.21		
18.03	Bt	32	40	1.55	0.22	1.55		
18.04	2Btqg1	40	66	2.62	0.37	9.72		
18.05	2Btqg	66	120	1.12	0.16	8.64		
18.06	3Kg	120	160	0.52	0.10	4.14		
8.01	Av	0	9	2.14	0.31	2.75	36.27	0.17
8.02	Bt1	9	21	3.53	0.50	6.03		
8.03	2Bt2	21	35	2.65	0.38	5.31		
8.04	2Kqm	35	68	2.24	0.38	12.44		
8.05	2r	68	100	1.52	0.22	7.14		
8.06	3Ck	100	210	0.17	0.02	2.69		
16.01	Av	0	13	1.39	0.20	2.59	40.46	0.37
16.02	Bw	13	30	0.95	0.14	2.30		
16.03	Bt	30	43	1.46	0.21	2.71		
16.04	2Btqr	43	58	3.00	0.43	6.43		
16.05	2Kq	58	100	1.33	0.19	7.45		
16.06	2Bqg (mc)	100	150	1.23	0.18	8.76		
16.07	3Bqg	100	150	0.82	0.12	6.11		
16.08	3Ckqm	150	207	0.44	0.06	3.57		
1.01	A	0	10	0.76	0.11	1.08	38.97	0.13
1.02	Bt	10	25	1.05	0.15	2.32		
1.03	2Btqm1	25	42	2.72	0.39	6.29		
1.04	2Btqm2	42	56	2.87	0.41	5.74		
1.06	3Kqmb1	56	70	1.75	0.22	3.07		
1.09	4Kqmb2	70	115	1.06	0.18	7.94		
1.10	5Bk	115	167	0.53	0.07	3.41		
1.11	5Cnk	167	195	0.66	0.08	2.32		
1.12	5Cn	195	250	0.55	0.07	6.45		
19.01	Av1	0	4	1.20	0.17	0.69	35.33	0.00
	Av2	4	9	1.68	0.24	1.20		
19.03	Bk	9	13	0.93	0.13	0.52		
19.04	Bw	13	17	1.17	0.17	0.67		
19.05	Btqm	17	29	2.87	0.41	4.92		
19.06	2Ktqm	29	47	3.13	0.45	8.04		
19.07	2Kqm1	47	72	1.46	0.21	5.21		
19.08	2Kqm2	72	150	1.26	0.18	14.07		

INDEX VALUE - RUBIFICATION & MELANIZATION ---)

Sample	Horizon	Depth (cm)		Horizon Index (Sum normalized prop/# prop)		% horizon thickness	Profile Index	Weighted Mean
6.01	Av	0	6	1.39	0.20	1.19	25.44	0.00
6.02	Bt	6	10	2.20	0.31	1.26		
6.03	2Btqm	10	52	1.41	0.23	9.84		
6.04	3Bmq	52	101	0.97	0.14	6.77		
6.05	3Bq	101	153	0.26	0.04	1.90		
6.06	3Cbkq	153	230	0.31	0.04	3.45		
6.07	3Cbkq+	230	300	0.07	0.01	1.04		
2.01	Av	0	3	1.21	0.17	0.52	58.12	0.30
2.02	A	3	10	0.89	0.13	0.89		
2.03	Bv	10	19	1.39	0.20	1.78		
2.04	2Bqmbv	19	34	2.58	0.37	5.54		
2.05	2Btqmy	34	70	2.97	0.42	15.28		
2.07	kBtqm	19	52	2.88	0.41	13.57		
2.08	kq	52	114	1.66	0.24	14.71		
2.09	2c	114	197	0.49	0.07	5.83		
22.01	Av	0	10	1.74	0.25	2.49	39.12	0.21
22.02	Bw	10	21	2.48	0.35	3.90		
22.03	k	21	62	1.94	0.28	11.35		
22.04	kB	62	92	1.13	0.16	4.63		
22.05	Bkqm	92	184	1.26	0.18	16.56		

INDEX VALUE - COLOR PALING & COLOR LIGHTENING

Sample	Horizon	Depth (cm)		Horizon Index (Sum normalized prop/# prop)		% horizon thickness	Profile Index	Weighted Mean
FWA-1				0.04	0.01	0.00		
FWA-2				0.17	0.02	0.00		
FWA-3				0.05	0.01	0.00		
FWA-4				0.21	0.03	0.00		
YWA-1				0.06	0.01	0.00		
YWA-2				0.15	0.03	0.00		
7.01	A	0	1.5	0.54	0.08	0.11	1.01	0.01
7.02	Cox	2	16	0.11	0.02	0.26		
7.03	2Cox	16	100	0.05	0.01	0.64		
4.01	A	0	3	0.92	0.14	0.41	16.12	0.16
4.02	Bx1	3	9	1.58	0.27	1.62		
4.03	2Bx2	9	60	1.66	0.24	12.12		
4.04	2Cxn	60	100	0.34	0.05	1.97		
17.01	A	0	6	0.87	0.12	0.75	6.21	0.05
17.02	Bw	6	24	0.55	0.08	1.48		
17.03	2Cxn	24	120	0.29	0.04	3.98		
13.01	A	0	9	1.21	0.17	1.55	8.97	0.06
13.02	Bw	9	21	0.79	0.11	1.35		
13.03	2Bqj	21	73	0.32	0.05	2.40		
13.04	2Cxqn	73	138	0.39	0.06	3.62		
15.01	A	0	18	1.04	0.15	2.67	20.67	0.09
15.02	Bw	18	46	1.12	0.16	4.47		
15.03	2Bqk	46	170	0.60	0.09	10.66		
15.05	2Cxn	170	220	0.40	0.06	2.87		
3.01	Av	0	5	1.64	0.23	1.17	22.01	0.10
3.02	Avkj	5	12	2.15	0.31	2.15		
3.03	2Btkj	12	45	1.81	0.26	8.55		
3.04	2Btjqak1	45	83	1.23	0.18	6.65		
3.05	2Btjqak2	83	107	0.94	0.13	3.23		
3.06	2Cxqn	107	210	0.02	0.00	0.25		
21.01	Av	0	4	1.85	0.26	1.06	30.87	0.13
21.02	Bw	4	15	1.97	0.28	3.10		
21.03	Bk	15	33	0.64	0.09	1.65		
21.04	2Btjqkjb1	33	55	1.91	0.27	6.02		
21.05	2Btjqakb1	55	144	0.82	0.12	10.40		
21.06	3Bqakb2	144	186	0.91	0.13	5.46		
21.07	3Cxqn	186	233	0.34	0.07	3.18		

INDEX VALUE - COLOR PALINE & COLOR LIGHTENING

Sample	Horizon	Depth (cm)		Horizon Index (Sum normalized prop/# prop)		% horizon thickness	Profile Index	Weighted Mean
11.01	Av	0	4	1.54	0.22	0.88	32.42	0.19
11.02	A	4	15	1.09	0.16	1.72		
11.03	2Btj	15	42	1.50	0.21	5.60		
11.04	2Btqk1	42	90	2.14	0.31	14.69		
11.05	2Bk2	90	150	0.78	0.11	6.71		
11.06	3kqmb	150	170	0.92	0.13	2.63		
12.01	Av1	0	4	0.98	0.14	0.56	35.22	0.19
12.02	Av2	4	14	1.06	0.15	1.52		
12.03	Bt	14	47	1.62	0.23	7.62		
12.04	2Bk1	47	105	2.22	0.32	18.36		
12.05	2Bk2	105	120	0.76	0.11	1.63		
12.06	2Btqmkb	120	144	2.02	0.29	6.53		
12.07	Bqkb	144	200	0.14	0.02	1.60		
14.01	A	0	8	1.21	0.17	1.38	35.55	0.15
14.02	Bw	8	28	1.05	0.15	3.01		
14.03	2Bt	28	54	1.09	0.16	4.05		
14.04	2Btjkq	54	107	0.66	0.09	4.98		
14.05	3Brjb	107	121	1.34	0.19	2.69		
14.06	3Bqm1b	121	152	1.37	0.20	6.09		
14.07	4Bqm2b	152	221	1.24	0.18	12.23		
14.08	4Brjb	221	230	0.88	0.13	1.13		
20.01	Av1	0	8	0.85	0.12	0.97	22.54	0.12
20.02	Av2	8	19	1.83	0.26	2.88		
20.03	Bw	19	42	1.28	0.18	4.20		
20.04	2Btjq	42	64	1.48	0.21	4.65		
20.05	2Btjqk1	64	76	0.91	0.13	1.56		
20.06	2Btjqk2-1	76	114	0.75	0.11	4.06		
20.07	2Btjqk2-2	114	152	0.44	0.06	2.41		
20.08	2Btjqk2-3	152	190	0.33	0.05	1.81		
5.01	A	0	5	0.44	0.06	0.31	33.44	0.13
5.02	Bw	5	20	0.35	0.05	0.75		
5.03	Bt	20	45	0.70	0.10	2.51		
5.04	2Btb	45	56	2.07	0.30	3.25		
5.05	2Btqmrb	56	106	1.38	0.20	9.85		
5.06	2ktqb	106	164	1.51	0.22	12.55		
5.07	2Cqm	164	203	0.30	0.04	4.22		

INDEX VALUE - COLOR FALING & COLOR LIGHTENING

Sample	Horizon	Depth (cm)		Horizon index (Sum normalized prop/# prop)		% horizon thickness	Profile index	weighted Mean
16.01	Av	0	11	1.45	0.21	2.25	26.46	0.17
16.02	A	11	33	0.25	0.04	0.80		
16.03	Bt	33	49	1.45	0.21	1.45		
16.04	2Btqm1	49	66	2.33	0.33	8.65		
16.05	2Btqm	66	120	1.19	0.17	9.15		
16.06	2Bt	120	160	0.82	0.10	4.14		
8.01	Av	0	9	2.14	0.31	2.75	33.97	0.17
8.02	Bt1	9	21	2.91	0.42	4.95		
8.03	2Bt2	21	35	2.38	0.34	4.75		
8.04	2Kqm	35	68	2.44	0.35	11.48		
8.05	2k	68	100	1.99	0.28	5.02		
8.05	2Ck	100	210	0.19	0.03	2.91		
16.01	Av	0	13	1.16	0.17	2.15	33.95	2.87
16.02	Bw	13	30	0.75	0.11	1.90		
16.03	Bt	30	43	1.19	0.17	2.20		
16.04	2Btqm	43	58	2.78	0.40	5.95		
16.05	2kq	58	100	1.39	0.23	9.32		
16.06	2Bqm (inc)	100	150	0.91	0.13	6.51		
16.07	2Bqm	100	150	0.54	0.08	3.85		
16.08	2Cxqm	150	207	0.23	0.03	1.66		
1.01	A	0	10	0.93	0.13	1.32	42.34	0.15
1.02	Bt	10	25	1.02	0.15	2.19		
1.03	2Btqm1	25	42	2.39	0.34	5.80		
1.04	2Btqm2	42	56	2.44	0.35	4.87		
1.08	3kqm1	56	70	2.38	0.39	4.16		
1.09	4kqm2	70	115	1.06	0.18	7.94		
1.10	5Bk	115	167	1.05	0.13	6.85		
1.11	5Cnk	167	195	0.60	0.07	2.09		
1.12	5Ck	195	290	0.69	0.07	7.10		
19.01	Av1	0	4	1.43	0.20	0.82	36.12	0.09
	Av2	4	9	1.97	0.28	1.41		
19.02	Bk	9	13	0.97	0.14	0.55		
19.04	Bw	13	17	1.02	0.15	0.59		
19.05	Btqm	17	29	2.29	0.33	4.61		
19.06	2ktqm	29	47	3.29	0.47	8.48		
19.07	2kqm1	47	72	1.77	0.25	6.32		
19.08	2kqm2	72	150	1.20	0.17	13.24		

INDEX VALUE - COLOR FADING & COLOR LIGHTENING

Sample	Horizon	Depth (cm)		Horizon Index (Size normalized prop'n prod)		x horizon thickness	Profile Index	Weighted Mean
1.01	Ap	0	5	1.27	0.18	1.09	16.53	0.09
1.02	Bt	5	10	1.91	0.27	1.09		
1.03	2Btg1	10	51	1.47	0.14	10.01		
1.04	2Btg2	51	101	0.59	0.11	5.57		
1.05	2Btg	101	151	0.70	0.10	5.22		
1.06	2Btkg	151	230	0.22	0.03	2.51		
1.07	2Btg2	230	254	0.07	0.01	1.14		
2.01	Ap	0	3	1.34	0.19	0.57	65.05	0.32
2.02	-	3	10	0.91	0.13	0.91		
2.03	Bw	10	19	1.16	0.17	1.49		
2.04	2Bgmn1	19	34	2.30	0.33	4.93		
2.05	2Btgmn	34	70	2.49	0.36	12.81		
2.07	2Btgn	19	52	3.08	0.44	14.53		
2.08	2Bg	52	114	2.11	0.30	16.67		
2.09	2R	114	197	0.94	0.13	11.14		
22.01	Ap	0	10	1.99	0.25	2.84	40.11	0.22
22.02	Bw	10	21	2.00	0.29	3.14		
22.03	Bt	21	62	2.14	0.31	12.55		
22.04	Btg	62	92	1.37	0.20	5.69		
22.05	Bkgm	92	184	1.19	0.17	15.69		

Appendix C. Laboratory Methods--particle size distribution (PSD), bulk density, percent carbonate, gypsum and soluble salts, percent organic carbon and loss on ignition (LOI), pH, silica, and clay mineralogy.

Particle Size Distribution (PSD)

Percent gravel (>2 mm) was measured on a weight basis by sieving the bulk sample in the laboratory. Measurements were checked with field estimates to make sure that gravel in bouldery deposits was not underestimated. If percent gravel was thought to have been underestimated, the value was corrected with field observations.

Carbonate, organic matter and then silica were removed before particle size analyses (Day, 1965). Carbonate was removed with 1N NaOAc or 10% HCl, and organic matter with either dilute H_2O_2 or "Clorox" bleach. Samples were heated in a water bath to just below boiling until the reaction was complete and subsequently rinsed before the next pretreatment. Pedogenic silica was removed by heating the sample in a 5% Na_2CO_3 solution to just below boiling. One hundred ml of solution was used for each 25 gm sample. Each sample was treated for about one hour, then rinsed. Treatment was repeated three times. However, samples from horizons that were well-cemented were treated up to 12 hours before being rinsed. PSD size fractions were measured in phi units, but will be reported in USDA size classes (Table 1). Sand, silt, and clay boundaries are equal in both methods; the major discrepancy is in the silt size fraction.

Table 1: Particle Sizes in Phi units and USDA Size Classes

mm	Measured: US Std sieve mesh number	Phi unit	Reported: USDA Size Classes
2.0			
1.0	18	0	very coarse sand (2.0-1.0 mm)
0.5	35	1	coarse sand (1.0-0.5 mm)
0.25	60	2	medium sand (0.5-0.25 mm)
0.125	120	3	fine sand (0.25-0.10 mm)
0.053	270	4.25	very fine sand (0.10-0.05 mm)
<0.031	pipet	5	co + med silt (0.05-0.02 mm)
<0.0156	"	6	fi + vfi silt (0.02-0.002 mm)
<0.00195	"	9	co + med clay (0.002-0.0005 mm)
<0.00049	"	11	fine clay (<0.0005 mm)
2.0-0.053		0-4.25	**total sand** (2.0-0.5 mm)
0.053-0.00195		5-6	**total silt** (0.05-0.002 mm)
<0.00195		9-11	**total clay** (<0.002 mm)

Bulk Density

Three to eight bulk density (BD) measurements were made on paraffin-coated ped samples from each horizon (Chleborad and others, 1975). After the density was measured, each ped was opened to assure that gravel was not present. In horizons where large percentages of gravel were unavoidable in the ped samples, measured bulk density was adjusted to account for the bulk density of the gravel. Equation (1.1) was used for gravelly ped samples to estimate the bulk density of the <2 mm fraction. The assumption is made that the known percent gravel measured from the bulk sample, not the ped sample, has a bulk density of 2.6 gm/cm^3

$$BD_{<2mm} = \frac{(\text{gm} < 2\text{ mm})}{(\text{cm}^3\text{ total volume}) - ((\text{gm} > 2\text{ mm})/(2.6\text{ gm/cm}^3))} \quad \textbf{Equation (1.1)}$$

The excavation method and Equation (1.1) were used to determine the bulk density of the fresh alluvium samples for Fortymile Wash and Yucca Wash alluvium. A shallow hole in the surface of the fresh alluvium was lined with a plastic bag, then filled with water to determine the volume. The weight of the > and <2 mm fractions were measured in the laboratory. Bulk density means and standard deviations were calculated for each horizon. When the standard deviation exceeded 0.1 gm/cm^3, the outlying density values were omitted.

Percent Carbonate, Gypsum and Soluble Salts

Pedogenic carbonate was measured on a Chittick apparatus (Dreimanis, 1962). Gypsum and soluble salts were measured in solution by electro-conductivity (Marith Reheis, U.S. Geological Survey, written communication, 1984).

Percent Organic Carbon and Loss on Ignition (LOI)

Organic carbon was measured using the Walkley-Black titration procedure (Allison, 1965). Loss on ignition (LOI) was calculated by the difference in weight loss at heat treatments of 105°C for 4 hours (soil moisture factor) and 540°C for 1 hour.

pH

pH was measured in a ratio of 1:1 soil:water slurry. After 1 hour of equilibration, samples were stirred with the electrode, allowed to stand for 1 minute, and then the pH was read.

Silica

The weight loss after the removal of carbonate, organic matter and silica cement is used to estimate the percent extractable pedogenic silica (Appendix C). The known percent of carbonate and organic matter are used to calculate the weight loss of these materials, and the remaining weight loss assumed to approximate the percent silica. Although this estimate is referred to as a percentage, it is at best an index or trend that correlates to field observations in relative amounts of pedogenic silica.

Clay Mineralogy

X-ray diffraction traces (CuK alpha radiation) were run on oriented samples of the clay and silt fractions on a 'MINIFLEX' defractometer. Samples were run air-dried, glycolated, and heated to 300°C and 500°C each for one hour. Tiles were placed face down on a glycol-saturated towel, instead of saturating in a desiccator.

Appendix D. Effects on the particle size distribution and clay mineralogy after the removal of opaline silica.

All of the particle size fractions were effected by the removal of silica. Particle size distribution for YW-16 was compared before and after silica removal (Table 1). The surface soil at YW-16 is late Pleistocene to early Holocene and due to the lack of silica cement, responded very differently to treatment than did the underlying buried mid-Pleistocene soil. Percentages of sand and clay increase or are virtually unchanged in the younger soil, whereas the percentage of silt decreases. This is probably due to (1) dissolving silica-cemented aggregates in the silt fraction, and (2) total or partial dissolving of silt particles high in silica. The latter could be the major cause as much of the ash and phytoliths are silt size. In contrast, the same treatment of samples of the buried soil results in major losses in the sand fraction and corresponding gains in the clay-size fraction (Table 1, Fig. 1). This seems to be due to the dissolution of the silica cement.

There are problems related to the above assumption that only the dissolution of pedogenic silica influences the PSD results. X-ray diffraction proves that some clays, notably tobermorite, are destroyed (Fig. 2). However this alone may not noticeably effect the abundance of clay-size fraction unless the mineral is abundant and is dissolved.

Synthetic Nepheline (Nepheline (syn)) were produced in the laboratory after samples were dispersed with sodium hexametaphosphate and (or) treated with sodium hydroxide to remove pedogenic silica cement. Nepheline has not been recognized in any of the rocks in the study area (Quinlivan and Byers, 1977).

Table 1. Comparison of sand, silt and clay before (1) and after (2) silica removal on soil profile YW-16. +'s represent a relative gain in the size fraction after the removal of opaline SiO_2, and -'s a relative loss.

Horizon		% sand	% silt	%clay	texture
Av	(1)	59.60	28.90	11.60	SL
	(2)	68.88	16.39	14.73	SL
		+9.28	-12.51	+3.13	
Bt1	(1)	48.37	40.30	11.30	L
	(2)	66.15	16.57	17.28	SL
		+17.78	-23.73	+5.98	
Bt2	(1)	57.00	26.30	16.60	SL+
	(2)	62.77	21.73	15.50	SL+
		+5.77	-4.57	-1.10	
2Btqkb	(1)	63.48	32.30	4.08	SL
	(2)	31.01	21.54	47.45	C
		-32.47	-10.76	+43.37	
2Kqb	(1)	80.30	14.50	5.20	LS
	(2)	42.93	24.88	32.18	CL
		-37.37	+10.38	+26.98	
2Bqmkb-1	(1)	82.74	16.00	1.10	LS
	(2)	69.16	14.68	16.17	SL
		-13.56	-1.32	+15.07	
2Bqmkb-2	(1)	74.60	22.90	2.60	LS
	(2)	56.24	24.11	19.65	SL+
		-18.36	+1.21	+17.05	
2Ckqnb	(1)	87.00	11.30	1.51	S
	(2)	82.16	12.31	5.53	LS
		-4.84	+1.01	+4.02	

Table 1 continued.

	% v co s			% co s		
depth	before	after	% change	before	after	% change
13	7.9	3.3	-4.6	6.0	3.8	-2.2
30	3.5	3.0	-0.5	4.3	3.1	-1.2
43	5.2	3.1	-2.1	5.2	3.0	-2.2
58 *	18.9	4.1	-14.8	14.8	4.4	-10.4
100 *	24.4	7.1	-17.3	18.8	5.2	-13.6
150 (1)*	20.2	9.8	-10.4	17.3	10.4	-6.9
150 (2)*	14.6	6.8	-7.8	14.8	5.0	-9.8
207+ *	40.5	18.0	-22.5	26.6	20.0	-6.6

	% med s			% fi s		
depth	before	after	% change	before	after	% change
13	6.4	7.4	1.0	37.8	31.0	-6.8
30	4.9	6.8	1.9	35.6	28.8	-6.8
43	6.4	6.2	-0.2	39.3	26.5	-12.8
58 *	10.4	4.3	-6.1	19.3	9.0	-10.3
100 *	13.0	6.0	-7.0	19.7	12.3	-7.4
150 (1)*	13.8	11.8	-2.0	31.4	20.2	-11.2
150 (2)*	13.9	7.9	-6.0	30.1	17.9	-12.2
207+ *	9.0	17.2	8.2	10.4	15.6	5.2

	% v fi s		
depth	before	after	% change
13	1.5	23.4	21.9
20	0.1	24.4	24.3
43	0.9	24.0	23.1
58 *	0.1	9.1	9.0
100 *	4.4	12.4	8.0
150 (1)*	0.0	17.0	17.0
150 (2)*	1.2	18.6	17.4
207+ *	0.5	11.3	10.8

* Field recognizable silica accumulations

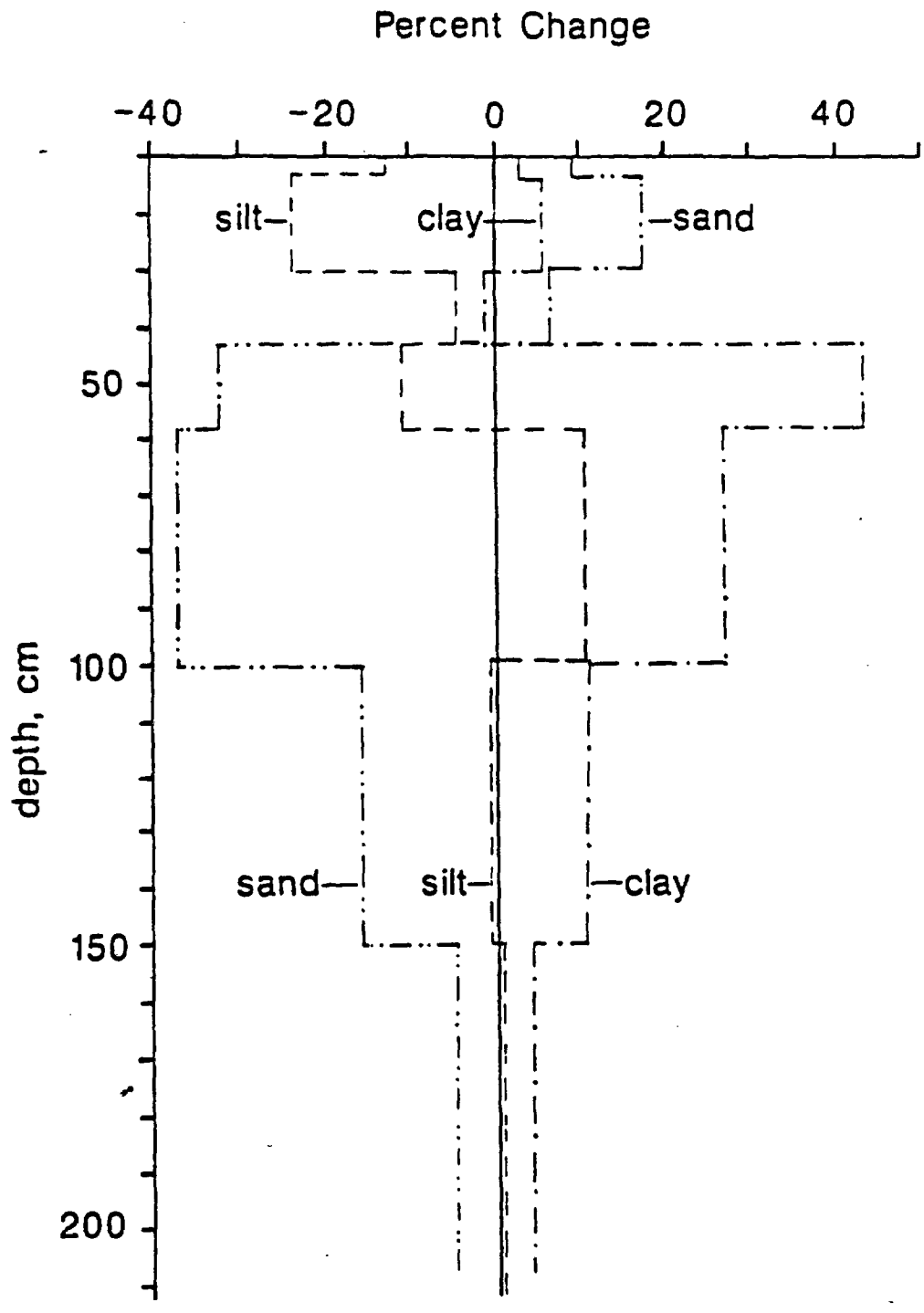

Figure 1. Percent change in particle size classes due to the removal of pedogenic silica cement in profile YW-16. Total % sand, % silt, and % clay are plotted vs depth.

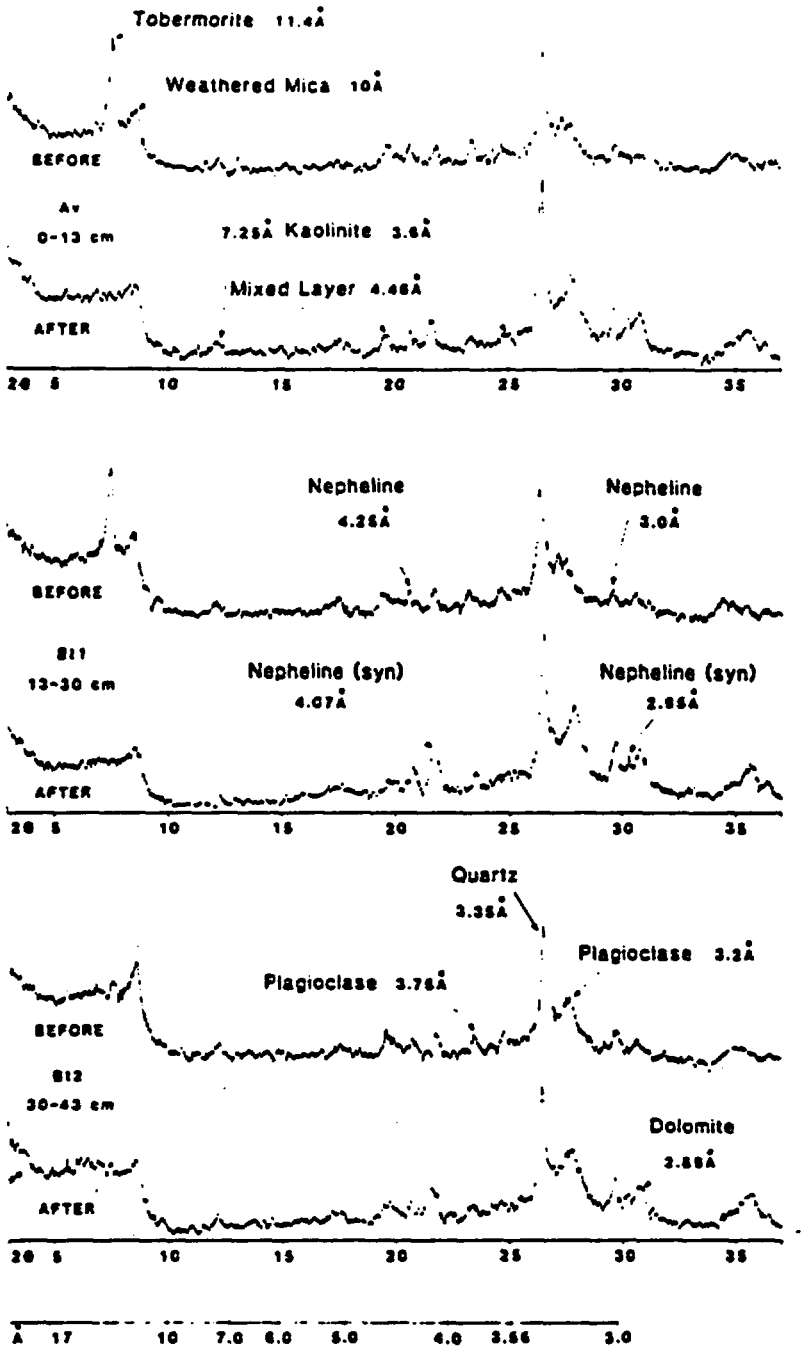

Figure 2. An example of clay mineralogy alteration owing to the removal of pedogenic silica. Traces are for profile YW-16 before and after the removal of pedogenic silica. The three horizons in a depth sequence all have approximately 15% clay, with a net gain or loss of +5 to -1% after treatment (Table 1). Tobermorite is the only clay mineral destroyed by the treatment.

Appendix E. Laboratory procedure for measuring pedogenic opaline silica using a spectrophotometer.

Introduction

There is little agreement on the best method to extract and measure pedogenic silica (Jackson, 1969; Yuan and Breland, 1969; Elgawhary and Lindsay, 1972; Torrent and others, 1980; Hallmark and others, 1982). A summary of the literature and subsequent laboratory tests produced an extraction and colorimetric determination to most accurately measure pedogenic silica

This procedure is based on the reaction of dissolved silica and ammonium molybdate in an acid medium (pH 1.0-2.0) to form the yellow silicomolybdate complex which is subsequently reduced by sodium sulfite to form blue molybdosilicate (Mo-blue). Because phosphate produces a similar molybdate complex that absorbs in the same wavelength range, oxalic acid is added to suppress phosphate interference.

All reactions when possible should be carried out in Ni, stainless steel, or plastic (polypropylene or nalgene) containers to avoid Si contamination from glass. Where plastic is specifically stated, either of the other two container types can be used. Glassware is used for dilutions, prolonged contact (>2 hours) with glass is not recommended.

Summary of Procedure

1) Grind, oven-dry, then weigh 1.0 gm soil sample for Si extraction.

2) Disperse by sonication

3) Remove both cementing agents $CaCO_3$ and iron-oxides, and organic matter.

4) Mix all the necessary reagents and working standard.

5) Extract soil silica.

6) Pipet working standard and sample aliquots into volumetric flasks.

7) Add reagents.

8) Run samples on spectrophotometer - consider time to warm up spectrophotometer if necessary.

Soil Sample Preparation

1) Sieve soil and crush to desired size. The size should vary with the largest particle size of your sample. A suggested size would be slightly larger that the dominant size fraction in fine-grained deposits (e.g., medium sand for a loess parent material), and ground finer in coarse-grained deposits. Only 1.0 gm of sample is required for the procedure.

2) Oven dry sample for one hour at 105°C, then lightly crush in an agate mortar to break up aggregates.

3) Weigh 1.0 gm of sample.

4) Wash sample with distilled water into a plastic centrifuge tube or bottle, filling to half the volume. Disperse by sonication (Busacca and others, 1984) for 10 minutes. Choose the sonicator setting that produces the most cavitation bubbles within the sample. To find that setting, simulate the sonication step with water only and same container so you can see the bubble action. Starting from the zero setting, as you

turn the dial, the number of bubbles is the setting to use for you samples. It is important to stir the sample while it is being sonicated, otherwise the grains just pack together at the bottom of the container and do not get the full benefit of the treatment. Since conventional stirrers do not fit inside the centrifuge tubes, Sharon Feldman (Dept. of Agronomy and Soils, Washington State University, Pullman, written communication, 1984) suggests blowing air into the sample. This is simply done with tygon tubing connected to the lab bench air valve. Blow in just enough air to keep the soil in suspension. Once the sonicator is on, it does not take much air to keep the soil in suspension.

5) Remove carbonate then organic matter with the same procedures used in grain size analysis, but do not remove the sample from the plastic tube. It is not necessary to remove organic matter from soils that contain very little of it (e.g., arid environment soils with <1% organic matter). If appreciable amounts of free iron oxides are present, they should also be removed by the dithionite method (Jackson, 1969).

6) Wash samples with distilled water. Centrifuge for a half an hour at a setting between 2500 and 3000 rpm, or until the supernatant is clear. Repeat if necessary. The time may vary for individual samples.

Reagents

6 N HCl - Dilute 50 ml concentrated HCl (37% or 12.1 N) to 100 ml.

Ammonium molybdate solution - Dissolve 100 gm ammonium paramolybate tetrahydrate (**ammonium molybdate**) [$(NH_4)_6Mo_7O_{24}\cdot 4H_2O$] in 600 ml H_2O, warm and stir to obtain complete dissolution. When cool, transfer to a volumetric flask, adjust pH to 7-8 with concentrated NaOH and dilute to 1.0 liter. 2 ml/sample is used.

Oxalic acid solution - Dissolve 100 gm **oxalic acid** ($C_2H_2O_2\cdot H_2O$) and dilute to 1.0 liter. 2 ml/sample is used.

Reducing Agent - Dissolve 0.5 gm **1-amino-2-napthol-4-sulfonic acid** and 1 gm **anhydrous sodium sulfite** (Na_2SO_3) in 50 ml water. Dissolve 30 gm **sodium bisulfite** ($NaHSO_3$) in 150 ml water. Mix the two solutions in a plastic bottle and allow the reagent to sit for a few hours in the refrigerator. The supersaturated solution should form a precipitate that must be filtered before use. If the precipitate is not allowed to form before using, it will form a white precipitate in your colored samples. If this happens throw the samples out and start again with a reducing agent that has formed a precipitate and has been filtered. Refrigerate this reagent when not in use; it is unstable and should be made fresh every week. Total volume 200 ml. 2 ml/sample is used.

Silica Extraction

1) Amorphous soil silica is extracted with 0.5 N KOH or 0.5 N NaOH. Sharon Feldman (Dept. of Agronomy and Soils, Washington State University, Pullman, written communication, 1984) prefers to use KOH because it is less damaging to the silicate clay minerals. See Jackson (1969, Sec. 11-27) for quantitative measure of the kaolinite and halloysite peaks following NaOH extraction of Si. Dissolve 2.3 gm reagent grade KOH pellets, or 2.0 gm NaOH pellets, in 100 ml of H_2O ia a plastic container, or dilute stock KOH or NaOH solutions to 0.5 N.
2) Soil:solution ratio is 1:50 (1 gm/50 ml or 0.5 gm/25 ml). Perform the entire extraction procedure under a fume hood.
3) Prepare a boiling water bath. It is important that the temperature remain stable. Heat the 0.5 N KOH (or NaOH) solution to 100°C.
4) Place the room temperature sample in a plastic container, in the bath, and add the correct amount of heated 0.5 N KOH (or NaOH). Allow reaction to continue for exactly 2.5 minutes (Torrent and others, 1980).
5) Remove from hot bath, and cool rapidly in an ice water bath. Remove and centrifuge the sample for 10 minutes at 1600 rpm, then immediately decant the 50 ml of supernatant into a 100 ml volumetric flask.
6) Add 10 ml room temperature 0.25 N KOH (or NaOH) per 1.0 gm sample to centrifuge tube. Mix well. Centrifuge and decant into the 100 ml volumetric flask containing the original 50 ml of extract. This completes the removal of amorphous Si.

7) Dilute to volume with distilled H_2O.

Standard Silica Solution

Stock Solution (use 1 or 2)

1) Clean pure quartz crystal in concentrated HCl for one hour, then rinse. Grind quartz to pass through a 100 mesh sieve. Heat quartz to redness in a crucible for a brief period to dry. Cool and store in an air tight vial. Add 0.1070 gm ground quartz to a Ni crucible containing 2.0 gm solid NaOH. Cover crucible and heat to a dull red for at least 10 minutes. After melt is cooled, dissolve in 50 ml of water and allow to sit overnight. The next day acidify with 1 N H_2SO_4 to a pH of 1.5. Transfer to a 1.0 liter volumetric flask and dilute to volume. Resulting stock solution is 50 mg Si/l (ug/ml or ppm). Store in a plastic bottle.

2) Use atomic absorption silicon standard available through American Scientific Products (1984-85 Cat # S7385-14, $13.91), 500 ml of 1000 mg Si/l.

Working Stock

1) Dilute 20 ml of the 50 mg Si/l standard stock (1) to 200 ml for a final concentration of 5 mg Si/l.

2) Dilute 1 ml of the 1000 mg Si/ l standard stock (2) to 200 ml. (1000 ug Si/ml)(1 ml/200 ml) = (5 ug Si/ml) = 5 mg Si/l.

Procedure

1) Add 1.0 ml 6 N HCl to a 50 ml volumetric flask and bring to volume with distilled H_2O.

Standard Curve Development

2) Pipette 1, 5, 10, 15, 20, (30, 40, 50) ml of the working stock into the 50 ml volumetric flasks. Use distilled water for your zero standard. When they are brought to volume (see instructions below), these standards will contain 0, 0.1, 0.5, 1.0, 1.5, 2.0, (3.0, 4.0, 5.0) mg Si/l. Label them.

Sample Color Development

3) Add a 1 ml aliquot of sample solution, from the silica extraction, to the volumetric flasks.

This next section applies to all standards and samples. Best results are obtained if the same period of time is allowed for color development in the standards and samples. Be careful to label everything.

4) Wash sides of flasks down carefully and dilute to 30 ml.
5) Add 2.0 ml ammonium molybdate solution
6) Swirl to mix and allow to react for 20 minutes. Yellowish color develops if Si is present.
7) Add 2.0 ml oxalic acid solution. Mix and let stand 10 minutes to complex any phosphates which may be present. Do not allow to stand much more that 10 minutes or low Si results will be obtained.

8) Add 2.0 ml reducing solution and take to volume with distilled water.

9) Wait 20 minutes for complete reaction. It will be blue if Si is present. NOTE: If a sample solution develops to a darker blue than the highest standard (2.0 or 5.0 mg Si/l), either 1) make a higher standard >2.0 mg Si/l, 2) redo it with a smaller sample aliquot, or 3) dilute the original (unknown) Si extract and use a 1.0 ml or larger aliquot.

10) Mix the solutions well. Measure the absorbence with a red phototube at 625 um. Adjust the sensitivity multiplier to position 2. The first cruvette should always contain the 0 standard. Measure standards at least three times.

11) If you have to redo any number of samples make up a new set of standards. They should be stable over the one half to one hour it take to do the initial reading, but no longer.

Comments

1) Aging of reagents changes the standard curve. Always run standard solutions with samples as a check.

2) Variatfon in sample temperature shows little colorimetric effect. Permissible range is 18-29°C (65-85°F)

Calculations

Determine the mg of Si in each sample from a regression on the absorbences of the standards:

1) Calculate the linear regression for the standards where

$$x = \text{mg Si/l of standard}$$

$$y = \text{absorbence reading}$$

The correlation (r^2 between x and y should approximate 1.0.

2) Take the calculated linear regression and solve for the curve value.

$$\text{absorbence} = b(\text{curve value}) + a$$

$$\text{curve value} = (\text{absorbence} - a)/b$$

3) Use this equation to determine the curve value of the Si in mg Si/l.

4)

$$\% \text{ Si} = \frac{\left(\frac{\text{mg Si}}{\text{ml}}\right)\left(\frac{\text{ml Mo-blue soln}}{\text{ml sample aliquot}}\right)(\text{ml diluted extract})\ 1000}{\text{gm oven-dried soil}}$$

(1000 combines conversion of mg Si to gm Si and conversion to %)

If you 1) use 50 ml volumetric flasks for Mo-blue solution, 2) dilute 50 ml Si extract to 100 ml, 3) use a 1 ml sample aliquot for Mo blue determination, and 4) use 1.0 gm soil, the calculation is:

$$\% \text{ Si} = \frac{\left(\frac{\text{mg Si}}{\text{l}}\right)\left(\frac{\text{50 ml}}{\text{1.0 ml}}\right)(\text{100 ml})\ 1000}{\text{1.0 gm}}$$

Appendix F. Laboratory Analyses--particle size, bulk density, carbonate, gypsum, soluble salts, organic carbon, oxidizable organic matter, loss on ignition, pH, and silica by weight. Starred (*) bulk density values are estimations.

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	Gravel %	SAND vco	SAND co	SAND med	SAND fi	SAND vfi	SILT coarse	SILT fine	CLAY coarse	CLAY fi
D1a	FWA-1		FWA-1				51	12.76	14.25	27.16	26.76	13.44	3.50	0.94	0.51	0.60
	FWA-2		FWA-2				0	0.57	3.29	9.97	24.56	37.29	11.31	1.91	0.96	1.04
	FWA-3		FWA-3				41	19.47	33.75	31.80	10.11	3.41	0.60	0.26	0.17	0.43
	FWA-4		FWA-4				60	23.17	30.57	28.83	10.46	2.59	1.61	1.15	[illegible]	[illegible]
D1a	YWA-1		YWA-1				67	29.44	40.69	22.67	5.52	0.82	0.25	0.17	0.08	0.74
	YWA-2		YWA-2				58	17.08	34.09	31.02	12.97	3.13	0.43	0.51	[illegible]	0.31
D1b	FW-7	3380	7.01	Al	0	2	18	7.24	12.70	23.60	28.50	21.33	4.23	0.69	0.57	1.14
			7.02	Cox	2	18	12	6.79	9.37	19.58	31.09	24.00	5.50	1.03	1.26	1.36
			7.03	2Cox	18	100	63	20.86	26.91	25.69	14.81	7.14	2.12	1.12	0.45	0.97
D1c	FW 4	3300	4.01	Al	0	3	19	2.33	3.49	7.79	30.62	40.32	6.65	2.72	1.66	2.41
			4.02	Bjl	3	9	7	1.60	3.25	9.16	34.42	33.32	5.07	5.58	4.39	3.21
			4.03	2Bt1	9	60	28	3.39	4.76	8.89	22.27	32.11	11.97	5.00	6.97	4.65
			4.04	2Cu1	60	100	67	8.56	8.27	12.82	21.91	30.47	10.45	3.43	1.67	2.45
D1c	FW-17	3540	17.01	A	0	6	40	9.12	8.60	10.77	17.98	23.60	21.05	4.00	1.91	2.56
			17.02	Bw1	6	24	40	9.32	10.16	13.26	18.84	24.61	15.65	3.66	1.67	2.93
			17.03	2Cu1	24	120	75	19.59	27.06	20.0[illegible]	15.11	10.13	3.75	1.35	0.68	1.19
D1c	YW-13	4155	13.01	A	0	9	53	12.77	14.30	15.95	18.33	20.40	9.84	3.94	1.79	2.68
			13.02	Bw	9	21	33	8.27	10.29	15.74	21.44	24.02	9.71	3.75	2.56	3.41
			13.03	2Bqj	21	73	48	17.01	19.53	18.47	16.65	15.90	5.45	2.73	1.57	2.73
			13.04	2Cl qu	73	138	67	15.85	25.78	21.06	16.39	13.28	3.31	1.60	1.0[illegible]	0.[illegible]
D1c	YW-15	4520	15.01	A	0	18	55	19.73	16.07	10.51	13.17	18.88	10.99	5.07	2.37	3.31
			15.02	Bw	18	46	62	22.55	17.57	10.94	12.28	16.54	8.85	5.07	2.42	3.12
			15.03	2Bql	46	170	78	13.49	13.64	11.51	14.43	17.91	10.02	8.62	5.26	5.10
			15.06	2Bql (1)	46	108	74	18.21	19.25	15.96	14.76	13.17	6.74	5.22	3.87	3.[illegible]1
			15.04	2Bql (2)	108	170	85	9.62	9.35	9.14	13.43	19.81	13.94	11.02	6.71	6.18
			15.05	2Cul	170	220	63	18.40	20.51	18.40	15.03	12.20	4.01	3.32	3.65	3.56
D2b	FW-3	3320	3.01	Avl	0	5	10	1.63	1.84	3.93	14.80	19.90	15.85	24.99	12.58	4.61
			3.02	Bt1	5	12	33	3.42	2.84	4.00	11.05	13.79	14.40	24.09	18.1[illegible]	2.42
			3.03	2Bt1	12	45	82	23.41	19.77	14.66	10.42	8.71	6.38	7.78	5.14	3.74
			3.04	2Bqml 1	45	83	81	19.98	26.20	23.22	10.24	5.97	4.29	5.29	3.0[illegible]	[illegible]
			3.05	2Bqml 2	83	107	83	27.52	36.79	22.76	5.31	2.03	1.14	1.60	0.91	1.[illegible]4
			3.06	2Cl qu	107	210	80	26.63	35.68	25.53	6.56	2.93	0.80	1.48	0.8[illegible]	1.[illegible]
D1c and D2b over D2c	YW-21	3850	21.01	Avl	0	4	19	2.15	3.08	6.76	18.18	21.27	16.81	22.12	6.37	2.46
			21.02	Bt1	4	15	17	2.51	4.87	8.27	18.32	20.62	15.02	19.09	7.95	[illegible]
			21.03	B	15	33	47	7.83	7.72	9.99	19.20	22.36	11.67	12.04	6.[illegible]	[illegible]
			21.04	2Bt qlb1	33	55	54	6.56	9.27	12.73	20.11	15.57	6.81	10.01	8.7[illegible]	1.[illegible]
			21.05	2Bt qmlb1	55	144	59	17.47	17.34	16.41	16.10	10.01	5.76	7.56	4.62	7.14
			21.06	2Bqml b2	144	106	40	14.20	17.47	18.83	19.20	14.49	4.77	6.71	1.54	[illegible]
			21.07	3Cl qplb2	106	2[illegible]	79	18.98	27.44	24.87	15.60	7.70	1.47	1.70	0.60	1.20

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	Gravel %	SAND vco	SAND co	SAND med	SAND fi	SAND vfi	SILT coarse	SILT fi+vfi	CLAY coarse+med	CLAY fi
D2b	YW-11	4180	11.01	Av	0	4	40	8.45	8.87	7.94	22.99	31.91	10.45	5.57	1.22	2.61
			11.02	Bt1	4	15	27	7.20	9.31	9.31	22.33	23.97	8.94	9.29	5.54	4.11
			11.03	2Bt2	15	42	29	6.45	8.10	8.58	20.51	23.07	9.36	9.90	8.10	5.94
			11.04	2Btqml	42	90	48	4.23	5.78	9.08	21.27	22.87	12.18	10.29	6.51	7.77
			11.05	2Bq	90	150	75	13.28	10.31	12.24	20.82	18.11	7.18	6.53	4.35	7.18
			11.06	3Bqml b	150	120	73	15.47	15.47	13.75	13.32	8.38	4.11	7.26	6.29	15.56
D1c over D2b	YW-12	4210	12.01	Av1	0	4	35	6.15	7.28	7.49	21.51	28.25	13.29	8.56	4.19	3.28
			12.02	Av2	4	14	25	4.76	6.02	7.38	20.78	30.41	12.19	9.97	5.36	3.14
			12.03	2Bt	14	47	26	5.34	6.85	8.17	19.50	23.80	11.32	11.80	8.77	4.46
			12.04	2Bt1	47	105	56	12.75	12.03	13.21	18.99	17.39	10.11	8.19	4.01	3.21
			12.05	2Bt2	105	120	10	18.24	18.60	16.45	15.67	12.10	7.43	6.72	3.12	2.65
			12.06	2Btqml b	120	144	66	24.97	21.02	19.59	14.77	8.39	3.38	3.70	1.45	2.74
			12.07	2Btqlb	144	200	80	26.39	21.02	14.61	13.39	10.10	4.98	4.83	1.90	2.78
D1c over D2b(?)	YW-14	4490	14.01	A	0	8	32	4.31	3.85	5.00	17.75	33.73	21.44	8.45	2.97	1.50
			14.02	Bt	8	28	24	3.00	3.38	4.34	16.68	36.36	17.93	9.06	5.07	4.1[illegible]
			14.03	2Bt	28	54	35	4.35	5.03	5.86	15.97	29.90	19.10	10.26	5.30	4.24
			14.04	2Bq	54	107	42	6.07	6.68	8.32	18.28	26.65	16.63	9.98	3.80	3.51
			14.05	3Bqlb	107	121	19	10.22	9.16	11.29	21.29	23.37	11.76	7.40	2.66	2.65
			14.06	3Bqml 2b	121	152	30	6.55	6.04	7.00	17.77	25.79	13.89	13.71	4.80	4.4[illegible]
			14.07	4Bqml 2b	152	221	63	12.45	11.80	12.15	18.65	18.75	8.61	9.46	3.80	4.22
			14.08	4Bqlb	221	230	80	16.81	13.37	11.80	16.96	17.98	7.70	7.07	3.59	3.97
D2b(?)	YW-20	4505	20.01	Av	0	8	38	5.42	5.15	5.36	21.56	34.72	15.06	8.07	1.97	2.65
			20.02	Bt1	8	19	24	3.06	4.57	5.48	18.59	26.38	13.97	15.24	7.98	4.7[illegible]
			20.03	Bt2	19	42	39	5.12	4.76	5.41	13.09	19.58	16.08	15.87	9.65	10.45
			20.04	2Bq	42	64	84	12.44	13.74	11.64	15.34	15.83	7.49	6.87	6.45	10.19
			20.05	2Bqt 1	64	76	84	18.61	12.74	9.57	13.00	12.87	8.02	8.69	6.24	10.2[illegible]
			20.06	2Bqt 2-1	76	114	68	18.77	18.45	11.84	12.23	10.29	5.68	7.65	5.68	9.4[illegible]
			20.07	2Bqt 2-2	114	152	89	7.30	9.75	9.40	13.82	16.35	11.14	10.59	7.58	13.[illegible]
			20.08	2Bqt 2-3	152	190	89	15.10	13.94	12.52	17.74	15.87	6.97	6.32	4.14	7.41
D1c over D2c	FW-5	3350	5.01	A	0	5	25	4.62	8.11	15.62	33.65	26.54	5.20	2.60	1.38	2.15
			5.02	AB	5	20	9	1.85	6.40	14.68	37.84	26.31	4.87	3.96	1.67	2.47
			5.03	Bt1	20	45	14	3.13	6.82	19.50	26.94	16.57	8.14	8.84	6.07	7.55
			5.04	2Bt1b	45	56	10	3.80	6.52	16.19	23.69	17.97	11.00	11.67	5.17	4.0[illegible]
			5.05	2Btqmlb	56	106	69	11.21	12.28	13.63	17.13	15.73	8.55	10.56	5.09	5.6[illegible]
			5.06	2Bqb	106	164	71	24.28	24.70	24.49	11.13	5.19	2.86	3.40	1.07	2.6[illegible]
			5.07	2Bqn	164	263	72	31.96	30.29	28.27	10.25	2.31	0.39	0.29	0.19	1.[illegible]
D2c over D1a	FW-18	3560	18.01	Avb	0	11	13	1.22	2.87	5.64	13.35	16.17	18.87	26.23	9.70	5.97
			18.02	Bt	11	33	24	6.13	9.38	11.65	18.56	18.40	13.06	14.28	5.40	3.1[illegible]
			18.03	Bt1 j	33	40	30	9.23	10.58	11.84	15.20	15.95	10.50	15.08	6.95	4.57
			18.04	2Btqlj1	40	66	53	10.52	14.88	18.24	17.95	13.63	6.66	10.[illegible]	4.23	3.7[illegible]
			18.05	2Btqlj2	66	120	72	23.10	22.87	23.14	12.06	4.80	2.05	5.82	2.08	3.05
			18.06	3b	120	160	76	21.69	27.30	26.26	9.62	4.54	2.20	3.69	1.9[illegible]	2.29

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	Gravel %	SAND vco	SAND co	SAND med	SAND fi	SAND vfi	SILT coarse	SILT (f+vf)	CLAY coarse	CLAY fi
D2a over D2c	YW-8	3930	8.01	Av	0	9	13	1.67	2.19	4.79	19.99	16.71	14.77	21.44	12.30	6.15
			8.02	Bt1	9	21	13	1.82	2.73	3.74	9.09	7.07	5.60	23.29	25.81	19.86
			8.03	2Bt2b	21	35	27	9.09	14.60	17.35	18.06	12.16	7.49	11.32	5.29	3.03
			8.04	2 qmb	35	60	18	23.00	20.63	16.78	13.66	9.09	4.14	6.21	2.82	3.58
			8.05	2 b	60	100	52	25.76	19.23	10.11	16.10	8.16	3.59	4.34	2.08	2.64
			8.06	2Cu1 b	100	210	62	13.67	14.58	10.76	24.31	17.10	4.26	3.24	1.36	2.73
D2a over D2c	YW-16	4300	16.01	Av	0	13		3.27	3.82	7.36	21.03	23.39	7.18	9.21	9.02	5.71
			16.02	Bt1	13	30		2.98	3.08	6.84	28.82	24.43	6.88	9.70	10.58	6.70
			16.03	Bt2	30	43		3.06	3.01	6.22	26.48	24.00	6.41	15.32	8.73	6.77
			16.04	2Bt qlb	43	58	44	4.12	4.44	4.28	9.04	9.12	5.18	16.36	18.54	28.91
			16.05	2 qb	58	100	57	7.07	5.21	5.99	12.28	12.58	7.30	17.58	12.61	19.50
			16.06	2Bqmb (nc)	100	150	56	9.80	10.78	11.70	20.18	17.01	5.72	8.95	7.21	8.95
			16.07	2 qmlb	100	150	85	6.79	5.02	7.93	17.89	18.60	10.72	13.40	8.93	10.71
			16.08	2C1 qmb	150	207	71	18.02	20.02	17.22	15.59	11.31	5.17	7.14	3.21	2.32
D1c/D2c	YW-1W	4310	1.01	A	0	10	27	3.86	4.57	4.96	19.51	20.76	11.72	11.54	7.82	7.26
			1.02	Bt	10	25	15	2.40	3.40	4.75	18.52	23.97	13.13	14.77	10.94	8.02
			1.03	2Bt qlj1b	25	42	47	3.27	4.52	4.91	9.76	11.20	7.74	13.49	15.48	29.63
			1.04	2Bt qlj2b	42	56	30	4.16	5.04	5.77	9.94	11.15	6.00	12.93	14.74	29.48
			1.05	2 b	56	70	46	5.47	7.50	8.34	9.80	10.00	5.28	17.02	13.50	25.01
D1c/D2c	YW-1E	4310	1.06	2Bt1 jqb		50	32	3.89	4.28	5.12	13.61	14.25	6.75	12.75	14.22	26.04
			1.07	2Bt qmlb	50	56	30	4.57	5.20	4.92	9.76	9.83	5.46	14.22	13.05	22.98
			1.08	2 qm1b	56	70	50	9.95	8.81	7.44	10.02	9.95	5.50	15.38	11.28	21.79
			1.09	4 qm2b	70	115	61	13.19	15.19	12.66	12.28	10.71	5.12	12.28	7.42	13.56
			1.10	5B1 b	115	167	66	15.41	18.37	16.89	13.36	9.95	4.99	7.59	4.77	8.67
			1.11	5C1 n1b	167	195	70	15.21	15.34	14.80	15.65	11.56	6.29	10.04	4.79	8.22
			1.12	5C1 n2b	195	290	67	19.74	25.64	20.61	9.64	4.74	2.19	6.60	4.21	6.45
D1a	FW-19	3500	19.01	Av1	0	9	5	0.65	1.56	5.07	16.47	16.95	15.81	25.26	12.72	4.72
			19.03	Bt	9	13	13	2.73	3.20	14.12	28.23	14.32	7.62	12.76	12.94	4.08
			19.04	Bt1	13	17	3	0.82	1.29	6.67	13.54	7.14	3.68	13.79	27.50	29.10
			19.05	Bt qmlj	17	29	11	0.79	1.57	9.79	21.15	10.00	3.62	10.28	16.65	26.06
			19.06	2 qm1	29	47		4.05	5.77	9.15	16.72	10.07	7.09	13.60	13.28	10.99
			19.07	2 qm2	47	72	34	2.60	2.67	9.35	18.32	13.20	6.76	13.03	14.52	19.54
			19.08	2 qm3	72	150	40	3.71	4.51	8.26	19.70	17.59	6.07	11.29	10.06	[illegible]
D1a	YW-6	3040	6.01	Av1	0	6	24	2.00	2.91	6.46	21.71	17.38	16.42	10.23	10.01	4.81
			6.02	Bt1	6	10	14	4.05	4.11	6.32	14.16	14.04	15.64	19.02	11.70	10.49
			6.03	2 mq	10	52		14.20	14.29	15.99	15.69	11.56	7.07	9.25	6.06	5.87
			6.04	2 qm	52	101	59	24.01	18.62	10.17	16.59	10.42	4.35	2.97	1.51	2.47
			6.05	2 q	101	153	67	28.02	18.35	10.07	18.77	10.47	3.47	2.60	0.95	2.21
			6.06	3B q	153	230	63	30.13	22.57	20.99	17.11	11.11	3.51	2.03	0.81	1.62
			6.07	3C1 qn	230	250	41	23.77	21.08	19.11	11.17	7.22	2.76	1.00	0.60	1.60

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	Gravel %	SAND vco	SAND co	SAND med	SAND fi	SAND vfi	SILT coarse	SILT fine	SILT coarse	SILT med	CLAY fi
DTa	YW-2W	3870	2.01	Avl	0	3	6	3.20	2.53	4.89	16.20	17.63	23.00	17.25	10.57	5.75	
			2.02	Al	3	10	9	1.95	2.87	5.20	16.60	19.96	19.36	20.27	8.95	4.75	
			2.03	Bty	10	19	12	2.16	2.02	4.11	14.83	19.07	20.26	19.57	9.79	8.19	
			2.04	2Btqmly	19	34	22	2.54	3.08	4.75	17.20	21.35	15.60	16.73	9.17	9.49	
			2.05	2Btqmy	34	70	33	4.96	4.40	6.43	16.65	18.08	14.17	14.63	10.28	10.51	
DTa	YW-2E	3870	2.06	Bt1	4	19	13	1.90	2.56	3.59	12.90	14.21	11.14	16.33	15.34	22.0[illegible]	
			2.07	2Btqm	19	52	39	2.43	2.88	3.87	7.37	6.02	6.07	21.26	16.09	34.01	
			2.08	2Bqm	52	114	48	6.00	9.92	11.92	20.93	17.43	6.76	10.42	7.04	9.57	
			2.09	2Bq	114	197	76	9.05	9.13	11.23	16.26	20.26	10.75	10.19	5.66	7.36	
DTa	YW-22	3965	22.01	Avl	0	10	5	1.19	2.00	5.32	16.01	16.64	12.69	17.92	17.92	8.69	
			22.02	Bt1	10	21	20	4.14	5.63	5.69	15.02	14.40	9.40	11.90	16.20	17.12	
			22.03	Bqm	21	62	42	6.75	7.72	8.00	10.94	14.54	6.76	14.00	12.07	10.05	
			22.04	2Bmq	62	92	54	11.34	13.68	13.46	16.09	13.31	6.42	10.62	6.92	8.15	
			22.05	2Bqm	92	184	52	13.46	13.06	12.38	10.44	16.29	6.59	8.41	5.68	5.69	

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	% Total by Summation sand	silt	clay	Density (od) gm/cc	CaCO3 %	(Gypsum) EC mho/cm	%	(Soluble Salts) EC mho/cm	%
D1a	FWA-1		FWA-1				94.37	4.52	1.11	1.75	0.43				
	FWA-2		FWA-2				84.78	13.22	2.00	1.51	0.51				
	FWA-3		FWA-3				98.55	0.85	0.60	1.40	0.24				
	FWA-4		FWA-4				95.63	2.76	1.61	1.32	0.31				
D1a	YWA-1		YWA-1				99.16	0.42	0.42	1.75	0.15				
	YWA-2		YWA-2				98.30	0.94	0.77	1.25	0.16				
D1b	FW-7	3280	7.01	A1	0	2	93.37	4.92	1.71	1.25	0.40				
			7.02	Cox	2	18	90.83	6.53	2.64	1.33	0.19				
			7.03	2Ldox	18	100	95.42	3.24	1.34	1.35	0.72				
D1c	FW-4	3300	4.01	A1	0	3	86.55	9.37	4.08	1.45	0.44	0.00000	0.00	0.00008	0.07
			4.02	B1j1	3	9	81.75	10.64	7.60	1.36	0.90	0.00002	0.01	0.00009	0.07
			4.03	2B1t	9	60	71.42	16.97	11.61	1.48	2.34	0.00003	0.02	0.00012	0.04
			4.04	2Lcd	60	100	82.03	13.80	4.08	1.42	1.59	0.00004	0.02	0.00010	0.03
D1c	FW-17	3540	17.01	A	0	6	70.07	25.06	4.87	1.35	0.07				
			17.02	Bwk	6	24	76.19	19.32	4.50	1.50	0.17				
			17.03	2Cuk	24	120	92.73	5.00	2.27	1.42	0.24				
D1c	YW-13	4155	13.01	A	0	9	81.75	13.78	4.47	1.42	0.14				
			13.02	Bw	9	21	80.57	13.46	5.96	1.42	0.12				
			13.03	2Bqj	21	73	87.56	8.18	4.26	1.61	0.15				
			13.04	2Lqn	73	178	93.15	4.91	1.94	1.81	0.22				
D1c	YW-15	4520	15.01	A	0	18	78.36	16.06	5.58	1.40	0.02				
			15.02	Bw	18	46	79.88	13.88	6.25	1.40	0.09				
			15.03	2Bql	46	170	70.98	18.64	10.38	1.48	0.13				
			15.06	2Bql (1)	46	108	80.46	11.96	7.58	1.42	0.21				
			15.04	2Bql (2)	108	170	61.35	25.77	12.88	1.40	0.29				
			15.05	2Lcd	170	220	85.35	7.33	7.31	1.60	0.24				
D2b	FW-3	3320	3.01	Avl	0	5	42.10	40.84	17.06	1.62	1.49	0.00003	0.01	0.00010	0.07
			3.02	B1t	5	12	35.11	29.29	25.60	1.72	0.85	0.00001	0.01	0.00011	0.07
			3.03	2B1t	12	45	76.96	14.16	8.87	1.80	0.18	0.00000	0.00	0.00018	0.07
			3.04	2Bqml 1	45	83	85.71	9.58	4.72	1.94	0.54	0.00001	0.01	0.00016	0.05
			3.05	2Bqml 2	83	107	94.40	2.74	2.85	2.00	0.57	0.00001	0.01	0.00021	0.07
			3.06	2Lqn	107	210	95.34	2.27	2.39	1.80	0.70	0.00002	0.01	0.00017	0.07
D1c and D2b over D2c	YW-21	3850	21.01	Avl	0	4	52.23	38.92	8.85	1.37	1.73				
			21.02	B1j1	4	15	54.58	34.11	11.31	1.39	1.03				
			21.03	B1	15	33	67.17	23.71	9.12	1.52	3.32				
			21.04	2Bt qlb1	33	56	64.23	16.82	18.95	1.71	0.79				
			21.05	2Bt qmlb1	56	144	77.33	10.92	11.76	1.95	0.48				
			21.06	2Bqmlb2	144	186	84.20	11.40	4.24	1.79	0.34				
			21.07	2Bqmlb2	186	233	94.57	3.16	2.26	1.80	0.36				

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	% Total by Summation sand	silt	clay	Density (od) gm/cc	CaCO3 %	Gypsum EC mho/cm	Gypsum %	(Soluble Salts) EC mho/cm	(Soluble Salts) %
D2b	YW-11	4180	11.01	Av	0	4	80.15	16.02	3.83	1.57	0.23				
			11.02	Bt1	4	15	72.12	18.23	9.65	1.59	0.18				
			11.03	2Bt2	15	42	66.71	19.25	14.04	1.54	0.20				
			11.04	2Bqml	42	90	63.25	22.47	14.28	1.61	1.14				
			11.05	2Bq	90	150	74.75	13.71	11.53	1.87	1.55				
			11.06	2Bqmlb	150	170	66.38	11.37	22.25	1.82	2.13				
D1c over D2b	YW-12	4210	12.01	Av1	0	4	70.68	21.85	7.47	1.56	0.07				
			12.02	Av2	4	14	69.34	22.16	8.50	1.40	0.20				
			12.03	2Bt	14	47	63.64	23.12	13.23	1.64	0.19				
			12.04	2Bt1	47	105	74.38	18.30	7.32	1.85	1.61				
			12.05	2Bt2	105	120	81.06	14.16	4.78	1.89	1.86				
			12.06	2Bqmlb	120	144	88.73	7.08	4.18	1.77	1.68				
			12.07	2Bqlb	144	200	85.51	9.81	4.68	#1.75	0.73				
D1c over D2b(?)	YW-14	4490	14.01	A	0	8	64.64	29.89	5.48	1.36	0.20				
			14.02	Bt	8	28	63.77	26.99	9.24	1.26	0.19				
			14.03	2Bt	28	54	61.10	29.35	9.55	1.39	0.92				
			14.04	2Bq	54	107	65.99	26.61	7.39	1.65	2.98				
			14.05	3Bqjb	107	121	75.34	19.16	5.50	1.62	0.91				
			14.06	3Bqml1b	121	152	63.14	27.60	9.26	1.83	1.53				
			14.07	4Bqml2b	152	221	73.82	18.07	8.11	1.67	0.87				
			14.08	4Bqjb	221	230	76.91	15.56	7.52	#1.75	0.74				
D2b(?)	YW-20	4505	20.01	Av	0	8	72.21	23.13	4.66	1.51	0.06				
			20.02	Bt1	8	19	58.08	29.22	12.70	1.53	0.09				
			20.03	Bt2	19	42	47.96	31.95	20.09	1.56	0.10				
			20.04	2Bq	42	64	69.00	14.36	16.64	#1.65	0.19				
			20.05	2Bql1	64	76	66.79	16.72	16.49	1.96	3.31				
			20.06	2Bql2-1	76	114	71.58	13.33	15.08	1.72	1.32				
			20.07	2Bql2-2	114	152	56.63	22.04	21.33	#1.72	4.77				
			20.08	2Bql2-3	152	190	75.16	13.29	11.55	#1.72	1.30				
D1c over D2c	FW-5	3350	5.01	A	0	5	88.53	7.80	3.67	1.54	0.29	0.00001	0.00	0.00006	0.02
			5.02	AB	5	20	87.07	8.82	4.11	1.44	0.13	0.00000	0.00	0.00005	0.02
			5.03	Bt1	20	45	72.97	16.98	10.05	1.64	1.94	0.00003	0.01	0.00011	0.0
			5.04	2Bt1b	45	56	68.16	22.67	9.17	1.66	0.39	0.00000	0.00	0.00009	0.0
			5.05	2Bqmlb	56	106	69.98	19.10	10.92	1.78	1.10	0.00000	0.00	0.00051	0.16
			5.06	2Bqb	106	164	89.80	6.27	3.94	1.86	4.51	0.00016	0.08	0.00091	0.17
			5.07	2Bqb	164	263	90.07	9.67	1.25	#1.80	0.19	0.00006	0.03	0.00045	0.14
D2c over D1a	FW-10	3560	10.01	Av1	0	11	39.27	45.10	15.63	1.72	2.34				
			10.02	A1	11	33	64.13	27.34	8.53	1.69	1.61				
			10.03	Bt1	33	40	62.90	25.58	11.52	1.81	0.19				
			10.04	2Bqlb1	40	66	75.02	16.05	7.93	1.79	0.52				
			10.05	2Bqlb2	66	120	85.97	7.87	6.16	#1.80	0.17				
			10.06	3b	120	160	89.81	5.97	4.22	1.82	14.42				

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	% Total by Summation sand	silt	clay	Density (od) gm/cc	CaCO3 %	(Gypsum) EC mho/cm	%	(Soluble Salts) EC mho/cm	%
O2a over O2c	YW-8	3930	8.01	Av	0	9	45.33	36.21	18.46	1.65	0.00				
			8.02	Bt1	9	21	25.44	28.88	45.67	1.52	0.07				
			8.03	2Bt2b	21	35	72.07	18.81	9.13	1.64	0.11				
			8.04	2Cqmb	35	68	83.24	10.36	6.40	1.56	19.41				
			8.05	2Cb	68	100	87.35	7.93	4.72	1.70	7.53				
			8.06	2Cqlb	100	110	88.42	7.49	4.09	1.75	4.00				
O2a over O2c	YW-16	4300	16.01	Av	0	13	60.88	16.39	14.73	1.26	0.00	0.00001	0.01	0.00013	0.04
			16.02	Bt1	13	30	66.15	16.57	17.28	1.49	0.05	0.00000	0.00	0.00007	0.02
			16.03	Bt2	30	43	62.77	21.73	15.50	1.48	0.07	0.00001	0.01	0.00005	0.02
			16.04	2Btqlb	43	58	31.01	21.54	47.45	1.76	2.18	0.00010	0.05	0.00012	0.04
			16.05	2Cqb	58	100	42.93	24.88	32.18	1.48	22.93	0.00001	0.01	0.00014	0.04
			16.06	2Cqmb (nc)	100	150	69.16	14.68	16.17	1.70	0.19	0.00001	0.01	0.00016	0.05
			16.07	2Cqmlb	100	150	56.24	24.11	19.65	1.70	1.01	0.00000	0.00	0.00015	0.05
			16.08	2Cqlb	150	207	82.16	12.31	5.53	1.84	0.07	0.00003	0.02	0.00008	0.02
O1c/O2c	YW-18	4310	1.01	A	0	10	61.66	23.26	15.07	1.47	0.06				
			1.02	Bt	10	25	53.13	27.90	18.97	1.52	0.14				
			1.03	2Btqlj1b	25	42	33.66	21.23	45.11	1.40	0.22				
			1.04	2Btqlj2b	42	56	36.06	19.73	44.22	1.62	0.24				
			1.05	3b	56	70	41.99	18.70	39.30	1.32	0.40				
O1c/O2c	YW-18	4310	1.06	2Btljqb		50	41.14	18.60	40.26	1.47	0.25				
			1.07	2Btqmlb	50	56	34.28	19.69	46.03	1.49	1.52				
			1.08	3Cqmlb	56	70	46.16	20.77	33.07	1.64	6.79				
			1.09	4Cqm2b	70	115	61.61	17.40	20.99	1.48	20.05				
			1.10	5Ab	115	167	73.98	12.58	13.45	1.71	8.58				
			1.11	5Clnlb	167	195	70.56	16.43	13.01	1.75	2.51				
			1.12	5Clnlb	195	290	80.36	8.98	10.66	1.75	0.92				
O1a	FW-19	3585	19.01	Avl1	0	9	41.49	41.07	17.45	1.61	3.30				
			19.03	Bt	9	13	62.61	20.38	17.01	1.75	2.96				
			19.04	Bt1	13	17	29.46	17.46	53.08	1.24	1.12				
			19.05	Btqmlj	17	29	43.30	13.99	42.71	1.43	0.37				
			19.06	2Cqml	29	47	46.57	20.77	32.67	1.59	8.99				
			19.07	2Cqm2	47	72	46.14	19.79	34.07	1.59	8.36				
			19.08	2Cqm3	72	150	53.85	18.16	27.90	1.72	16.33				
O1a	YW-6	3840	6.01	Avl	0	6	50.53	34.65	14.82	1.46	1.97	0.00002	0.01	0.00010	0.02
			6.02	Bt1	6	10	43.47	34.66	21.86	1.31	0.95	0.00002	0.01	0.00010	0.02
			6.03	2Cmq	10	52	71.74	16.32	11.95	1.50	30.32	0.00004	0.02	0.00015	0.04
			6.04	3Cqm	52	101	87.81	8.22	3.97	1.60	19.58	0.00006	0.03	0.00058	0.18
			6.05	3Cq	101	153	90.69	6.15	3.15	1.84	15.27	0.00080	0.43	0.00193	0.61
			6.06	3Cq	153	230	92.03	5.54	2.43	1.73	6.18	0.00024	0.13	0.00120	0.37
			6.07	3Cqm	230	250	93.15	4.57	2.28	1.77	2.01	0.00054	0.29	0.00165	0.5[illegible]

Surface	Profile	Elevation ft	Soil No.	Horizon	Depth cm top	Depth cm base	% Total by Summation sand	silt	clay	Density (od) gm/cc	$CaCO_3$ %	(Gypsum EC mho/cm	) %	(Soluble Salts) EC mho/cm	%
Dla	YW-2W	3870	2.01	Avl	0	3	43.44	40.24	16.32	1.53	1.72				
			2.02	Al	3	10	46.67	39.63	13.70	1.52	0.51				
			2.03	Bty	10	19	42.19	39.83	17.98	1.30	0.21				
			2.04	2Btqmly	19	34	48.92	32.32	18.76	1.80	0.29				
			2.05	2Btqmy	34	70	50.41	28.79	20.80	1.79	0.11				
Dla	YW-2E	3870	2.06	Btl	4	19	35.17	27.47	37.36	1.31	1.19				
			2.07	2Btqm	19	52	22.57	27.33	50.10	1.36	5.64				
			2.08	2Bqm	52	114	66.21	17.18	16.61	1.63	12.90				
			2.09	2Bq	114	197	66.04	20.94	13.02	1.73	7.96				
Dla	YW-22	3965	22.01	Avl	0	10	42.81	30.61	26.58	1.58	5.26				
			22.02	Btl	10	21	44.88	21.30	33.82	1.37	0.08				
			22.03	Bqm	21	62	56.31	20.76	22.93	1.66	20.10				
			22.04	2Bmq	62	92	67.88	17.05	15.07	1.42	22.36				
			22.05	2Bqm	92	104	73.63	15.00	11.37	1.75	6.18				

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	Carbon % org	Carbon % oxid OM	Carbon % 01	P Pa mg %	pH 1:1H2O	Iron Fe-d %	Iron Fe-o %	Iron Fe2/Fed %	SiO2 % by wt
D1a	FWA-1		FWA-1				0.05	0.08	0.44		8.10				1.80
	FWA-2		FWA-2				0.17	0.30	0.67		7.75				3.11
	FWA-3		FWA-3				0.03	0.05	0.31		8.15				1.27
	FWA-4		FWA-4				0.07	0.11	0.44		8.70				2.09
D1a	YWA-1		YWA-1				0.01	0.02	0.32		7.75				0.49
	YWA-2		YWA-2				0.02	0.03	0.30		7.30				1.06
D1b	FW-7	3380	7.01	A1	0	2	0.18	0.31	0.30		7.75				2.02
			7.02	Box	2	18	0.09	0.16	0.32		7.80				2.58
			7.03	2Cox	18	100	0.10	0.17	0.25		8.15				2.14
D1c	FW-4	3300	4.01	A1	0	3	0.09	0.16	0.46		7.30				2.70
			4.02	Bt1	3	9	0.25	0.43	0.42		7.35				2.95
			4.03	2Bt1	9	60	0.11	0.20	0.48		7.60				6.16
			4.04	2Cu1	60	100	0.07	0.12	0.46		7.80				4.60
D1c	FW-17	3540	17.01	A	0	6	0.35	0.61	0.54		7.50				4.37
			17.02	Bw1	6	24	0.18	0.31	0.40		8.00				2.70
			17.03	2Cu1	24	120	0.09	0.15	0.36		8.10				1.13
D1c	YW-13	4155	13.01	A	0	9	0.61	1.05	0.48		6.80	0.48	0.023	0.05	6.16
			13.02	Bw	9	21	0.25	0.43	0.47		7.10	0.51	0.021	0.04	3.80
			13.03	2Bgj	21	73	0.12	0.20	0.35		7.40	0.45	0.019	0.04	2.68
			13.04	2C1gn	73	138	0.06	0.10	0.25		7.60	0.42	0.017	0.04	2.10
D1c	YW-15	4520	15.01	A	0	18	0.56	0.96	0.71		7.20				4.48
			15.02	Bw	18	46	0.39	0.68	0.55		7.30				2.76
			15.03	2Bgj	46	170	0.21	0.36	0.75		7.55				3.49
			15.06	2Bgj (1)	46	108	0.14	0.25	0.40		7.75				3.08
			15.04	2Bgj (2)	108	170	0.29	0.51	0.76		7.65				4.56
			15.05	2Cu1	170	220	0.09	0.16	0.35		7.95				1.85
D2b	FW-3	3320	3.01	Avl	0	5	0.08	0.14	0.47		7.75				6.61
			3.02	Bt1	5	12	0.07	0.13	0.67		7.65				7.27
			3.03	2Bt1	12	45	0.11	0.19	0.45		7.65				7.90
			3.04	2Bgmt1	45	83	0.07	0.12	0.37		7.60				2.25
			3.05	2Bgmt2	83	107	0.04	0.07	0.25		7.60				1.32
			3.06	2C1gn	107	210	0.05	0.08	0.21		7.90				2.59
D1c and D2b over D2c	YW-21	3850	21.01	Avl	0	4	0.11	0.19	0.32		8.00				6.08
			21.02	Bt1	4	15	0.13	0.22	0.40		7.50				5.74
			21.03	B1	15	33	0.22	0.38	0.39		7.45				7.69
			21.04	2Bt1gb1	33	55	0.07	0.11	0.38		7.50				20.62
			21.05	2Bt1gmb1	55	144	0.03	0.05	0.34		8.10				10.19
			21.06	2Bt1gmb2	144	186	0.06	0.10	0.34		7.35				5.61
			21.07	2C1gnb2	186	233	0.03	0.05	0.32		7.70				2.67

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	Carbon % org	Carbon % oxid OM	XLOI	P Pa mg %	pH 1:1H2O	Iron Fe-d %	Iron Fe-o %	Iron Feo/Fed %	SiO2 % by wt
D2b	YW-11	4180	11.01	Av	0	4	0.20	0.34	0.36		7.00				5.05
			11.02	Bt1	4	15	0.12	0.21	0.41		7.20				5.24
			11.03	2Bt2	15	42	0.19	0.33	0.57		7.05				6.46
			11.04	2Btqml	42	90	0.07	0.12	0.76		7.90				18.70
			11.05	2Btq	90	150	0.18	0.31	0.86		7.95				21.39
			11.06	3Bqmlb	150	170	0.07	0.13	0.75		8.00				29.78
D1c over D2b	YW-12	4210	12.01	Av1	0	4	0.58	0.99	0.73		7.20	0.61	0.040	0.07	6.43
			12.02	Av2	4	14	0.27	0.46	0.46		7.80	0.65	0.042	0.06	4.56
			12.03	2Bt	14	47	0.20	0.35	0.48		7.50	0.68	0.039	0.06	5.41
			12.04	2Bt1	47	105	0.23	0.39	0.41		7.80	0.54	0.023	0.04	5.69
			12.05	2Bt2	105	120	0.23	0.40	0.47		8.60	0.51	0.025	0.05	5.76
			12.06	2Bqmlb	120	144	0.14	0.24	0.57		7.95	0.46	0.030	0.07	7.80
			12.07	2Bqlb	144	200	0.11	0.19	0.42		7.85	0.47	0.027	0.06	5.27
D1c over D2b(?)	YW 14	4490	14.01	A	0	8	0.29	0.50	0.38		7.15				5.29
			14.02	Bt	8	28	0.22	0.37	0.45		7.15				4.32
			14.03	2Bk	28	54	0.26	0.45	0.59		7.80				5.25
			14.04	2Bq	54	107	0.22	0.38	0.48		8.05				6.51
			14.05	3Bqjb	107	121	0.14	0.25	0.45		8.05				2.57
			14.06	3Bqml1b	121	152	0.11	0.18	0.46		8.00				3.25
			14.07	4Bqml2b	152	221	0.11	0.19	0.53		8.00				1.85
			14.08	4Bqjb	221	230	0.10	0.18	0.44		8.50				1.02
D2b(?)	YW-20	4505	20.01	Av	0	8	0.17	0.29	0.28		6.90				5.57
			20.02	Bt1	8	19	0.16	0.28	0.36		6.90				7.02
			20.03	Bt2	19	42	0.18	0.31	0.41		6.75				17.19
			20.04	2Bq	42	64	0.25	0.44	0.49		7.30				19.12
			20.05	2Bql1	64	76	0.27	0.47	0.44		7.80				24.06
			20.06	2Bql2-1	76	114	0.07	0.13	0.31		7.95				22.91
			20.07	2Bql2-2	114	152	0.34	0.59	0.56		8.00				27.45
			20.08	2Bql2-3	152	190	0.06	0.10	0.25		8.00				22.42
D1c over D2c	FW-5	3550	5.01	A	0	5	0.20	0.34	0.41		7.55				1.71
			5.02	AB	5	20	0.13	0.22	0.35		7.30				1.67
			5.03	Bt1	20	45	0.13	0.22	0.33		7.45				2.74
			5.04	2Btlb	45	56	0.09	0.16	0.42		7.55				6.50
			5.05	2Btqmlb	56	106	0.05	0.09	0.46		7.50				7.71
			5.06	2Bqb	106	164	0.08	0.14	0.42		7.65				7.91
			5.07	2Cqm	164	263	0.02	0.03	0.22		7.50				0.56
D2c over D1a	FW-18	3560	18.01	Av1	0	11	0.09	0.16	0.50		8.10				7.14
			18.02	A1	11	33	0.10	0.18	0.36		8.00				2.96
			18.03	Bt1j	33	40	0.08	0.13	0.38		7.55				4.53
			18.04	2Bqjl1	40	66	0.08	0.13	0.45		7.35				3.74
			18.05	2Bqjl2	66	120	0.06	0.11	0.40		7.10				2.27
			18.06	3b	120	160	0.17	0.29	0.64		7.90				19.21

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	Carbon % org	Carbon % oxid OM	%LOI	P Pa aq %	pH 1:1H2O	Iron Fe-d %	Iron Fe-o %	Iron Feo/Fed %	SiO2 % by wt
D2a over D2c	YW-8	2930	8.01	Av	0	9	0.14	0.24	0.49		7.40				3.38
			8.02	Bt1	9	21	0.20	0.34	0.91		7.30				8.93
			8.03	2Bt2b	21	35	0.16	0.28	1.20		7.45				7.39
			8.04	2t qmb	35	60	0.27	0.47	0.92		7.90				22.70
			8.05	2t b	60	100	0.10	0.18	0.52		8.15				13.32
			8.06	2Cu1b	100	210	0.08	0.14	0.59		7.75				9.05
D2a over D2c	YW-16	4300	16.01	Av	0	13	0.38	0.66	0.47	20.8	7.05	0.55	0.038	0.07	8.28
			16.02	Bt1	13	30	0.26	0.45	0.38	12.7	7.55	0.58	0.037	0.06	5.38
			16.03	Bt2	30	43	0.23	0.39	0.45	11.3	7.60	0.55	0.036	0.07	5.60
			16.04	2Btqlb	43	58	0.19	0.32	0.64	9.0	7.70	0.51	0.028	0.05	37.47
			16.05	2t ql	58	100	0.39	0.75	0.66	21.2	7.90	0.25	0.008	0.03	45.65
			16.06	2Bqmb (nc)	100	150	0.03	0.05	0.37	6.8	7.65	0.37	0.020	0.05	22.74
			16.07	2Bqmlb	100	150	0.04	0.07	0.31	4.8	7.90	0.36	0.019	0.05	43.12
			16.08	2Cl qnb	150	207	0.02	0.03	0.21	6.9	7.90	0.42	0.024	0.06	6.27
D1c/D2c	YW-1W	4310	1.01	A	0	10	0.23	0.41	0.58		7.25	0.76	0.073	0.10	9.47
			1.02	Bt	10	25	0.21	0.35	0.60		7.20	0.96	0.163	0.17	8.84
			1.03	2Bt qlj1b	25	42	0.30	0.51	0.85		7.30	0.74	0.037	0.05	23.60
			1.04	2Bt qlj2b	42	56	0.27	0.47	1.14		7.40	0.60	0.025	0.05	26.70
			1.05	2t b	56	70	0.26	0.45	1.11		7.70	0.72	0.020	0.04	28.30
D1c/D2c	YW-1E	4310	1.06	2Bt1jqb		50	0.19	0.32	0.98		7.60	0.66	0.036	0.05	23.42
			1.07	2Bt qmlb	50	56	0.11	0.19	1.56		8.10	0.59	0.024	0.04	29.92
			1.08	4 qmlb	56	70	0.18	0.32	1.93		8.15	0.42	0.017	0.04	33.18
			1.09	4l qm2b	70	115	0.17	0.29	2.19		8.40	0.27	0.008	0.03	36.05
			1.10	5Bt b	115	167	0.10	0.17	1.24		8.10	0.37	0.014	0.04	28.20
			1.11	5Cl n1b	167	195	0.02	0.04	0.85		8.40	0.60	0.017	0.03	25.97
			1.12	5Cl n2b	195	290	0.01	0.02	0.43		8.40	0.55	0.016	0.03	30.10
D1a	YW-19	3585	19.01	Avl1	0	9	0.08	0.14	0.46		8.45				7.66
			19.03	Bt	9	13	0.07	0.12	0.29		8.15				5.92
			19.04	Bt1	13	17	0.09	0.16	1.04		7.80				26.00
			19.05	Btqmlj	17	29	0.08	0.15	0.68		7.70				29.92
			19.06	2t qm1	29	47	0.20	0.35	0.94		7.30				31.15
			19.07	2t qm2	47	72	0.17	0.29	0.87		7.40				31.49
			19.08	2t qm3	72	150	0.15	0.26	0.80		7.60				26.59
D1a	YW-6	3840	6.01	Avl	0	6	0.10	0.17	0.49		7.70				7.67
			6.02	Bt1	6	10	0.08	0.14	1.70		7.60				8.57
			6.03	2t mq	10	52	0.42	0.72	0.64		7.75				25.61
			6.04	2t qm	52	101	0.13	0.22	0.37		7.80				19.01
			6.05	2t q	101	155	0.06	0.10	0.25		7.60				16.79
			6.06	2Bt q	155	230	0.04	0.07	0.25		7.60				0.60
			6.07	2Cl qn	230	290	0.02	0.04	0.26		7.70				4.64

Surface	Profile	Elevation ft	Soil No	Horizon	Depth cm top	Depth cm base	Carbon % org	Carbon % oxid OM	Carbon %LOI	P Na mg %	pH 1:1H2O	Iron Fe-d %	Iron Fe-o %	Iron Feo/Fed %	SiO2 % by wt
Dla	YW-2W	3870	2.01	Avl	0	3	0.04	0.08	0.58		7.95				9.09
			2.02	Al	3	10	0.04	0.07	0.32		7.95				9.19
			2.03	Bty	10	19	0.04	0.07	0.29		7.60				25.06
			2.04	2Bltqmly	19	34	0.07	0.13	0.32		7.50				25.12
			2.05	2Bltqmv	34	70	0.04	0.07	0.33		7.50				26.26
Dla	YW-2E	3870	2.06	Bt1	4	19	0.26	0.44	0.50		8.20				31.30
			2.07	2Bltqm	19	52	0.26	0.45	0.66		8.20				40.20
			2.08	2Bltqm	52	114	0.10	0.18	0.32		8.00				29.95
			2.09	2Bltq	114	197	0.07	0.12	0.36		7.55				27.81
Dla	YW-22	3965	22.01	Avl	0	10	0.17	0.30	0.73		8.50				18.50
			22.02	Bt1	10	21	0.24	0.41	0.87		8.00				19.70
			22.03	Bltqm	21	62	0.22	0.37	1.05		7.90				35.01
			22.04	2Bltqmq	62	92	0.13	0.23	0.96		7.65				35.73
			22.05	2Bltqm	92	104	0.08	0.13	0.67		7.65				26.47

Appendix G. Dates for the Quaternary stratigraphy, NTS

Stratigraphic Unit	Material Dated	Age[1] (ka)	Method	Location
Q1b		140 years		channel trenching correlation (Bryan, 1925)
Q1c	Charcoal in fluvial gravel	8.3±0.075	^{14}C	Amargosa River, Beatty NV
Q2a	Slopewash	40±10	U-trend	Crater Flat Trench 3, NTS
	Slopewash	41±10	U-trend	Yucca Mountain Trench 13, NTS
	Fluvial gravel	47±10	U-trend	Yucca Mountain Trench 2, NTS
Q2b	Fluvial gravel	145±25	U-trend	Yucca Mountain Trench 3, NTS
	Fluvial gravel	160±18	U-trend	Gravel Pit, Shoshone CA
	Colluvium	160±90	U-trend	Yucca Mountain Trench 13, NTS
Q2s	Fluvial sand	160±90	U-trend	Jackass Flat ETS Trench, NTS
Q2c (younger)	Fluvial gravel	270±30	U-trend	Crater Flat Trench 3, NTS
	"	270±30	U-trend	Jackass Divide Trench, NTS
	Fluvial gravel	310±30	U-trend	Rock Valley Trench 1, NTS
Q2c (older)	Fluvial gravel	430±40	U-trend	Jackass Divide Trench, NTS
	"	430±60	U-trend	Crater Flat S Trench, Beatty
Q2e	Bishop Ash	738±3	Geochemical correlation	Jackass Flat and Amargosa Desert, NV
QTa	Basalt Ash (older than)	1.11±0.3 my	Geochemical correlation	Yucca Mountain Trench 8, NTS, and Crater Flat Trench 1, Beatty NV
	Ash (younger than)	2.1±0.4 my	Fission track	Carson Slough, Amargosa Desert

[1] Analyzed by:

^{14}C: S. W. Robinson, U.S. Geological Survey, Menlo Park, CA.
U-trend: J. N. Rosholt, U.S. Geological Survey, Denver, CO.
Geochemical correlation on Bishop Ash:
G. A. Izett, U.S. Geological Survey, Reston, VA.
Geochemical correlation on Basalt Ash:
D. Vaniman, Los Alamos National Laboratory, Los Alamos, NM.
Fission track on Zircon:
C. W. Naeser, U.S. Geological Survey, Menlo Park, CA.

Appendix H. Use of pollen, spores, and opal phytoliths from three different aged deposits as paleoclimatic indicators.

Three soil horizons from different aged deposits (Table 1) were submitted to the University of Kansas Palynology Laboratory to evaluate the potential for stratigraphic and paleoenvironmental use of Quaternary pollen, spores and opal phytoliths. Samples were selected at depth in an attempt to look at pollen and phytoliths deposited with the unit and out of the range of modern infiltration. The analyses were preformed by Glen Fredlund, Wakefield Dort, Jr., and William C. Johnson, and completed in January of 1985.

Table 1. Samples analyzed For pollen, spores and opal phytoliths

Sample No.	Unit	Age	Profile No.	Horizon	depth
1	Q1c	10 ka	FW-4	2Btk	9-60 cm
2	Q2a	40 ka	YW-1W	2Btqkjlb	25-42 cm
3	Q2b	150 ka	FW-3	2Btk	12-45 cm

Pollen

The pollen count in the soil horizons was low compared to similar aged lake sediments, but not insignificantly so. The major problems in interpretation are associated with redeposition of older pollen and post-depositional translocation from the surface. An additional problem is the predicted slow response of vegetation in arid environments to climatic change (Thompson, 1984). Evidence from the comparison of packrat midden microfossils and pollen data suggest that pollen is a much more continuous record of vegetation change, but does not offer the very local taxanomically precise discontinuous records of packrat middens (Thompson, 1984).

Taking these limitations of pollen data interpretation into consideration, the three samples do suggest some interesting preliminary results. Consistently Sample 2 biotically represents a wetter and (or) cooler environment than Samples 1 and 3.

Very little aboreal pollen (AP) including pine (P) which indicates a wetter or cooler climate, were present in the three samples (Fig. 1). The greatest amount is found in Sample 2, and where no other AP is found in Samples 1 and 3, a small amount is present in Sample 2.

Nonaboreal pollen (NAP) taxa dominates the three pollen assemblages (Fig. 1). All of the species identified are currently present in the study area. Therefore at best these data can be used to interpret wetter and (or) cooler climatic conditions, than indicators of aridity. Of major interest, is the fact that in most cases or subdivisions of the NAP, Samples 1 and 3 are similar and Sample 2 has more or less than the other like samples.

The final subdivision of pollen is either deteriorated or mechanically damaged. There is significantly a greater amount in Sample 1 (10 ka) which could be associated with the increased eolian activity due to decreased vegetative cover associated with the Holocene.

In summary, the 40 ka Sample 2 is probably correlative to the onset of cooler and (or) wetter glacial climatic conditions in the NTS area. Samples 1 and 3 represent warmer and (or) drier interglacials.

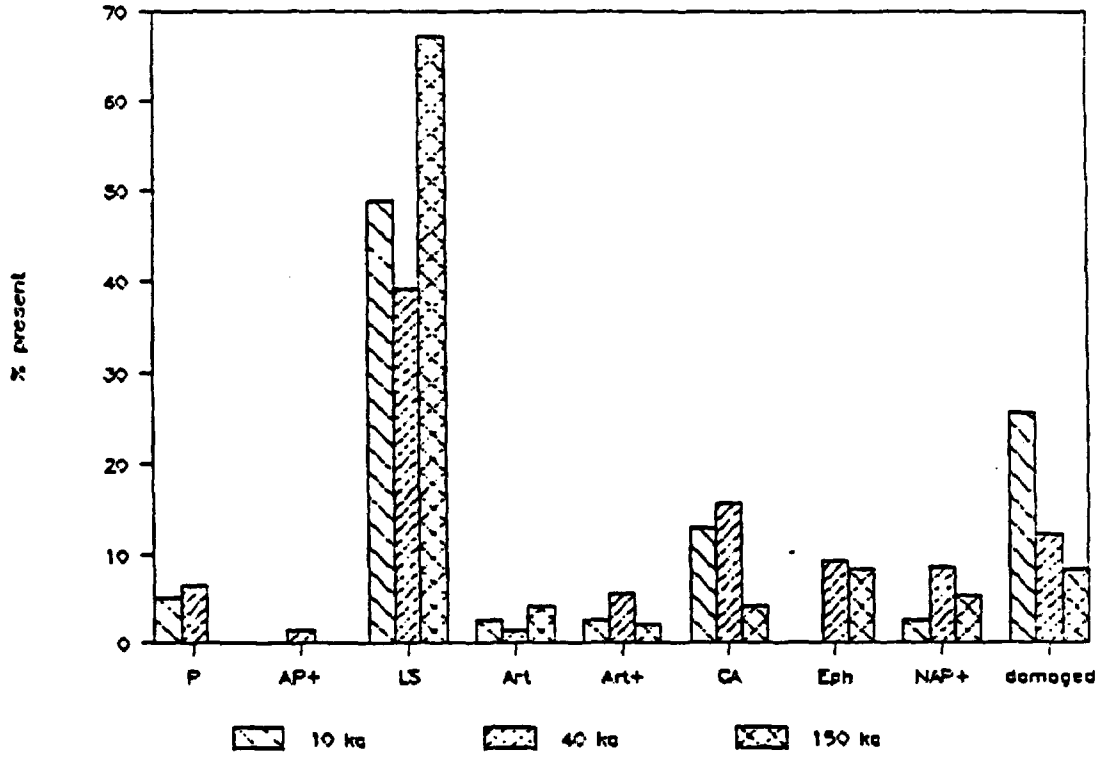

Figure 1. Relative frequency of pollen in three different aged soil horizons. Sample 1 is 10 ka, Sample 2 is 40 ka and Sample 3 is 150 ka. (P) Pinus sp. or Pine; (AP+) other aboreal pollen primarily Juniperus sp. and Quercus sp.; (LS) low spined Asteraceae or ragweed; (Art) Artemisia sp. or sage; (Art+) other Artemisia sp.; (CA) Chenopodiaceae-Amaranthaceae or Cheno-Am primarily Atriplex sp. or saltbush; (Eph) Ephedra sp. or Morman tea; (NAP+) other nonaboreal pollen including grasses; (damaged) deteriorated, mechanically damaged or indeterminate pollen.

Opal phytoliths, aquatic organisms and ash.

Other information on paleoclimate could come from the examination of opal phytoliths and aquatic organisms in the same samples used for pollen analyses. Heavy-liquid fractionation permits recovery of other light silicates along with opal phytoliths. Opal phytoliths are formed by the precipitation of silica in and among the living cells of plants. These silicate bodies maintain their morphological consonance after the death and decay of the plant. A simple morphological classification of these bodies is the grass family (Poaceae) and non-grass families (Twiss and others, 1969; Twiss, 1983) (Fig. 2). Aquatic organisms recovered include diatoms, sponge spicules and chrysomonad cysts. Volcanic ash shards were also retrieved.

There is no significant difference in the percent of grass and non-grass phytoliths present with age of the sample (Fig. 2). The major difference between samples occurs in the aquatic organisms and ash. Aquatic organisms do not necessarily represent a local wet environment because they are easily wind-transported great distances from dry playas. Ash can be derived both from the eolian component and *in situ* weathering of the parent material. The greater amount of aquatic organisms and ash in Sample 2 could be interpreted as (1) a drier climate increasing the possibility that playa sediments are susceptible to eolian transport, or (2) a wetter climate capable of tranlocating aquatic organisms and ash into the soil profile. I favor the latter of the two mechanisms.

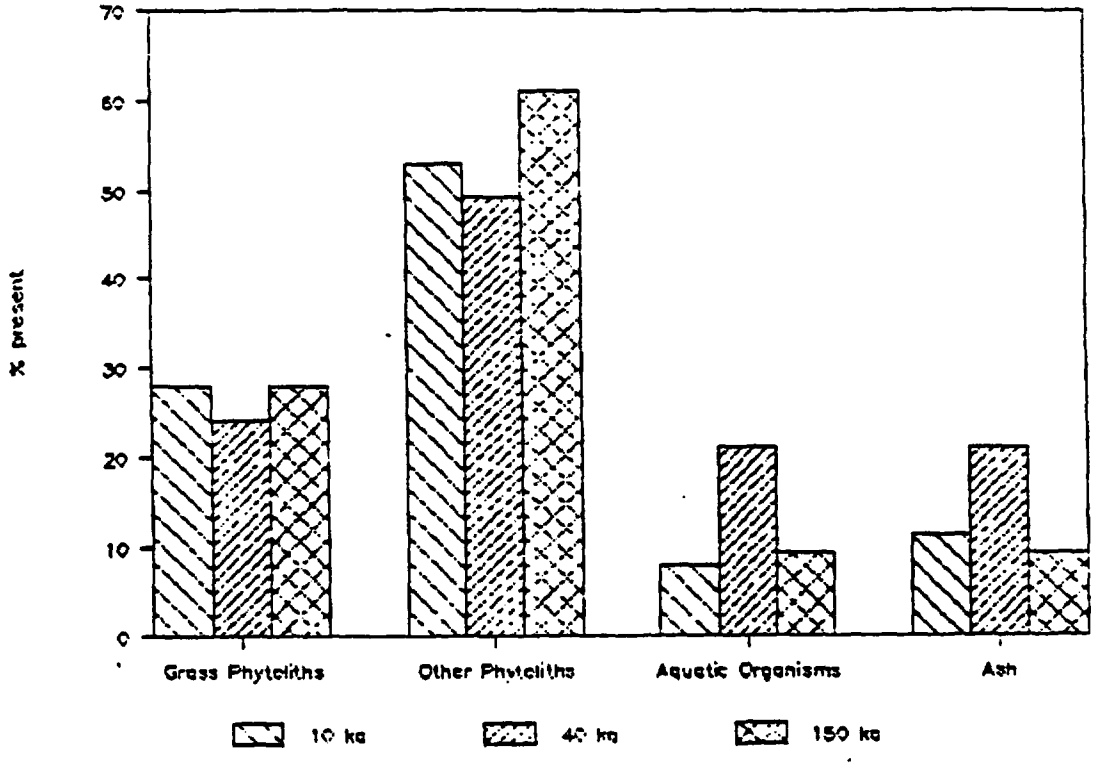

Figure 2. Relative frequency of opal phytoliths, aquatic organisms and volcanic ash in three different aged soil horizons. Sample 1 is 10 ka, Sample 2 is 40 ka and Sample 3 is 150 ka. **Grass Phytoliths** - total Poaceae family phytoliths; **Other Phytoliths** - irregular, aberrant and unique phytoliths; **Aquatic Organisms** including diatoms, sponge spicules and chrysomonad cysts; **Ash** - 'light' volcanic glass shards.

Grass Phytoliths

In order to look at the paleoclimate in more detail the grass phytoliths were subdivided to the tribe level (Fig. 3). Each tribe exhibits a unique adaptive propensity reflecting the regional climate. Festuceae grasses are associated with cooler sagebrush steppes like the Snake River Plateau today, Chlorideae are short-grasses and associated with warmer and more arid regions like the American Southwest today, and Paniceae is associated with the native tall-grasses of the true prairie vegetation in the Eastern Great Plains today. Phytoliths in the elongate catagory have no subfamily implications and occur in other monocots as well as grasses (Fig. 3).

The data indicate that grass phytoliths from Sample 2 are from a slightly wetter and (or) cooler climate than that of the other two samples. The presence of greater amounts of Festuceae suggests that during the formation of these phytoliths the climate was more temperate, like that in northern Nevada today. Samples 1 and 3 are more alike and indicate drier and (or) warmer conditions than that of during the deposition of Sample 2 (Fig. 3).

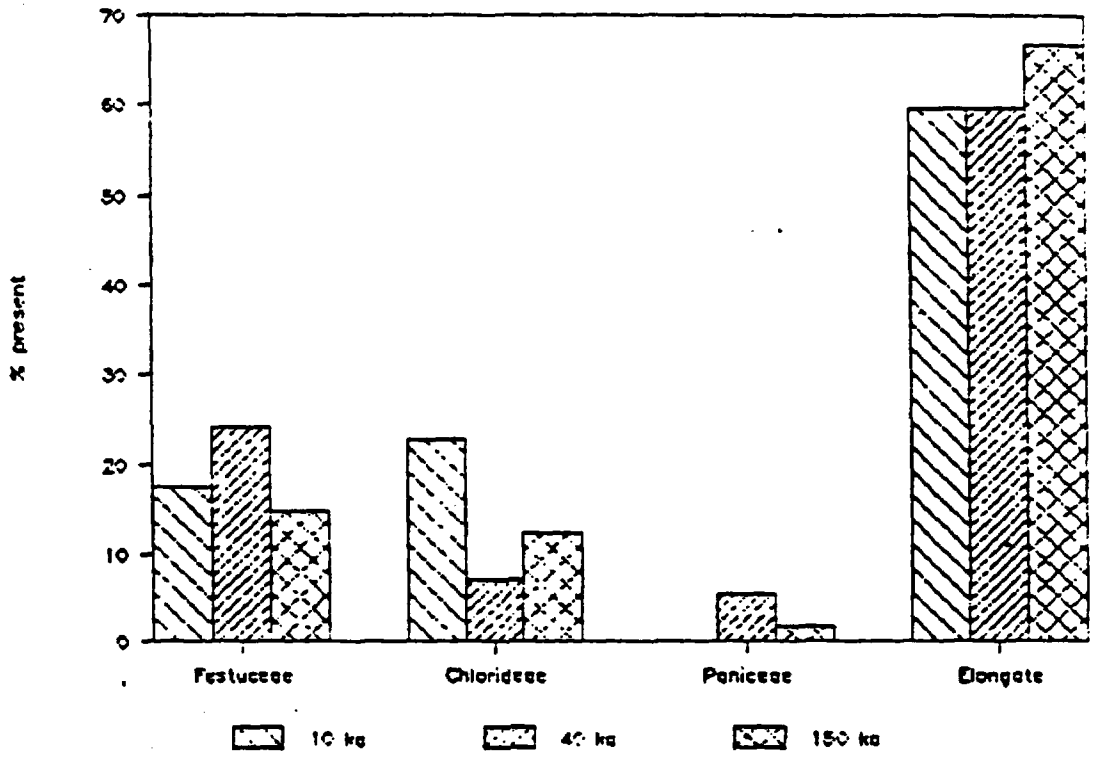

Figure 3. Relative frequency of grass (Poaceae) phytoliths in three different aged soil horizons. Sample 1 is 10 ka, Sample 2 is 40 ka and Sample 3 is 150 ka.

Appendix I: Soil parameters used to model calcic soil development. Parameters define a fresh alluvial sample with a sand texture and minimum vegetation. The maximum rooting depth is between 40 and 60 cm.

Twenty compartments each 10 cm thick. Particulate carbonate equals 0.1 $gm/cm^2/10^3yr$. Climatic data are in Table 3.

Compartment	Moisture Content			Parent		Soil	
	AWC 1/	Present	Permanent Wilting Point	Material $CaCO_3$	PCO_2 2/ 10^{-exp}	Temperature 3/ °C	ET Index 4/
1	0.049	0.02	0.018	0.27	3.50	16.5	0.25
2	0.049	0.02	0.018	0.27	3.20	17.9	0.20
3	0.049	0.02	0.018	0.27	3.00	18.8	0.15
4	0.049	0.02	0.018	0.27	2.70	19.0	0.10
5	0.049	0.02	0.018	0.27	2.50	19.3	0.10
6	0.049	0.02	0.018	0.27	2.50	19.3	0.10
7	0.049	0.02	0.018	0.27	2.55	19.3	0.05
8	0.049	0.02	0.018	0.27	2.60	19.3	0.05
9	0.049	0.02	0.018	0.27	2.63	19.3	0
10	0.049	0.02	0.018	0.27	2.66	19.3	0
11	0.049	0.02	0.018	0.27	2.68	19.3	0
12	0.049	0.02	0.018	0.27	2.70	19.3	0
13	0.049	0.02	0.018	0.27	2.75	19.3	0
14	0.049	0.02	0.018	0.27	2.80	19.3	0
15	0.049	0.02	0.018	0.27	2.90	19.3	0
16	0.049	0.02	0.018	0.27	3.00	19.3	0
17	0.049	0.02	0.018	0.27	3.10	19.3	0
18	0.049	0.02	0.018	0.27	3.20	19.3	0
19	0.049	0.02	0.018	0.27	3.30	19.3	0
20	0.049	0.02	0.018	0.27	3.40	19.3	0

1/ Calcultaed for sand from Salter and Williams (1965).

2/ Atmospheric PCO_2 at surface, decreasing until the maximum rooting depth between 40 and 60 cm, and again gradually increasing with depth.

3/ Actual soil temperature values from Rock Valley, NTS, averaged from 3/67 to 12/72 (Romney and others, 1973).

4/ Estimated percent of total evapotranspiration occuring in each compartment.

Appendix J. Horizon weights of carbonate, clay, silt, and opaline silica.

Soil no	linear age	thickness	% Gravel	Bulk Density	% Carbonate lab	IN	gm/cm2	prof sum	rate of acc per 1 yr	Unit Avg	AVERAGE PROFILE SUM USING 0.0 rate 0.01 Estimated	Pic rate 0.04 10ka profile	Pic rate 0.02 20ka sum	avg	Art prof sum avg
FWA-1	0	0	51	1.35	0.43	0.35	0.00								
FWA-2	0	0	0	1.31	0.51	0.35	0.00								
FWA-3	0	0	41 %	1.40	0.34	0.35	0.00								
FWA-4	0	0	60	1.32	0.31	0.35	0.00	0.00	0.00						
YWA-1	0	0	67	1.35	0.15	0.15	0.00			(alov)		Alluvium			(alov)
YWA-2	0	0	58	1.35	0.16	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
7.01	150	2	18	1.35	0.40	0.35	0.00								
7.02	150	17	17	1.33	0.19	0.35	-0.03			(01b)	(01b)	(01b)	(01b)		(01b)
7.03	150	82	63	1.30	0.72	0.35	0.15	0.12	0.01	0.01	0.00	0.01	0.00		0.12
4.01	10000	3	19	1.45	0.44	0.35	0.00								
4.02	10000	6	7	1.36	0.90	0.35	0.04								
4.03	10000	51	28	1.48	2.34	0.35	1.10								
4.04	10000	40	67	1.42	1.59	0.35	0.24	1.39	0.14						
17.01	10000	6	40	1.75	0.07	0.35	-0.01								
17.02	10000	18	40	1.50	0.27	0.35	-0.01								
17.03	10000	96	75	1.42	0.24	0.35	-0.03	-0.06	-0.01						
13.01	10000	9	53	1.42	0.14	0.15	0.00								
13.02	10000	12	33	1.42	0.12	0.15	-0.00								
13.03	10000	52	48	1.61	0.15	0.15	0.01								
13.04	10000	65	67	1.01	0.22	0.15	0.04	0.05	0.01						
15.01	10000	18	55	1.40	0.02	0.15	-0.01								
15.02	10000	28	62	1.40	0.09	0.15	-0.01								
15.03	10000	124	78	1.48	0.13	0.15	-0.00								
15.06	10000	62	74	1.42	0.21	0.15	0.02								
15.04	10000	62	85	1.40	0.20	0.15	0.01			(01c)	(01c)	(01c)	(01c)		(01c)
15.05	10000	50	63	1.60	0.24	0.15	0.03	0.03	0.00	0.04	0.08	0.[illegible]	0.10		0.[illegible]
3.01	150000	5	10	1.62	1.49	0.35	0.09								
3.02	150000	7	33	1.72	0.85	0.35	0.05								
3.03	150000	33	82	1.00	0.38	0.35	0.01								
3.04	150000	38	81	1.94	0.54	0.35	0.04								
3.05	150000	24	83	2.00	0.57	0.35	0.03								
3.06	150000	103	80	1.80	0.70	0.35	0.16	0.38	0.00						
21.01	150000	4	19	1.37	1.73	0.15	0.07								
21.02	150000	11	17	1.39	1.03	0.15	0.11								
21.03	150000	18	47	1.52	3.32	0.15	0.46								
21.04	150000	22	54	1.71	0.79	0.15	0.12								
21.05	150000	89	59	1.95	0.48	0.15	0.27								
21.06	150000	42	40	1.79	0.24	0.15	0.05								
21.07	150000	47	79	1.00	0.26	0.15	0.05	1.12	0.01						

Soil no	linear age	thickness	% Gravel	Bulk Density	% Carbonate lab	FH	gm/cm2	prof. sum	rate of acc per H yr	Unit Avg	AVERAGE FROM THE SUM USING 0.4b rate 0.01	0.4 10ka	0.2 20ka	Act prof sum avg
											Estimated profile sum avg			
11.01	150000	4	40	1.57	0.23	0.15	0.00							
11.02	150000	11	27	1.59	0.18	0.15	0.01							
11.03	150000	27	39	1.54	0.10	0.15	0.02							
11.04	150000	48	40	1.01	1.14	0.15	0.46							
11.05	150000	69	75	1.07	1.55	0.15	0.40							
11.06	150000	29	73	1.82	2.13	0.15	0.20	1.09	0.01					
12.01	150000	4	35	1.56	0.07	0.15	-0.00							
12.02	150000	10	25	1.40	0.20	0.15	0.01							
12.03	150000	33	26	1.64	0.19	0.15	0.03							
12.04	150000	58	56	1.05	1.61	0.15	0.70							
12.05	150000	15	10	1.69	1.06	0.15	0.45							
12.06	150000	24	66	1.77	1.69	0.15	0.32							
12.07	150000	56	80	1.75	0.73	0.15	0.17	1.52	0.01					
14.01	150000	8	32	1.36	0.20	0.15	0.00							
14.02	150000	20	24	1.26	0.19	0.15	0.01							
14.03	150000	26	35	1.39	0.92	0.15	0.10							
14.04	150000	53	42	1.65	1.90	0.15	1.44							
14.05	150000	14	19	1.62	0.91	0.15	0.14							
14.06	150000	31	30	1.03	1.53	0.15	0.56							
14.07	150000	69	63	1.67	0.87	0.15	0.32							
14.08	150000	9	80	1.75	0.74	0.15	0.02	2.67	0.02					
20.01	150000	8	28	1.51	0.06	0.15	-0.01							
20.02	150000	11	24	1.53	0.09	0.15	-0.01							
20.03	150000	23	39	1.56	0.10	0.15	-0.01							
20.04	150000	22	84	1.65	0.19	0.15	0.00							
20.05	150000	12	84	1.96	3.31	0.15	0.12							
20.06	150000	20	68	1.72	1.72	0.15	0.25							
20.07	150000	28	69	1.72	4.77	0.15	0.34			(02b)	(02b)	(02b)	(02b)	(0.1
20.08	150000	38	89	1.72	1.29	0.15	0.08	0.78	0.01	0.01	1.26	5.31	2.65	1.1-
5.01	300000	5	25	1.51	0.29	0.35	-0.00							
5.02	300000	15	9	1.44	0.13	0.35	-0.04							
5.03	300000	25	14	1.64	1.94	0.35	0.58							
5.04	300000	11	18	1.66	0.39	0.35	0.02							
5.05	300000	50	60	1.78	1.10	0.35	0.33							
5.06	300000	58	71	1.86	4.54	0.35	1.31							
5.07	300000	99	72	1.80	0.19	0.35	-0.04	2.16	0.01					
10.01	300000	11	13	1.72	2.34	0.35	0.34							
10.02	300000	22	24	1.69	1.61	0.35	0.38							
10.03	300000	7	30	1.81	0.19	0.35	-0.01							
10.04	300000	26	53	1.79	0.22	0.35	-0.01							
10.05	300000	54	72	1.80	0.17	0.35	-0.03							
10.06	300000	40	76	1.02	14.42	0.35	2.47	3.16	0.01					

Soil no	linear age	thickness	% Gravel	Soil Density	% Carbonate lab	FM	gm/cm2	prof sum	rate of acc per M yr	Unit Avg	AVERAGE PROFILE SUM USING DCb rate 0.01	DIc rate 0.04 10ka	DIc rate 0.02 20ka	Act prof sum avg
											Estimated profile sum avg			
8.01	300000	9	13	1.65	0.00	0.15	-0.02							
8.02	300000	12	13	1.52	0.07	0.15	-0.01							
8.03	300000	14	27	1.64	0.11	0.15	-0.00							
8.04	300000	33	18	1.56	19.41	0.15	8.16							
8.05	300000	32	52	1.70	7.53	0.15	1.92							
8.06	300000	110	62	1.75	4.08	0.15	2.86	15.91	0.04					
16.01	300000	13	15	1.56	0.00	0.15	-0.02							
16.02	300000	17	10	1.49	0.05	0.15	-0.02							
16.03	300000	13	25	1.48	0.07	0.15	-0.01							
16.04	300000	15	44	1.76	2.10	0.15	0.31							
16.05	300000	42	57	1.41	20.93	0.15	6.10							
16.06	300000	50	56	1.70	0.17	0.15	0.03							
16.07	300000	50	85	1.70	1.01	0.15	0.11							
16.08	300000	57	71	1.04	0.07	0.15	-0.01	6.49	0.02					
1.01	300000	10	27	1.47	0.06	0.15	-0.01							
1.02	300000	15	15	1.52	0.14	0.15	0.00							
1.03	300000	17	47	1.40	0.22	0.15	0.01							
1.04	300000	14	30	1.62	0.24	0.15	0.02							
1.08	300000	14	50	1.64	6.79	0.15	0.77							
1.09	300000	45	61	1.48	20.05	0.15	5.11							
1.10	300000	52	66	1.71	8.58	0.15	2.57							
1.11	300000	28	70	1.75	2.51	0.15	0.35			(0%)	(0%)	(0%)	(0%)	(0%)
1.12	300000	95	67	1.75	0.92	0.15	0.45	9.27	0.03	0.02	2.52	10.61	5.21	6.80
19.01	1500000	9	5	1.61	3.30	0.15	0.44							
19.03	1500000	4	13	1.75	2.96	0.15	0.17							
19.04	1500000	4	3	1.34	1.32	0.15	0.05							
19.05	1500000	12	11	1.43	0.27	0.15	0.02							
19.06	1500000	18	25	1.59	8.99	0.15	1.90							
19.07	1500000	25	34	1.59	8.36	0.15	2.15							
19.08	1500000	78	49	1.72	16.33	0.15	13.00	17.72	0.01					
6.01	1500000	6	24	1.46	1.97	0.15	0.12							
6.02	1500000	4	14	1.31	0.95	0.15	0.04							
6.03	1500000	42	48	1.50	30.32	0.15	9.09							
6.04	1500000	49	59	1.60	19.58	0.15	6.26							
6.05	1500000	52	67	1.84	15.27	0.15	4.04							
6.06	1500000	77	63	1.73	6.18	0.15	2.96							
6.07	1500000	20	41	1.77	2.01	0.15	0.39	24.49	0.02					
2.01	1500000	3	6	1.53	1.72	0.15	0.07							
2.02	1500000	7	9	1.52	0.51	0.15	0.04							
2.03	1500000	9	12	1.70	0.21	0.15	0.01							
2.04	1500000	15	23	1.00	0.29	0.15	0.04							
2.05	1500000	26	23	1.79	0.11	0.15	-0.00							
2.07	1500000	23	29	1.76	5.64	0.15	1.30							
2.08	1500000	62	46	1.63	13.90	0.15	6.69							
2.09	1500000	83	76	1.73	7.96	0.15	2.66	11.00	0.01					

Soil no	linear age	thickness	% Gravel	Bull Density	% Carbonate lab	FM	gm/cm²	prof sum	rate of acc. per 10 yr	Unit Avg	AVERAGE PROFILE SIMULATIONS, 0.01 Estimated profile	0.04 10ka sum	0.02 20ka avg	Act prof sum	Act prof avg
22.01	1500000	10	5	1.58	5.26	0.15	0.77								
22.02	1500000	11	20	1.37	0.80	0.15	0.09								
22.03	1500000	41	42	1.66	20.10	0.15	7.96								
22.04	1500000	30	54	1.42	22.36	0.15	4.73			(01a)	(01a)	(01a)	(01a)	(01a)	
22.05	1500000	92	52	1.75	6.18	0.15	4.68	17.62	0.01	0.01	17.60	5.06	16.57	17.16	

Soil no	CLAY lab	CLAY FH	gm/cm²	prof sum	rate of arc per 10 yr	Unit Avg	AVERAGE PROFILE SUM USING Ocb rate 0.07	Olc rate 0.24 100 a	Olc rate 0.17 200 a	Act prof sum avg
							Estimated profile sum avg			
FWA-1	1.11	1.00	0.00							
FWA-2	2.00	1.00	0.00							
FWA-3	0.60	1.00	0.00							
FWA-4	1.61	1.00	0.00	0.00	0.00					
YWA-1	0.42	1.00	0.00			(alluv)		Alluvium		(alluv)
YWA-2	0.77	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.01	1.71	1.00	0.01							
7.02	2.64	1.00	0.71			(Olb)	(Olb)	(Olb)	(Olb)	(Olb)
7.03	1.34	1.00	0.14	0.46	3.09	3.09	0.01	0.05	0.03	0.46
4.01	4.08	5.00	-0.02							
4.02	7.60	5.00	0.20							
4.03	11.61	5.00	3.87							
4.04	4.08	1.00	0.57	4.64	0.46					
17.01	4.87	5.00	-0.01							
17.02	4.50	5.00	0.00							
17.03	2.27	1.00	0.46	0.45	0.05					
13.01	4.47	5.00	-0.02							
13.02	5.96	5.00	0.14							
13.03	4.26	1.00	1.51							
13.04	1.94	1.00	0.46	2.09	0.21					
15.01	5.58	5.00	0.09							
15.02	6.25	5.00	0.31							
15.03	10.38	5.00	2.37							
15.06	7.58	5.00	0.65							
15.04	12.88	5.00	1.07			(Olc)	(Olc)	(Olc)	(Olc)	(Olc)
15.05	7.33	1.00	1.91	6.29	0.63	0.74	0.74	3.37	1.68	3.37
3.01	17.06	20.00	0.03							
3.02	25.60	20.00	0.80							
3.03	8.87	5.00	0.53							
3.04	4.72	1.00	0.57							
3.05	2.85	1.00	0.10							
3.06	2.39	1.00	0.62	2.73	0.02					
21.01	8.85	5.00	0.17							
21.02	11.31	5.00	0.82							
21.03	9.13	5.00	0.60							
21.04	10.95	1.00	3.13							
21.05	11.76	1.00	7.09							
21.06	4.24	1.00	1.[illegible]7							
21.07	2.16	1.00	0.27	14.[illegible]	0.10					

Soil no	CLAY lab	CLAY FM	um/cm2	prof sum	rate of acc per 10 yr	thst avg	AVERAGE PROFILE SUM USING D2b rate 0.07	D1c rate 0.34 10ka	D1c rate 0.17 20ka	Act prof sum avg
							Estimated profile sum avg			
11.01	3.83	5.00	-0.02							
11.02	9.65	5.00	0.69							
11.03	14.04	1.00	3.74							
11.04	14.28	1.00	6.08							
11.05	11.53	1.00	3.03							
11.06	22.15	1.00	2.09	15.22	0.10					
12.01	7.47	5.00	0.13							
12.02	8.50	5.00	0.39							
12.03	13.23	5.00	3.64							
12.04	7.32	1.00	3.09							
12.05	4.78	1.00	1.04							
12.06	4.18	1.00	0.49							
12.07	4.68	1.00	0.77	9.54	0.06					
14.01	5.48	5.00	0.04							
14.02	9.24	5.00	0.75							
14.03	9.55	1.00	2.00							
14.04	7.39	1.00	3.32							
14.05	5.50	1.00	0.86							
14.06	9.26	1.00	3.36							
14.07	8.11	1.00	3.08							
14.08	7.52	1.00	0.21	13.60	0.09					
20.01	4.66	5.00	0.01							
20.02	12.70	5.00	1.06							
20.03	20.09	5.00	3.45							
20.04	16.64	1.00	0.94							
20.05	16.49	1.00	0.59							
20.06	15.06	1.00	3.00							
20.07	21.33	1.00	1.50			(D2b)	(D2b)	(D2b)	(D2b)	(D2b)
20.08	11.55	1.00	0.76	11.31	0.08	0.07	11.12	50.52	25.26	11.12
5.01	3.67	5.00	-0.05							
5.02	4.11	5.00	-0.11							
5.03	10.05	5.00	2.09							
5.04	9.17	1.00	1.26							
5.05	10.97	1.00	3.62							
5.06	5.94	1.00	0.99							
5.07	1.25	1.00	0.26	8.05	0.03					
18.01	15.63	20.00	-0.01							
18.02	8.53	5.00	1.29							
18.03	11.52	5.00	0.69							
18.04	7.93	1.00	1.57							
18.05	6.16	1.00	1.47							
18.06	4.33	1.00	0.61	5.63	0.02					

Soil no	CLAY Lab	CLAY FM	gm/cm2	prof sum	rate of acc per 10 yr	thist Avg	AVERAGE PROFILE SUM USING Dth rate 0.07	Dic rate 0.34 10ka	Dic rate 0.17 20ka	Act prof sum avg
							Estimated profile sum avg			
8.01	18.46	20.00	0.37							
8.02	45.67	20.00	4.43							
8.03	9.13	1.00	1.39							
8.04	6.40	1.00	0.34							
8.05	4.72	1.00	1.02							
8.06	4.09	1.00	0.40	11.05	0.04					
16.01	14.73	5.00	1.31							
16.02	17.28	5.00	2.09							
16.03	15.50	5.00	1.58							
16.04	47.45	1.00	6.92							
16.05	37.18	1.00	8.37							
16.06	16.17	1.00	5.80							
16.07	19.65	1.00	2.43							
16.08	5.53	1.00	1.47	30.77	0.10					
1.01	15.07	5.00	1.13							
1.02	18.97	5.00	2.84							
1.03	45.11	1.00	5.56							
1.04	44.22	1.00	6.91							
1.08	33.07	1.00	3.73							
1.09	30.99	1.00	5.16							
1.10	13.45	1.00	2.04							
1.11	13.41	1.00	1.78			(0%)	(0%)	(0%)	(0%)	(0.0)
1.12	10.66	1.00	5.50	36.45	0.12	0.06	20.24	101.04	50.52	18.54
19.01	17.45	20.00	0.10							
19.02	17.01	5.00	0.80							
19.04	53.08	5.00	2.10							
19.05	42.71	5.00	5.78							
19.06	32.67	1.00	6.81							
19.07	34.07	1.00	8.67							
19.08	27.58	1.00	21.80	46.25	0.03					
6.01	14.82	20.00	-0.25							
6.02	21.86	20.00	0.06							
6.03	11.95	1.00	3.62							
6.04	3.97	1.00	1.00							
6.05	3.15	1.00	0.77							
6.06	2.43	1.00	0.80							
6.07	2.28	1.00	0.32	6.33	0.00					
2.01	16.32	20.00	-0.06							
2.02	13.70	20.00	-0.29							
2.03	17.98	20.00	-0.29							
2.04	18.76	1.00	3.72							
2.05	20.00	1.00	0.26							
2.07	50.10	1.00	17.41							
2.08	16.61	1.00	0.37							
2.09	1[illegible].02	1.00	4.15	37.48	0.02					

Soil no	CLAY Lab	CLAY FM	gm/cm2	prof sum	rate of acc per 10 yr	Unit Avg	AVERAGE TOPSOIL SAMPLING Dib rate 0.07	Dic rate 0.24 10a	Dic rate 0.17 20a	Act prof sum avg
							Estimated profile sum avg			
22.01	26.58	20.00	1.41							
22.02	33.82	5.00	3.50							
22.03	29.93	1.00	8.81			(01a)	(01a)	(01a)	(01a)	(01a)
22.04	15.07	1.00	3.75			0.02	111.22	565.22	292.61	20.67
22.05	11.77	1.00	3.17	24.65	0.02					

Soil no	SILI Lab	FM	gm/cm2	prof sum	rate of acr per 11 y	Unit Avg	AVERAGE PROFILE SUM USING U2h rate 0.13	Olc rate 0.41 10ka	Olc rate 0.20 20ka	Act prof sum avg
							Estimated profile sum avg			
FWA-1	4.52	1.00	0.00							
FWA-2	13.22	1.00	0.00							
FWA-3	0.85	1.00	0.00							
FWA-4	2.76	1.00	0.00	0.00	0.00					
YWA-1	0.42	1.00	0.00			(aluv)		Alluvium		(aluv)
YWA-2	0.54	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.01	4.92	1.00	0.07							
7.02	6.53	1.00	1.07			(Olb)	(Olb)	(Olb)	(Olb)	(Olb)
7.03	3.24	1.00	0.91	2.04	13.63	13.63	0.02	0.06	0.03	2.04
4.01	9.37	15.00	-0.16							
4.02	10.64	15.00	-0.32							
4.03	16.97	15.00	1.83							
4.04	13.88	1.00	2.45	3.80	0.38					
17.01	25.06	15.00	0.49							
17.02	19.32	15.00	0.95							
17.03	5.00	1.00	1.40	2.84	0.28					
13.01	13.78	15.00	-0.03							
13.02	13.46	15.00	-0.09							
13.03	8.18	1.00	3.24							
13.04	4.91	1.00	1.54	4.71	0.47					
15.01	16.06	15.00	0.18							
15.02	13.88	15.00	-0.09							
15.03	18.64	15.00	2.02							
15.06	11.96	15.00	-0.52							
15.04	25.77	15.00	1.50			(Olc)	(Olc)	(Olc)	(Olc)	(Olc)
15.05	7.33	1.00	1.91	5.00	0.50	0.41	1.34	4.09	2.04	4.09
3.01	40.84	40.00	0.54							
3.02	39.29	40.00	0.64							
3.03	14.16	15.00	0.30							
3.04	9.58	1.00	1.35							
3.05	2.74	1.00	0.17							
3.06	2.27	1.00	0.58	3.49	0.02					
21.01	38.92	15.00	1.07							
21.02	34.11	15.00	2.48							
21.03	25.71	15.00	1.50							
21.04	16.82	1.00	2.76							
21.05	10.92	1.00	7.29							
21.06	11.40	1.00	4.21							
21.07	3.16	1.00	0.43	19.75	0.13					

Soil no	SILT lab	FM	gm/cm2	prof sum	rate of acc per 11 y	Unit Avg	AVERAGE TABLE SUM USING Dlc rate 0.13	Dlc rate 0.41 10la	Dlc rate 0.20 20la	Act prof sum avg
							Estimated profile sum avg			
11.01	16.02	15.00	0.12							
11.02	18.23	15.00	0.70							
11.03	19.25	1.00	4.67							
11.04	22.47	1.00	9.77							
11.05	17.71	1.00	3.64							
11.06	11.37	1.00	1.03	19.92	0.13					
12.01	21.85	15.00	0.36							
12.02	22.16	15.00	0.81							
12.03	23.12	15.00	4.30							
12.04	18.30	1.00	8.27							
12.05	14.16	1.00	3.43							
12.06	7.00	1.00	0.91							
12.07	9.01	1.00	1.79	19.03	0.13					
14.01	29.89	15.00	1.10							
14.02	26.99	15.00	2.10							
14.03	29.35	1.00	6.62							
14.04	26.61	1.00	13.01							
14.05	19.16	1.00	3.36							
14.06	27.64	1.00	10.59							
14.07	18.07	1.00	7.28							
14.08	15.56	1.00	0.46	44.52	0.30					
20.01	23.13	15.00	0.72							
20.02	29.22	15.00	2.04							
20.03	31.95	15.00	4.15							
20.04	14.36	1.00	0.80							
20.05	16.72	1.00	0.60							
20.06	13.33	1.00	2.63							
20.07	22.04	1.00	1.36			(0.b)	(0.2b)	(0.2b)	(0.2b)	(0.b)
20.08	13.29	1.00	0.89	13.38	0.09	0.13	20.15	61.31	20.66	20.15
5.01	7.80	15.00	-0.32							
5.02	8.82	15.00	-1.03							
5.03	16.98	15.00	1.63							
5.04	22.67	1.00	3.37							
5.05	19.10	1.00	6.55							
5.06	6.27	1.00	1.71							
5.07	0.67	1.00	-0.04	11.78	0.04					
10.01	45.10	40.00	2.25							
10.02	27.34	15.00	4.37							
10.03	25.58	15.00	1.20							
10.04	16.16	1.00	3.53							
10.05	7.07	1.00	1.94							
10.06	5.97	1.00	0.92	14.29	0.05					

Soil no	SHI lab	SHI IH	qm/cm²	prof sum	rate of acc per H y	thst avg	AVIGOM INCHIT SUMMISING 0.0c rate estimated	0.1c rate 0.41 inla profile	0.1c rate 0.2c inla sum avg	0.1c rate	net prod sum avg
8.01	36.21	40.00	0.46								
8.02	28.08	40.00	-1.06								
8.03	18.81	1.00	3.01								
8.04	10.36	1.00	4.02								
8.05	7.93	1.00	1.05								
8.06	7.49	1.00	4.06	13.13	0.04						
16.01	16.39	15.00	0.05								
16.02	16.57	15.00	0.67								
16.03	21.73	15.00	1.16								
16.04	21.54	1.00	3.08								
16.05	24.88	1.00	6.42								
16.06	14.68	1.00	5.24								
16.07	24.11	1.00	3.00								
16.08	12.21	1.00	3.54	23.16	0.08						
1.01	23.26	15.00	1.03								
1.02	27.90	15.00	2.85								
1.03	21.23	1.00	2.55								
1.04	19.73	1.00	3.01								
1.08	20.77	1.00	2.30								
1.09	17.40	1.00	4.14								
1.10	12.58	1.00	3.58								
1.11	16.43	1.00	2.27			(0)c)	(0)c)	(0)c)	(0)c)	(0)c)	
1.12	8.98	1.00	4.57	26.40	0.09	0.06	40.30	122.63	61.31	17.75	
19.01	41.07	40.00	1.05								
19.02	20.38	15.00	0.54								
19.04	17.46	15.00	0.05								
19.05	13.99	15.00	-0.03								
19.06	20.77	1.00	4.26								
19.07	19.79	1.00	4.94								
19.08	18.16	1.00	13.93	24.75	0.02						
6.01	34.65	40.00	-0.16								
6.02	34.66	40.00	-0.30								
6.03	16.32	1.00	5.05								
6.04	8.22	1.00	2.37								
6.05	6.15	1.00	1.73								
6.06	5.54	1.00	2.32								
6.07	4.57	1.00	0.79	11.81	0.01						
2.01	40.24	40.00	0.22								
2.02	39.63	40.00	0.41								
2.03	39.83	40.00	-0.19								
2.04	32.32	1.00	6.53								
2.05	28.79	1.00	12.11								
2.07	27.33	1.00	7.19								
2.08	17.18	1.00	8.57								
2.09	20.94	1.00	6.84	41.60	0.03						

Soil no	SILT Lab	SILT FM	gm/cm2	prof sum	rate of Acc per H y	Unit Avg	AVERAGE PROFILE SUM USING D2h rate 0.13 Estimated profile sum avg	D1c rate 0.41 10la	D1c rate 0.20 20la	Act prof sum avg
22.01	30.61	40.00	-0.55							
22.02	21.30	15.00	0.79							
22.03	20.76	1.00	7.94							
22.04	17.05	1.00	3.14			(D1a)	(D1a)	(D1a)	(D1a)	(D1a)
22.05	15.00	1.00	10.97	22.30	0.01	0.02	201.49	613.13	306.56	35.14

Soil no	est % SiO_2 lab	IM	gm/cm2	prof sum	rate of acr per 1 yr	Unit avg	AVERAGE FIGURE SUM USING Ulb rate 0.08 estimated profile sum avg	Ulc rate 0.32 10la	Ulc rate 0.16 20la	Out prof sum avg
FWA-1	1.00	0.00	0.00							
FWA-2	3.11	0.00	0.00							
FWA-3	1.27	0.00	0.00							
FWA-4	2.09	0.00	0.00	0.00	0.00					
VWA-1	0.49	0.00	0.00			(alov)		Alluvium		(alov)
VWA-2	1.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7.01	2.02	0.00	0.07							
7.02	2.08	0.00	0.50			(D1b)	(D1b)	(D1b)	(D1b)	(D1b)
7.03	2.14	0.00	0.07	1.40	9.36	9.36	0.01	0.05	0.02	1.40
4.01	2.70	0.00	0.09							
4.02	2.95	0.00	0.22							
4.03	6.26	0.00	3.45							
4.04	4.60	0.00	0.07	4.62	0.46					
17.01	4.37	0.00	0.21							
17.02	2.78	0.00	0.45							
17.03	1.13	0.00	0.39	1.06	0.11					
13.01	6.16	0.00	0.37							
13.02	3.88	0.00	0.44							
13.03	2.60	0.00	1.18							
13.04	2.18	0.00	0.03	2.03	0.20					
15.01	4.48	0.00	0.51							
15.02	2.76	0.00	0.41							
15.03	3.49	0.00	1.42							
15.04	3.08	0.00	0.70							
15.04	4.56	0.00	0.61			(D1c)	(D1c)	(D1c)	(D1c)	(D1c)
15.05	1.85	0.00	0.54	4.19	0.42	0.32	0.04	3.17	1.59	3.17
3.01	6.61	0.00	0.48							
3.02	6.27	0.00	0.51							
3.03	3.90	0.00	0.41							
3.04	2.75	0.00	0.39							
3.05	1.37	0.00	0.11							
3.06	2.59	0.00	0.98	2.08	0.02					
21.01	6.08	0.00	0.27							
21.02	5.74	0.00	0.73							
21.03	7.69	0.00	1.11							
21.04	20.62	0.00	3.56							
21.05	20.19	0.00	14.39							
21.06	5.61	0.00	2.29							
21.07	1.65	0.00	0.47	22.73	0.15					

Soil no	est % SiO2 lab	est % SiO2 FM	gm/cm2	prof sum	rate of acc per 11 yr	Unit Avg	AVERAGE PROFILE SUM USING O2b rate 0.08	O1c rate 0.32 Tola	O1r rate 0.16 Tola	Act prof sum avg
							Estimated profile sum avg			
11.01	5.05	0.00	0.19							
11.02	5.14	0.00	0.67							
11.03	6.46	0.00	1.64							
11.04	18.70	0.00	8.40							
11.05	21.29	0.00	6.00							
11.06	29.20	0.00	2.86	19.76	0.13					
12.01	6.43	0.00	0.26							
12.02	4.56	0.00	0.48							
12.03	3.41	0.00	1.36							
12.04	3.69	0.00	1.73							
12.05	3.76	0.00	0.86							
12.06	7.80	0.00	1.12							
12.07	3.27	0.00	0.65	6.45	0.04					
14.01	3.29	0.00	0.24							
14.02	4.32	0.00	0.83							
14.03	5.35	0.00	1.13							
14.04	6.51	0.00	3.29							
14.05	3.57	0.00	0.47							
14.06	3.25	0.00	1.30							
14.07	1.65	0.00	0.78							
14.08	1.82	0.00	0.06	8.16	0.05					
20.01	5.57	0.00	0.41							
20.02	7.02	0.00	1.00							
20.03	17.19	0.00	3.76							
20.04	19.12	0.00	1.13							
20.05	24.86	0.00	0.93							
20.06	22.91	0.00	4.81							
20.07	27.45	0.00	2.00			(O2b)	(O1b)	(O2b)	(O1b)	(O1b)
20.08	22.42	0.00	1.59	15.63	0.10	0.08	12.60	47.59	23.79	12.60
5.01	1.31	0.00	0.07							
5.02	1.67	0.00	0.33							
5.03	3.74	0.00	1.32							
5.04	6.52	0.00	0.98							
5.05	7.71	0.00	2.75							
5.06	7.91	0.00	2.44							
5.07	0.55	0.00	0.18	8.17	0.05					
18.01	7.14	0.00	1.18							
18.02	7.46	0.00	1.13							
18.03	4.51	0.00	0.49							
18.04	2.[illegible]4	0.00	0.73							
18.05	1.17	0.00	0.62							
18.06	19.31	0.00	2.17	7.43	0.05					

Soil no	est % SiO2 lab	IM	gm/cm2	prof sum per	rate of acc II yr	Unit Avg	AVERAGE PROFILE SUM USING 0.2b rate 0.08	Dic rate 0.32 10la	Dic rate 0.16 20la	Act prof sum avg
							Estimated profile sum avg			
8.01	3.38	0.00	0.44							
8.02	8.93	0.00	1.42							
8.03	7.39	0.00	1.24							
8.04	22.70	0.00	9.60							
8.05	1[illegible].72	0.00	3.45							
8.06	9.05	0.00	6.54	22.69	0.08					
16.01	8.28	0.00	1.16							
16.02	5.38	0.00	1.02							
16.03	5.60	0.00	0.82							
16.04	37.47	0.00	5.55							
16.05	45.65	0.00	12.22							
16.06	32.74	0.00	12.76							
16.07	43.22	0.00	5.57							
16.08	6.37	0.00	1.92	40.81	0.14					
1.01	9.47	0.00	1.02							
1.02	8.84	0.00	1.72							
1.03	23.68	0.00	2.98							
1.04	26.10	0.00	4.19							
1.08	33.18	0.00	3.83							
1.09	36.25	0.00	9.31							
1.10	28.20	0.00	8.56							
1.11	25.97	0.00	3.77			(02c)	(02c)	(02c)	(02c)	(02c)
1.12	20.10	0.00	11.18	46.58	0.16	0.08	25.21	95.18	47.59	25.13
19.01	7.86	0.00	1.09							
19.03	5.92	0.00	0.36							
19.04	26.80	0.00	1.28							
19.05	29.92	0.00	4.55							
19.06	31.15	0.00	6.67							
19.07	31.49	0.00	8.22							
19.08	36.59	0.00	29.34	51.51	0.03					
6.01	7.65	0.00	0.51							
6.02	8.57	0.00	0.39							
6.03	25.61	0.00	8.39							
6.04	19.01	0.00	6.11							
6.05	16.39	0.00	5.23							
6.06	8.68	0.00	4.23							
6.07	4.64	0.00	0.96	25.83	0.02					
2.01	9.09	0.00	0.39							
2.02	9.19	0.00	0.09							
2.03	35.06	0.00	2.59							
2.04	25.12	0.00	5.19							
2.05	36.16	0.00	11.34							
2.07	42.20	0.00	11.52							
2.08	39.95	0.00	20.93							
2.09	37.01	0.00	12.03	65.70	0.04					

Soil no	est % SiO2 lab	est % SiO2 IM	gm/cm2	prof sum	rate of acc per 10 yr	Unit Avg	AVERAGE HIGHFILL SUM USING Ub rate 0.00	Dic rate 0.32 10/a	Dic rate 0.16 20/a	Dic rate Estimated profile sum avg	Act prof sum avg
22.01	18.50	0.00	2.76								
22.02	19.78	0.00	2.39								
22.03	25.01	0.00	13.95			(01a)	(01a)	(01a)	(01a)	(01a)	(01a)
22.04	25.73	0.00	6.96			0.03	126.03	475.90	237.95		47.17
22.05	25.47	0.00	19.63	45.65	0.03						

p11 CO_2 in [illegible]

17

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CARBON DIOXIDE AND THE SOIL ATMOSPHERE

The importance of CO_2 for karst processes

by Franz-Dieter Miotke, Geographical Institute, Technical University of Hannover, W.-Germany

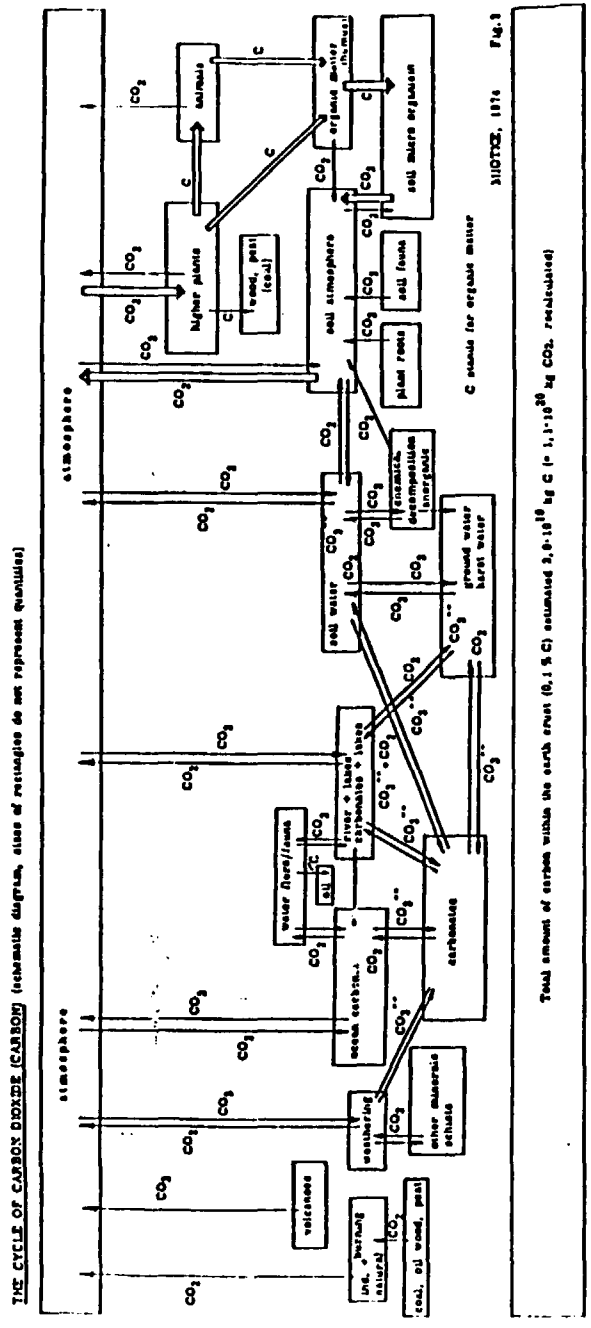
INTRODUCTION

Carbon dioxide plays a major role within the solution of carbonates. We have to analyse where the CO_2 is evolved and which processes are involved in the CO_2-production and in the CO_2-exchange within the soil atmosphere.

The normal CO_2-content of the atmosphere averages 0,03 vol.% (depending on the weather situation 0,02 to 0,04 vol.%CO_2) or 0,3 ml CO_2 within 1000 ml air. This percentage is surprisingly constant all over the earth. The partial pressure of CO_2 decreases only slightly with altitude, 0,000 29 atm (0,029 vol.%) at 21 km altitude versus 0,00033 atm (0,033 vol.%) at sea level (Twierskoj, 1962 cited in Ek et al., 1969).

The CO_2-percentage is slightly higher, close to the surface of the soil; this is also valid for the wood atmospheres. The weight of 1000 ml CO_2 is 1,9768 at 0°C and 760 Torr, consequently the specific gravity of CO_2 is 1,529 times higher than that of air under the same conditions. The normal CO_2-percentage within the atmosphere around 0,03 vol.% results in 0,5 to 0,6 mg CO_2 within 1000 ml air (mg/l).

The carbon mass fixed within the whole plant mass of the earth is estimated to be $300 \cdot 10^{12}$kg C or $1105 \cdot 10^{12}$kg CO_2. The carbon existing within the soil correlates $1100 \cdot 10^{12}$kg CO_2. The atmosphere of the earth contains $2100 \cdot 10^{12}$kg CO_2. Every year the growing plants assimilate between 50 and $80 \cdot 10^{12}$kg CO_2. If there were not a constant recharge of CO_2 into the atmosphere, caused by decomposition of organic matter, which equals the loss, the CO_2-reserve soon would be



Applying the biogenetic carbon cycle to the soil, with regard to the CO_2-production we find different sources which evolve carbon dioxide into the soil atmosphere. These are the CO_2-respiration by micro organism (fauna and flora), by small fauna (insects etc.), by small mammals and by the roots of higher plants. Algaes living within the soil environment assimilate CO_2 out of the soil atmosphere.

Besides these organic sources great quantities of CO_2 are brought into the soil by rain and snow waters.

Acids washed out of horizons, having a very low pH, can cause a disintegration of carbonates in lower horizons, evolving CO_2. This is known to happen when acid horizons are ploughed into deeper underground containing limestones (Zöti, 1960, in Beck, 1968).

Besides the loss of CO_2 out of the soil atmosphere into the atmosphere by different processes, greater amounts of soil CO_2 are washed out by draining water and are used to dissolute carbonates within the soil and the deeper underground. The hydrocarbonates ($Ca(HCO_3)_2$) as well as the CO_2 dissolved in water, finally reach the ocean, which explains the high concentration of CO_2 and CO_3^{--} in the oceans.

THE CO_2-PRODUCTION WITHIN SOILS

1. CO_2-evolution processes, introduction

Carbon dioxide is the link within the cycle of the biosphere (see fig. 2). CO_2 is used for forming organic matter out of inorganic components. Green plants (chlorophyll) are able by using CO_2, H_2O and the energy of light to build up organic molecules (carbohydrates), the base of organic life. During the assimiliation the green plants absorb CO_2 out of the atmosphere and evolve O_2 into the atmosphere. These plants are the food for animals. Both plants as well as animals build up organic matter which will finally become decomposed back to inorganic material. The decomposition is very complex, the end of a long line of intermediate stages are again the molecules CO_2 and H_2O. Organic matter becomes again inorganic. The fastest way to decompose organic matter

can become supersaturated if water evaporates or becomes warmed up, so that CO_2 diffuses into the soil atmosphere. On the contrary not saturated water invades the soil and absorbes CO_2 out of the soil atmosphere or the soil water which stays in equilibrium with the CO_2 partial pressure of the soil atmosphere cools down and can absorb more CO_2. Also the ion activity of other soluted compounds can play an important modifying role in these processes.

6. CO_2 invading the soil by rain and snow water

Rain drops falling through the atmosphere dissolve small amounts of CO_2 which in their heights depend on various factors. The CO_2-capacity of pure water within the temperature range of rain varies from 1,0 mg CO_2/l at 0°C, 0,76 mg CO_2/l at 10°C down to 0,48 mg CO_2/l at 25° (all data at 1 atm.).

During the fall of 1000 m through the atmosphere a rain drop of 50 mg weight washes out 16,3 l air. Dobroklonski and Wawilow (cited by Alekin 1962) calculated that due to the large surface of falling rain drops 1 l rain washes $3,26 \cdot 10^5$ l air. We should assume that under those conditions rain water reaching the soil should be in equilibrium with the CO_2 partial pressure of the atmosphere, but measurements of the solution activity of different rain forms like showers (big drops) compared with drizzle rain (small drops) showed (Miotke, 1968), that due to different drop surface (drop size) and different fall velocity the CO_2-content of rain water is not always the same as should be because the CO_2 partial pressure of the atmosphere is quite constant (see also Dixon and Russel 1950, and Dixon and Hands 1957). Another explanation for the chemical variability of rain water is the influence of different other compounds which exist in the air. Those ions become washed out by the rain drops too and change the solution conditions for the CO_2 within the rain drops. Alekin, 1962, cites data of Cl^- which cover a wide range from 2 mg/l up to more than 20 mg/l. Especially near the coast lines or in areas where salt soils are exposed the chlorid rates rise considerably. The average ion content of atmospheric precipitations within Russia after Burkser, cited by Alekin, 1962, is

ions	mg/l	
Cl^-	5,46	
SO_4^{--}	9,17	
HCO_3^{--}	18,20	(recalculated CO_2 13,1)
NO_3^-	1,7	
Na^+	5,12	
Mg^{++}	1,74	
NH_4^+	0,21	

It is evident that industrial areas have extreme high contents of ions which can influence the CO_2 absorption by rain water.

Falling snow (ice crystals) absorb much less gases or dry particle out of the atmosphere. Data by Woronkow (in Alekin, 1962) of snow out of the Waldai area (Russia) show that the absorption is less than the average rain absorption. (SO_4^{--} up to 2,7 mg/l and Cl^- below 1 mg/l). Taking into consideration that ice has also a very low CO_2-capacity (Essery, 1952), which is around 150 mg CO_2/l at -5°C under 1 atm CO_2 atmosphere and below 50 mg CO_2/l at - 20°C (compare 3347 mg CO_2/l at 0°C under 1 atm CO_2) it is not surprising that freshly melted snow water has a much lower CO_2-content than we should expect due to the CO_2 partial pressure of the atmosphere (CO_2 diffusion into the water seems to be rather slow under natural conditions). The CO_2 contribution of melted snow water into the soil environment is small in comparison with amounts of CO_2 brought in by rain water. The same reasons are responsible for the fact that melted snow water has only small solution aggressiveness compared with rain and soil water (Miotke, 1968, Ford, D.C. 1971).

ANAEROBE FLORA

Relationship to different soil conditions (after Poschenrieder and Beck, in Beck 1968)

soil typ	depth in cm	pH (KCl)	gas exchange	permeability	total bacteria population per 1 g soil	anaerobe bacteria population per 1 g soil	quotient aerobe/anaerobe bacteria
pseudogley-pelosol	0 - 4	6,8	good	good	14 400 000	230 000	63 : 1
	16 - 20	4,9	bad	very bad	1 630 000	100 000	16 : 1
	40 - 44	4,3	bad	very bad	270 000	10 000	--
lime-pelosol	0 - 4	7,3	suffic.	good	20 500 000	380 000	54 : 1
	20 - 24	7,3	bad	very bad	2 400 000	145 000	16 : 1
	40 - 44	7,4	bad	very bad	1 970 000	10 000	--
sandy brown earth	0 - 4	5,7	good	good	4 600 000	80 000	57 : 1
	18 - 22	5,5	good	good	1 430 000	10 000	--
	30 - 34	6,1	good	good	430 000	10 000	--

Fig. 5

bic and anaerobic conditions although their optimum can be obtained in both situations. Often it can be observed that anaerobic bacteria are more numerous in aerobic conditions where favourable food or other favourable environment characteristics are present than in deeper soil horizons with a more anaerobe environment (Poschenrieder and Beck, in Beck, 1968).

2. Actinomycetes

The actinomycetes which are neither the bacteria nor fungi, rank in second behind the most widespread bacteria. Also their size and metabolism are similar to the bacteria.

3. Soil fungi

The soil fungi, which represent one quarter to one half of the biological mass within the soil micro organism, are characterized by their thread-like hyphens. The hyphen texture can form in some soils, especially under wood a net of 10 to 500 m length per 1 g soil. The population of soil fungi diminishes with depth of the different soil horizons, because living conditions are less favourable due to less oxygen and accumulation of CO_2. The bacteria/fungi quotient depends upon the soil pH.

4. The algaes

On the contrary the remaining micro organism of the soil, the algaes have the ability to assimilate CO_2 out of the soil atmosphere and evolve O_2. Algaes are settled near the soil surface where sunlight is at least diffusedly available. The chlorophyll containing algaes have different body forms, single cells, threads or multi cell colonies are common. Compared with bacteria and fungi the algaes have a small population within the soil. The activity of algaes increases in spring and at the end of autumn. Some species are very important for the first stage of soil development and weathering. Although algaes subtract CO_2 from the soil atmosphere for their assimilation, their CO_2 respiration, concentrated at the place of residence, causes increased solution (weathering).

space between the soil particles depends as well as the inner surface on the particle sizes. Sand offers less inner surface than silt or clay. Besides the space between the grains there are also root and animal conduits and cracks produced by shrinking of drying clays. The total pore volume in a soil averages 40% to 55% but mostly lying in between 42% and 50% (Scheffer and Schachtschabel, 1966).

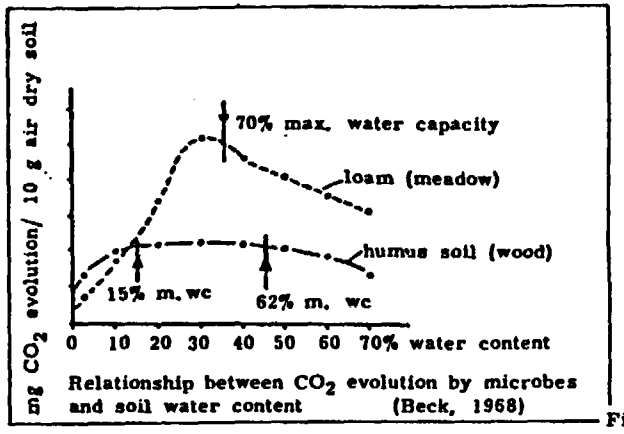
The coarse pores (≥ 25 μ) serve the air exchange, mostly the middle fine pores drain the water, and the pores, smaller than 5 μ, hold the capillary water. Below 40% pore volume the biological activity becomes disadvantageous. The micro organisms need absorption places, and contact with the soil particles. Often every available surface is occupied, restricting any further population increase.

Grain sizes and the pore volume are not homogeneous within the different soil horizons; also the pore volume as well as the inner surface can become temporarily diminished by water and when the clay minerals expand due to higher water saturation. The soil atmosphere in that part of the pores which are not water filled is important for the respiration of the micro organisms. If the oxygen content decreases extremely to some percent O_2, the respiration and consequently the metabolism becomes slowed down. As the low oxygen contents are mostly combined with high CO_2 partial pressures, the atmosphere can become toxic for many species. Many micro organisms stop growing when the CO_2 concentration rises above 10%, although there are special species which are quite CO_2-tolerant. These species live predominantly in deeper soil horizons with normally less favourable air exchange (Beck, 1968).

Anaerobic conditions are only favourable for special micro organisms adapted to very low or zero O_2-concentrations. A good air exchange between the atmosphere and the soil atmosphere is essential for optimum metabolism.

The living conditions of the soil edaphon directly depend on the relative water saturation of the soil. The total amount of water, which a soil can hold against the gravity is called water capacity of a soil. The

finer the soil substratum, the higher is the water capacity. Micro organisms grow best within the range of 50 to 80% water capacity, although different species have different optima within this range. The lowest water capacity at which micro organism activity can be expected is 5% (Beck, 1968). The number of population as well as the activity of existing micro organisms intensively decreases under extreme dry conditions.

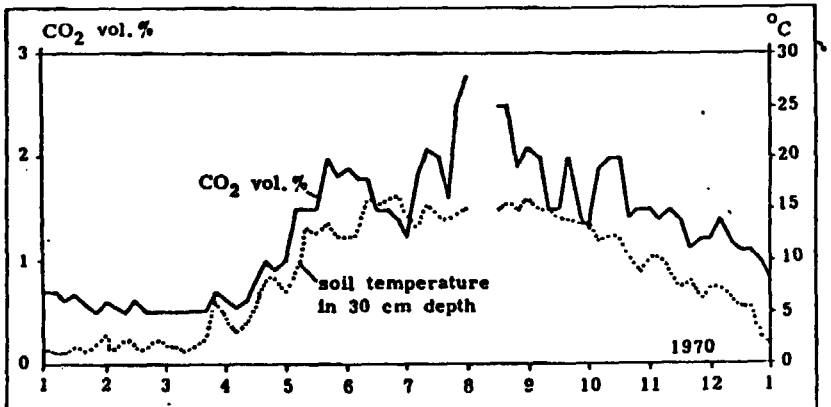


Relationship between CO_2 evolution by microbes and soil water content (Beck, 1968)

Fig. 8

Water is adsorbed at the surface of the soil particles as a film. The first monomere layer, covering the particle surface is bound with about 6000 atm. The second layer is above the first one only with 2500 atm (Olphen, 1963). With increasing distance the water is less strongly held. Those first boundary layers are not available for the plants and micro organisms; they have special physical characteristics. The freezing point is deeper, probably also the CO_2 solution capacity is higher too (cit. Richter 1972c). With increasing water contents first small capillaries become water filled, then wider conduits will drain the water into the saturated ground water zone. The water films, covering the surface of the soil particles, are a popular environment for bacteria and other microbes. As the capillaries still maintain a waterfilm during dry periods, the small microbes are able to use this as a refugium

produce large amounts of CO_2. The changing water situation (dry, optimal water capacity or saturated conditions), and its influence on the biological activity, directly controls the CO_2-production into the soil atmosphere. That is the reason, why the CO_2-evolution reflects so directly any moisture change during the day and along the yearly seasons of different climates.



Soil CO_2-concentration and soil temperature (Gerstenhauer, 1972)
in a German soil (34% sand, 55% silt, 11% clay)

The correlation between the yearly temperature change and the CO_2-concentration is very obvious. Fig. 10

As water one of the major factors of climate is of direct importance for the activity of soil metabolism the temperature of a certain location also has direct influence on the biological activity and consequently on the CO_2-evolution. Normally all chemical reactions occur with higher speed when the temperatures increase. The biochemical reactions which decompose the organic matter within the soil are with temperature related. The metabolism, ruled by complex catalyst reactions, increases with temperature up to the point where destruction of protein sets the limit. The lower temperature limit is around and under freezing point, when all activities are stopped, although the organism mostly can endure even very cold periods without dying. The optimal temperature range is different with different species (Beck, 1968).

	minima	optima	maxima
psychrophile organism	-5 to 10°C	10 to 20°C	20 to 30°C
mesophile organism	10 to 15°C	15 to 35°C	35 to 40°C
thermophile organism	25 to 40°C	40 to 65°C	65 to 80°C

Jensen (cited by Beck, 1968) found that 10^9 soil bacteria produced during one day a CO_2-quantity in percentage of the dry weight of those micro organisms at 15°C 16%, at 28°C 30% and at 37°C 50%. Up to 45°C the soil respiration of CO_2 still can increase. On the other side even tundra soils, which are most of the year frozen, have a numerous bacteria population. Dry resistant desert plant roots lodge great numbers of bacteria. We can conclude that under extremely disadvantagous climatic conditions the soil micro population is active although the greatest productivity can be observed where optimal temperature ranges prevail. This means more or less great quantities of CO_2 are produced in soils of all climate zones.

Related to the different climatic conditions the plant cover produces different quantities and different qualities of organic matter which after it has filtrated into the soil serves as nutrition for the micro organism. To a smaller degree also the fauna contributes nutrition for the soil population. The fertility of a soil (mineral and organic matter reserves) is of direct influence on the CO_2-production because good nutrient conditions allow numerous micro populations to develop high decomposition activity. It is known that the highest micro biological activity (CO_2-production) is to observe in those upper soil horizons where most of the nutrients are available. Experiments showed that introduction of organic matter into a soil always causes fast increasing CO_2-evolution, although we have to consider that in middle altitudes one third of the decomposed organic matter is used by the increasing population of the micro organisms for their own growth. There is evidence that most of the respiration, producing CO_2, is done by the bacteria rather than other microbes. There is a direct relationship between the number of bacteria and the respiration activity (Beck, 1968).

The pH of a soil which can vary considerably within very close distances

within the soil, the oxygen concentration decreases and the CO_2-concentration increases. Both facts have negative influence on the metabolism of the soil life. More important for the karst processes is, that the soil water due to higher CO_2-concentrations and additative the lower pH becomes more aggressive to dissolve carbonates. It is obvious that even with slow production, CO_2 will be accumulated up to a high percentage if the gas exchange is restricted enough and if there is enough time available. As will be shown later we can expect very high or very low CO_2 partial pressures within the soil atmosphere in all climates respectively under all production conditions.

2. The gas exchange mechanisms

The gaseous exchange between the soil atmosphere and the open atmosphere by most authors is explained by mechanical gaseous diffusion caused by the different partial pressures of the soil gases, which establish a concentration gradient (Buckingham 1904, Romell 1922, van Bavel 1951, Baver 1956, Currie 1961 and others).

"The diffusion of gases through porous media (like soil) may be viewed as essentially similar to diffusion in free gas with only the medium present as an additional gas". (van Bavel, 1951) Because the pores and conduits within the soil wind very much around the soil particles the real way length of the air transport is much longer than the straight distance from a given soil location to the atmosphere.

The main components of the soil atmosphere are nitrogen, oxygen and carbon dioxide. Oxygen is absorbed during the soil aerobic respiration and CO_2 is produced. To maintain the respiration an oxygen flux from the atmosphere into the soil and a CO_2 flux into the opposite direction must occur. This exchange proceeds through the gas and liquid phases within the larger and the micro pores of the soil which form a connected system. Often this pore system can become partly or completely restricted for example when water fills the pores and blocks the diffusion flux. Closing or diminishing the pores by expansion of water saturated clays causes the same blocking of the diffusion stream. Currie,

1961, distinguishes between two pore phases "with large pores between the structural units (the inter-crumb pores), corresponding approximately to the familiar non-capillary and capillary pores, respectively. At field capacity (water capacity) the capillary pores are filled with water, and gaseous diffusion occur exclusively through the inter-crumb pores." Wood and Greenwood, 1971, demonstrated this because of the different molecule weights the rates of diffusion for the gases must be different too. This causes small differences of total pressure, which initiate negligible mass flow for the three gases including nitrogen. Air flow due to atmospheric pressure changes and temperature differences do not play a dominant role (van Bavel, 1952).

Richter, 1972 b, showed that thermal diffusion can be a transport mechanism for soil gases, which is as important as the mechanical diffusion. "While the carbon dioxide flux crossing the soil surface shows a distinct daily cycle the corresponding concentration gradient as well as the diffusion coefficient do not fluctuate to any extent. Thus the diffusion cannot explain the flux alternation. It seems probably, however that the thermal gradients in the upper soil layer, changing parallel to the surface production flux of carbon dioxide, may be responsible for this production cycle " (Richter, 1972 b). It is evident that the main direction of the thermal diffusion flux is in the warm season contrary to the cold season of the year, due to the opposite thermal gradients within the soils.

Jakucs, 1971, explains very distinctive changes in the CO_2-concentration of croatian soils during the day by the temperature and moisture changes. These cause different micro-biological activity (see figure 20). The daily temperature curves show close similarities to his CO_2-concentration curves. If the soil atmosphere is not closed by a higher water saturation even slight winds will tend to diminish the CO_2-concentration faster, probably by better soil ventilation. It is noteworthy that the CO_2-percentage curves by Jakucs are quite similar to those Richter attained by measuring the CO_2-production by a bell jam method. While Richter found no change in the daily CO_2-concentrations, with no changing daily concentration gradient, Jakucs shows maximum daily changes of some percent within the upper horizons.

striction for the CO_2 diffusion out of snow as dense illuviation horizons or tight sediment layers are within soils.

It is not surprising that clay containing soils mostly have restricted air exchange and consequently, specially in humid climates, they show higher CO_2-concentrations. If those clay soils contain carbonate particles - most carbonate soils develop clay residuum - we can expect favourable conditions for the solution of carbonates. First the average CO_2-content will be rather high and second the soil water remains a longer time within the soil compared for instance with a sandy soil. This means that there is much more time available for the water to absorb CO_2 out of the soil atmosphere which can be used to maintain carbonate solution until carbonate saturation is reached, before the water gets into the deeper underground. As the CO_2-concentration in clay containing soils is extraordinary high it is understandable that areas where those soils are exposed above limestones it is possible they highly carbonate saturated waters. If those waters, which established their carbonate saturation equilibrium under high CO_2 partial pressure get into a cave system, the loss of absorbed CO_2 into the cave atmosphere causes carbonate precipitations (Miotke and Palmer, 1972).

METHODS FOR CO_2-DETERMINATIONS IN SOIL AND CAVE ATMOSPHERES

The CO_2-production within the soil atmosphere has always been of great interest in soil science because in general it was assumed that the CO_2-respiration reflects the biological activity of the soil. The literature on the measurement problems such as taking soil gas samples and the determination of CO_2 within those samples is extremely numerous and cannot be discussed in detail here. The soil respiration gas exchange into the atmosphere is analyzed by trapping the gas which diffuses out of the soil surface in flasks and the determination of the partial CO_2 pressure in those samples is accomplished by different methods, see Romell 1922, Lundegardh, 1924, Domsch, 1963 (here 400 references), the Bibliography on Measurements of Soil Atmosphere, 1965, Franken, 1966, Richter, 1972 b).

The apparatus by Lundegardh, 1924, using a volumetric method, was modified by Koepf, 1952, who introduced electrolytical titration. The Koepf-method was further developed by Delecour et al., 1968, and Ek et al., 1968, to be used easier in the field and especially in caves. In recent works of Richter, 1972 c, the handy Draeger-device and also gas chromatography is used for soil respiration measurements.

Gas samples, obtained by trapping the gas flow at the surface or gas quantities sucked out of limited soil localities with a sonde, were analysed for CO_2-concentrations generally by using the following methods:

1. The sampled CO_2 gas is absorbed by alkaline solutions (NaOH, $Ba(OH)_2$) and is colometrically (phenolphthalein) or electrolytically titrated (Koepf, 1952, Nichols et al., 1966, Lee and Woolhouse, 1966, Thomas and Hiefge, 1966, Delecour et al., 1968).
2. CO_2 partial pressures are directly measured by test tubes (Martin and Pigott, 1965), the most widespread method now being used is the Draeger device (Miotke, 1968, 1972).
3. CO_2 gas samples are analysed by gas chromatographic methods using samples collected by sondes or surface covering flasks (Ritchie, 1965, Richter, 1972 c).
4. Determinations of CO_2 in micro quantities necessary to get information about the differences in micro soil pores and in capillary water are possible by using micro-electrodes. The partial pressure is re-calculated from ionic activity equations, using data on the hydrogen ion activity, the bicarbonate ion activity and other ionic activities (Ponnamperuma et al., 1966, Hack, 1956, Scholander and Evans, 1947).
5. Isotopic tracers are used to measure the diffusion velocities in soils under natural conditions (Blankfeld, 1962) or the decomposition rates of plant material in soil (Freytag, 1962).

The methods to measure the CO_2-evolution and concentrations in soils are meanwhile very precise but mostly require a laboratory equipment which is difficult to use in field work, especially for karst research in strenuous mountain areas and caves. Here we need a handy not too expensive method, which enables us to get data in a relatively short time at the sample location. So far the DRAEGER-device which was intro-

from Draegerwerk Lübeck, 24 Lübeck 1, Postfach 1339, W-Germany.

YEARLY AND DAILY CO_2-EVOLUTION AND CO_2-CONCENTRATION CURVES

Yearly curves of the CO_2-evolution(respiration) in soils or CO_2-concentration curves clearly show the predominance of a few of the discussed factor which control the production of CO_2 and the air exchange of soils.

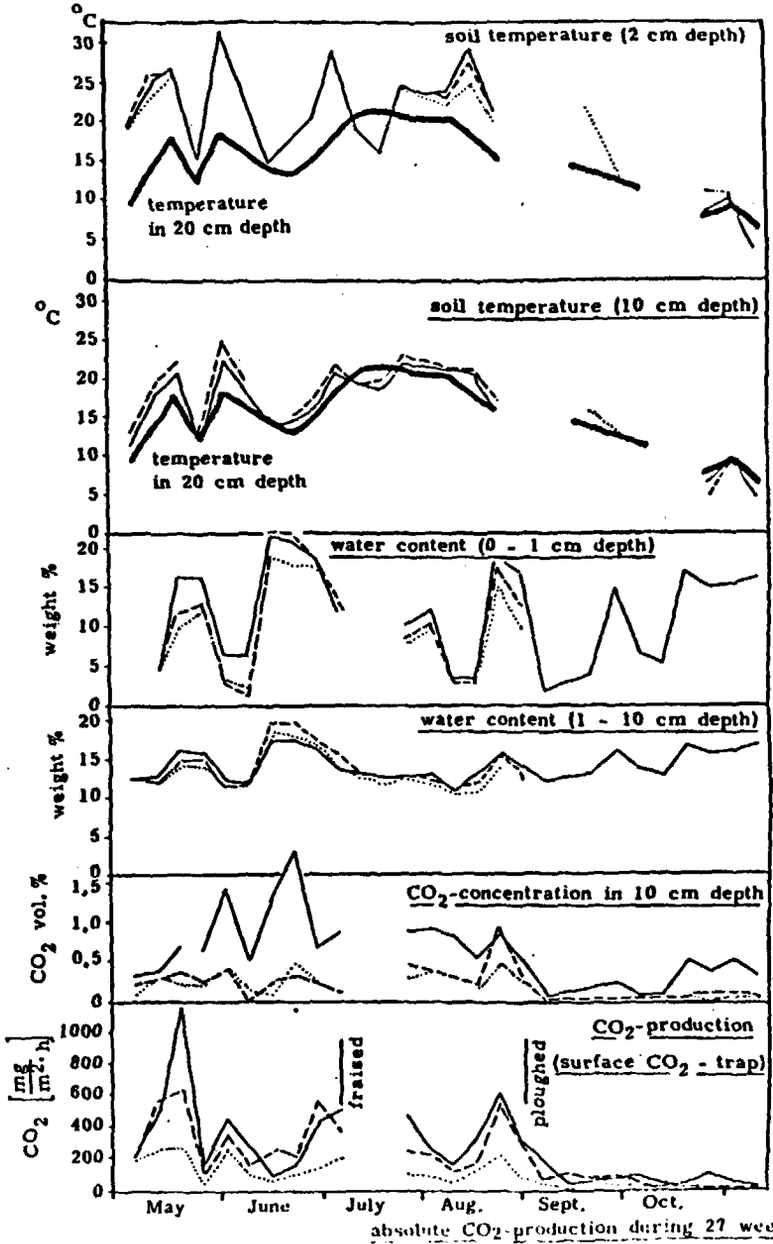
Recognizing the individual situation of a soil concerning climate region, vegetation cover, geologic factors and the altitude of the soil location, which can be considerably different, we still find a few factors which are dominant in nearly all different locations. These are the temperature, which regulates in combination with the moisture conditions the biological activity (CO_2-production), and the water saturation of a soil, which has especially in always denser clay soils a great negative influence on the gas exchange of the soil atmosphere. The soil water has a double function. As long as the soil does not get flooded, the CO_2-production generally increases due to higher biological activity. If the gas exchange is not too reduced by soil water and the clay expansion higher CO_2-evolution does not necessarily cause high CO_2-concentrations within the soil atmosphere. But when the upper horizons are water saturated even sandy soils can accumulate CO_2-concentrations up to 10 vol.% (Beck, 1968).

Richter and Jacobs, 1972, measuring CO_2-concentrations in a sandy soil never found data far above 1 vol.% CO_2 (Fig.16), whereas Boynton and Reuter, 1939, in a silty clay orchard subsoil found increasing CO_2-concentrations with depth up to 12 vol.% CO_2 in 1,80 m (Fig.17). Comparing a silty clay, a light silty clay loam and a sandy loam subsoil it becomes evident that the grain size becomes best indicated by the different CO_2-concentrations in deeper horizons (Boynton and Compton, 1944) (Fig.18).

Most of the CO_2-concentration curves given in the literature are of limited usefulness for our purposes because they are incomplete to inform about the conditions of the soil location during the sampling time. As demonstrated it is of major importance to know besides the CO_2-concen-

CO_2-PRODUCTION and CO_2-CONCENTRATION in 10 cm depth of a sand soil

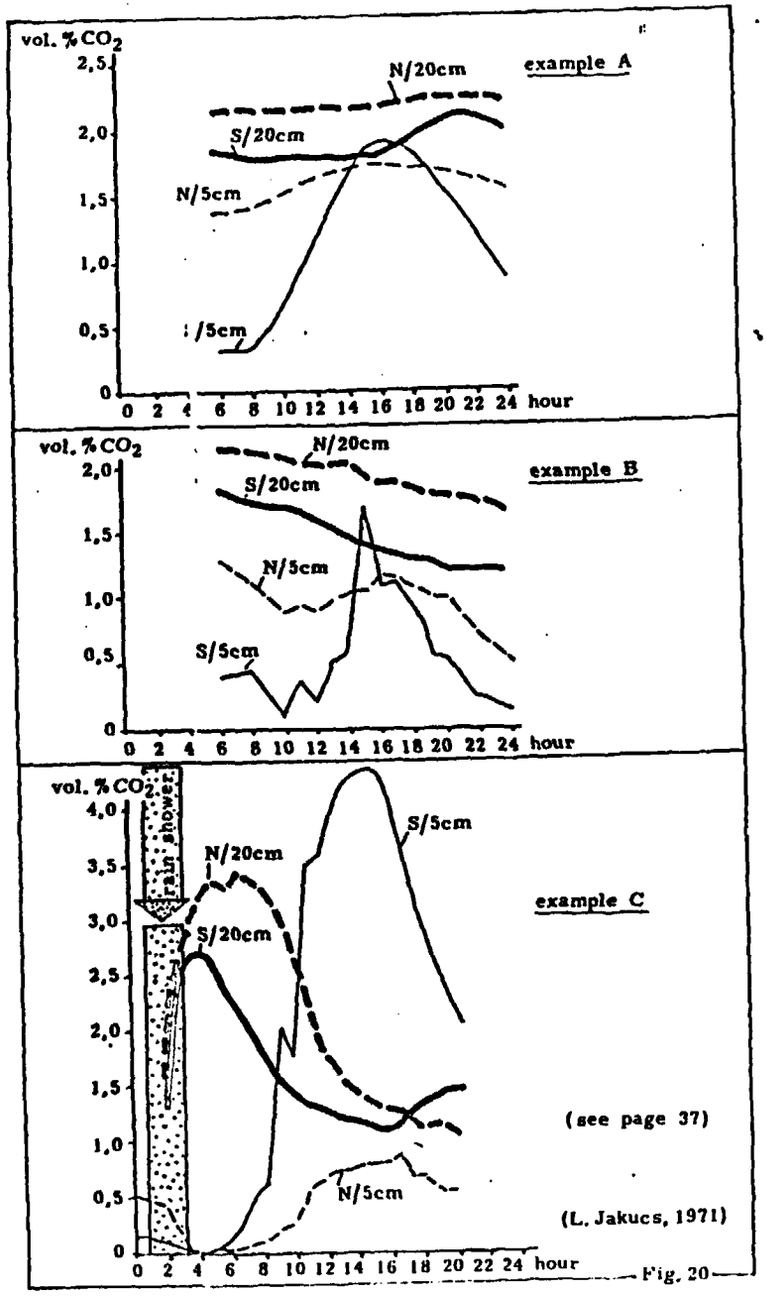
All data including soil moisture and temperature measured at 10.30 am. No vegetation covered the W-German soil. (Richter and Jacobs, 1972)



absolute CO_2-production during 27 weeks:

field A-----straw ploughed into the soil ~ 990 g CO_2/m^2

field B·····soil without straw ~ 445 g CO_2/m^2



(see page 37)

(L. Jakucs, 1971)

Fig. 20

DAILY CO_2 -CONCENTRATION CURVES (Jakucs, 1971) (see page 36)

SAMPLE LOCATION sinkhole near Karlovac, Croatia, within a terra rossa covered plateau under dense pteridium aquilinum vegetation. Doline slopes declining about 20 degree, covered by a red loamy rendcina.

example A. clear calm summer day (July 14, 1968)

The CO_2-concentration curves within all soil depths (5 and 20 cm) reflected the daily temperature changes. The south exposed soil having extremer daily temperature changes showed especially within the 5 cm horizon the highest daily CO_2-concentration peak.

As long as the north exposed soil is more humid than the south exposed soil, the CO_2-concentrations are destinctively higher on the north exposed doline slope. Also the CO_2-concentration in the more humid lower horizons (20 cm depth) is always higher, due to better ventilation in the upper soil horizons (5 cm depth).

example B. 60% clear windy summer day (July 15, 1968)

Slight wind causing better soil ventilation decreased the CO_2-concentrations in the upper horizons. The short calm period (around 3 pm.) when the CO_2 exchange was temporarily slowed down, was clearly indicated by a sharp peak in the south exposed soil (5 cm-horizon). The more humid north exposed horizons were less influenced by the wind and show CO_2-concentrations. All curves, except the temporary increased at 3 pm. within the 5 cm-horizons, indicated decreasing CO_2-percentages on that windy day.

example C. clear, calm day after abundant rainfall during the night (1.10 am til 3.35 am) July 16, 1968

The great amount of rain water saturating the upper 5 cm of the soils absorbed most all of the existing CO_2-reserves or (and) stopped the biological activity of the aerobe bacteria. The water saturated upper soil horizon restricted the gas exchange out of the lower (20 cm) horizons, in which since the beginning of the rain showers CO_2 started to accumulate, increasing the CO_2-concentrations. The concentration peak in the lower (20 cm) horizons diminished during the day, when the soils dried and again allowed better gas exchange.

The CO_2-concentration peaks in the lower horizons are mainly due to restricted gas exchange, whereas the peaks in the upper (5 cm) horizons are due to increased biological activity (higher CO_2-production).

the carbonate concentration of water quantities passing through the soil drop down to very low values, although the CO_2-concentration of the soil atmosphere rises mostly to higher percentages, than during the preceding not so wet periods, when the spring and river water had higher carbonate concentrations. This indicates that either the diffusion of CO_2 out of the soil atmosphere into the soil-passing water is not fast enough, or the carbonate solution processes are too slow to reach those carbonate concentrations within the through passing water, which would fit to the even increased soil CO_2 partial pressures. These problems, which are not yet clear, show at least that high CO_2 partial pressures in soil atmospheres do not necessarily cause high carbonate concentrations in draining waters, if there is not enough time available. The CO_2 partial pressure in soils and the amount of precipitation are only two, though major factors among others. Heavy but short rain showers cause different corrosion (and/or erosion) than temporal wider distributed slow rains both precipitating the same total water quantities. Rain quantities and intensities as well as different temperatures, sun radiation, wind velocities etc. in their daily or yearly successions, which represent the climate, have a great importance for changing the soil conditions including the CO_2 partial pressure of the soil atmosphere as demonstrated. Consequently the different climates after all are responsible for the different physical conditions, which rule the complex corrosion processes, for which the CO_2 presence within soils and in the atmosphere is only one but important factor. For instance comparing the subarctic in Alaska with tropical areas like Puerto Rico we have to consider, that even finding similar CO_2-concentrations within exposed soils in those regions or having similar carbonate concentrations in springs or rivers, this does not mean that both areas have the same amount of carbonate solution over a longer time. In the studied area of Northern Puerto Rico we have more rain falling through the year although with changing quantities, whereas in arctic regions during a period of the year the strong frost stops nearly all surface solution activities or looking back into the pleistocene past, Puerto Rico did not have too different climate conditions from recent ones. It always had solution activity all the year round while the arctic regions as well as northern now temperate regions,

which were or were not covered by ice, had only temporary solution activity certain times during the pleistocene or during the year when water was unfrozen and the limited biosphere became active.

We need much mor data on the processes in different climates to enable detailed balance accounts of closed systems in limited areas, which can show us the efficiency of single factors involved in the very complex karst solution processes. The concentration of CO_2 in the atmosphere and within the soil atmosphere is only one of the major factors of carbonate solution.

CO_2 - CONCENTRATIONS IN SOIL ATMOSPHERES OF AMERICA
based on nearly 500 measurements by the author from 1969-1972

	vol. % CO_2
PUERTO RICO (Febr. 1969)	
mogotes slopes (relatively dry)(wood atmosphere 0,08%)	0,08 - 1,2
cockpit soil, clay containing, water saturated	1,5 - 7,0
FLORIDA (April/May 1972)	
Key Largo, stony soil	0,2 - 0,4
Everglades, grass	0,7 - 2,2
Cape Kennedy, wood (air 0,04 %)	0,4 - 0,5
Waverly, wood, dry sandy soil	0,15 - 0,3
Waverly, meadow, dry sandy soil	0,16 - 0,2
The measured data represent the end of the dry season at the beginning of the rainy summer season.	
ROCKY MOUNTAINS, SOUTHEAST CANADA (July/August 1971)	
Crowsnest Pass and Mt. Castleguard, Banff National Park (1500 - 2600 m)	
atmosphere	0,018
in perennial snow	0,01 - 0,01 - 0,014
frost debris	0,04 - 0,1
alpine tundra	(0,04) - 0,15 - (0,38)
alpine meadow	0,1 - 0,4
wood, conifers	0,1 - 0,25 - (0,5)
SEWARD PENINSULA, ALASKA (At the end of Aug. 1971)	
air	0,02
tundra, mostly above perma frost	
a) marine terrace	0,18 - 0,4 - 1,2
b) frost debris, polygone soil	0,05 - 0,15
c) humid moss, pulvinate above moraines dry	0,18 - 1,5 - 3,8 wet
in perennial snow patches	0,02

snow atmosphere into the melted snow water is not favourable to cause a rapid rising CO_2-concentration within the melted snow water. The same applies for melted glacier ice. These facts explain the very low aggressiveness of snow and melted ice waters (Ek, 1964). CO_2-concentrations in snow atmospheres above 0,03 vol.% are only possible, where seasonal snow covers soil atmospheres, which due to an active summer CO_2-production and slow air exchange diminish their CO_2-storage during the winter into the snow atmosphere (Miotke, 1972).

2. CO_2 PARTIAL PRESSURE IN CAVE ATMOSPHERES[1)]

Cave atmospheres have more or less efficient air exchange with the atmosphere. Different atmospheric air pressures, different temperatures in different parts of the cave and outside the cave cause air flow of which the direction depends upon the seasons of the year. In alpine mountain caves the air flow along steeper conduit gradients is more important than in low relief landscapes. The CO_2-concentrations near the cave entrances have mostly the same percentages as the local atmosphere. Further inside the cave and especially in deeper parts of the cave system, which have less developed air exchange, we often encounter higher CO_2 partial pressures. The main source for those higher concentrations are the soil atmospheres which stay in air exchange with the cave atmosphere along joints and fissures. This also makes understandable why parts of a cave deep under the soil-covered surface can have lower CO_2-concentrations than those we encounter nearer the main source.

Soil water, sometimes highly carbonate saturated, seeps into the cave passages, where it partly loses CO_2 while establishing a new equilibrium with the lower CO_2 partial pressure of the cave atmosphere. Soil water entering the cave is only carbonate saturated if there was enough time to reach equilibrium with the high CO_2-concentrations in the soils. It is known, that after long rain periods the water passes through the soil atmosphere so rapidly that it is still very aggressive when entering the cave passages. Under these conditions the cave water does not

1) For CO_2 existing in deeper rock underground and the age of those deep CO_2-reserves see Kunkler, 1969.

diffuse CO_2 into the cave atmosphere but absorbs CO_2. This means that instead of precipitating carbonates - the water dissolves. As the average weather conditions in some climates change during the year, saturated and aggressive water can temporarily reach the same part of the cave, precipitating carbonates by losing CO_2 or dissolving carbonates by absorbing CO_2 out of the cave atmosphere.

As the CO_2-production in soils is directly dependent upon climatic conditions the CO_2 partial pressure of cave atmospheres in general, are lower in alpine mountains or cold climates than in flat areas of temperate or warm climates which are covered by a dense vegetation and maintain a very active soil biosphere (Schoeller, 1950, 1962). Ek et al., 1969, found in caves of the Polish Tatra during the snow melting period very low CO_2-concentrations in the cave atmospheres, which were explained by the stagnated biological activity and the small amounts of CO_2 within the water entering the cave. CO_2-values within the cave passages ranged from 0,016 to 0,10 vol.% CO_2, concentrations collected from fissures ranged from 0,10 to 0,17 vol.% CO_2.

Renault, 1972, reported that French alpine caves mostly have less than 1 vol.% CO_2, whereas shallow relief caves having fewer open connections to the surface which permit air exchange, combined with a very active soil cover, reach up to 7% CO_2 (see also Roques, 1959). From October 1971 til June 1972 the author measured CO_2-concentrations within caves of the Mammoth Cave National Park area in Kentucky from 0,03 to 0,11 vol.% CO_2. The soil atmospheres ranged from 0,3 to 5,0 vol.% CO_2 (Miotke and Palmer, 1972).

Caves which maintain sufficient air flow in general do not have high CO_2-concentrated atmospheres. The gas exchange in the atmosphere under such conditions is fast enough to hold percentages little above 0,03 vol.% CO_2. Restrictions for the air exchange within the cave system like diminished passage cross sections or siphon conduits can cause greater differences of CO_2-concentrations within short distances. Very high CO_2-concentrations are due to volcanic exhalations into the cave. Renault, 1972, reports 6 to 30 vol.% CO_2 from the region of

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