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An inceptisol formed in calcareous loess on the 'Dast-i-Esan Top' plain in North Afghanistan. Fabric, mineral and trace element analysis

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Summary

Under semi-arid climat conditions a Calcixerollic Xerochrept has developed in calcareous loess in North Afghanistan. The soil consisting for 50 % of coarse silt and with a bulk density of 1.1 g per cm^3 is prone to subsidence and caving especially when irrigated.

Micromorphological study showed faunal activity and carbonate to be very important in soil genesis and with regard to land-use. The low bulk density of the soil in its top 100 cm is primarily caused by current activity of the soil fauna. Termite structures (especially recognizable at depths greater than 100 cm) are considered a pedorelict. The bulk of the carbonate is thought to be allogenic; pedogenic redistributed carbonate primarily occurs in the form of glaebules.

The mineral composition of the soil shows a clear particle size function, its heavy fraction is characterized by a hornblende-epidote-(zoisite)-mica association.

The content of eight trace elements was determined; these are on average V 0.6, Cr 11.0, Co 23.2, Ni 49.1, Cu 19.4, Zn 75.9, Sr 18.7, and Ba 525 mg/kg. Sr and Ba closely follow the redistribution of $CaCO_3$ in the soil.

The main trace constituents are higher than in Russian soils of the same character which have formed in loess.

Introduction

Extensive loess deposits occur in Afghanistan as well as in the adjacent countries of

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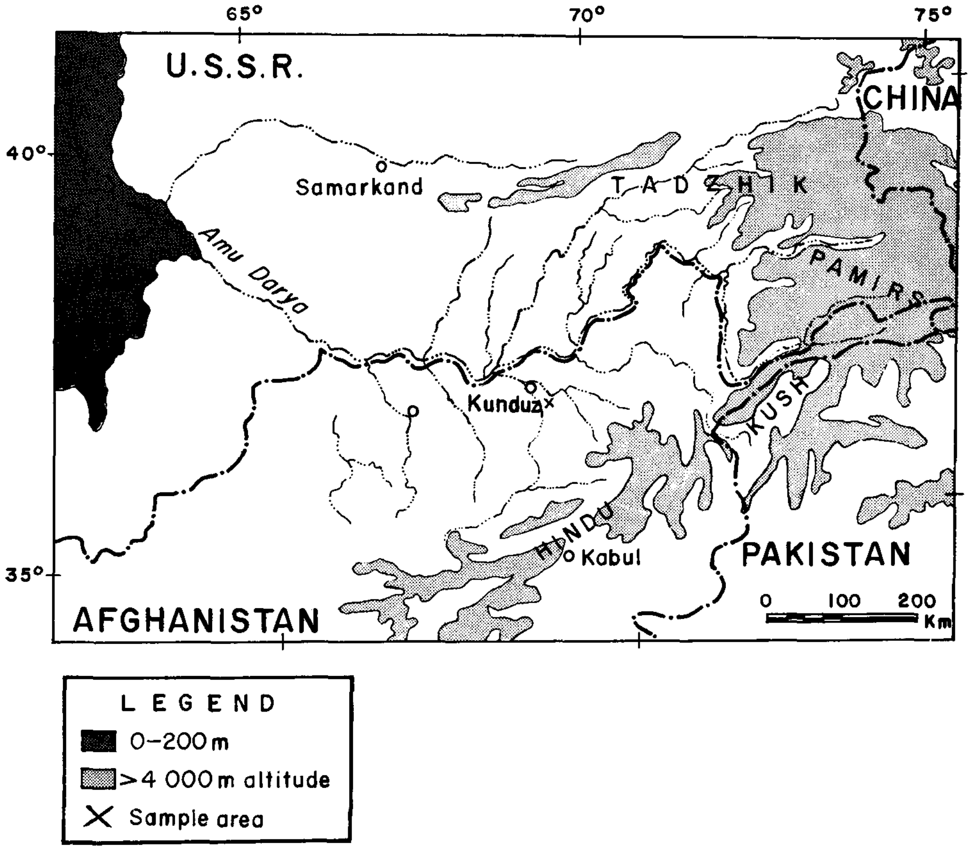


Fig. 1. Location of study area.

Iran and the Southern USSR on bedrock of the most diversified origin. Thick loess deposits were reported upon in a soil survey of part of the Kunduz-Khan Abad river basin, a southern tributary system of the upper Amu Darya, the border river between Afghanistan and the USSR (Buursink & Boerma, 1969) (Fig. 1). The loess principally constitutes the parent material for serozem-type soils (Rozanov, 1951; Suslov, 1961).

The objective of this study is to present detailed information on the micromorphology, physical characteristics, and mineral and trace element composition of such a serozem-type soil developed in this loess.

The present study is considered important not only for understanding the genesis of this soil. It is also meant to provide a means of understanding its use for agriculture. Moreover it may have some importance for advances in loess research in general.

Landscape, land-use and climate

Loess packets cover the North Afghanistan steppe to well over 50 m. In southerly direction, away from the possibly Aralo-Caspian source region, the loess diminishes in thickness where it reaches the foothills of the Hindu Kush mountains. Here the presumably eolian materials have primarily settled on the south sides of the valleys because of prevailing northerly winds (Hinze, 1964; Lister, 1968).

The Kunduz and Khan Abad rivers which drain part of the north flank of the Hindu Kush are incised in the loess cover, creating a series of terrace-like edges. Near the town of Kunduz (36°40′ N, 68°54′ E) these rivers join and a flat and level loess plain occurs, the 'Dast-i-Esan Top', at an altitude of approximately 450 m, some 30 m above the present flood plain (Fig. 2).

This upland surface exhibits the erosional features typical of relatively recent loess deposits: natural wells, pits, pipes, and sinks that form long gashes in the surface of the plateau. Very characteristic for this loess is its proneness to subsidence upon saturation with water, a serious hazard when this region will be irrigated (see description of Land-use). This was observed in roads where rainwater could collect. Unger (1970) described how subsequent to trial irrigation on the 'Dast-i-Esan Top' a microrelief was formed featuring amphitheatre-like depressions with the centre

Fig. 2. View on loess plateau of 'Dast-i-Esan Top' (left) and Khan Abad flood plain (right) under thin snow cover.

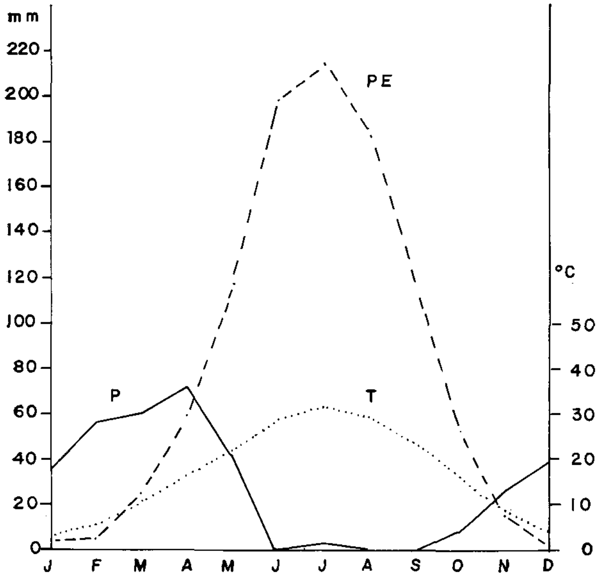


Fig. 3. Annual temperature (T), precipitation (P), and potential evapotranspiration (PE) at Kunduz.

some 1.5 m below the periphery. These observations confirm Glukhov's (1956) report on presumably closely similar soils (in loess) in the Waksh valley, a northern tributary of the Amu Darya. Subsidence ranging from 0-1.8 m occurred here after one year's irrigation of a 111-ha area. Similar subsidence phenomena, also associated with water saturation, were observed by Obruchev (1945) in loess in the Ukraine.

In Afghanistan scattered arable land occupies about 40 % of the country, according to Salem & Hole (1969), the rest is in high mountain land and in arid wastelands. The 'Dast-i-Esan Top' region is at present used for dry-land farming of wheat, barley, and sesame, but is under consideration for irrigated crop production. For detailed information on the development of land-use in Central Asia one is referred to Kovda (1961).

The climate of the Kunduz area is middle-latitude semi-arid with dry summers. Based on observations over a ten-year period, the average annual temperature is 16.7 °C, precipitation 325 mm, and the frost-free period 306 days. The annual regime of temperature, rainfall, and potential evapotranspiration (Thornthwaite & Mather, 1957) appears from Fig. 3. Since soils receive no water other than the precipitation that falls on them, the soil moisture regime is inferred from the data of Fig. 3 to be 'xeric'. The soil temperature regime is considered 'thermic' (Anon., 1967b, 1970). Although the present-day snow line occurs at an altitude of 4700 m to 5000 m, Grötzbach (1966) concluded to a late Pleistocene limit at or above 900 m, thus leaving the study area unglaciated.

Material

The soil at the 'Dast-i-Esan Top' plain is calcareous throughout and has no textural profile development. A 10YR4/3 (moist) weak, fine, subangular blocky ochric epipedon of 25 cm thick on average overlies a cambic horizon with soft powdery lime and characteristic evidence of intense biological activity. The 10YR4/4 (moist) C-horizon starts at depths ranging from 45-60 cm from the surface and shows slight carbonate accumulation as well as intense biological activity in the form of anastamosing filled channels. A description of the profile is given in Appendix 1.

The soil is a Typic Xerochrept (Anon., 1967b). In the latest edition of the Soil Taxonomy system this calcareous kind of soil is excluded from the Typic subgroup and named a Calcixerollic Xerochrept (Anon., 1970).

At two sites on the 'Dast-i-Esan Top' plain samples of this soil were collected down to a depth of 2 m, at other sites 12 surface samples were taken.

Methods

Undisturbed samples were collected for preparation of thin sections according to the procedure described by Jongerius & Heintzberger (1963). The unsaturated polyester resin Vestopal 130 was used for impregnation.

Laboratory preparation of bulk samples was carried out according to procedure 1B1b of Soil Survey Investigations Report No 1 (Anon., 1967a).

Grain size analysis proceeded without pretreatments with HCl and H_2O_2, sodium pyrophosphate was used as dispersing agent, and samples were thoroughly shaken after diluting with distilled water to 1000 ml. Sand was separated by washing samples on a 50-μm sieve, and sands were further separated with a nest of sieves. Clay and silt fractions were prepared by centrifuging according to procedures given by Jackson (1968).

Determination of the bulk density was done on undisturbed soil, collected by pressing metal rings of 100 ml volume into the soil. The oven-dry weight of these core samples was determined to express bulk density in grams per cm^3 at pF 2.0.

Carbonates were determined by shaking soil during 1-3 hours in a Scheibler apparatus and measuring the evolved CO_2.

X-ray diffraction analysis was made with a Philips unit on random powder specimens of fine and very fine sand, coarse and fine silt, and clay fractions. Parallel orientation specimens were prepared whenever required for essential diffraction data. Saturation of the clay fraction with Mg and ethylene-glycol solvation, as well as with K (in preparation for heating treatments up to 600 °C) were done according to methods of Jackson (1968). Machine conditions may be summarized as follows: radiation CoKα, filter Fe, scanning speed 1° per minute, full scale 400 counts per second, time constant 2 seconds. Diffractograms were evaluated by peak areas of high-order reflections.

Bromoform (sp.gr. 2.89) was used to separate the heavy and light mineral fractions of very fine sand. The determination and line counting of both groups of mounted mineral species was according to standard procedures (Milner, 1962). Of the heavy isolate first the mutual percentages of opaque and transparent grains were determined and subsequently 100 transparent grains identified per sample. In addition, 200 grains were counted and identified for each specimen of the fine sand and the coarse silt fraction.

The determination of total V, Cr, Co, Ni, Cu, Zn, Sr and Ba was carried out by atomic absorption spectrometry with Techtron model AA_4. The Na_2CO_3-$Na_2B_4O_7$ fusion technique was used to prepare the soil sample for flame analysis. More detailed machine conditions have been described by Buursink (1971).

Results

Micromorphological description

This description of the micromorphology of the soil — covering both its s matrix

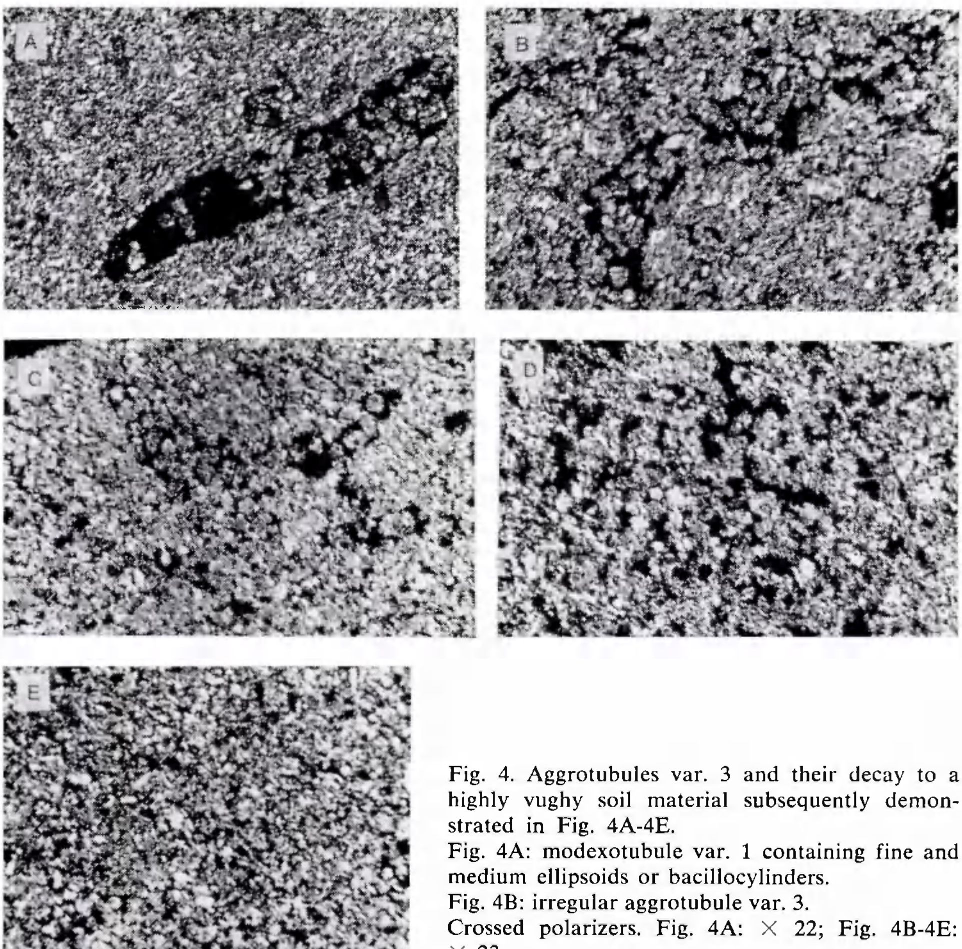


Fig. 4. Aggrotubules var. 3 and their decay to a highly vughy soil material subsequently demonstrated in Fig. 4A-4E.
Fig. 4A: modexotubule var. 1 containing fine and medium ellipsoids or bacillocylinders.
Fig. 4B: irregular aggrotubule var. 3.
Crossed polarizers. Fig. 4A: × 22; Fig. 4B-4E: × 23.

and the pedological features — is according to the system of Brewer (1964), unless otherwise stated.

S matrix

The soil is essentially apedal. Its basic fabric is highly vughy agglomeroplasmic (associated with simple and compound packing voids) with parts intergrading to porphyroskelic and intertextic fabric. All vughs are irregular, strongly interconnected, and mostly with a cross sectional size of from 10-200 μm (Fig. 4D and 4E). In addition, ortho- and metachannels (300-400 μm in diameter) occur in varying quantities. Immediately adjacent to the surface of the metachannels a zone of densely packed s matrix is often present, identified as a particular type stress neo-cutan (Bal, 1973, p. 50).

As of about 90 cm from the soil surface porphyroskelic fabric tends to increase with depth.

The plasmic fabric is calci$^{100(-200)}$-silasepic (the prefix 'calci-' according to Bal, 1975a). In this plasmic fabric the accumulations of carbonate are single or clustered crystals, and nodules; they are randomly distributed throughout the s matrix (see: Fig. 6 and 7 in Bal, 1975a). These accumulations vary in size of from less than 2 μm up to 100(200) μm. To give more detailed information the accumulations larger than 10 μm will also be described separately as intercalary crystals, and nodules, respectively.

Pedological features

The features recognized include pedotubules, excrements, glaebules, intercalary crystals, and cutans.

Pedotubules. Distinguished are aggrotubules, (meta-)isotubules, and meta-fragmotubules.

1. Aggrotubules var. 3: These tubules have a diameter of from 200-700 μm, in places even up to 1100 μm and contain aggregates of from 50-250 μm. Two subtypes occur, one which is regular or irregular in shape containing irregular aggregates (Fig. 4B), another in which the aggregates are regular in shape recognized as modexotubules var. 1 (Fig. 4A). The latter contain modexi (i.e. excrements with a shape) fine and medium in size and ellipsoidal to bacillocylindrical in shape (Bal, 1973, pp. 58-59, 60-64). The aggrotubules are common practically throughout the soil. Moreover, some tubulic distributed organic ellipsoids about 20-50 μm in size are present. In addition, some modexotubules var. 3, with a cross-sectional size of approximately 500 μm, are present in small amounts in the topsoil only.

2. Isotubules: These tubules, which may also be conceived of as striotubules, consist of single circular tubes of from 4-6 mm in cross-section filled with soil material in a highly vughy agglomeroplasmic fabric. They are also characterized by an extremely thick stress neocutan with dense porphyroskelic fabric with the skeleton grains (in particular the lattice type ones) arranged approximately parallel to the channel wall.

The thickness of this neocutan increases from 600 μm along the channel's wall to 4000 μm at its bottom end. These isotubules are a common feature in the topsoil only.

3. Meta-fragmotubules[1] *and meta-isotubules (Fig. 5A).* These tubules are circular, occur in an anastomosing pattern of branching, and have a diameter of from 10-13 mm. The meta-fragmotubules consist of angular fragments of the compound cutan discussed below (ranging in size from 150 × 300 to 600 × 2200 μm) and of the skeleton grains and plasma in a highly vughy agglomeroplasmic fabric (together with simple and compound packing voids). The meta-isotubules are composed of skeleton grains and plasma usually in a porphyroskelic fabric with common vughs of 70-200 μm in cross-section.

These tubules are located in channels with a diameter of approximately 15 mm, which are coated by a compound cutan. Associated with the channel wall a stress neocutan occurs. Both cutan and neocutan are extremely thick and often separated by a planar void.

The compound cutan of 1-3 mm thick is made up of more or less concentric or lenticular plasman-skeletans of approximately 125-250 μm thick, and plasmans of some 20 μm thick (terminology of Bal, 1973, pp. 45 and 50) (Fig. 5B and 5C). The plasman-skeletans consist of plasma and skeleton grains in a porphyroskelic fabric

[1] Fragmotubules according to Jongerius (1970) contain reworked soil of widely varying dimensions. The term aggrotubules cannot be used here in view of the presence of angular fragments.

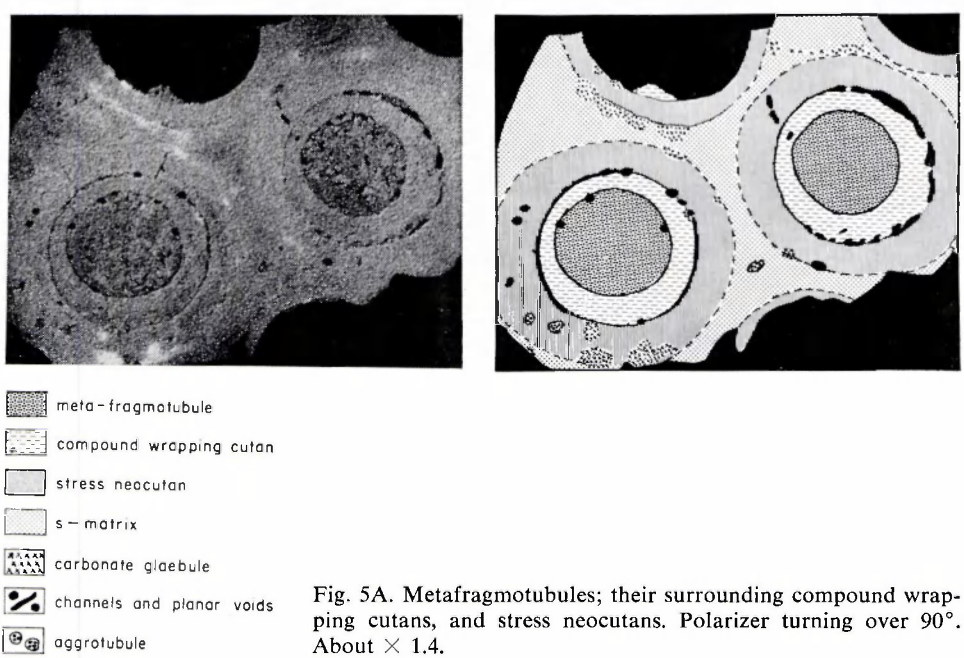
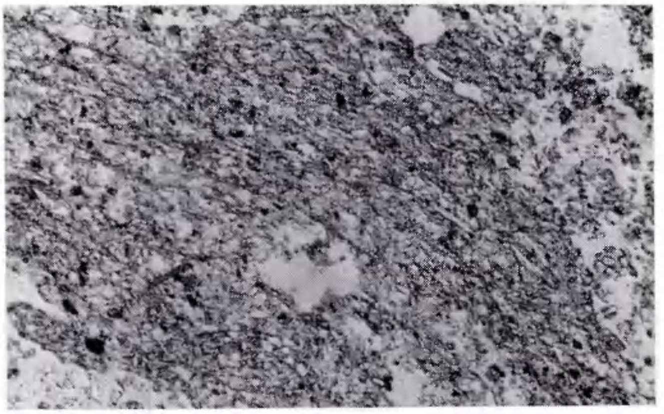


Fig. 5A. Metafragmotubules; their surrounding compound wrapping cutans, and stress neocutans. Polarizer turning over 90°. About × 1.4.



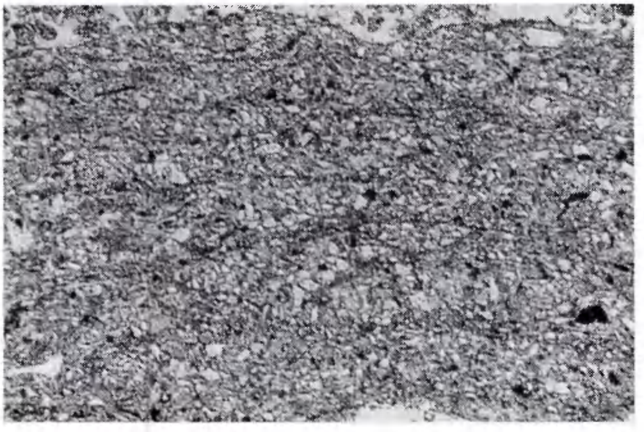


Fig. 5B (top) and 5C (bottom). Details of the compound wrapping cutans shown in Fig. 5A. They are composed of plasmans, and lenticular and/or concentric plasman-skeletans. Plain light. × 32.

such that the grains (and in particular the lattice ones) are arranged parallel to the channel wall; they are separated from each other by plasmans. These plasmans are characterized by accumulated plasma, which is thought to be organic.

The stress neocutan of from 2-4 mm thick has a dense porphyroskelic fabric with a weakly developed arrangement of the skeleton grains parallel to the channel wall. The tubules, cutans and neocutans each may contain aggrotubules var. 3 as described under 1.

The abundance of the channels appears from the distance of only 3-5 mm separating the neocutans of neighbouring channels.

Undisturbed channels occur at depths below 100 cm from the soil surface; between 50 and 100 cm only their remnants are present. The exception is a channel observed in one sample from 20-50 cm depth which has a diameter of about 1800 μm and an extremely thick (125-300 μm) brownish (sesquioxidic and organic plasma) neocutan with porphyroskelic fabric. The channels contain coarse fragments of the neocutan (60 × 75 and 650 × 250 μm), and skeleton grains and plasma in an agglomeroplasmic fabric, thus constituting a meta-fragmotubule.

Excrements. Some excrements were described above under aggrotubules, others are listed below.
1. Mineral excrements: In the topsoil some large bacillocylinders of 400-800 μm have been observed inside modexotubules as well as in a strongly welded basic distribution pattern (Bal, 1973, pp. 60, 69) in the s matrix.
2. Organo-mineral excrements: Only one 700-μm organo-mineral ellipsoid (Bal, 1973) was observed embedded in the stress neocutan of an isotubule.

Glaebules. Distinguished are small and large carbonate nodules, as well as soil nodules.
1. Small carbonate nodules: These glaebules vary in size of from 50-100 μm; they are discrete units, ellipsoidal, spherical or sometimes irregular in shape and with sharp boundaries. They have a fine crystic fabric and are sometimes impregnated by sesquioxides. Some nodules contain remains of Foraminifera. The nodules are common and occur at random throughout the soil (see Fig. 6 and 7 in Bal, 1975a).

2. Large carbonate nodules: These glaebules vary in size of from 300-3000 μm; some are observed in the field. They are irregular in shape, have diffuse or infrequently sharp boundaries, and are grayish in plain light. Their internal fabric is porphyroskelic, locally somewhat vughy, with a random fine crystic plasmic fabric. The smaller representatives of these nodules often have fibrous plasmic fabric[2] (Fig. 6A and 6B) and possibly represent the soft nodules observed in the field.

3. Soil nodules: These glaebules vary in size of from 180-600 μm, they are either spherical and irregular in shape with diffuse boundaries or lenticular with sharp boundaries. Their composition is practically identical to the s matrix. They differ in having a dense porphyroskelic fabric and a colour which is often yellowish brown in plain light, indicative of traces of organic plasma. The lenticular nodules appear to be characterized by a lamellar internal fabric. The nodules are common and occur scattered throughout the soil down to depths of approximately 100 cm.

Intercalary crystals. Distributed at random throughout the s matrix many single or clustered carbonate crystals occur varying in size of from 10-200 μm; the crystals are usually rounded and may be broken. Part of them appear to have been developed by recrystallization of small carbonate nodules, their rounding due to as yet unchanged nodules (see: fig. 6 and 7 in Bal, 1975a).

Cutans. Patchy, thin calcitans occurring on the surface of vughs, channels, and

[2] Bal (1975 a) distinguished three carbonate plasmic fabrics, i.e.: *crystic, calcic,* and *fibrous.* In fibrous plasmic fabric the $CaCO_3$ occurs as needle-shaped crystals (lublinite).

Table 1. Particle size distribution (mean values of 22 samples and standard deviation)

	Fine sand (250–100 μm)	Very fine sand (100-50 μm)	Coarse silt (50–20 μm)	Fine silt (20–2 μm)	Clay (< 2 μm)
% by weight	0.4	5.9	49.7	29.5	14.5
Standard deviation	0.2	1.1	3.4	3.3	1.6

excrements were observed primarily in the topsoil. They consist of fine crystal needles. Sometimes a void is completely filled with such needles thus forming a crystallarium. The number of cutans decreases with depth. This needle-shaped calcite is often termed lublinite (e.g. Kowalinski et al., 1972), it denotes the specific X-ray detectable habit of this mineral (Dana et al., 1932; Sehgal et al., 1972).

Physical characteristics

The granulometry of the soil presents remarkably little variation, as shown in Table 1. Both medium and coarse sand are notably absent. With the vast preponderance of grains in the 50-20 μm fraction goes the relatively smallest standard deviation. The weight percentage of the various fractions are all within the ranges given by Rozanov (1951) for loess in Central Asian foothills (allowing for slightly different size limits employed by the latter). The arithmetic quartile deviation of the size distribution is 15 μm, the geometric deviation or sorting coefficient according to Trask (1932) is 2.8 indicative of a normally to well sorted sediment. The arithmetic quartile skewness is –2.2 which shows the slightly asymmetric distribution of the grain size with the median value nearest to the high quartile value.

Apart from its typical loess texture the soil is loosely packed. This is evidenced by a low bulk density of 1.1–1.2 g per cm^3 and calculated pore space of 53–57 %.

Mineral composition

The soil was found to be composed of seven sorts of minerals or groups of minerals: quartz, calcite, feldspars, micas, chlorites, and a 'rest group' (i.e. few amounts of other minerals), as well as X-ray amorphous material.

The $CaCO_3$ observed includes calcite and biogenic carbonates which contain remains of Foraminifera. A detailed description of the various fabrics in which $CaCO_3$ occurs in the soil is given in the section on micromorphology.

The feldspars, as observed on sand fraction minerals, consist of K-feldspars (mostly orthoclase, further microcline) and Na-feldspars only (mostly albite with some oligoclase). The ratio K-feldspar/Na-feldspar is 2.3 for the fine sand, 1.6 for the very fine sand, and 0.9 for the coarse silt fraction.

Minerals of the mica-group, when of sand size, mainly consist of biotite and muscovite, whereas also minor amounts of sericite were detected. X-ray diffraction

Table 2. Heavy mineral composition of the very fine sand fraction (average counts of 10 samples and standard deviation).

Mineral	% by number	SD	Mineral	% by number	SD
Opaque	15	3.6	Sillimanite	tr	—
Tourmaline	tr	—	Epidote	14	2.1
Zircon	1	—	Zoisite	8	2.4
Garnet	4	1	Hornblende	45	4.6
Rutile	tr	—	Augite	1	—
Anatase	tr	—	Hypersthene	tr	—
Brookite	tr	—	Chlorite	6	1.9
Titanite	tr	—	Mica	13	4.6
Staurolite	1	—	Apatite	tr	—
Disthene	tr	—	Alterite	7	1.2

analysis, however, showed the preponderance of illite among these minerals in the finest fractions.

Relative to the chlorites present it was found on X-ray diffraction analysis that these minerals gave weak first and third order reflections (1.42 and 0.47 nm, respectively), but strong second and fourth order ones (0.70 and 0.35 nm, respectively). This, according to Grim (1953), is indicative of chlorites rich in iron.

The rest group is essentially made up of the heavy isolate. Table 2 details its composition in the very fine sand fraction of the soil. The heavy fraction appears to be characterized by a hornblende-epidote(zoisite)-mica association, constituting 80 % of the total fraction. The minerals derived from metamorphic rocks: staurolite, disthene, and sillimanite, as well as the stable minerals tourmaline, zircon, garnet, and the titaniferous minerals, all are very minor constituents. The heavy isolate constitutes 2.5 $\pm$ 0.6 % of the total weight of the 50-100 μm fraction. This percentage is within the range of 2-5 % given by Rozanov (1951) as characteristic of loess deposits in Russian Central Asia.

Relic minerals, such as weathered feldspars which were microscopically identified, are grouped here with X-ray amorphous materials.

The minerals that make up the soil show a clear particle size function, although a high degree of qualitative similarity between size fractions exists. Our quantitative estimates of the mineral composition per major grain size fraction are based on X-ray diffraction analyses of each of these fractions, on microscopic observations, and on chemical analyses of the carbonate content. Results are presented in Table 3. Each fraction appears to be dominated by one or two mineral species.

Thus, micas alone constitute more than half of the fine sand fraction. The unweathered feldspar and quartz are particularly present in the very fine sand, and coarse silt fractions; calcite tends more or less to prefer the fine silt fraction, whereas chlorites are predominant in the clay fraction. These data combined with the results of the particle size distribution of Table 1 and the determination of the carbonate content (Table 6) provide the basis for our computations on the average mineral composition of the soil. This is estimated to consist on average (10 samples) of 25 %

Table 3. Mineral make-up per particle size fraction.

Mineral	Estimated percentages by number per particle size fraction				
	fine sand 250-100 μm	very fine sand 100-50 μm	coarse silt 50-20 μm	fine silt 20-2 μm	clay < 2 μm
Quartz	15	25	30	20	5
Calcite	10	20	20	25	20
Feldspars	15	25	20	10	tr
Micas	55	20	15	10	10
Chlorites	<5	<5	<5	25	50
Rest group	tr	<5	<5	tr	tr
X-ray amorphous	<5	<5	10	10	15

quartz, 20 % $CaCO_3$, 15 % feldspars, 15 % micas, 15 % chlorites, 2-3 % of rest-group minerals, and about 10 % of X-ray amorphous material. Differences in mineral composition between the various soil horizons were looked for, but no significant changes could be detected, except in carbonate content. Carbonate ranges from 17 to 25 % due to slight redistribution within the soil as discussed below (Table 6).

The quartz/feldspar ratio of the total soil materials is 1.7 (it is 1.2 for the sand fraction), but increases markedly with decrease in grain size, primarily due to the diminishing feldspar content in these fractions.

Köhler & Hellmers (1938), the first to study the mineralogy of Afghan loess – sampled in the Wardak valley, west of Kabul – concluded to a broadly similar composition. They showed the sand fraction to mainly consist of quartz, Na- and K-feldspar, biotite, augite, hornblende, and zircon; however, here the silt fraction contained less quartz and more mica and hornblende.

Our findings on the clay mineral composition are a corroboration of the French research on clays of similar loess deposits in N. Afghanistan, as reported by Anon. (1967) and Pias (1971).

Trace element composition

For an assessment of the trace element status of the soil studied, the total content of eight such constituents was determined. This content varies within narrow ranges as might be expected for this homogenous soil (Table 4), and no pedogenetically induced depth function occurs, except for the elements Zn, Sr, and Ba. There is a slight enrichment of Zn in the A-horizon of up to 85-90 mg/kg, whereas Sr and Ba reach maximum values in the ca-horizon or slightly above.

Table 4. Trace element composition (mean values of 10 samples and standard deviation).

	V	Cr	Co	Ni	Cu	Zn	Sr	Ba
Content in mg/kg	0.6	11.0	23.2	49.1	19.4	75.9	18.7	525.0
Standard deviation	0.5	4.7	8.1	7.7	3.7	5.7	4.3	112.0

The total content of all elements determined is well below the average values found for the crust of the earth. Yet the content of Co, Ni, Cu, and Zn, whose physiologic importance is known is at or above the average computed for soils as 8, 40, 20 and 50 mg/kg, respectively (Kovda et al., 1964). The values found for both V and Sr are unusually low according to the range given by Mitchel (1964). It is of interest to note that Kovda et al. (1964) presumed the former four elements to be possibly deficient in serozems in loess deposits in the USSR – a major reason for their analysis in the serozem on the 'Dast-i-Esan Top' plain. The above authors reported the average total trace element content of Russian loess to be mostly lower than found here, with Co about one-third, Ni and Zn about one-half, and Cu about equal to the mean values given in Table 4.

Discussion

This chapter will be separated into three sections, i.e.:
- genesis of the soil
- source of the parent material (loess) of the soil
- agricultural aspects of the soil.

Genesis

In the loess on the 'Dast-i-Esan Top' plain soil formation has only limited advanced, as expressed in the classification as an Inceptisol of the soil developed. This is evidenced by the 'freshness' of the mineral grains on microscopic observation, and the lack of textural or mineral profile development. Our observations on the mineralogy corroborate the evidence obtained from grain size analysis with relation to the striking uniformity of the soil; it has to a large extent retained its original mineral composition. Only the amounts of $CaCO_3$ and of the elements Zn, Sr, and Ba vary with depth. Moreover, the unconsolidated nature of the soil materials might be indicative of the relatively young stage of formation of the soil (Glukhov, 1956).

Thus, only faunal activity, calciumcarbonate, and some trace elements remain important for the genesis.

Faunal activity

Essential in the genesis of the present soil is its fauna. Our micromorphological research, in particular of the pedotubules, amply demonstrates this point.

The aggrotubules var. 3 containing irregular aggregates have been formed by burrowing animals (e.g. Cicada?; Hugie et al., 1963). The modexotubules originated from animals which ingest soil material at random filling the channels with their excrements. It is suggested that a very small earthworm species might have been instrumental in their formation. A suggestion which is quite possible as a few small species of earthworms can survive in deserts and semi-deserts, for instance in Serozems (Kubiena, 1953; Kollmannsperger, 1956). Moreover, similar observations were made by Siderius (1973) in semi-arid soils of Botswana. However, based on the size of the excrements and the diameters of the channels the species seems to be very small compared to the size encountered in temperate region soils (Bal, 1976). As evidenced by the number of excrements earthworm activity is low. A considerable portion of the soil down to some 100 cm depth consists of the above pedotubules or their remains.

Due to the burrowing activity of soil animals, the ageing of the excrements (Bal, 1973, p. 82) and the decay of the tubules a highly vughy soil has developed (demonstrated in Fig. 4A, B, C, D and E). The shape and pattern of the voids and, consequently, the low bulk density appear to be induced by biological activity. Thus, this low bulk density is by no means a mere depositional (geogenetic) feature as is usually suggested.

In addition, study of the meta-pedotubules (Fig. 5A) proved of pedogenetic importance. The channels in which these occur have probably been formed by animals which push through the soil mass – producing a thick stress neocutan – and subsequently plaster their channel with mineral and organic material – forming the compound cutans (coined compound wrapping cutans by Bal, 1973, pp. 47-48)[3] observed (Fig. 5B and 5C). The cross-sectional size of the channels, and the thickness of the stress neocutan suggest their formation by a rather large animal species, for example an earthworm species. However, in view of the nature of the compound cutans, the intensive branching of the channels at greater depth, and the lack of excrements, formation of these channels by earthworms is considered unlikely.

It is also thought unlikely that wasps would have made the channels, because of the great depth in the soil at which these channels occur, and because of the abundancy of these. On the other hand, the channel, the cutan, and the neocutan strongly resemble constructions made by termites (Gennart et al., 1961; Lee et al., 1971). Formation of stress neocutans by *Coptotermes acinaciformis* and *C. brunneus* was described by Greaves (1962). The build-up of the compound wrapping cutans was described by Ratcliffe et al. (1940), Kalshoven (1941), Adamson (1943), Stoops (1964) and Lee et al. (1971, pp. 28-40) as a lining of the wall of the channel with excrements or soil material combined with saliva.

Formation of the tubules can be explained by filling of the termite galleries with material from horizon above. The filling of termite galleries by materials from less great depths (observed at depths of 8.5 m) also is not unusual (Robinson, 1958; Watson, 1960; Lee et al., 1971).

These meta-pedotubules are considered a relic feature as evidenced by the following considerations:

– Undisturbed channels only occur at depths below 100 cm from the surface and they are entirely filled with surface soil and relatively large fragments of the compound wrapping cutans. This filling may have been caused by burrowing of the fauna active at present.

– At less greater depth only remnants of compound cutans (pedorelicts) are present. Here the tubules have been destroyed due to current fauna activity (which forms the aggrotubules var. 3). Also, the soil nodules described above are interpreted to be pedorelicts: transformed remains of the compound wrapping cutans.

[3] '*Wrapping* cutans are formed through actively wrapping up or plastering a soil material with the cutanic material by organisms.' (Bal, 1973, p. 47.)

– Field observations show that these relic features are not an isolated phenomenon, but occur continuously over extensive areas.

In the Central Asian part of the USSR termites of the family Hodotermitidae in particular of the genus *Anacanthotermes* are of the utmost importance (Ghilarov, 1962). They are typically soil termites, and tunnels of *A. ahngerianus* are reported by Ghilarov to reach a depth of 10-15 m in the Golodnaya steppe. In view of its nearness to the USSR and more or less similar conditions, it is not impossible that also an *Anacanthotermes* sp. formed the galleries in the soil presented in this paper.

Other biological features of minor importance include the isotubules in the surface soil formed by insects, and the organic ellipsoids (described under aggrotubules) interpreted to be formed by Oribatid mites.

Carbonate

By translocation the content of calcium carbonate increases from 16-20 % in the top 25 cm to 22-25 % between 25 and 150 cm (Table 6).

The vertical distribution of Sr, and of Ba in the soil repeat that of $CaCO_3$ (Table 6). This very distribution may be expected as in calcareous soils relatively large amounts of Sr occur as $SrCO_3$ (Goldschmidt, 1954), and calcite serves as host mineral for Sr and Ba (Mitchell, 1964; Krauskopf, 1967). The same behaviour of Sr relative to Ba has also been observed in soils of Central Sudan (Buursink, 1971).

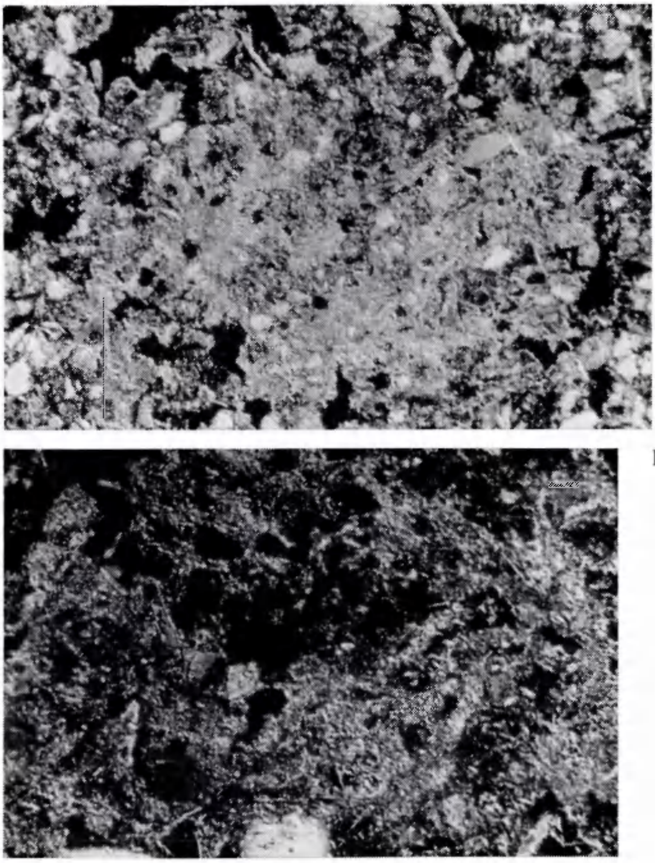
The trace element Zn, on the contrary, accumulates in the surface soil up to 85-90 mg/kg (average Zn content of the soil 76 mg/kg; Table 4). This might be considered to be associated with some accumulation of organic substances.

Our field and micromorphological observations show this carbonate differentiation to be primarily due to the formation of the *large carbonate nodules* below about 50 cm from the soil surface. In view of their shape and often diffuse boundary and their formation in the soil s-matrix, these glaebules are considered to have formed in situ. The glaebules with sharp boundaries appear to be isolated from the material in which they are embedded by faunal activity.

The translocation of carbonate is further evidenced by the presence of lublinite in cutans and carbonate glaebules. This is because the crystal needles of lublinite occur in voids which pleads in favour of their authigenic character; moreover such needles can hardly be allogenic because they would not survive a drastic transportation in a water stream or a dust storm (Bal, 1975a).

Lublinite is a form of calcium carbonate only to be preserved in xeromorphic soils. This is a confirmation of observations made by Kowalinski et al. (1972) on a soil in loess in China and appears to be in agreement with the finding of Sehgal et al. (1972) that in Indian soils lublinite occurs only above the highest water table.

The authors observed that the calcium carbonate nodules formed in situ as described above may start with an accumulation of lublinite (representing soft glaebules) which may change into firm glaebules with a dense fine crystic fabric (Fig. 6A and 6B). This same phenomenon was observed in a German Vermustoll (Tschernosem) by Bal (1975a). It may corroborate the general assumption that hard carbonate glaebules formed in si'u originate from soft powdery forms, an assumption



A

B

Fig. 6. Carbonate nodule (Fig. 6A: crossed polarizers; × 64), part of which consists of lublinite (Fig. 6B: crossed polarizers; × 200).

which has been demonstrated by Wilbert (1962).

In situ formation of carbonate nodules has been described by a number of authors for various soils (Boulaine, 1957, 1966; Durand, 1959; Gile, 1961; Tolchelnikov, 1962; Wilbert, 1962; Gile et al., 1965, 1966; Blokhuis et al., 1968-1969; Hrasko et al., 1972; Sehgal et al., 1972).

Thus, forms of carbonate accumulation in arid region soils have come to be regarded as diagnostic for the stage of soil development (Singh et al., 1946; Tolchelnikov, 1962; Suprychev, 1963; Gile et al., 1966; Sehgal et al., 1972). In the genetic sequence of carbonate accumulation developed by Gile et al. (1966) for non-gravelly soils, the common carbonate nodules accumulated in the present soil qualify for stage II in this sequence of four divisions, indicative of a relatively young stage of soil development. Apart from climatic reasons the formation of glaebules in this soil proceeds slowly because of the relatively intense biological activity. Only when a glaebule has attained a certain consistency can it continue to harden without being affected by disruptive influence of the soil fauna.

Although small carbonate nodules may be formed by disruption of large, but rather soft nodules, elucidation of the origin of the *small carbonate nodules* and *intercalary crystals* is more ambiguous, not only because of their distribution, but also in view of their size and rounded shape.

With reference to their distribution the Russian author Minashina considers calcite crystals in loess as ,primary' if they are uniformly disseminated throughout the deposit (in Parfenova et al., 1965, p. 89). Although Minashina's idea is understandable, we agree with the statement of Parfenova et al. (1965, p. 89) that uniform distribution of carbonate crystals is no sufficient indication for their geogenetic character. As shown above redistribution of carbonates occurs in the present soil. Therefore it is also possible that carbonate crystals and small carbonate nodules have formed in situ.

With reference to their size Minashina considers crystals of calcium carbonate in loess as 'primary' if their dimensions are similar to those of the bulk of the primary minerals (Parfenova et al., 1965, p. 89). But, according to Parfenova et al. the similarity in the dimensions of the crystals of carbonate and primary minerals again cannot serve as proof that the former are also inherited. In view of their lower stability calcite crystals would not retain their dimensions during transport to the same extent as, for example, quartz or feldspars. Both its weatherability and high specific gravity would favour the calcite grains to be of smaller size than the bulk of the mineral grains As appears from Table 3, the amount of carbonates in the fine silt fraction is in fact higher than in the coarse silt part, which comprises the bulk of the soil materials.

Brewer (1964, p. 293), Parfenova et al. (1965, p. 89) and Sehgal et al. (1972) suggested that the rounded shape of this feature is due to abrasion during transport, the latter basing their idea on the observations of such rounded 'primary' calcite crystal grains in aeolian deposits of the Indian Thar desert (Wadia, 1966). However, in our opinion, rounding does not necessarily imply transportation from elsewhere:

– Rounding of the large crystals appears to be due to the stage of recrystallization of the small carbonate nodules from which they may be formed. The roundness then is a part of the nodules not yet changed.

– Another type of rounding may be achieved by partial dissolution of carbonate by soil moisture or its passage through the intestinal tracts of the soil fauna.

Although the origin of the intercalary crystals and small carbonate nodules is not certain, some of the carbonate is considered primary as also recognizable Foraminifera are present In addition, the size distribution might be considered an indication of the allogenic nature of part of the $CaCO_3$. But, apart from this we do agree with Parfenova et al. (1965, p. 90) that it is impossible to distinguish primary carbonate crystals from secondary ones when these occur scattered throughout the soil, unless the crystals are large and not rounded.

It is of interest to note that currently the calcareous character of this kind of soil is well-expressed in its classification at the Subgroup level as calcixerollic (Anon., 1970).

Source of loess

The mineral composition gives some indication on the source of derivation of the loess. The minerals quartz, orthoclase, microline, albite, and mica all are inferential of acid igneous or metamorphic rock provenance. Sericite is invariably secondary and is a stress mineral (Milner, 1962). Whereas chlorite is of hydrothermal or low grade metamorphic origin, a (metamorphized?) limestone component as source of derivation is required for calcite. This is in agreement with the mineral composition of the heavy fraction of the soil: a hornblende, epidote (zoisite), mica association. Epidote and hornblende are also the dominant heavy minerals of loess in central Afghanistan (Loger valley near Kabul), but here micas are lacking (Pias, 1971).

An indication that both igneous and metamorphic rocks served as source material for the loess on the 'Dast-i-Esan Top' plain is given by Rozanov's (1951) work. The analysis of the heavy fraction of loess in the S.W. Tadzhik SSR, north of Amu Darya, shows traces of epidote only, the typical metamorphic component. Rozanov further observed a preponderance of mica together with amphiboles and pyroxenes.

Another indication of the source area of this loess might be obtained from the content of trace elements. In particular the relatively low amounts of Ni, Cu, Zn, V, and Cr reflect the inheritance of the soil materials from the felsic type of rock concluded to on the basis of our mineralogical observations (Kovda et al., 1964; Mitchel, 1964). The average Co values of 23 mg/kg are too high for this, but are at the same level as given for silt carried by the Amu Darya of 16 mg/kg (Kovda et al., 1964). Since limestones are generally low in Co too, a high content of Co might be assumed for such rest group minerals as the hornblendes and micas, in particular the biotites.

However, more mineralogical research as well as a better knowledge of the geology of the region would be required to pinpoint the source area of this loess.

Agricultural aspects of the soil

Two aspects are of importance, i.e. chemical fertility, and the physical behaviour of the soil when it is wetted.

Chemical fertility

The ferromagnesian minerals, such as the hornblendes and biotites, as well as the iron chlorites present in the soil are held to contain a considerable variety of trace metals. Minor elements need not necessarily to be built up into crystal lattices of their host minerals; they can also occur in micro-fissures in these minerals as components of a material, principally iron and aluminium oxides and silica (Goni, 1966). On the basis of ionic radii the smaller ions chromium, cobalt, and nickel tend to substitute for magnesium, whereas the larger ions, vanadium and zinc, prefer iron in these minerals. Copper may also substitute for sodium in feldspars. K-feldspars and calcite in particular serve as host mineral for the elements strontium and barium (Nockolds et al., 1948; Goldschmidt, 1954; Mitchell, 1964; Krauskopf, 1967). As a

Table 5. Average trace element status (in mg/kg) of two Serozems formed in loess, i.e. the soil presented in this study and the other from the U.S.S.R.

Trace element	Afghanistan	U.S.S.R. (after Kovda et al., 1964)
Cobalt	23.2	8.5
Nickel	49.1	25.5
Copper	19.4	18
Zink	75.9	40

result of this the potential chemical productivity of the soil might be expected to be high as far as Ca, K, Mg, Fe, and trace elements are concerned.

Our findings on the micronutrient supply of the soil in the North Afghan loess confirm Rozanov's (1951) idea that this type of soil is sufficiently provided, indeed. The content of Co, Ni, and Zn equals or exceeds that in Russian Chernozems, believed to be characterized by an optimum combination of microelements (Kovda et al., 1964). As for Cu, Mitchel (1964) states that 10-50 % of the total content generally is in available form. With the lowest total copper content in the surface horizon of the present soil about 15 mg/kg, this would leave available copper not alarmingly low.

When the content of the major trace constituents Co, Ni, Cu and Zn is compared with Russian Serozem soils, the superiority of the present soil is evident (Table 5). The trace element status of the Russian soil was reported upon by Kovda et al. (1964).

Physical behaviour

An agriculturally disadvantageous effect is the proneness of the soil to subsidence when it is wetted. Sinking of the fluffy, porous soil when it is wetted is either due to soil compaction or to subsurface removal of soil material (by a subterranean river course?) or both. Attention must be paid to this phenomenon because the 'Dast-i-Esan Top' plain is considered for irrigated crop production. Some possibilities for this very susceptibility will be suggested here:

- The highly vughy basic fabric.
- The presence of subterranean channels.

Highly vughy basic fabric. In this highly vughy soil (bulk density 1.1 g per cm^3) with high susceptibility to surface slaking (as observed in the field), compaction is entirely conceivable with soil material saturated by water. For example, the stability of the fabric may be lost, by which the vughs will be closed and consequently the fabric will change into porphyroskelic.

It might be possible that this compaction is also induced because the soil material turns into a mobile slush and the soil particles moving down (much like the process of internal slaking described by Jongerius, 1970).

However, compaction alone would require the consolidation of loess to considerable depth. Formation of a 1 meter deep depression, for example, would necessitate

Table 6. Vertical distribution of $CaCO_3$, Sr, and Ba in a representative profile of the Calcixerollic Xerochrept.

Depth (cm)	$CaCO_3$ (% w/w)	Sr (mg/kg)	Ba (mg/kg)
0– 25	19.5	15	510
25– 60	24.1	24	660
60– 90	25.2	25	630
90–120	24.9	20	520
120–150	22.3	15	510

the increase in bulk density from 1.1 or 1.2 to 1.4 g per cm^3 for a 5-7 m deep soil column.

Subterranean channels. On the other hand, sinking and caving of the soil may well be combined with piping or tunnelling (see: Description of the landscape) wherein also the subsoil erodes from under the surface leaving tunnels. Such a phenomenon was described by Fletcher et al. (1954). A network of pipes would permit mechanical transportation of particles underground and cause the soil above it to settle. In this context it is of interest to consider the large channels in the subsoil which might have been formed by termites. Ghilarov (1962) observed, near Samarkand (in the Southern part of the USSR), the formation of deep karst-like funnels due to destruction and washing away of soil and subsoil layers when irrigationwater penetrated deep into termitaries along branched channels.

Most likely a combination of soil compaction and subsurface removal of soil material would affect the soil on the 'Dast-i-Esan Top' plain when irrigated. Finally, the possibility should not be excluded that subsidence is enhanced by earthquakes, a frequent phenomenon in the area.

In the Tadzhik SSR, when such loess land is prepared for irrigation or as building site, the subsidence is actually accelerated through repeated artificial saturation of the soil with water and by levelling the land (Glukhov, 1956). According to Glukhov soils in loess with bulk densities of 1.4 g per cm^3 or more are not susceptible to subsidence any more. In view of the limited area of cultivable land in Afghanistan intensified use of the soil on the 'Dast-i-Esan Top' plain may well warrant a similar procedure.

Conclusion

The soil formed in North Afghanistan loess is in a relatively recent stage of development and classified as Calcixerollic Xerochrept (Anon., 1970). Its uniform texture, mineral build-up, and low bulk density (by its highly vughy fabric) all testify to this. The extent of redistribution of $CaCO_3$ combined with Sr and Ba, however, reveal best the degree of pedogenesis.

Despite its recent character the soil contains pedorelicts which may be filled tunnels of soil termites. This fauna disappeared probably due to change in soil moisture conditions, which is thought to be associated with the rapid downcutting of the riversystem through the loess deposit. Although termites are a feature of the past they still belong to the 'soil morphologically characteristic fauna' (Bal, 1970) which is composed of cicadas and earthworms (?), termites, insects and oribatid mites.

If this soil is to be irrigated two soil phenomena deserve particular attention at an early stage: soil subsidence, and the establishment of a fauna adapted to a different moisture regime. With regard to these the following two recommendations are made:
1. Acceleration of subsidence and levelling of land along procedures described by Glukhov (1956); and
2. Mass introduction of earthworm species suited for maintaining good tilth in the presence of a satisfactory level of organic matter as described for comparable conditions in the Southern USSR by Ghilarov et al. (1966). This is because of the good results of such introductions with respect to the physical constitution of the soil, breakdown of organic matter, and to crop yield. These results were not only obtained in the USSR, but also in other regions, e.g. in New Zealand, Australia and the Netherlands (Stockdill, 1959; Stockdill et al., 1966; Barley et al., 1964; Rhee, 1963, 1965, 1969a, 1969b, 1971, 1975; and others, see: Edwards et al., 1972, pp. 168-173).

Suitable earthworm species must be chosen with deliberation. This is because different species have their own particular function in the decomposition and translocation of organic materials in the soil as well as in the formation of soil structure (Bal, 1976).

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Appendix 1

Typical profile: description according to FAO 'Guidelines for soil profile description'.

A_1 0 - 21 cm: Brown to dark brown (10 YR 4/3) moist, silt loam; weak fine subangular blocky; slightly sticky and slightly plastic, very friable, soft; common very fine tubular pores; strongly calcareous; many very fine roots; clear smooth boundary.

B 21 - 45 cm: Brown to dark brown (10 YR 4/3.5) moist and pale brown (10 YR 6/3) dry, silt loam; weak fine subangular blocky; slightly sticky, slightly plastic, very friable, slightly hard; many very fine tubular pores; strongly calcareous, very few small spots of soft white $CaCO_3$ mycelia; very few, very fine roots; gradual smooth boundary.

C 45 - 160 cm: Dark yellowish brown (10 YR 4/4) moist and light yellowish brown (10 YR 6/4) dry, silt loam; slightly sticky, slightly plastic, very friable, slightly hard; many very fine tubular pores; strongly calcareous, very few small hard

whitish $CaCO_3$ nodules; filled anastamosing animal burrows; very few very fine roots.
C 160 - 300 cm: Similar to horizon above.

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