Formation and Reclamation Properties of Some Piedmont Plains in the Arid Zone of the USSR

V. V. EGOROV

Dokuchaev Soil Institute, Moscow (USSR)

Lands of the alluvial plains are extensively used by man. Vast areas of such lands in Central Asia have long since been used for irrigated farming which was greatly facilitated by the flatness of these lands, availability of water sources suitable for irrigation and certain favourable properties of the alluvial soils.

Irrigation is closely associated with the peculiar, structural features of the alluvial plains. Certain methods of the preservation of the irrigated lands' fertility have been inherited from the past and some of them have not lost their significance even nowadays. However, these methods are specific for the alluvial surfaces and should be defined more exactly when employed on territories of different origin. A non-critical approach to their application on lands of different origin was not infrequently responsible for serious failures which resulted in an unsatisfactory exploitation of some irrigation systems and necessitated their subsequent reconstruction sometimes accomplished not very successfully.

It is obvious that a careful consideration of natural peculiarities is a prerequisite of a better utilization of both the experience of the past and the newest scientific data.

It should be emphasized that the alluvial plains have not yet been fully investigated and this paper aims at filling the gap in the knowledge of the structure and reclamative properties of one of the specific types of alluvial plains formed in the zones of deep piedmont troughs.

Soviet literature on this subject holds to the opinion that the variation of natural and reclamative peculiarities within certain territories is closely associated with their geomorphological structure. Apprehension of the geomorphology of a terrain usually contributes to the knowledge of its other significant peculiarites. For instance, within the framework of geomorphological subdivisions there regularly vary such indices as the character of terrain topography, composition of rocks, hydrogeological and geochemical peculiarities, properties of the soil cover and a number of other elements determining the structure of a natural landscape. In this connection various soil changes resulting from the economic activity of man can be observed within the confines of a natural geomorphological region. In regions of this kind implementation of reclamation measures may usually be more effective.

Peculiar features of the formation of alluvial plains in the zones of piedmont troughs

Piedmont alluvial plains (the term "piedmont plains" implies that they differ from the foothill sloping plains of deluvial-proluvial origin) of this type are formed in the foothills of mountain systems in the zones of deep compensational troughs. The vaster a trough zone, the sooner will a considerable surface (river) runoff carrying large amounts of fragmental products make for it.

Accumulation of fragmental products at the base of the alluvium (first close to the mountains) results in the formation of easily permeable pebble layers, later supplemented by sand-gravel deposits. These layers are more frequently formed within a system of alluvial fans and in the course of time they are often buried by new layers of alluvium. Being buried, such layers, composed of pebble, gravel and sand, significantly influence in the future the reclamative properties of lands in a certain portion of such plains.

The main thickness of alluvial deposits is formed (especially in the subsequent stages) due to the precipitation of the suspensions from the slowly moving or stagnant waters which periodically or continuously flood the trough surface. This process is characterized by a specific differentiation of the suspensions according to particle size. Further distribution of sediments is influenced by the simultaneously formed peculiar alluvial mesorelief (lithomorphogenesis).

While analysing the peculiar features of the structure of alluvial thicknesses of different age and using the data of modern observations over the contemporary forms of river accumulation occurring in similar conditions, it is possible to reveal the successive stages in the formation of piedmont alluvial plains, to reconstruct characteristic features of their former structure and to establish regularities of the lithogenesis as well as some other structural peculiarities which continue to affect the contemporary processes occurring near the earth surface.

At an early stage of a trough zone filling with alluvium, a river stream escaping the mountain area comes to a slopeless surface. The character of water flow quickly changes: there appear slowly moving jets, floodings of stagnant water, lakes and waterlogged areas. Large amounts of water coming to the plain remain here and are subsequently spent on evaporation. The transportation of the suspended solid particles is followed now by their deposition and accumulation. This process simultaneously results in the accumulation of chemical products.

The formation of stagnant-water floodings is the most vivid but, with respect to consequences, not the main feature of the future alluvial plain development. Having come onto a slopeless surface, the river stream cannot instantly stop and some water jets continue moving (under the effect of the energy contained in the stream) in the flooded area transporting part of the suspended material which gradually sediments in the direction of the inflowing jets. This results in the formation of a knoll or a submerged spit along every jet and in the development of the first, earliest forms of the future alluvial topography.

By decreasing the depth of water, the submarine spits formed in the directions of the inflowing jets slow them down and make the water stream deviate to the left and to the right.

For this or maybe for some other reasons the most intensive sedimentation is soon taking place at the jet edges where the jets adjoin the stagnant-water floodings and are most intensively slowed down. The accelerated sedimentation is also facilitated at the jet edges by the appearing above-water vegetation and primarily by the reed (Phragmites communis). Some time later, in the direction of each jet there appears the subsequent alluvial form having a shape of a peculiar chute with a somewhat uplifted bottom and even more uplifted edges. Over a certain period of time the river jet moves inside such a chute penetrating still further into the flooded area. The subsequent accumulation of alluvium on the submerged banks (along the jets) heightens them to such an extent that they emerge from the water and can serve as an arena of further sedimentation only when covered with flood waters.

For the stream to be able to move in the created bed there should exist certain gradients which are formed by the stream itself by leaving a somewhat bigger part of the suspended material at the beginning of its movement. Gradually such gradients are created on the entire plain due to the migration and dissipation of the runoff. These gradients are always small and usually do not exceed 0.0002–0.0003. Nevertheless, they ensure the low-water flow. However, during the floods the turbid waters continue overflowing the banks, transporting part of the suspensions beyond the beds. The coarser suspensions sediment in the riverain zone. The flood waters become completely free of the suspensions in the flooded area of the surrounding plain.

The contrast forms of the topography are not created by the flood-water sediments which uniformly cover flat surfaces, on the contrary, they contribute to their flatness.

Thus, this stage results in the development of the two principal forms of the primary accumulative relief: the near-bed elevations (crests) with the river streams on their tops, and the vast flat plains between them periodically flooded by temporary streams. Outside the main accumulation zone, closer to the outer edge of the trough, there remain the flooded areas where the streams stop flowing.

The flowing of the stream on the elevated elements of the topography is a common feature of the majority of accumulative plains though the formation of such elements of the relief in the closed troughs results in a subsequent transformation of the land surface and in the appearance of new conditions of sedimentation.

As a matter of fact, the once developed forms of topography affect the further distribution of the river discharge because the position of the stream on an ever increasing elevation cannot remain stable for a long time. The stream banks during floods are broken by separate jets which escape into the depressions. From time to time some of them develop into vigorous concentrated streams eroding the crest slopes. The higher the crests, the greater are the possibilities for erosion to occur. At a certain moment one of the escaped jets may increase to such an extent as to intercept the bigger part of the channel flow and direct it to the adjacent depression. From now on the fate of the former bed below the place of the break-through is predetermined: the water flow ceases rather quickly, the stream channel gets silted and almost completely disappears and only the elevation remains for a long time in the topography of the plain.

It is possible to point out approximately the maximum height of a separate crest, amounting to about 4 – 5 metres above the surrounding surface, when the stream flowing on its top becomes unstable and there is a real possibility for breaking one of the banks and flowing in a new direction.

Having abandoned the former bed, the stream floods the neighbouring depression with turbid waters. A new stream channel is formed later on among the flooded areas and all the forms specific of the preceding cycle develop.

Following the formation of a new crest stretching from the former one, the stream, in the course of time, will again become unstable; flooding of the area and breaking of the banks will occur more frequently and the former cycle, involving the development of similar alluvial forms, will be roughly repeated.

This process, however, cannot occur for a long time without changing the resultant forms. Upon the formation of several parallel crests the conditions for further sedimentation on the plain will change which will result in conditions suitable for the development of new forms somewhat differing from the former ones.

By limiting the dissipation of the runoff, the previously formed crests make the area of the accumulation of new deposits narrower and narrower increasing at the same time the rate of accumulation and preparing the conditions for a new stage in the formation of the plain.

The initial period of this new stage may be described as follows. Having reached the critical status on one of the previously-formed crests and having flown into a depression, the stream here is squeezed by the previously developed, closely-spaced elevations. It will fill the narrow depression with sediments relatively quickly and further accumulation of the alluvium will make the newly-formed elevation higher than the neighbouring old crests. The latter become relatively lower and lower and the alluvium from the acting stream channel will first cover their foot areas and slopes and then their central parts which will result in the formation of an exceptionally large alluvial form — a macrocrest at the place of the former intercrest depression. The slopes of this macrocrest overlap the two neighbouring, previously formed crests and a part of the depressions on their outer side. The height of the macrocrests may reach 10 – 15 m relative to the elevation of the depressions.

With the development of a macrocrest there appear conditions for the occurrence of new extensive lateral floodings fed by the overflowing flood waters from the main stream channel. Part of the flood waters will run over the gentle, prolonged slopes feeding groundwaters, moistering soils and leaving new layers of sediments.

Considering the forms of the surface of the plains in question, we should dwell on one of the erroneously treated peculiarities of their modern topography.

Literature on the subject holds to the opinion that the depressions between the stretching elevations were at one time formed due to the erosional activity of the river and represent the former valleys. Although such opinions have been expressed by many researchers they are in sheer contradiction with the character of the plain forming processes. All the principal forms of topography on the accumulative surfaces are the derivatives not of erosion but of the accumulative processes. The contrasting forms of the topography observed on such surfaces are nothing else but the consequence of a non-uniform rate of the sedimentation process in the different parts of the plain. The negative forms of topography occur in those places where accumulative activity is not excluded but manifests itself to the lowest extent which is always the case far from the river channels. In other words, depressions are not the active but the relatively more passive forms that also developed under the conditions of the accumulative activity of river waters.

There is only one particular element in the topography of the plains under consideration which is really of an erosional origin and is, most probably, responsible for the above-mentioned opinion.

Inside a chain of adjacent depressions half-divided by small secondary crests there seldom occur some broken stretches of shallow river beds which are obviously of an erosional origin. These forms developed in those places where large interbed depressions were partitioned off by the deposits brought by the lateral temporary streams. Their flooding resulted in the formation (starting from the upper sites of a certain macrodepression) of a peculiar cascade of small water basins. The overflow of water from the upper basins to the lower ones was responsible for the appearance of the above mentioned erosional down cuttings in the small secondary crests. Such down cuttings never occur either above or below these secondary crests. They are always local. Depressions must already exist for these erosional forms to appear.

Water transparency is another prerequisite for the development of the down cuttings. The inflow of turbid waters into depressions does not result in scouring but intensifies accumulative processes and brings about flattening of the surface up to the elevation marks of the small secondary crests, which rules out erosion. Any attempts in such cases to explain small erosional forms inside a depression as one continuous river bed of the main water discharge are not justified. The traces of the former beds should be sought neither inside the depressions nor in the places of the erosional down cuttings but on the elevations of the accumulative relief, i.e. on the crests where the most intensive accumulation of the suspended material was formerly going on. The bigger the crest, the more reasons are there to suppose that an exceptionally large stream or the main river bed were located exactly on its surface.

Speaking about the cyclic recurrence of the phenomena under consideration, one should take into account the possible burial of the early forms of the surface by the new ones which was accompanied by the formation of new strata. The subsidence of many piedmont plains during the Quaternary amounted to tens or hundreds of metres and this determines the thickness of their alluvium. The formation of such considerable thicknesses of alluvium was only possible owing to the multifold recurrence of the new alluvial forms at different levels which could not but make their structure more complex. However, either of the above-described forms of surfaces appeared each time and was fixed on the day surface.

Peculiar facies of alluvium

The general regularities governing the distribution of suspensions on the alluvial plains according to the particle size are, in many respects, obvious from the above-considered material.

A facies of sediments consisting of relatively coarser particles is formed on the elevations stretching along the river streams. More finely dispersed and thin-layered deposits are formed on the slopes of the elevations. The deposits on such surfaces may, on the whole, be assessed as medium and light loams with the inclusions of fine sand and silt-like (aleurite) intercalations. Fine-silt and clay sediments characterized by thin, sometimes hardly noticeable lamination are accumulated at the foot of the slopes. Relatively coarser intercalations appear there only sporadically. They were left by the streams which penetrated there after short-term floods. Such inclusions somewhat diversify the predominantly clayey and heavy-loamy composition of the alluvium in the depressions as well as in the flooded and lacustrine areas.

Apart from other peculiarities, the flood plain alluvium is often enriched with remains of organic matter which contribute to its darker colouring and account for the effects of reduction processes noticeably affecting its physical and physico-chemical properties and making them unfavourable.

The greatest possibilities for the formation of heavy grounds of the flood-plains exist at an early stage of plain development when its surface is practically not yet divided by the near-bed elevations and there are better conditions for flooding extensive areas. The thickness of such sediments cannot be considerable as they are dispersed on a vast area. When layers of these sediments are found in situ, they are related either to lacustrine or lacustrine-boggy ones. There is really close similarity between them, though they are not quite identical.

Upon transition to the further stages of plain formation, the zone of accumulation of particularly finely-grained rocks is localized on smaller plots mainly at the outer edge of the subsidence zone.

Further transformation of the facies conditions occurs at the stage of macrocrest formation. Clay deposits left in separate depressions during the previous stage of sedimentation are overlain by series of coarser deposits from the new crests. After that the coarser alluvium of the old crests is also overlain by the new, more finely-grained alluvium of the macrocrest slopes. Accumulation of flood plain clay or heavy loams recommences in the distant periphery of the macrocrests.

Thus, the process of sedimentation is not uniform in the different stages of formation of the plains under consideration.

At first, the sedimentation zones become narrower in the flooded areas. This is accompanied by an increase in the area of accumulation of the near-bed facies and aggravation of the conditions for the differentiation of the suspensions. Later, with an enlargement of the positive forms of topography, the area of alluvium accumulation on the flooded territory somewhat increases again shifting to the sides of the crests and to the general outer edge of the trough.

Environmental changes which had been occurring over long periods of time could not but affect the character of the composition of the alluvial thicknesses alongside with the above-mentioned changes caused by the plain-forming process itself. The changes in climate and vegetation, as well as development of river basins and melting of glaciers are known to have occurred during the Quaternary which could not but influence the mechanical and chemical compositions as well as the volume of fluvial suspensions, the character of their distribution and the rates of sedimentation.

The fact that great amounts of the material which gave rise to the formation of loessial covers had been brought to the plains in the middle of the

Quaternary (time of the development and completion of extensive mountain glaciation) was, for instance, of great significance for the conditions of Central Asia. The loessial rocks in some places serve even now as an arena of soil formation. The subsequent contraction and disappearance of some of the glaciers, as well as some other reasons had caused the changes in the composition of the suspensions and resulted in the fact that the later types of the alluvial formations in Central Asia scarcely resemble the loess-like rocks of the preceding epochs.

The modern period in the development of plains

The modern stage in the history of plains in Central Asia was characterized by the transition to the conditions of a relative tectonic rest. It could not but affect the surfaces we are interested in.

Under the conditions of tectonic rest rivers flowing on a piedmont plain could fill the former troughs with their alluvium, create minimum gradient all along their channels, escape after that from one tectonic trough and rush to a new base level of runoff. This was followed by the development of an erosional valley depending on the new base level.

However, the river cannot extend its erosional activity to the former accumulative area at once. It can be done after a sufficient deepening of the down cutting in the bedrocks confining the zone of subsidence.

Judging by the fact that in all the cases known to us rivers make only one down cutting in such rocks (usually as a narrow gorge), it is a difficult and time-consuming procedure. Only after making a sufficienly deep down-cutting in the bedrocks does the river extend its erosional activity to the area of former accumulation.

From this very moment great changes occur in the character and direction of natural processes going on in the plain: the river stream is confined to one deepening channel; former flooding of the plain and accumulation of the alluvium stop; vegetative and soil cover undergo transformation; the hydromorphic stages of alluvial-accumulative soil formation come to an end; there occurs a change in the general appearance of the landscape and only previously created forms of the topography retain their relatively unchanged shape for a long time.

Groundwaters and processes of salt accumulation

During the first stages of an accumulative plain's existence groundwaters are continuously fed by the river stream. Their reserves are replenished due to water percolation in the flooded areas and to infiltration from the river channels. The latter way is facilitated by the uplifted position of river channels on the plain and by the larger particle size of the alluvium in the riverain zone. The abundant recharge of the groundwaters ensures their high level in the flooded zone. At this period of time groundwaters can be spent only on evaporation into the atmosphere. Great amounts of water are transpired by vegetation. In the conditions of Central Asia, for instance, the total expenditure of groundwaters on evapotranspiration may reach 2000 mm annually.

This structure of water balance contributes to the near-surface continental salt accumulation. If one takes into consideration the fact that even relatively fresh waters of the Central Asiatic rivers contain from 0.2 to 0.4 g/l of dissolved compounds then it can be calculated that evaporation in the above-mentioned amounts will annually leave about 600 tons of different salts on every square kilometre of the terrain. Apart from the easily soluble compounds, these salts include considerable amounts of calcium and magnesium carbonates, as well as gypsum.

Exceptionally great amounts of chemical products, which in many respects determine the economic indices of the piedmont plains, had to be accumulated (under drainless conditions) in the thicknesses of alluvium during the Quaternary period. Easily soluble salts, for instance, constantly participate in the salinization of soils, grounds and groundwaters and may cause the so called secondary salinization of irrigated soils. All this results, as a rule, from the former history of the piedmont plains.

Under the present conditions when rivers turn from sources of groundwater recharge into drains, the former processes of salt accumulation do not usually occur any longer. However, those salts which were accumulated in the grounds, groundwaters and soils in the past are preserved for a long time. Formation of a river valley does not create conditions for their more or less significant removal. This is explained by the fact that the draining effect of a valley is seldom felt farther than 1 or 2 km from the river, whereas the total width of plains of this type may reach dozens or hundreds of kilometres.

But there is another reason for the preservation of former salt reserves.

Under arid conditions there occurs a comparatively rapid lowering of the water table (irrespective of the drainage conditions) as soon as the abundant recharge of groundwaters ceases. The only reason for this phenomenon to occur is intrarock evaporation. The rates of the lowering of the water table due to this reason are sufficiently great and comparable with the effect of horizontal outflow to the near-by natural drains.

Under the desert conditions of Central Asia the water table is lowered in this way to 15 – 20 m below the surface over several dozens of years. Over an age-long period of time the water table lowering may reach 50 metres or more (if there is no groundwater recharge at all) which may lead to a complete exhaustion of the first aquifer.

The water table lowering under the effect of evaporation affects the distribution of easily soluble salts in the desiccated zone in a peculiar way. The dissolved salts are only to a small extent or hardly at all concentrated in the remaining portion of groundwaters and gradually pass into the solid phase of the soils as soon as the pore space is freed of the soil solution. The amount of salts in the solid state approximately equals that in the dissolved state.

To apprehend this process one should recall the peculiarities of salt accumulation near the soil surface caused by the solonchak-formation process accompanied by increasing salinity. Under an active solonchak-forming process, the position of the capillary fringe is almost stable since the level of groundwaters is maintained by their recharge in spite of evaporation.

Intrarock evaporation accompanied by the lowering of the water table results in the stretching of the capillary fringe and in the disruption of capillaries. There appear isolated capillary-suspended solutions whose moisture is subsequently spent on evaporation and precipitating salts are uniformly distributed in the soil and geological layers. The salt concentration in the groundwater itself remains close to the initial one when such a process occurs.

These considerations make it possible to explain the frequently observed coincidence between the salt contents of the deep-seated groundwaters and the entire thickness of soils and grounds overlying them. Explanations can be furnished for the existence of local lenses of almost fresh groundwaters surrounded by saline ones. While undergoing little changes, they could remain from the time of an abundant flooding and freshing of the overlying soil plots in the past. Such phenomena are observed in some lands where irrigation was abandoned due to the extinction of civilization and which are characterized by stagnant groundwaters. On the other hand, saline waters which had existed at the time of former irrigation and then their level was lowered have been preserved in such lands over a long period of time. Waters of this kind occur in the Khorezm Delta of the Amu Darya, in the Murgab oasis and in other places.

Soil cover

The development of the hydromorphic stages of soil formation in many accumulative plains of Central Asia was completed in the remote past. On the larger part of their area the present soils have been developing as automorphic or zonal ones over several thousand years.

On the basis of theoretical prerequisites and analogies with the soils of younger alluvial plains of the same soil-climatic zones, it is possible to reconstruct (in a general way) the former development of soils on the surfaces under consideration. Such analogies with the contemporary stage are justified in this particular case because on different types of alluvial plains affected by flooding one can observe: similar surface formations; identical laws of sedimentation; generally similar aspects of water regime; as a rule, similar phasic development and change of hydromorphic-zonal biogeocoenoses. All this indicates a certain proximity in the conditions of soil formation. It is also of certain significance that in all the alluvial plains the soil-forming series of sediments colonized by the first vegetation and turned into the first soils are fragments of the soils which previously existed and then were destroyed by the streams in their upper reaches. In spite of the fact that the substance composition of the former soils changes in the course of erosion and transportation, the sediments contain some soil organic matter, available phosphorous compounds, incidental colonies and spores of microorganisms. It is no mere chance that river alluvium is easily colonized by plants and rapidly transformed into fragmentary but sufficienly fertile soils. In the genetic respect such soils can, at the first stages of their development, be related to the low-developed swampy and then meadow kinds of soils characteristic of one or another soil-climatic zone. At the same time, being situated on different elements of topography, in various conditions of moistening, soils within the confines of alluvial plains appear to be diversified indicating a difference in their ways of evolution.

The first soils appear on the uplifted sites of the riverain zone most abundantly colonized by vegetation.

Quite often plots in the riverain zone are first overgrown with reed and then with other water-loving cereals. Later, according to the observations made in different regions of Central Asia, trees begin to grow along the river channels, forming the so called corridor or riverain forests with shrubs and grasses. In Central Asia such groupings are called tugais. They consist mainly of several species of poplars *(Populus hibrida, P. diversifolia, P. alba* etc.), of willow *(Salix sp.)*, of tamarisk *(Tamarix sp.)*, elaeagnus *(Elaeagnus angustifola)*, etc.

The light composition of the alluvium in these places of plant growth usually unfavourably affects the soil-forming process. The predominance of quartz particles does not contribute to the formation of highly fertile soils. Not only the accumulation of fine earth and plant residues, but also their seasonal outwash during flooding are of certain significance. The role of tree species in the soil-forming process is not always favourable under the local conditions owing to the fact that the litter-fall is predoominantly distributed on the surface. The litter-fall is weakly fixed in the soils and the active surface layer of the soil remains shallow. Quite often it consists of a single sod layer immediately underlain by the alluvium which is only slightly affected by the soil-forming process. We have to relate such soils to the meadow-forest or soddy types with a relatively slight manifestation of the hydromorphic elements of soil formation.

The physical properties of soils in the river-channel belt are determined mainly by the light particle-size composition of the soil-forming rocks. The soils are loose, usually non-structural; they have good water permeability and low water capacity and hardly retain nutrients. Later on, when such soils are affected by the desert forming process, they become subject to desertic deflation earlier than other soils. The abundance of vegetation growing on the soils under consideration during the first stages of their development is explained by the favourable composition of groundwaters in the riverain zone which remain fresh here owing to a constant replenishment by the infiltrating river water.

The development of soils located on the slopes of the crests is going on in a different way. In the beginning, proper meadow soils are formed here. Subsequently, the meadow forms of soil formation change into meadow-solonchakous ones due to a gradual increase in the salinity of the underlying groundwaters and to the accumulation of easily soluble salts caused by evaporation. In the lower parts of the slopes the meadow-solonchakous soils are often changed to solonchakous ones, and solonchaks appear quite frequently at the foot of the crests.

The subaerial formation of soils in the depressions can be preceded by the sub-aquatic soil-forming process. Shallow, sun-heated flooded areas are easily overgrown by above-water and sub-aquatic vegetation. Slow accumulation of suspensions in the standing water of the flooded areas does not prevent ash nutrients and humus-like compounds from being accumulated in the root layer.

While drying, the sub-aquatic soils become an arena of subaerial soil formation. These soils, if they were affected by oxidation processes, and if they still remain covered with water, easily turn into meadow or meadow-swampy soils. They owe their oxidation to special properties of boggy vegetation. Such plants as reed, cattail, and a number of others can transport oxygen of the air through their stems and rootstock to the root ends which results in the oxidation of the suboxide products formed in the flooded rock.

On the other hand, the appearance of non-oxidised deposits on the dry surface does not allow an active soil forming process to occur at once. On the dried up surfaces with such deposits a break in biological activity is frequently observed. The former subaquatic soils covered with algae residues remain without vegetative cover for quite a long period of time. Later on, even at the stage of swampy and then of meadow soil formation such soils are distinguished by lower fertility.

The swampy-meadow forms of soil formation in the depressions are maintained by periodical floodings and shallow groundwaters until their salinity degree is not high. However, under the effect of moisture evaporation and accumulation of easily soluble salts, here as well as on the slopes the meadow forms of soil formation change into the meadow-solonchakous ones resulting in a decrease in soil fertility

Further changes in the development of the soil cover occur after the general drying up of the plain. From this time on, the majority of soils is developing in the direction of the zonal types. Nevertheless, for quite a long time they still preserve certain features of the former hydromorphic development which can be traced in their appearance and in some of their properties. The most frequent features of this kind are as follows: residual salinity, residual gleyization, presence of ferric and manganese oxides, as well as those of other elements, stratification and somewhat peculiar soil structure.

At the same time the upper horizons of soils undergo noticeable changes. Under the effect of precipitation they can gradually get rid of the easily soluble salts which may be leached down to a depth of 0.5 – 1.5 m below the surface thus increasing their amount at this depth. Soils with such distribution of salts are commonly related to the solonchakous or residually saline ones. In the case of lands irrigated in the past, besides the above-mentioned distribution of salts, one should take into account the after-effects of salt distribution caused by prolonged irrigation. A rather detailed description of such after-effects may be found in the special literature.

The fate of soils which existed at the intermediate stages of the formation of a plain before their burial under new layers of alluvium may be of certain interest. One can not say too much about them. The remains of soils formed in flooded areas occur more often and are better preserved in a buried state. They are found at a certain depth as interlocations darkly coloured with organic matter. Soils of riverian elevations are preserved rather seldom and only as fragments after their scouring by water jets.

With the new cycles of burial the easily soluble salts contained in the former soils had to pass into the solution and then they participated in the general salinization of the plain. Soil layers with gypsum represent an exception. Gypsum accumulations are frequently found in the buried horizons. The appearance of gypsum interlocations proves that salt accumulation processes were also characteristic of the past stages in the formation of the surfaces of plains resulting in the development of saline soils.

It is also possible to guess that with the enlargement of the forms of topography, the initial diversity of soil cover and its small-contour pattern had to be substituted by more and more homogeneous contours. The subsequent transition to the zonal conditions of soil formation was obviously accompanied by further levelling of the former differences in the soil cover.

While attempting to reconstruct the former development of soils on the plains in question, one more problem should be elucidated. At the closing stage of deposit accumulation on a number of piedmont plains of Central Asia, there occurred, as has already been pointed out, accumulation of relatively uniform loessial rocks. Their upper series were, most probably, formed during the middle Quaternary (Q_3). In many cases these loessial covers became widespread.

The products of nival weathering and glacial destruction of rocks in the high-mountain zone, most likely, constituted the sources of loessial rocks.

As is generally known, there is an aeolian hypothesis explaining the origination of loesses. It has lost its former popularity among the Soviet experts but not all its supporters as yet. Any obscure point in this respect could, to a certain extent, hamper the reconstruction of the former stages in the development of the present soil cover.

It is not an easy task, however, to dispute the alluvial hypothesis for the origin of covering rocks on the plains of the type considered here. Many peculiarities relating particularly to the nature of such plains are in a rather good logical agreement with this hypothesis which explains well the character of the present residual salinization of soils and grounds including the loessial thickness.

Effect of irrigation on soils of piedmont plains

Construction of irrigation systems and irrigation of lands on the drained plains re-create some features of the former situation which was characteristic of the period of natural flooding. This concerns mainly the water regime of soils, the status of their groundwaters and, partly, the accumulation of new mineral deposits.

When irrigation water is brought to the fields through a system of canals usually located on the elevations with light composition of rocks and unprotected against infiltration, there occur considerable losses of water replenishing groundwaters. Similar losses of water are observed in the fields under any system of irrigation.

It has been proved a number of times that up to 50% of water used for irrigation is lost on infiltration from the irrigation network in old irrigation systems. These losses of water result in a rapid rise of the water table after the start of irrigation, during the first period at a rate amounting to 1 – 2 m per year.

When groundwaters rise, their initial salinity frequently remains constant or even increases. It can decrease gradually only some time later. This increase in groundwater salinity is associated with the dissolution of salts contained in the solid phase of soils and grounds. Later, when the water table rises nearer to the soil surface and settles at a depth of 3 – 4 m, its rise is slowed down and the depth of groundwaters is stabilized by evaporation. An immediate consequence of this is the so called secondary salinization of soils.

When irrigation is applied for a long period of time, part of the lands, due to the effect of local movements of solutions, becomes less and less saline even if general drainage is lacking but the bigger part of the land becomes even more affected by salinization. Numerous attempts made in the past at irrigating such lands with shallow saline groundwaters without providing for drainage always ended in a failure. Moreover, they led to the deterioration of the salt status of the neighbouring, previously developed lands. Such consequences are quite natural. Any attempts at leaching and irrigating additional areas without constructing a drainage system increase the replenishment of groundwaters and result in a general rise of their level. At the same time evaporation on laylands decreases due to the reduction in their area which brings about a subsequent increase in evaporation on the irrigated fields. This results in deranging the mechanism which managed to maintain part of the lands in a state of unstable desalinization.

The case is somewhat different with lands adjoining a deeply cut river bed. The weak outflow of groundwaters from such lands ensures under the conditions of irrigation the removal of salts and the freshing of soils.

Thus irrigation is responsible for the specific changes in the distribution of salt accumulations. In the course of time these changes are observed not only in the soils, but also in the groundwaters to an ever increasing depth. Apprehension of these processes makes it possible to evaluate past experience correctly and not to repeat old mistakes under new conditions.

The irrigation water transports suspended particles to the fields thus gradually increasing the thicknesses of soils and changing their properties.

Desalinization of soils and their growing thickness under the conditions of prolonged irrigation are not the only positive results of the economic activity of man directed towards soils. Under the influence of abundant irrigation, cultivation, introduction of mineral and other fertilizers, sowing of legumes, alongside with the accumulation of agro-irrigational deposits there occurs a further improvement of some lands which manifests itself in an increased thickness of the humus layer, appearance of specific structure, density decrease, transformation of water-physical properties. The productivity of such lands increases.

Specific soils having no analogs among the natural formations have developed on old irrigation systems as a result of the above-described process. In the Soviet literature it has been suggested to relate such soils to special types of cultivated-irrigational or agro-irrigational soils of one or another zone.

Alongside with the formation of new cultivated soils another part of soils deteriorated under the conditions of land development without constructing drainage which dominated in the past. Such soils predominantly occur in depressions and on lower sites on the slopes of crests.

Apart from frequent secondary salinization, the properties of these soils are affected by some other causes, e.g. silt deposition from waste waters. Accumulations of such deposits remain uninfluenced by biological processes due to the scanty, or even lacking vegetation on them. This results in increasing clay content, ashy structure of the upper layer and deterioration of its water-physical properties. Such soils are also affected by the economic activity of man but they must not be related to the type of cultivated-irrigational soils; most likely, they belong to regressive formations — peculiar products of the former, spontaneous, drainageless cultivation of lands.

The Hungry Steppe alluvial plain

The Hungry Steppe alluvial plain is one of the prototypes of the formations under consideration. It is situated in a vast piedmont trough at the foothills of the Turkestan and Chatkal mountain structures. The trough here had been formed in the pre-Quaternary time but subsidences continued to occur during the larger part of the Quaternary and, apparently, stopped by the end of the epoch. After that the trough zone was filled with the alluvium of the Syr Darya and its tributaries — the Chirchik and Angren as well as a number of smaller rivers. The total thickness of the alluvium deposited during the Quaternary epoch reached 400 – 1200 m in the central part of the trough. Close to the mountains the deposits contain coarse-particle as well as pebble layers representing the remains of the buried alluvial fans. In the upper part of the profile there is a developed series of sands and fine-particle deposits left by a system of wandering streams in the flooded areas. This upper series of deposits originated at least during two subsequent stages. The last one ended in the formation of three macrocrests developed in different degree, and the concomitant depressions.

The earliest of them — the south-western one — is the most extensive. It is rather an independent alluvial, lacustrine-deltaic plain finally formed, probably, during the $Q_2 - Q_3$ epoch. Starting from the south-western flank of the Syr Darya alluvial fan, it also serves as a watershed between the Syr Darya alluvium and the complex of formations connected with the alluvial fan and dry delta of the Jizak river in the west within the confines of the same trough zone. The portion of the Hungry Steppe under consideration comprizes the Central Hungry Steppe plateau, an alluvial-lacustrine (after M. A. PANKOV) plain joined with the surface of the macrocrest. This complex terminates in the pre-kyzyl-kum depression. The trains of the foothill deluvial-proluvial inclined plain (bordering upon it in the south) on the side of the Turkestan mountain ridge partially overlap the alluvial forms and flatten the zone of contact depressions. But in some places these depressions remained. They are called Juzhnaya and Agatchinskaya.

The second well-developed macrocrest is situated to the east and north-east of the first one, and is separated from it along the entire stretch by the Jitysai, Sardoba and Karoiskaya depressions. This macrocrest includes the Bayaut loessial upland, the Mirsachul loessial ridge and the North-Western loessial upland which in the north-west gradually turns into the marginal Arnasai depression which has not been completely filled with alluvium.

The deposit composition of the entire second complex is in a close agreement with the formations of this kind superimposed on a vast zone of clayey deposits of the previously existed macrodepression with separate small crests.

The third (most eastern) macrocrest is not only the smallest one, but also the most strongly affected by the erosional processes. It is sepatated from the second macrocrest by the well pronounced Shuruzyak depression and the less pronounced Pakhtaaral depression. In the north-eastern portion of the trough the third macrocrest approaches the second one and together with the latter terminates before the Arnasai depression.

With the onset of the period of tectonic rest the Syr Darya river had completed filling the trough with alluvium in this last direction and, having got outside the trough along the eastern crest (formed at a later period of time), created on the plain a deeply down-cut valley. Later on the development of the Syr Darya valley was complicated by the formation of the two low terraces: the flood-plain terrace and the terrace above the flood-plain. The existence of these two terraces gave grounds to refer to the main surface of the alluvial plain as the third terrace which is at variance with the origin of this surface, its structure and reclamation properties.

At the place where the Syr Darya escapes the accumulative plain, it developed a narrow gorge cut by the stream in Tertiary rocks (urochishche Chardara).

During recent years a dam with a water reservoir, as well as hydro-power station have been constructed here. They are mainly aimed at ensuring further development of irrigation in this region.

A strict system of the distribution of alluvial deposits over the entire area of the Hungry Steppe plain has not been established. Nevertheless the available data do not contradict the general scheme which has been considered above. Thus, lighter deposits which may belong to one of the earlier buried crests are stripped under the heavy (according to their composition) grounds in the central depression (Shiruzyak). Such structure of the alluvium facilitates at present the successful operation of vertical drainage systems.

According to the data obtained in deep profiles (wells), the so called, lacustrine or lacustrine-boggy layers with the inclusions of organic matter residue are stripped at the foot of the subaerial-alluvial series of sediments. They may be considered to be analogous to the sediments deposited in the primary flooded areas.

The lighter deposits of the slopes of macrocrests (of the western one in particular) overlie the heavy loamy-clayey sediments of the flooded areas.

The state of groundwaters on the territory of the Hungry Steppe corresponds to the above-mentioned general concepts.

Here before the beginning of irrigation, in the majority of cases, groundwaters occurred at a considerable depth which amounted to 15—20 m on the elevations of the topography and to 5—7 m in the depressions. Near the Syr Darya they were weakly drained by the valley. On the rest, an incomparably larger portion, of the area lowering of the water table could occur only as a result of prolonged intrarock evaporation in the conditions of a very weak replenishment of groundwaters by the groundwater streams flowing from the surrounding foothills.

The salts which remained in the soils and grounds after lowering of the water table were not removed and made their presence felt at the beginning of this century when irrigation was started here.

Before irrigation the soil cover in the Hungry Steppe was represented mainly by light solonchakous and deeply solonchakous sierozems derived on sufficiently thick loessial loams.

Irrigation brought about a rapid rise of groundwaters and, consequently, was responsible for the appearance of grave forms of soil salinization. The secondary salinization processes affected a considerable part of the cultivated area. Those soils which were situated close to the depressions were first of all and to a great extent affected by secondary salinization. The calamity was so enormous that the very existence of irrigation in this region was, at one time, put at stake. This induced the Russian scientists to start various investigations with the object of elucidating the reasons for the salinization of irrigated lands and devising methods for desalinizing them. The experiments carried out for the first time in the Hungry Steppe greatly contributed to the establishment of the theoretical prerequisites for the development of agricultural reclamation in Russia and made it possible to apply practical measures to control the salinization of irrigated lands. There were substantiated and introduced into practice the norms of water use corresponding to the local conditions. Systems of horizontal and, later on, those of vertical drainage were also tested. These cardinal measures were recommended for introduction in combination with other agrotechnical and organizational measures. Based to a considerable extent on the materials and data obtained in the course of this experimental work, the teaching about saline soils has taken shape in the USSR. The development of reclamation pedology and reclamation hydrogeology would have been impossible without using these materials.

Natural-reclamative regionalization of the piedmont plains

The materials presented in this paper, as well as the experience obtained while developing the Hungry Steppe and other similar territories make it possible to substantiate some of the concepts relating to the subdivision of the plains under consideration into natural-reclamation districts or regions, whose lands almost equally need reclamation. Such subdivision may be based on the differences in the origin and structure of various surfaces, variation in their lithological complexes, as well as other features, characteristic of the landscape in general, which are almost always dependent upon the peculiarities of the structure of a certain territory.

Proceeding from these criteria, the piedmont plains of deep troughs may schematically be subdivided into the following parts (groups of regions):

Regions situated close to the foothills. Lands within these regions contain buried or partially exposed pebble and other coarse-particle deposits which may own their origin to the former alluvial fans.

From the point of view of reclamation this part of the plains is considered as a zone of possible or existing manifestation of weak local head of groundwaters (including waters of subartesian origin). The existence of head waters is stipulated by the peculiarities of the lithological structure of the abovementioned deposits. River waters infiltrating the pebble layers in the upper parts of alluvial fans and having no satisfactory outflow, create the head spreading to the overlying groundwaters in the fine-earth.

The unfavourable effect of even weak head upon the reclamation situation is sufficiently well known. In areas of its manifestation groundwaters are situated closer to the surface, evaporation and salt accumulation increase, reducing the effectiveness of leaching and horizontal drainage. Under such circumstances it is necessary to resort to the construction of vertical drainage systems or to combine vertical drainage with the horizontal one. When combining these two types of drainage, the latter is expedient while improving strongly saline soils. Application of these two types of drainage results in a quicker desalinization of soils and in a faster removal of the upper saline solutions beyond the area under development. If there is only vertical drainage, these solutions have to move downwards which is not always favourable from the viewpoint of utilizing the waters of the lower water-bearing horizons, which are often fresh and suitable for irrigating farm crops.

Regions in the central parts of the plains and, primarily, on the macrocrests. Plain surfaces within these regions are relatively favourable for irrigation. Lands here are in better conditions as to both their elevation and composition of soils and grounds, as well as their relatively smaller degree of general salinity. When irrigating such lands, there exists a better local outflow of waters into the drains. In the past when irrigation without drainage was implemented, people managed to develop separate irrigated plots exactly on such soils more rapidly by using the local outflow of solutions in the direction of depressions.

Further evaluation of the quality of lands on the macrocrests is accomplished depending on the character of alluvial deposits down the profile. To the worse category should be related those surfaces where fluvial facies are underlain at a relatively small depth by heavy loams and clays originated in the flooted areas. The latter may play the role of a local impermeable bed restricting the effective range of drains and the efficiency of leachings.

Regions of modern depressions. The reclamative properties of lands in these regions are, on the whole, inferior to those of the above-discussed lands in the majority of indices. Depressions with coarse-grained deposits occurring at a certain depth under the buried crests may be related to a relatively better category among other depressions. When the alluvium, formed under the conditions of flooded areas, is underlain by large buried crests, application of vertical drainage for the desalinization of lands is not excluded. In those instances when surface fine-earth horizons are of great thickness and are characterized by small water-yielding capacity, horizontal drainage (more closely spaced at the period of land development) may preferably be recommended.

Among these main categories of lands it is possible to single out some intermediate surfaces situated on the slopes of crests. Apart from the lower plots of the slopes they will also include the surfaces of the collateral alluvial fans which penetrated into depressions.

The last group of regions (singled out according to the conditions of reclamation) includes *regions in the peripheral parts of piedmont plains usually situated at the greatest distance from the mountains or at trough edges.* During the greater part of the history of the formation of subsidence zones, the outlying districts of the flooded territories were characterized by the predominance of sedimentation in the conditions of the flooded area and most prolonged accumulation of fine-grained sediments which are notable for their poor water-physical properties and, consequently, hamper desalinization of soils. Both soils and groundwaters in these regions are most saline.

However, even in such regions there can be encountered relatively better plots whose formation was associated with the wandering of separate streams. The existance of such plots should not be overlooked.

Further subdivision of different parts of a plain will greatly depend upon the local conditions which are specific and often unique and, therefore, should be taken into consideration. While attempting the evaluation of a territory from the point of view of reclamation, one should not entirely base it on the ready general schemes. Every time it is necessary to undertake a detailed study of the peculiarities in the structure of the object under investigation. At the same time, beginning with the stage of such investigations and then in the course of generalizing the accumulated factual materials, it is useful to make use of the principal schemes which will make it possible to organize and carry out the investigations purposefully and to elucidate the general and individual features distinguishing the given object. The obtained data will provide a more comprehensive and concrete characterization and evaluation of the territory under investigation.