UNITED NATIONS ENVIRONMENT PROGRAMME (UNEP)
USSR COMMISSION FOR UNEP

PRINCIPLES AND METHODS OF SHIFTING SANDS FIXATION

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INTRODUCTION

The desertification problem involves as its significant constituent the control of shifting sands, that cause sand drifts to irrigated or dry lands, human settlements, canals, railways, motor roads, and various civil structures, which is an enormous damage to the countries' economies and interference with their production efforts.

According to the United Nations Environment Programme (UNEP) data total area of lands subjected to desertification amounts up to 48.3 million sq. km (36.3 per cent of the world's land surface).

The estimated area of the world's sandy deserts which are a source for shifting sands is one-third or one-half of the total area 14.01 million sq. km of true deserts.

The sandy areas in the USSR cover about 1 million sq. km., i.e. more than 4 per cent of the country's total territory. The shifting sands occupy 12–15 per cent of the total sandy area. In the Turkmen Soviet Socialist Republic alone, the sandy areas make up about 257 thousand sq. km., 40 thousand sq. km. being shifting and semi-shifting sands. These are Djilikum, the Primorsk (coastal) sands, the northeastern fringe of the Trans Unguz land, the Yaskhan massif, some localities of the Amudarya sands, etc. Shifting sands can also be found in the European part of the USSR, Uzbekistan and Kazakhstan.

Shifting sands in sandy deserts are commonly considered to have resulted from aeolian processes, due to high-velocity winds, insufficient amount of precipitation, sparse vegetation and widely occurring loose Quaternary deposits. A typical feature of the landscapes in sandy deserts is their fragility and instability. Shifting sands comprise dynamic relief forms. Their drift depends upon the velocity and direction of the prevailing wind, their granulometric composition.

With the advent of industrial and agricultural development of the desert's natural resources, in a number of regions there extend the areas where the processes evolving within them can be described as a dynamic disbalance. In such localities deflation of sands starts gradually overcoming the processes of sand fixation and development of vegetation. Fixation relief forms give way to classical types of shifting ones. With time the basic landscapes of deserts, semi-deserts and dry steppes with a well-developed vegetation cover which stabilize surface masses of sands and sandyloam soils turn to landscapes of shifting sands retarding restoration of destroyed ecosystems in the arid areas.

In the previous centuries, masses of shifting sands were formed due to unsparing use of sand vegetation for livestock grazing and as firewood. This resulted in emergence of sand tracts round the wells or on the outskirts of oases. Later, when construction of railways and motor roads reached the deserts and semi-deserts, shifting sands appeared near railway stations. In the recent years considerable areas of overgrown sands in the arid lands were destroyed, when laying of oil and gas pipelines, constructing of industrial enterprises and settlements near them.

Besides, in many desert regions where exploration drilling is carried out or oil and gas deposits are exploited, the desert and semi-desert shrubs were either felled down or destroyed over considerable areas when heavy drilling rigs were hauled over them.

As a result, in all the arid areas the world over man has now to exert much effort to avert the danger coming from shifting sands.

Proceeding from the data to be found on the desertification map of the UNEP/FAO/UNESCO, [Balba, 1982] determined that 577 million hectares of the world's land are subjected to desertification due to the drift of sands: 319 million ha in Africa, 116 million ha in Asia, 137 million ha in Australia and 4.6 million ha in South America. The area which faces an immediate danger of desertification due to shifting sands amounts up to 44 million ha, out of which 43.5 million ha are in Africa and 0.5 million ha in Asia. 15 million hectares of these areas, are in the arid regions. The remaining 29 million hectares of semiarid regions are mainly located in Africa.

According to the UNEP experts' data, during the recent 50 years the Sahara has engulfed as much as 65 thousand sq. km of fertile lands in the region of Sahel, while during the same period the Thar Desert in Asia advanced one km every year. It resulted in an annual loss of 130 sq. km of arable lands in India and Pakistan. In Sudan the border of the desert zone moved 6 to 7 km southwards every year. The winds carry away about 60 million tons of fertile soil from its upper horizon. In Somalia the sand barkhans moving at a speed of 15 m a year cover the roads and fields, bury villages and destroy the communication lines.

Taking into consideration the significance of the problem, recommendation related to control of shifting sands has been included into the Plan of Action to Combat Desertification: "To maintain and protect the existing vegetation, to take special measures to revegetate denuded areas and then to maintain and protect them to promote soil conservation, and to stabilize moving sands".

To carry out this recommendation, it is desirable that the urgent nation-wide actions should be taken in the regions where settlements, communication lines and farming lands or other facilities face an immediate danger.

To control sand drifts and stabilize sand dunes the following measures should be taken:

– investigation into the velocity of sand and dust movement and into the rate of dune drift, determination of effective wind conditions and detection of sand and dust sources;

– restraining of sand movement by stabilizing the sand surfaces, construction of the barriers, restoration of the vegetation cover in the regions of sand sources and provision of protection strips;

– stabilization of sand dunes by using mats, mulches, chemical or bituminous and other economically reasonable products, selection of sand-fixator plants, changing the shape of dunes and destroying steep slopes wherever necessary;

– proper management of land utilization in the regions of stabilized dunes to prevent their destabilization.

Thus, various methods for shifting sands control can be classified into mechanical, biological and physico-mechanical means.

The scientists of the USSR have developed and are making use of a wide complex of reclamation measures to stabilize sand surfaces, viz. stabilization of shifting sands by mechanical protection, by provision of protective films of bitumen, nerozine, crude oil, polymer materials and other preparations, as well as by afforestation of sands.

Various methods for protection of the economic units against sand drifts and deflation are being developed by many research institutions, for example the Desert Institute (Ashkhabad), the Central-Asian Research Institute for Forestry (Tashkent), the All-Union Research Institute for Agroreclamation and Afforestation (Volgograd), the Tashkent Institute of Railway Engineers, and others. The working programmes of these institutes stipulate for investigation into the theory underlying stabilization of sands, the causes for formation and spreading of shifting sands in this country, the making up of the maps showing the types of sands, the elaboration of the programme allowing the most efficient location and protection of industrial and other facilities in the sandy desert, study of ecological features of sand-fixator plants and behaviour of chemical covers search for new preparations, improvement of sand stabilizing practice and development of chemical devices for application of protective means for crops and for planting the psammophytes.

Integrated work for development of efficient methods for stabilization of shifting sands and systematic sand-stabilizing practice carried out over extensive areas made it possible not only to considerably decrease the foci of shifting sands but also to convert them in more productive lands in some of the regions.

This work provides a basis for the Soviet delegation to the UN Conference on Desertification held in Nairobi in 1977 to propose that workshop courses on stabilization of shifting sands be organized and held for university educated specialists. This proposal was accepted and entered into the Conference Action Plan (Recommendation 23).

The courses have become an annual event in the Soviet Union since 1978. To carry out the adopted syllabus it was necessary to provide the instructors and students with teaching aids and manuals on stabilization of shifting sands.

In 1980 the scientists of the Desert Institute of the Academy of Sciences of the Turkmen Soviet Socialist Republic compiled and published the teaching manual "Shifting Sands in the Deserts of the USSR: Stabilization and Afforestation".

In the present manual the authors have generalized and analyzed extensive data on shifting sands, and they do hope it will contribute to further solution of this global problem.

I. ECOLOGO-GEOGRAPHICAL FEATURES OF THE WORLD DESERTS

1.1. SANDY DESERTS OF THE WORLD

Vast natural areas with an extremely arid and hot climate, scanty rainfall, and comparatively sparse vegetation are termed deserts. Deserts are characterized not only by a low amount of rainfall (less than 250 mm) but by its uneven seasonal distribution, extreme variability, and great predominance of evaporation over precipitation. They are also characterized by the absence of permanent surface run-off, occurrence of dry beds of intermittent watercourses, and increased soil salinity [Babaev, Freykin, 1977].

The latest World Map of Desertification, 1977, published by UNEP/FAO/UNESCO/WHO shows these territories as distinguished by the aridity index (i.e., the ratio of annual rainfall to potential evaporation) ranging from 0.20 to 0.03. In the most extraarid zones, i.e., deserts, this index is below 0.03, with the evaporation in these zones exceeding the rainfall capable of evaporating over 33 times.

According to the UNEP experts, deserts proper or true deserts (extraarid and arid territories) take up more than 28 million sq. km or 18.8 % of land area. They are found on all continents, except the Antarctica, and occur, depending on thermal conditions, in the three natural zones – temperate, subtropical and tropical, occupying five main latitudinal and meridional regions.

Deserts of the first meridional region are situated in North America in the temperate and subtropical zones between 22 $^{\circ}$ and 44 $^{\circ}$ N.L. and stretch for over 2.500 km. These are the deserts of the Great Basin, Majave, Chiwawa and Sonora. The total area of arid lands in North America is 4,256 mln sq. km or about 20 % of the continent area (Table 1). The true deserts occupy here about 9 % of the territory; they stretch not latitudinally but meridionally and occur in intermontane plateaus, highlands, and intermontane depressions.

The second desert region is in South America. The narrow strip of the Peruvian-Chilean deserts (Sechura-Atacama) runs for almost 3,000 km along the Pacific coast from 5 $^{\circ}$ to 30 $^{\circ}$ S.L. It takes up mostly foothills and coastal valleys in the three climatic zones – tropical, subtropical and temperate. Arid lands take up about 19 % of the South American territory while deserts proper about 9 % or 3.69 mln sq. km. This region also includes some Argentinian plains (the Patagonian deserts and Gran-Chaco).

The third Afro-Asian desert region extends over enormous area stretching in a continuous belt for almost 11,000 km from the Atlantic coast to the Hwangho valley in China. It is a real kingdom of the greatest world deserts, such as Sahara, Arabian deserts, deserts of Central Asia, Iran, Thar, Takla-Makan, Gobi, etc.

On the African continent deserts cover a territory approximately between 15 $^{\circ}$ and 30 $^{\circ}$ N.L.; in Asia between 15 $^{\circ}$ and 35 $^{\circ}$ N.L. in Arabia; between 22 $^{\circ}$ and 48 $^{\circ}$ N.L. in Near and Central Asia; between 36 $^{\circ}$ and 46 $^{\circ}$ N.L. in Central Asia. Deserts of the central and northern parts of Asia belong to the temperate zone, while the deserts of Middle East, south of Central Asia and Iranian Plateau, North Africa and Arabian Peninsula belong to the tropical and subtropical zones [Petrov, 1973] .

Arid lands in North Africa take up 51 % of the continent, while deserts, where only Sahara extends over 7 mln. sq. km, make up about 37 % (Table 1). In Central Asia and Kazakhstan deserts occupy 55 %, in Middle East more than half of its territory, on Arabian Peninsula – 95 %, in India – 11 %, and in Pakistan – 88 %. The total area of arid lands on the Asian continent is over 15 mln. sq. km or 37 % of its territory, deserts taking up over 9 mln sq. km or about 22 %.

The fourth desert region is found in the southwest of Africa. It occupies over 2.3 mln sq. km of arid lands in the tropical and subtropical zones between 6 $^{\circ}$ and 33 $^{\circ}$ S.L. Three deserts and semi-deserts locate here: the Namib Desert, deserts and semi-deserts of Kalahari, and the highland semi-desert Great Karru. The Namib Desert somewhat resembles the Chileau Atacama Desert. It is a desolate strip of land a thousand km in length stretching along the ocean coast.

The Australian deserts belong to the fifth region. Arid lands occupy about 80 % of the continent (Table 1). Yet deserts proper are confined largely in the tropical zone between 20 $^{\circ}$ and 34 $^{\circ}$ S.L. and take up about 3.9 mln sq. km.

Beside these five regions deserts are found in Europe in the North Near-Caspian region and the Kura downstream and take up about 2 % of the land area. Yet semi-deserts, or semi-arid territories, occupy over 752,000 sq. km, or about 7,5 % of the continent.

The survey of the world deserts would be incomplete if we failed to mention arid territories that lie outside the regions mentioned. These are the northwestern tip of the Ukatan Peninsula, the Carribean coast of Colombia, the eastern extremity of Brazil, the south-western extremity of Madagascar, and the eastern coast of Ceylon.

Generally, arid lands take up over 47.7 mln sq. km or about 31 % of the world land area. This vast territory, extending through the temperate, subtropical, and tropical zones, feature great diversity of natural conditions. The UNESCO "World Map of Desertification" (UNESCO, 1977) specifies 44 areas exhibiting the whole diversity of climatic conditions in various desert regions of the world.

However, regarding a seasonal rainfall pattern which together with the air temperature regime has the greatest, in ecological terms, effect on plant growth, the four main desert types may be identified [Walter, 1968] :

1) deserts with winter rainfall and dry summer season;

2) deserts with summer rainfall and dry winter season;

3) desert territories with two rainfall seasons or without a clear-cut rainy season;

4) desert territories with irregular seasonal rainfall pattern or without any rainfall whatsoever.

Table 1

Arid Land on Continents

Continent	Territory thou km²	Semiarid		Arid		Extraarid		Total area of arid lands	
		thou km²	%	thou km²	%	thou km²	%	thou km²	%
America									
North	21280	2340.8	11	1489.6	7	425.6	2	4256	20
Central	882	4.4	0.5	0	0	0	0	4.4	0.5
South	17755	1597.9	9	1420.4	8	355.1	2	3373.4	19
Total	39917	3943.2	10	2910	7.5	780.7	2	7633.9	19.5
Africa									
North	–	4089.1	14	6425.8	22	4381.2	15	14896.1	51
South	–	1314.4	4.5	876.2	3	146.0	0.5	2336.6	8
Total	29208	5403.5	18.5	7302	25	4527.2	15.5	17232.7	59
Madagascar	589	53	9	23.6	4	0	0	76.6	13
Total of Africa	29797	5456.5	18.5	7325.6	24.5	4527.2	15	17309.3	58
Asia	42365	6354.8	15	8049.4	19	1271	3	15675	37
Australia	7703.8	2234.1	29	3929	51	0	0	6163.1	80
Europe	10032.1	752.5	7.5	200.5	2	0	0	953	9.8
Total	129815	18741	14.5	22414.4	17	6578.9	5	47743.3	36.5
Other continents: Antarctica, Oceania, etc.	234.18	–	–	–	–	–	–	–	–
Total of area	153233	18741	12.2	22414.4	14.6	6578.9	4.2	47743.3	31

Despite the great diversity of natural conditions in the world deserts, certain similarities may be defined. The comparative study of the desert landscapes was given by M.P. Petrov (Table 2).

Firstly, deserts have some common climatic features such as extreme aridity, permanent moisture deficiency, and great predominance of evaporation from the water surface over precipitation.

Secondly, they display classical features of desert hydrology, e.g. transit or temporary watercourses, drying lakes and limited runoffs.

Thirdly, all deserts have much in common in terms of dynamics of water regime of the surface sand horizons. Water supply to the surface layers of sand dune sands and their water regime dynamics are entirely dependent on the amount and time of rainfall, temperature conditions and intrasoil condensation.

Soils of all deserts belong to the arid type, but they show zonal differences depending on the climatic zone. Grey-brown soils are characteristic of the temperate zone, sierozems of the subtropical, while the tropical zone is represented by red-brown desert soils. Solonchaks of inland depressions and coastal lowlands are similar in all the world deserts as well as saline and meadow-saline soils of river deltas and valleys.

The greatest differences in the specific composition and the grouping patterns are observed in the flora and fauna. The following genetic types of flora are established: Central-Asian, Irano-Turanian, Saharo-Indian, West-Saharan, South-African (Capean), Australian, North-American and South-American.

Desert vegetation is represented by the fairly depleted xerophyte (hypsophytes and psammophytes), succulent, and halophyte communities. Extraarid regions are devoid of higher forms of vegetation over vast expanses.

Common features of desert vegetation are its scarsity, depleted specific composition, and the constant presence of plants-edificators.

Many of these features were introduced by Walter (1911) into the definition of a desert. "This is the country of geographical paradoxes and it is equally difficult to form an unbiased view on the characteristic features of a desert landscape and to put this view into words. Clouds without rains, springs without streams, rivers without estuaries, lakes without runoffs, dry valleys, dry delta sediments, dry lakes, waterless depressions below the sea level . . . gigantic troughs leading to no valleys . . . intensive weathering without decay products . . . These and other unique phenomena may be seen by any attentive observer of the present-day desert".

Having this in mind I.P. Gerasimov (1954) considers contemporary desert territories to be vast arenas of the predominantly destructive activity of elemental aeolian processes which remove the traces of all previous activities, other than desertification processes, and create huge geological formation devoid of life – "gigantic heaps of rock fragments", "vast deposits of sand", and the like.

Eolian processes, or so called, wind activity, appear to play a major role in modifying the relief of deserts. The direct result of this activity over a prolonged geological period is the emergence of vast areas under sandy deserts composed of a thick (of up to several dozens of meters) series of reblown sand.

Sands are believed to take up about 1/3 or 1/2 of the total areas of deserts proper (true deserts) which amounts to 4.6 to 7.0 mln sq. km. This makes up from 3.0 to 4.6 % of the total Earth surface. Twenty thousand sq. km of inland sands in the humid zones may be added here.

The distribution of sandy deserts in arid and semiarid zones is well illustrated by the following figures. In North America the sands cover 4 % of the arid territory; in Sahara 21 % of sands is concentrated in the Eastern and Western ergs; in the Soviet Union sandy deserts take up 80 % of the arid zone; in China sandy deserts occupy over 80 % of the total desert area including Gobi; in Australia sands devour 50 % of the continent or 75 % of its arid zone. South Africa and South America boast of negligible sandy areas.

The greatest sand area of the world is the deserts of Arabian Peninsula where only Rub-El-Khali occupies 789,000 sq. km, and the Great Nefud desert takes up 80,000 sq. km. The area of ergs in Sahara is 600,000 sq. km. Ergs are especially common in the West Sahara and Lybian desert and flank the plateau of Central Sahara on the north and the south. They may be represented either by small accumulations of sand in dunes with S-shaped ridges (sifs) or by their chains (dras) stretching for tens and hundreds of kilometers. The dunes resemble sea waves, hence, Sahara is often called "the sea". The largest ergs are the Great Western and Great Eastern ergs, Murzuk, Ubari, Shesh and others. The area of large ergs reaches several thousand square kilometers.

Ergs are located zonally. M. Lelubre, a French geologist, defined three erg zones. The first zone stretches from Senegal through Algeria and includes Shesh, the Great Eastern and Great Western ergs. The second zone is situated on both sides of Akhaggar, it includes the Niger ergs as well as Ubari and Murzuk in Fezzan hollow. The third zone surrounds Tibesti Plateau and includes the ergs of the Lybian desert in the north-east.

Ergs are usually confined to the margins of depressions composed of the youngest alluvial-lacustrine accumulation where the corresponding deposits in dried-up lakes emerge as parent rocks. One of the world's largest sandy deserts, Takla-Makan, with the area of 271,000 sq. km, is situated in Central Asia. It occupies the central part of intermontane Tarim hollow. Takla-Makan is composed of loose quaternary alluvial deposits several hundred meters thick. This thickness is reblown and covered by eolian sands of up to 300 m deep.

The eolian relief is fairly complex. Transverse and longitudinal sand ridges, varying from 30 to 150 m in height, 250 to 500 m in width, are met here along with cellunar sands and complex sand dune ridges. The highest are pyramidal dunes rising to 200–300 m above sand dunes.

In the USSR the largest sandy deserts are Karakum and Kyzylkum which will be discussed later.

Let us dwell on other world's deserts.

Apart from Takla-Makan, the major part of Alashan desert in Asia is covered by shifting sand dunes forming three sandy massifs: Badan-Jhareng in the southwest; Tengeri in the southeast and Ulanpuho in the northeast. Besides, there are smaller areas of shifting sands scattered over the remaining territory. Sand stabilization is poor here, thus they are constantly on the move. Medium-size and large sand dunes, their height occasionally reaching 200–250 m (Badan-Jhareng) are found here. Sand dune chains in the Alashan desert stretch from the northwest to the southwest.

In the Beishan desert sands take up a minor area in the northeast part, to the west of the Edzin-Gol river downstream.

In Ordos sands are wide spread and cover almost the whole territory. In the vast plain elevated to 1000 m sand dunes alternate with vast areas, covered by ridgy-hillock sands.

In Jhungaria the sandy deserts occupy its central and northern parts. These are Dzosotyn-Elisun sands extending over 1600 km southward. Shifting sand dunes take up particularly large areas in the southern peripheral parts. They also occur as small isolated spots in the northern foothill plain of Tien-Shan, e.g. in the area of Ebi-Nur lake and others.

The origin of the shifting sands in deserts and semi-deserts of Central Asia took two pathways.

The first is associated with the natural processes of deflation as they occur in the parent rocks of various genesis, particularly loose sand deposits widely distributed in the arid central and western areas of inner Asia: Kashgaria, Jhungaria and Alashan.

The second is associated with the man's irrational economic practices in desert and semi-desert areas, i.e., with the antropogenic factor. Deserts of Central Asia are known to have been inhabited for long. Deserts and semi-deserts have been used as pastures for over a thousand years. Agriculture of the eastern and central parts of China and Kashgaria is as old. Overgrazing, exessive use of both shrubs and even grasses for fuel and, occasionally, ploughing of overgrown sands without proper soil-protection measures for over a millennium have resulted in the elimination of natural vegetation and destabilization of sand, thus, giving rise to shifting sand dunes. Almost all ancient agricultural areas bordering on the sandy deserts and semi-deserts and wells in the deserts are surrounded by a wide belt of shifting sand dunes. Masses of sand are always encountered in the margins of the fields or settlements, i.e., where antropogenic factor is most operative. Such sands in the deserts and semi-deserts of Central Asia are very numerous.

In the Thar desert eolian sands take up about 90 % of its territory. Three main types of the eolian relief forms are longitudinal ridges, sand dunes, and parabolic and rake-like dunes transverse to the wind. Longitudinal ridges, extending from the northeast to the southwest, dominate in the southern part. On the average, they are 10–15 m high, 5–10 km long and 150–200 m wide. Sand dunes occupy comparatively small areas. The sand dune relief has evolved in the sites where ridge crests had been a prey to blowout through the unwise use of vegetation. Well-shaped sand dunes are relatively few in number.

In Pakistan part of the Thar desert, where the climate is more arid sand dunes exhibit wider distribution with the length of isolated sand dunes and sand dune chains varying from 100 to 200 m and their height reaching 20 m [Petrov, 1973] .

The northeastern desert border is dominated by large solitary sand ridges oriented from the south-southwest to the north-northeast with the heights of 8–10 m and widths of 200–225 m. Their slopes are flatter than those in the south, and they are moving very slowly.

In the northern Thar partially saline clay desert patches occur in the inter-ridge depressions.

In the north of Hindustan in the interfluve of the Indus-Gelal and the Trimab there is the Thal desert. It is composed mainly of the old-alluvial deposits of these rivers. The landscape of sandy desert with active eolian processes is reigning here. The sand consists of evenly-grained quartz particles, feldspar, hornblende and other minerals.

The Iranian plateau comprises the sandy deserts of Deshte-Lut, Registan, and Haran. The deserts are noted for their distinct eolian accumulative relief. Deflation of loose surface deposits produces all typical eolian relief forms characteristic of the Asian sandy deserts: ridges, hillock sands and sand dunes.

Deshte-Lut desert lies in the southeast of Iran and stretches from the northwest of the southeast for about 1100 km [Petrov, 1973] . The landscapes are varied and present not only sandy deserts but also solonchaks, rock-debris and mountainous stony deserts. The central parts of this desert hold such forms of weathering and shifting sand reliefs as sand accumulations in the lee side of low mountains, crescentic dunes and great accretions of sand dunes, blowout niches and residual forms.

The prevailing relief-forming winds are the north and northwest ones. Respectively, large masses of sand migrate to the southern regions of the desert, forming sand dune chains 10–15 m in height.

The Registan desert is situated in the eastern part of the vast intermontane depression and occupies the western bank of the Gilmend river and its tributary the Argendab. This is the most arid and deserted part of Afghanistan. It is covered by sparsely overgrown sand dunes with a ridge-type relief oriented meridionally. In some localities sand dunes reach 60 m in height.

The largest desert on the Arabian Peninsula is Rub-El-Khali which is mainly composed by alluvial deposits. The relief forms of shifting sands are fairly diverse, ranging from isolated sand dunes to powerful accumulations in the form of longitudinal dunes or isolated sandy massifs up to 200 m high.

The sand dune chains on the greater part of the desert stretch from the northeast to the southwest, and in the eastern part of the desert they have almost a latitudinal direction [Brawn, 1960] .

The area is characterized by the following types of sands [Kingdom . . . 1956–1964] :

1. Transverse relief forms. Mainly simple and complex shifting sand dunes and simple circular ridges transverse to the reigning wind.

2. Longitudinal relief forms, generally characterized by elongated arrangement parallel to the reigning wind. They are frequently stabilized by sparse vegetation.

3. Elongated nearly parallel forms of narrow sand ridges with sharp crests and sand dune chains separated by wind sand fields including usually elements of sands of the first type.

4. Sand hills. Great sand accretions with ridges of 50–300 m high often with superimposed dunes forming various types of complex sand dunes. The usual forms are gigantic sigmoidal and pyramidal sands as well as huge oval or elongated sand hills.

The central part of the Arabian Peninsula contains several smaller sand deserts: Great and Minor Nefud, Nefud-Daki, El-Hasa, etc. The Syrian desert takes up the northern part of the peninsula.

North Africa holds the vast Sahara desert covering an area from the Atlantic coast to the Nile valley. The deserts roll over onto the right bank of the Nile forming relatively small Arabian and Nubian deserts. The sandy Sahara deserts vary geomorphologically both in form and age. R. Kapo-Rey (1958) subdivides them into young, mature, old and dead ergs.

Young ergs are formed by deflation of young alluvium in river valleys (wadis). The effect of a surface runoff in mature ergs ceases and the balance between deflation and eolian accumulation sets in. In old ergs active eolian processes occur. As a result, the primary surface becomes completely deformed and is covered by a powerful layer of eolian sands. Overgrown sands are classified as dead ergs. They are characterized by a smoothed-over relief where sands are compact and immobile.

R. Kapo-Rey describes the formation of the Sahara shifting sand relief in the following sequence: a sand dune in its classical form; sif, i.e., sand accumulation without a clear-cut form and with an S-shaped crest. Sifs aggregate into chains, ridges and massifs. Pyramidal sands may be identified as a specific relief form. The diversity of the eolian relief forms in Sahara is associated with a variety of wind patterns. South Africa holds three deserts: the Namib sandy desert which stretches in a narrow strip, along the Atlantic coast; Kalahari covering the central plateau, and the Great Karru highland semi-desert.

The Namib desert is situated on the coast of South-West Africa between the Orange and the Kunene rivers on the sloping piedmond plain, composed of marine, proluvial, and alluvial deposits which overheat easily. These conditions trigger the sand movement. In the lower reaches of the Orange river the narrow strip of shifting sands encroaches into the mainland. The sand dune relief includes combinations of large and small sand accumulations often producing complex forms of the ridgy-sand dune-type dozens of meters high. In its northern part the Namib desert forms a vast sandy expanse about 450 km long and with sand ridges of 30–40 m high. Their mobility is low [Petrov, 1973] .

Four desert regions are found in North America: Chiwawa, Sonora, Mojave and Great Basin. The specific feature of the geomorphological structure of the arid territories in North America is that the morphostructures of similar types occupy but small areas. More common are the complex morphostructures where low ridges alternate with wide intermontane depressions covered with alluvial, lacustrine and proluvial deposits [Petrov, 1973].

Surface deposits are largely represented by young proluvial and alluvial loose sandy, pebble and rock-debris deposits. Part of them is reblown and deposited as the eolian relief. Deserts in California and Colorado lowlands which occupy vast old-alluvial and coastal valleys are more homogenous in relief.

In South America deserts run along the western coast in Peru and Chile and on the Patagonian plateau. In the coastal deserts of Peru and Chile surface series and relief forms are indicative of the extraarid climate. The eolian relief is common here and represented mainly by solitary sand dunes and sand dune chains. There are also several large and complex sand dune areas non-stabilized by vegetation owing to the aridity.

The greater part of the Peruvian and Chilean coast is taken up by stony deserts and saline crusts. In some localities they are replaced by pebbly deserts and vast tracts of shifting sands.

Sandy deserts originate in ancient valleys and deltas. They were formed mainly by deflation of old alluvial sand, that had been carried out from the mountains by rivers and mud flows. In some sites eolian relief is represented by composite sand dune ridges [Kosok, 1965] .

As has been noted above, deserts in Australia are very vast. They include the Great Sandy Desert with overgrown sand ridges, the sandy Simpson Desert, the stony-pebble sandy Gibson Desert, Great Victoria Desert, and the sandy-pebble Nallarbor Desert.

J. Mabbutt (1968) distinguishes the following eolian relief forms in Australia: sandy deserts, ridgy sands of various types, reticulated sands and sand dunes. Ridgy sands are typical of all Australian deserts varying from elongated ridges to less oriented, short ones turning occasionally into irregular reticulated relief forms. Ridges are normally 10–25 m in height, less frequently 5–35 m, with 300–500 m spacings. Ridges stretch for dozens of kilometers parallel to each other; sometimes they join at an angle. Their orientation varies from the northern and northwestern in the southeast to the western in the north.

Vast lake depressions hold sands with a reticulated ridge form. On the banks of some salt lakes of the Western Australia peculiar eolian sand dune relief forms are formed.

The Great Sandy Desert is situated in the northwestern part of the continent. It occupies 360,000 sq. km. The greater part of it is taken up by overgrown ridgy sands. The ridges are arranged latitudinally, they run parallel to one another, with a distance between them of 400–800 m. The average length of ridges is 40–50 km with the height of about 15 m [Madigan, 1936] .

The southern part of Central Australia holds the Great Victoria Desert with a relief form of latitudinal alternating ridges similar to those of the Great Sandy Desert in length, width and height. The Gibson Desert lies in-between these two deserts and is covered in part with overgrown sandy ridges and in part with sandy-pebbly and stony desert around isolated ridges.

The western part of the Great Artesian Basin holds the Simpson Desert which is a complex of stony, sandy-pebbly, sandy and clayey deserts. Ridgy sands stretch from the north-west to the southeast which may be attributed to various wind patterns in the desert.

1.2. NATURAL CONDITIONS OF THE USSR DESERTS

The Soviet Union's deserts cover about 250 million hectares making up over 10 per cent of its area. The overwhelming part of deserts (94 per cent) lies within Kazakhstan, Uzbekistan and Turkmenistan. The northern boundary of the deserts coincides with the southern fringe of the lightchestnut soils and the isohyet of 180 mm of the mean annual amount of precipitation [Fedorovitch et al., 1963] . During a cold season, passing along the northern boundary of the deserts is the axis of the western offset of the Siberian anticyclone dictating the weather features in winter. Thus, the northern boundary of deserts as an isolated physico-geographical region, is determined not only by landscape features but also by a very important climatic boundary according to a circulation factor [Chelpanova, 1963] .

The deserts form a wide belt between 36 and 48 $^{\circ}$N latitude and between 48 and

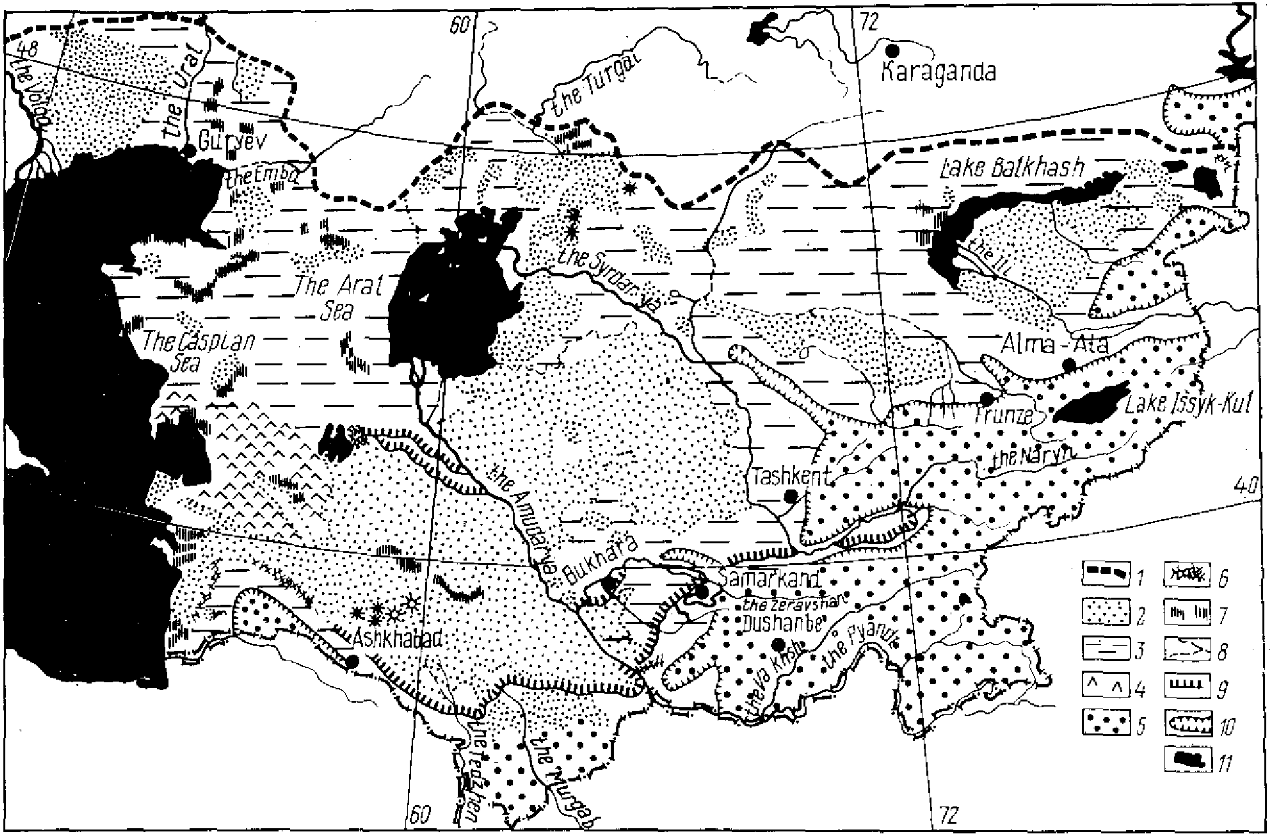

Fig. 1. Deserts of Central Asia and Kazakhstan:
1 – The northern border of the desert; types of deserts; 2 – sandy desert; 3 – clayey desert; 4 – gypsum desert; 5 – loess desert; 6 – isolated and areal takyrs; 7 – solonchak; 8 – intermittent streams and dry river beds; 9 – main canals; 10 – mountain regions; 11 – seas and lakes

82 °E longitude covering the territory from the Apsheron peninsula and the left-bank side of the Volga delta to the piedmonts in the south and southeast of the USSR. This vast territory stretching for about 1500 km from north to south and for over 2500 km from west to east accommodates all the well-known desert areas: the stony deserts of Ustyurt, Bet Pak Dala, the Caspian Sea coastal sandy-clayey plain, the sandy deserts of Karakum, Kyzylkum, Muyunkum, Sary-Ishykotrau, the Aral Sea coastal Karakum, the clayey desert of Golodnaya Steppe, the Kara-kalpak Steppe, the Karshinsk Steppe, the sands of Sundukli and other relatively smaller territories (Fig. 1).

On the northern coast of the Caspian Sea, in the interfluve of the Volga River and the Ural River, adjacent to the desert belt are extensive semi-desert tracts of the Naryn sands while stretching over the eastern coast of the Caspian are Tersk-Kumsk sands, the Milsk and Mugansk dry steppes. They are also considered to be the continuation of the desert belt in the USSR.

The USSR deserts lie on the low plains whose height varies in the range of –28 m on the Caspian Sea coast to –129 m in the Karagie basin and to +300 – +400 m on the residual-mountain plains. In the east the plain spaces represented mainly by the Turan lowland are traversed by a system of mountain ridges and residual-mountain uplands – Sultan-Uisdag (485 m), Bukantau (758 m), Tamdytau (888 m), Kuldjektau (784 m), as well as by the mountain ridges of Karatau (2176 m) and Nuratau (2169 m) which belong to the Tien Shan mountain system.

In the south, adjacent immediately to the Turan lowland is the mountain system of Kopet Dag (Great Balkhan, Mallyi Balkan, Kurendag and Paropamiz), and in the east the ridges of the Pamir-Alai mountain system.

In the northwest and north the Turan lowland turns into heavely rugged Krasnovodsk plateau with a mean height of 220 m and an extensive hilly Ustyurt plateau with a height of 150–230 m, in the northeast it turns into Turgai and North-Kazakhstan hilly plains.

The plains of the Central Asia and Kazakhstan are of different origin, the most conspicuous distinctions being the age and geological structure of their deserts. The oldest rocks occur in the north of the desert belt. This is a hummocky topography of the Kazakh folded region, the Bet Pak Dala desert and Kyzylkum inselbergs formed by Paleozoic and Mesozoic rock masses and the outcrops of crystalline rocks.

The northwestern part of Turkmenistan extending from the Caspian Sea coasts to the dry river bed of the West Uzboi is also of Paleozoic and Mesozoic deposits mainly of the Cretaceous and Jurassic periods.

Of a much younger geological age are western, central and southern parts of the deserts. The Ustyurt and Krasnovodsk plateaux are composed of Neocene, and later on of Tertiary deposits. Since there are no rivers and the precipitation is scanty the relief of the plateaux is not too heavily dissected. The formation of rock debris eluvium in conjunction with grey-brown gypsiferous soils brought about a rock debris desert [Petrov, 1973] .

The formation of the Zaungusk Karakum belongs to the Pliocene period. The Zaungusk rock mass was mainly formed in the period from the Upper Sarmatian to the Pontian inclusive.

The low plains of Central Asia were formed either during the Early Quarternary period or occur in recent valleys and deltas of the Amudarya, Syrdarya, Murghab and Tedzhen rivers. The alluvial plains occupying vast territories of the Turan lowland are composed of thick sand mass. The deposits of the recent river valleys and deltas are characterized by a frequent alteration of thin layers of various mechanical composition while the eolian sands are represented by a uniform mass of mainly fine sands' [Petrov, 1973].

The geological history has determined the structure and the thickness of strata as well as the occurrence of rocks and the relief of deserts. The sandy deserts are characterized by aeolian relief forms. The main form of the sandy relief in the Central Asian deserts and southern Kazakhstan is ridges of sand dunes stretching parallel to one another. They are markedly elongated and less developed in height. The length of sand ridges varies from hundreds of meters to several dozens of kilometers while their width is from 10–20 m to 1 km, occasionally they are wider, the height is 5–6 to 60 m. Their parametres differ from one part of the desert to another. Long high ridges are occasionally connected to each other by transverse short and low ridges. In such localities the landform becomes of a honeycomb pattern.

In addition to the sand ridges the relief is abundant with hillocky sands with a height of 2 to 15–18 m covered with grass and shrubs. Occasional deflation foci can be found between the hillocks. The vegetation of the hillocky sands contributes to the existance of considerable amount of fine earth particles favouring the formation of primitive sandy desert soils. Unlike the ridgy forms the hillocky sands are usually dispersed disorderly. Some spots in the deserts of Central Asia and southern Kazakhstan are occupied by vegetated sand dunes formed beneath the plants of the shrubs as well as by flat-rolling sands which are more easy to develop [Babayev, 1973].

Sand dunes present a peculiar aeolian form in the desert. The height of typical sand dunes is usually 1–2 m. The desert has few typical sand dune forms since ideal conditions for their formation are not found here and there. In most cases a desert has large accumulations of sands in the form of sand dune chains. The lower parts of deserts are mainly occupied by takyr or solonchak soils.

The rugged character of the desert's landform becomes more pronounced where dry beds of desiccated rivers and temporary water channels are frequent. The longest dry river bed of the West Uzboi used to be a living river in the remote past and received excess water from the Sarakamysh Lake connected in its turn with the Amudarya.

Latitudinally, the Karakum desert is divided into two parts by the depression of Unguz which is a trough accommodating takyrs, solonchaks, aeolian forms of sands.

In the Kyzylkum desert the moderate uplifts of up to 1000 m and higher rise over the surrounding desert as well as the closed basins and dry river beds stand out amidst the general plain relief. The alluvial deposits of the Syrdarya are a very important factor in the formation of the Kyzylkum topography.

The mountains and the desert are separated by the piedmont plain composed of fine-grained and psephitic proluvial material. The surface of the piedmont plain is covered with a thick mass of loess-like fine-grained sediments. Such plains are usually cut by small rivers flowing from the mountain flumes, the lower riches of the rivers forming alluvial cones. Loose and loamy masses of proluvium produce a favourable water regime in the loess piedmont deserts.

The near-Kopet-Dag piedmont plain in the west and southwest turns into a takyr plain formed by the mass of heavy clay and loams up to 8–10 m thick. The width of the takyr plain varies, the largest areas covered by it being in the southwest in the region of Atrek, to the north of Kyzyl Arvat and near the Tedzhen delta. Water regime of the takyr deserts is too severe to support any higher plants.

As to their lithological and landscape features the deserts in Central Asia and South Kazakhstan can be classified into the following main types: sandy, stony, clayey and solonchak deserts which in turn are subdivided into lower taxonomic stages depending on the lithological and petrographical, geomorphological and facial features of the component rocks.

The sandy deserts are the most classical example of deserts. They occur on thick loose sandy drifts mainly alluvial and marine. According to their genesis, M.P. Petrov (1973) classifies the sandy deserts into four subtypes: old alluvial plains, coastal plains, piedmonts and old structural plains composed of Tertiary and Cretaceous deposits. The first subtype includes Lowland Karakum, Sary Ishikotrau, Muyunkum, Aral coastal Karakum, the second subtype includes the North Caspian coastal sands. The sandy deserts of the piedmonts occur as small tracks in the Kopet Dag piedmonts. Considerable areas of sandy deserts are found over structural plains in the Trans-Unguz Karakum and Kyzylkum.

When the conditions are favourable, i.e. with sufficient atmospheric moistening, when the level of fresh or moderately mineralized ground water is high, the wind regime is temperate and the soils are not too saline, the masses of aeolian sand get stabilized by psammophyte plants which grow over them. Unfavourable conditions of afforestation or poor management of economic activities in the sandy deserts easily result in the formation of the tracts of barren shifting sands.

The stony deserts were formed mainly in the areas, where solid bedrocks appear on the surface. This type of deserts, according to the genetic conditions is subdivided into three varieties: deserts formed on solid elevated plains; the deserts formed on peneplains; the deserts developed on the proluvium of the piedmonts, on the rock debris cones of temporary streams [Babayev, Freikin, 1977] .

The vegetation of stony deserts is poor and suppressed due to bad soil conditions. Prevailing plants are wormwoods and other small shrubs (cherkez tamarisk). The soils are underdeveloped.

Clayey deserts are divided into loess, loamy, takyr and badland types. The clayey loess deserts are found on the inclined piedmont plains formed by proluvial and alluvial clayey and loamy drifts. The soils are of a gray-earth type and slightly saline. The vegetation is represented by grassy communities of an ephemeral type.

Loamy deserts occupy vast plains built of horizontal strata and plateaux of Kazakhstan. The soils are grey-brown, slightly mineralized and covered with wormwood and woodworm-solonchak communities.

Takyr clayey deserts occur in piedmont plains and old deltas of the Amudarya, Syrdarya, Murghab, Tedzhen, Kashkadarya and other rivers, whereas badland deserts occupy low piedmont of the western Kopet Dag, the low mountain relief of the Central Mangyshlak and the southern part of the Kazakh hummocky topography [Petrov, 1973] . The vegetation in these type of deserts is very scanty.

Salt deserts occur locally over the entire desert zone as isolated areas. Solonchaks result from the vertical transmission of salty moisture from the upper soil horizons to the surface in depressions. As a rule they are found on the outskirts of dry old and recent deltas, terraces and occupy desiccated saline shores of the sea and lake basins, the bottoms of large basins without outflow. The main feature of salt deserts is a shallow occurrence of salty ground waters, the lack of outflow and poor drainage of the territory. Salt deserts are the most barren formations.

The features of natural conditions of the USSR deserts are determined by their geographical situation in the interior of the Asian continent, the neighbourhood of the Mediterranean, Hindustan, Central Asia and Siberia. The influence of these territories can be easily traced when considering the climate of the area in question.

The situation of the USSR deserts in the centre of the vast Euroasian continent, a considerable latitudinal and longitudinal extension of the area, the mountain massifs in the south, southeast and east, the openness of the territory in the north are the factors which determine the continentality and aridity of the climate. The continentality of the climate manifests itself in abrupt changes of meteorological elements in diurnal and annual variations, the aridity manifests itself in the small amount of precipitation, considerable dryness of air, slight cloudiness and high evaporation.

The latitudinal zonality and the peculiarity of the atmospheric circulation lead to considerable differences in the climatic conditions between the northern and southern parts of the territory both during cold and warm seasons.

During the colder half a year the northern part of the desert territory is influenced by the Siberian anticyclone activities. This is why winter is too severe for this very latitude, the frosts are heavy and the snow cover is steady. The cyclones carrying with them cloudy weather and snowfall only occur when the influence of the Siberian anticyclone is reduced. In the southern part of the desert area the winter weather is governed by some other atmospheric processes. In this season the Iranian branch of the polar front develops an intensive cyclonic activity which reaches its maximum during the second half of winter and in spring months. This accounts for a relatively mild and changeable winter weather in the southern part of the desert area.

During the warm season the differences in the atmospheric circulation persist over the northern and southern areas, summer cyclonic activity is very sluggish, and from the later half of May till October these parts of the desert experience clear, hot and dry weather. Since June a thermal low sets in bringing about a regular hot dry weather. The rainless period lasts for more than three months. The influence of the thermal low does not extend over the northern regions of the deserts where in warm seasons the cyclonic activity is developing rather forcefully. For this reason, in southern regions the stronger cyclonic activity proceeds with a gradual increase in atmospheric precipitation; the maximum of the latter is observed in March–April. Then the sharp reduction of precipitation occurs, coming to zero in July. In northern regions, the annual occurrence of precipitation is more regular with two small maxima being in late autumn and late spring.

An analysis on the annual occurrence of precipitation over the territory of Central Asia and southern Kazakhstan showed that summer precipitation decreases spasmodically to a negligible minimum in the region between 42 and 45 °N latitude. It is this turning point that is usually taken for the boundary between the northern and southern zones of the deserts: from the northern part of Kara-Bogaz Gol Gulf across the Amudarya delta over the southern margin of the Bukantau mountains to the Karatau ridge. In the east, this turning-point line of precipitation runs along the Karatau ridge and Talask Alatau [Chetyrkin, 1960] . Here also runs the northern boundary of the territory which is fully provided with thermal resources required for fast-growing kinds of cotton, the boundary being in a fair agreement with the sums of mean diurnal temperatures of air over 10 °C equal to 4000 °C.

According to the classification of climates by A.A. Grigoryev and M.I. Budyko (1959) the subzone of the northern deserts is characterized by dry climate with a warm summer, moderate winter with little snow, and the southern subzone has dry climate with a very warm summer and moderate dry winter.

The high midday solstice over the horizon and slight cloudiness during warm season determine long sunshine period – from 2000 hrs in the north to 3000 hrs per year and over at the southern borders of the deserts. Sunless days are very rare here and the probability of clear sky amounts to 90–95 per cent. Only at the northern margin of the desert zone there may be about 60 cloudy days a year. In the southern subzone of the desert the number of sunless days is as few as 25–30 a year.

This leads to the great amount of solar radiation received in the desert area. The total annual radiation varies from 120 kkal/sq. cm in the northern desert subzone to 160–170 kkal/sq. cm in the southern one. In spite of considerable effective radiation and albedo the mean annual values of radiation balance are equal to 35 kkal/sq.cm for the northern area and over 70 kkal/sq. cm for the south of the Central Asian deserts [Pivovarova, 1977] .

Owing to high aridity of the desert climate almost all the arriving solar radiation is spent on heating the underlying surface and air. This means that little heat is left to be consumed for evaporation in summer months making up on the average 10 kkal/sq. cm per year in sandy deserts. At the same time the annual value of the turbulent heat exchange between the underlying surface and the air varies from 20 kkal/sq. cm in the north to 40 kkal/sq. cm and more in the south [Berlyand, 1948] .

High values of the turbulent heat exchange dictate the temperature regime of the air. The annual mean temperatures of the air increase southwards from 5.0 ° to 11.0 °C in the northern subzone and from 13.0 ° to 16.6 °C in the southern subzone of the deserts. In the annual cycle of air temperature the minimum is everywhere in January and the maximum in July.

Since the area is extensive the air temperature varies greatly between the northern and southern subzones of the deserts. In the northern part of the area the temperature regime of the winter months is relatively stable. The thaws may occur one to five times every ten years. The January temperature varies in a wide range. The coldest are the northern outskirts of the area where the mean January temperature is –18 °C while in the southern subzone of the northern deserts it is –6 °C. To the north from January isotherms of –6 °C is the area with an absolute predominance of non-vegetation winters characteristic of moderate zone climates [Babushkin, 1964] .

The winter severity in the northern subzone becomes rapidly milder changing over from a very cold one with extremely heavy frosts in the northern part to a moderately cold with tangible frosts in the central regions and to a mild with medium frosts in the south of the subzone. In occasional very cold years the air temperature may drop to –45 °, – 48 °C in the southeast and to –30 °C in the lower reaches of Amudarya. The weather turns even more rigorous due to the prevailing northern wind bringing continental cold air from the Siberian anticyclone.

The area of the southern subzone has very mild winters with moderate frosts in the middle and southern parts and light ones in the south. In Southeast Karakums and in the southwest of Turkmenia the mean January temperature do not drop below zero. Though the general level of the winter temperatures in the southern subzone of deserts is rather high, in winter the changeability of temperature becomes more appreciable, and cold intrusions may make the minimum temperature drop up to –32 °C in the north and –26 °C in the south. However heavy frosts never persist here too long while warm days usually alternate with night frosts.

The number of days of steady frosts varies from 160 on the northern outskirts of the desert northern subzone to 80 at the southern border. With a transition to the southern desert subzone the duration of the frosty period shortens with steady frosts in the south of the subzone occurring in less than 50 per cent of winters.

In 75- 80 per cent of all the summers July proves to be the hottest month while August is the hottest in only 10- 12 percent of summers [Chelpanova, 1963] . The July mean temperature of air varies in the northern subzone from 24 to 27 °C, the possible maximum temperatures never exceeding 40–45 °C. The southern subzone usually experiences very hot weather in July with mean diurnal temperatures from 25 to 35 °C. The maximum values of air temperatures here are 46–48 °C with an occasional rise to as high as 50 °C (Repetek, Termez), the soil surface on such days becomes heated up to 79 °C.

The annual amount of precipitation is negligible both in the northern and southern subzone varying from 80 to 200 mm to increase in the piedmont loess deserts. The most arid are the deserts of Karakum, Kyzylkum and Bet Pak Dala, the western coast of the Balkhash Lake, the Ferghana Valley and the valley of the Ily where precipitation is less than 100 mm a year.

The annual distribution of precipitation varies widely: in the northern zone precipitation of the warm period is higher than, or equal to, that in the cold one while in the southern subzone precipitation of the cold period prevails.

This leads to division of the year in this area into two seasons as far as natural moistening is concerned: a dry season from mid-May to mid-October and a humid season lasting for the rest of the year.

During four months of the warm period the total amount of precipitation in the southern subzone is insignificantly negligible varying from 1 mm in southeast Karakum to 10 mm on the border with the northern subzone [Chelpanova, 1963] . This negligible amount of precipitation during the warm period is of no practical value. Although the northern subzone enjoys rather little precipitation during the warm period, viz. 15–60 mm., it proves enough to support the growth of wormwoods. Besides, precipitation occurs evenly during all the summer months.

The cold period brings about regular precipitation throughout the desert area. However the northern subzone experiences snowfall with snow cover lying steadily while in the south the rainfall and snowfall alternate.

Precipitation not only occurs unevenly throughout the year, it is also very changeable. In some of the years it is insignificantly negligible throughout the warm periods whereas in some other years a single spring month brings almost as much precipitation as there should be within the whole year.

The desert's weather is usually the one with no precipitation, the number of days with precipitation being less than 100. The localities with fewest precipitation days, viz. 40 days a year is found in Karakum. The Ferghana Valley, the Caspian and Aral Sea coasts, the Balkhash Lake experience fewer than 60 precipitation days a year. In spring, in southern deserts the recurrence of weak and moderate precipitation is 30–50 per cent of the days every spring month, that of considerable precipitation 7–25 per cent. The number of days with the considerable amount of precipitation (9 mm and over per 12 hrs) in the southern subzone varies from 2 to 6 [Subbotina, 1977] .

High summer temperatures of air, insufficient amount of precipitation and the absence of surface water determine air dryness from June till September the southern subzone having a decrease in relative humidity up to 22–25 per cent. In occasional, very hot, periods with the air temperature exceeding 40 °C the air humidity in the daytime may drop to 3–5 per cent. In such days the air humidity deficit can reach very high values. Thus, in Utsh-Adji on July 8, 1944 at 1 p.m. it reached 108.7 mb. [Chelpanova, 1963] .

High values of temperature and humidity deficit lead to considerable evaporation. The maximum annual values of evaporation are characteristic of the Southeast Karakum exceeding here 1700 mm [Zubenok, 1976] . When one moves northwards the evaporation gradually decreases to vary in the range of 900–1300 mm in the northern subzone.

General aridity of climate can be described by an aridity index showing the ration between evaporation and the annual amount of precipitation. In the northern subzone the aridity index rises from 3.0 in the north to 8.0–9.0 in the south, for the southern zone these figures are 10.0 and 16.0, respectively. This proves considerable aridity of climate in the Central-Asian deserts.

High aridity of climate in the deserts, mobility of soil substratum and sparse natural vegetation favour storms of drifting sand and sand storms even though the wind velocity may rise insignificantly. The sand storms occur mainly with the wind of 9–14 m per sec. However in many regions the wind velocity to 6–8 m per sec. would be enough to bring about a sand storm (Orlovsky, 1962; Romanov, 1960). Sand storms take place all the year round and depend largely on local features. In Central Asia the maximum annual number of days with sand storms occurs in the Central Karakum and in western Turkmenistan where the average annual amount of days with sand storms is 50. The major part of Karakum, the Middle and Upper reaches of the Syrdarya are characterized by 30 to 50 days with sand storms a year for the northern part of Turkmenistan, in Kyzylkum and Ferghana Valley these figures are 10 to 30 days. In the east of Ustyurt the average annual amount of days with sand storms is 5 to 10 [Sapozhnikova, 1970] .

Quickly drying-up soil and strong winds prove favourable to generation of springtime sand storms in Karakum. The observations made in Kyzylkum desert evidence that the summer maximum of sand storms recurrence is related to the summer maximum recurrence of considerable wind velocities. In the Kopetdagh piedmont autumn is a season favourable to sand storms. For the diurnal variation in sand storms recurrence two maxima are commonly observed, those at 10–13 hrs and 19–22 hrs. In most cases a continuous duration of sand storms does not exceed 3 hrs. In the west and in the extreme southeast of Turkmenistan, and in some regions of the Central Karakum one can observe the most lasting sand storms, 5 per cent of them being longer than 24 hrs. In May of 1950, in Nebit Dagh a sand storm lasted for 73 hrs, and in November of 1951 in Aidin a sand storm lasted for more than 70 hrs [Orlovsky, 1962] .

The climatic conditions determine development and growth of natural vegetation as well as the periods of, and methods used for carrying out phyto-reclamation works.

Precipitation produces soil moisture reserves which are used by plants during vegetative season. However the prolonged impact of precipitation will not favour the growth and development of vegetation unless it acts along with temperatures favourable for the vital activity of plants. This is why every type of a plant responds the impact of environment in a different way in accordance with its biological peculiarities: the vegetative season of some of them is associated with winter–spring or spring periods (ephemerals, ephemeroids), that of others occur in a spring–summer periods still others have their vegetative season in summer (summer annuals) and finally some of them have it from spring till late autumn.

The aridity of climate goes along with an utter absence of local watercourses throughout the desert territories. According to a figure of speech used by V.L. Shults (1965), the desert territories of Central Asia are the lands where the runoff which originates in the mountains gets dispersed. One can identify two subregions in the runoff-dispersing area:

a) that of dispersion of the surface and subsurface runoff;

b) that of dispersion of the subsurface runoff only. The plain region receives on the average 96 mm of atmospheric precipitation and 201 mm as a runoff coming from the mountains only to expend all this moisture (297 mm) as evaporation.

The river system in deserts is very poor. Many rivers either dwindle in the sands making dry beds and deltas or are taken up for irrigation purposes. Only the Amudarya and Syrdarya, the two largest rivers, prove capable of traversing the sandy deserts and bringing their waters up to the Aral Sea. Besides, in the southwest the Atrek empties its waters into the Caspian Sea, and the Ily and Karakol which run in the northeast empty their waters into the Balkhash Lake.

The rivers of the Central Asian deserts have two floods a year, one occurring in the first third of a year during the season of heavy spring rains and snow melting in the adjacent low mountains, the other being in early summer when permanent snows and glaciers start melting in the high ridges of mountain systems. Some of the rivers get dried up in summer or serve as a runoff for ground waters when their beds act as natural drains absorbing underground waters running in alluvial deposits. During heavy summer rains and snow melting the beds of temporary watercourses which are usually dry get filled up with water.

The arid climate and the variety of parent rock types account for a diversity of soil-cover complexes. In desert areas, the parent soil formative are alluvial, marine, proluvial, proluvio-alluvial, and eolian deposits, and rock eluvium.

The arid climate also accounts for a low rate of biological and soil formation processes. The typical features of desert soils are a low humus content, a low degree of structure formation, and a high salinity. The soil cover largely consists of desert brown-gray, sandy, sandy-loam, and loamy soils, takyrs, and solonchaks. River valleys and deltas, enjoying redundant soil-ground humidification have hydromorphic soils, such as alluvial meadow, meadow takyr and others. Sierozems formed on loess deposits are typical of piedmont plains, which are more humid thanks to a greater amount of precipitation [Lobova, 1960] .

Desert sandy soils are the most primitive soils formed on overgrown sandy tracts. The humus content in such soils is as low as 0.3 to 0.5 per cent, but they are highly permeable to moisture and effectively preserve it in their horizons, which is extremely favourable for desert plants. Small wonder that the vegetation cover on such soils is richer by far than on adjacent clayey areas.

Gray-brown soils are predominant in Ustyurt, Mangyshlak, the Krasnovodsk Plateau, the Trans-Unguz area, Betpak-Dala, and the ancient delta plains of the Amudarya and Syrdarya Rivers. The upper horizon of these soils is strongly compacted, slightly solonetz-like contains up to 8 per cent of gypsum and interspersed with gravel and small-size break stone. Natural fertility of gray-brown soils is low, because the humus content is only 0.5 to 0.8 per cent.

Sierozems prevail on sloping piedmont plains, foothills, and low mountain ranges. The humus content in sierozem is higher than in the soil of the plains and may reach 1.5 per cent. Sierozems are solonetz-like and contain considerable amounts of phosphorus and potassium. Of all desert soils, these are the best suited to agriculture.

The sierozem foothills flatten out into a stretch of takyrs and takyr-like soils. The humus content in takyrs never exceeds 0.5 per cent. The dense crust of clay is almost impermeable to water. As a result, sodium salts, which are detrimental to plants, accumulate at a depth of 15 to 30 cm.

Residual meadow soils occur in the alluvial valleys of the Amudarya and Syrdarya Rivers, the northwestern part of the Murgab, Tedjen and Zeravshan Deltas, the Sarykamysh Depression, the Western Uzboy Valley, and the southwest of Turkmenistan. Patches of such soils are divided from one another by stretches of sand. Meadow soils contain as much as 3 to 4 per cent of humus.

In oases, many years of irrigation have led to the formation of a peculiar type of irrigated soil whose upper agroirrigational horizon is more than two meters deep and contains 6 to 8 per cent of humus.

The different mechanical compositions and agrohydrological properties of the foregoing soil types account for differences in their water regime. In conjunction with the climatic conditions, the latter factor determines the composition of the vegetation cover, the rhythmic of its development and productivity. For the most part, the vegetation consists of psammophytes, xerophilous subshrubs, and halophytes.

M.P. Petrov (1973) marks out the following basic types of desert vegetation in Central Asia (the vegetation of river valleys is not considered):

– psammophilous trees and shrubs (Haloxylon persicum, H. aphyllum, Calligonum caputmedusae, C. setosum and others; Salsola richteri, Ammodendron conollyi, Ephedra strobilacea and others) which grow in sandy and sandy-pebbled deserts;

– hypsophyllous small shrubs (Salsola arbuscula, S. rigida, S. gemmascens, S. laricifolia, Anabasis salsa, Hammada leptoclada and others) growing in stony and rock debris deserts of Tertiary Plateaux;

– ephemeral-ephemeroid herbaceous plants (Poa bulbosa, Carex pachystylis) growing in loess deserts;

wormwood and subshrubs (Artemisia semiarida, A. kemrudica, Kochia prostrata, Eurotia ceratoides), perennial grasses (Agropyrum desertorum, Stipa cappillata), as well as ephemerals and ephemeroids growing in loamy deserts;

– algae, lichens and thallophytes with peculiar groupings of desert lichens (Diploschistes albissimus, Squataria lentigera and others) or blue-green algae (Phormidium Microcoleus) growing in takyr areas;

– shrub-like halophytes (Halocnemum strobilaceum, Halostachys caspica, Tamarix laxa) and annual halophytes (Salsola, Halogeton, Suaeda) growing on solonchaks.

Desert soils and vegetation covers are patchy and form diverse complexes. This is due to differences in topography, the structure of soils, and the moisture content in them.

Hydrothermal differences between the northern and southern subzones of the desert manifest themselves in specific soil and vegetation cover types.

The northern subzone is an area of brown-gray desert soils which are highly solonetz-like and solonchak-like. The accumulation of carbonates is strongly inhibited by the moderate hydrothermal regime.

Precipitation is scanty, but uniformly distributed throughout the summer period, which provides favourable conditions for late-maturation perennial subshrubs, such as wormwood and saltwort. Thus the northern subzone is a desert with wormwood vegetation. The climate gets drier as one moves to the south, but the increasing aridity does not change the type of vegetation cover except for the appearance of more xerophytic varieties of wormwood. The vegetation is thin and patchy.

The vegetation cover is richer by far in the sandy deserts of Sam, Muyunkumy, Bolshye Barsuki, and Malye Barsuki [Kurochkina, 1978] . Plants in this part of the northern subzone are for the most part mesophytes and xerophytes.

In the southern subzone, the soils are gray-brown and gray, with a high carbonate content. The latter factor is due to extremely hot and dry summer period. This hydrothermal regime is conducive to the accumulation of carbonates in soil horizons and underlying strata. Because of spring rains, the vegetation is more abundant than in the northern subzone where there are no rainy periods. Warm and wet springs account for such specific plant species as ephemerals and ephemeroids which are seldom found in the northern subzone. With the onset of hot and dry summer period, ephemeral plants wither and die.

In the northern subzone, the ecological conditions are favourable for plant growth during the warm season. In the southern subzone, they are more favourable for plant growth during the cold season. In the former subzone, plant growth is impossible in winter because of low temperatures and a thin snow cover, while in the latter subzone the winter climate is conducive to the growth of ephemerals and ephemeroids. In the southern subzones, even xerophytes cannot grow in summer due to very high temperatures and lack of precipitation. In the northern subzone, only late-maturation desert xerophytes can grow in summer.

The northern and southern subzones feature three basic desert types which include sandy, gypsum, and clay deserts. Sandy deserts stretch in wide tracts in the northern subzone and occupy most of the southern subzone. The vegetation cover of sandy deserts in the northern subzone consists mostly of shrubs and herbaceous plants. There are also different species of wormwood and other subshrubs. The typical shrubs are Haloxylon and different types of Calligonum and shrub-like saltwort (Salsola) species. The vegetation of sandy deserts of the southern subzone ranges from tall shrubs to annual ephemerals. The typical plant formation is a two-story one, consisting of shrubs and herbaceous plants. In a sandy desert, there are 300 to 600 trees and shrubs per hectare, i.e., one plant per 20 to 25 m^2. These plants cover 12 to 15 per cent, and in some places 20 to 25 per cent, of the desert area, although on tops of sand ridges they only account for 1 to 5 per cent of the area (Ovezliyev et al., 1979).

Gypsum deserts are quite common both in the northern and southern subzones. Their soils are brown-gray, with a low carbonate content. The carbonate content gradually increases as one moves to the south. Brown-gray solonetzic and saliniferous soils with streaks of gypsum prevail in the southern subzone.

In gypsum deserts of the northern subzone, the predominant plant formations are those of wormwood and saltwort. In the southern subzone, the typical plant formation is that of scattered shrubs and subshrubs with a small sprinkling of ephemerals. In an area of the hectare, there are scores of thousands of subshrubs which are 0.2 to 0.5 m high and have a crown 0.1 to 0.5 m in diameter. They cover 10 to 20 per cent of the desert surface. Despite the harsh climatic conditions, these plants do not seem to be affected by grazing and their numbers dwindle down only because they are used for fuel.

Clay deserts of the northern subzone are noted for tall shrub formations with an abundance of black Haloxylon and different tamarisk species. In clay deserts of the southern subzones, heavy texture and highly saline soils account for the predominance of saltwood. Ephemeral formations are usually thin. The canopy coverage of these plants does not exceed 10 to 20 per cent of the desert area.

Small tracts of stone desert are found between the mountains and the piedmont plain. The soil cover is thin and patchy, with an abundance of rock debris and a small percentage of fine-grain particles. The vegetation cover largely consists of shrubs and subshrubs with an abundance of different wormwood species (Artemisia).

Loess deserts occupy most of the piedmont area. Sierozem is the predominant soil-type. The two-story vegetation cover is quite dense and consists of herbaceous plants with occasional wormwood formations.

2. RECLAMATION OF SHIFTING SANDS

2.1. THE WORLD PRACTICE OF SHIFTING SAND RECLAMATION

Considerable experience has been gained in stabilization of shifting sands in the arid zones throughout the world. The most traditional and widely applied methods to combat desertification in the arid zones of Middle and Central Asia, Middle East, and in some countries of North Africa are phytoreclamation along with sand stabilization by mechanical and physico-chemical methods [Petrov, 1974] .

These methods are sufficiently reliable allowing considerable areas of fertile soils to be reclaimed for agricultural purposes.

Sand stabilization programmes in various countries are different in scope and execution, depending on the soils and climatic conditions, on availability of planting and chemical material, on financing, technology and labour. A description of these programmes and their geography is given below.

Arid zones in **Iran** occupy 80 million hectares or about 50 per cent of the country's territory. Solonchaks and stony deserts almost devoid of vegetation are an estimated quarter of this area. Sandy deserts occupy 12 million hectares, with about 5 million hectares being shifting sands.

Irrigation, development of natural resources, and construction of roads and industrial units have promoted further desertification. Especially severe damage has been done by poor agricultural practices and overgrazing, destruction of vegetation by uprooting for provision of fuelwood [Iran Changing . . . 1977] . The desertification danger is particularly grave in the environs of Jazd, Kerman, Katanz, Tabas, Kishan, Akhvaz and Sabsevar.

The first attempt to combat shifting sands in Iran was undertaken in 1945, but a large-scale sand stabilization programme was launched in 1965–66, after Iranian desertification control experts had studied the experience of sand stabilization techniques, gained in the USSR and Pakistan [Miknam, Ahranjani, 1976] .

Sand stabilization and afforestation to reclaim desertified areas in Iran is planned and carried out mainly in the interior of the country on separate tracts, and is based on several independent projects. The projects provide for the required extent of sand stabilization and afforestation, for setting up such facilities as seedling nurseries to produce seedlings with open and covered root systems, and for construction of production facilities, water supply installations, etc. Sand fixation is achieved by mechanical means or by mechanical application of binding substances.

The project, based on mechanical means used for sand stabilization is primarily designed for protecting human settlements, communication lines and agricultural lands from sand drifts.

Work in areas under reclamation starts with the fixation of sand surface. Different mechanical means strategies are employed in various localities displaying certain degrees of erosion. Then planting is done by hand. They use arboreal species of sand-fixator plants of the local flora, Haloxylon aphyllum mainly.

During the first vegetation plantings are watered 1–3 times depending on the locality. Sometimes they are watered during the second vegetation as well. Water is brought in tanks pulled by trucks. High-quality seedlings with a covered root system grown in polyethylene bags in watered nurseries are used in the procedure.

Shifting sands fixation projects also provide for afforestation by seeding arboreous and herbaceous species in localities with favourable conditions. Yet, planting proved to be more efficient.

By the mid-70's the area under shifting sands fixation by mechanical means covered 330 thousand hectares, which made it possible to improve about 3 million hectares of rangeland.

Mechanization of sand stabilization proved feasible thanks to chemical binding substances. This method constitutes a special branch in sand stabilization practices. Research in this direction was started in 1968 as it was necessary to stabilize large tracts of shifting sands to protect a number of motorways and railroads. The bytumen emulsion (mulch) has been tested and is used now as a binding substance. It is applied on sand surface mechanically with a device mounted on caterpillar tractors or on special carts pulled by tractors. Mulch input is 3–4 tons per hectare. Sand stabilization by mulching is usually performed after seeding or planting Haloxylon aphyllum or Calligonum.

Mulching is an effective technique in sand stabilization and afforestation; by 1976 in Iran over 58 thousand hectares of shifting sands had been fixed and afforestated using this technique [Miknam, Ahranjani, 1976] .

All areas subjected to sand fixation and afforestation in Iran are placed under military guard and any economic activity there is prohibited. These measures guarantee normal development of plants and ensure natural revegetation of the areas reclaimed.

The sand stabilization programme involves the creation of a green belt around the eastern and northern Iranian deserts over an area of 2.5 million hectares [Iran . . . 1977] . By 1977, 137 thousand hectares had been planted with Haloxylon, Tamarix, Calligonum and other plants; Haloxylon had been sown on 248 thousand hectares; and shelter belts over 6,000 km long had been established. 534 hectares had been cultivated as nurseries, and 2.5 million hectares of arid land threatened with soil degradation had been placed under guard to protect the soil and plant cover [Conservation . . . 1977] .

The same desertification hazard and similar environmental conditions are observed in Afghanistan, Pakistan, India and Turkey. The territory of **Afghanistan** is threatened with desertification, except some areas in the east and north-east of the country. 62 per cent of the territory (40 million hectares) are rangeland. Uncontrolled grazing of 30 million livestock causes degradation of the soil and plant cover. The spreading use of dry farming and the felling of trees (up to 10 thousand hectares annually) lead to a further soil degradation [Problems . . . , 1983] .

The actual extent of shifting sand formation has not yet been estimated but shifting sand areas in the north are quite large. Areas under sand dunes stretch for thousands kilometres along the border with the USSR. According to the field observations, their formation results from the destruction of the plant cover and deflation of upper quarternary alluvial deposits of the Amudarya river. Sand dune relief is different and depends on the locality. Along the Amudarya, sand dunes form high chains with heights drop from 10 to 15 m. Further to the south, aeolian deposits grow thinner. Enveloping beddings of sand deposits 0.3 to 2–3 m thick are found along the border with alluvial foothill deposits.

In the sites of sand deposits, where deflation takes place the sand is poorly graded. The grey colour and the presence of mica testify to the insufficiently long aeolian exposure. In the periphery the sand is well-graded, enriched by powder particles, and partially saline.

A sand stabilization works are being carried out today in Afghanistan to protect various economic units particularly motorways. The technique of sand surface covering with clay is employed. Clayey soil is displaced and scattered over the sand by bulldozers. They plan to use chemicals to prevent blowout of sand near economic units.

Pakistan faces several problems linked with desertification such as wind and water erosion in the areas of dry farming and wind erosion in sands. Factors, processes and the scope of desertification differ in various regions and are determined by physico-geographical conditions, by human and livestock populations and land use pattern.

Desertification is spreading in the arid zones of **India** where 45 per cent of arid lands are cultivated and gathering of fuelwood goes on a large scale. It has been estimated that if fuelwood gathering in the Thar desert goes on at a rate of 3 million tons, which was registered in 1971, the plant cover will be completely destroyed in six decades. In recognition of this problem afforestation was attempted in the states of Rajasthan, Haryana and Gujarat situated in the arid zones.

It should be noted that in the western part of Rajasthan 13 million hectares out of a total of 21.4 million hectares is taken up by shifting and semi-fixed sand dunes of various types.

Vigorous efforts aimed at shifting sands stabilization and afforestation have been made in India since 1952 when the government established the Desert Afforestation Station in Jodhpur which was reorganized into the Desert Afforestation and Soil Conservation Station in 1957, and into the Central Arid Zone Research Institute (CAZRI) in 1959. The main task of these research centres has been the study of natural conditions of the Thar desert and the development of shifting sand afforestation techniques and rangeland reclamation methods, as well as the creation of shelter belts and planting of trees and shrubs in settlements in desert areas.

Over the past 25 years, 112 species of Eucalyptus, 65 species of Acacia, and 82 species of other plants from various countries of America and Australia were introduced into various regions of Thar.

Research allowed CAZRI to work out the following recommendations on afforestation, depending on the local conditions:

1) Thick sand soils – Acacia tortilis, Prosopis juliflora, P. cineraria, Albizzia

lebbek, Azadirachta indica, Tecomella undulata, Eucalyptus melanophloia, E. camaldulensis, E. terminalis, E. hyrid, etc..

2) Thin alluvial soils – Azadiachta indica, Prosopis juliflora, Albizzia lebbek, Acacia nilotica, A. tortilis, Eucalyptus terminalis, E. camaldulensis, E. sideroxylon, etc..

3) Sandy-stony areas – Acacia tortilis, A. senegal, Azadirachta indica, Prosopis juliflora, Anogeiussus rotundifolia.

4) Rock debris – gravel areas – the same as in 3.

5) Shifting sand dunes – Acacia tortilis, A. senegal, Prosopis juliflora, P. cineraria, Calligonum polygonoides, Parkinsonia aculeata, Albizzia lebbek, etc..

6) Heavily saline areas – Acacia tortilis, Prosopis juliflora, Salvadora oleoides, S. persica, Tamarix artilata, etc.

After prolonged experiments on sand stabilization, CAZRI worked out the following techniques:

1. Protection of dunes from biotic influences by fencing.

2. Protection of dunes subject to blowout by establishing mechanical guards made of indigenous shrubs. They are placed from the crest to the foot of a sand dune in rows or in checkers and serve as micro wind-breaks.

3. Creation of an artificial vegetation cover by planting or replanting of seedlings of indigenous or introduced species grown in non-baked earthenware pots or in a container.

4. Planting of cuttings or sowing of herbs and castor trees on the leeward side of mechanical guards.

5. Constant and proper use of mechanical guards until the expenses are justified (10–15 years).

Fencing. Fences are made of barbed wire fixed on posts, made of angular iron put in lines with a spacing of 6 m. Fences are also made of Zizyphus nummularia shrub-type when available.

Mechanical guards made of shrubs. The following species are used: Crotolaria burhia, Leptodenia spartium, Zizyphus nummularia Aeruva psudotomentosa, Calligonum polygonoides, Panicum turgidum. Shrubs are collected on site and are buried into the ground vertically with crowns downward in rows, spacings between them being from 2 to 5 m. The aim is to reduce the wind velocity near the surface of sand dunes.

Creation of the vegetation cover. To stabilize dunes in areas with different annual amounts of rainfall the following trees, shrubs, and herbs are recommended:

1. 150–300 mm mean rainfall zone.

Trees: Prosopis juliflora, Acacia tortilis, A. senegal.

Shrubs: Calligonum polygonoides, Zizyphus sps.

Herbs: Lasiurus sindicus.

2. 300–400 mm mean rainfall zone.

Trees: Acacia tortilis, A. senegal, Prosopis cineraria, P. juliflora, Tecomella undulata.

Shrubs: Zizyphus sps., Calligonum polygonoides, Ricinus Communis.

Herbs: Cenchrus ciliaris, C. setigerus, Lasiurus sindicus. Saccharum munja.

3. The zone with a mean precipitation of over 400 mm.

Trees: Prosopis cineraria, P. juliflora, Acacia nilotica, A. senegal, A. tortilis, Tecomella undulata, Parkinsonia aculeata, Ailanthus excellsa, Albizzia lebbek.

Shrubs: Cassia auriculata, Ricinus communis, Zizyphus sps.

Herbs: Cenchrus ciliaris, C. setigerus, Panicum autidotale, Saccharum munja.

To protect economic units, sand stabilization and afforestation techniques for various cultivation conditions (on shifting sands, rocky soils and pastures) have been developed to improve range land and supply population with fuelwood.

Activities aimed at creating protective forest-belts around settlements and planting greenery there have proved to be successful. Forest-belts of Acacia nilotica and Dalberdia sissoo, 102 km long, were laid in Suratgarh. In various parts of Thar forest-belts in the form of alleys, about 200 km long, were planted along railroads. Acacia tortilis plantations stretch for hundreds kilometers in Haryana and Gujarat. An extensive afforestation programme has been adopted for the 1980–1985 period. It envisages the establishment of forest plantations in the desert, to provide fuelwood, over an area of 5 thousand hectares, shifting sands fixation on 7.1 thousand hectares, planting of 2 million trees for construction purposes on 5.2 thousand hectares, and the foundation of mixed plantations.

In the zone of the Rajasthan canal it has been planned to create a protective forest-belt 75 km long, plant trees on 500 hectares, set up a fuelwood reserve on 300 hectares and carry out afforestation of 4 thousand hectares of shifting sands [Mann, 1981] .

In **Turkey**, the coastal regions and the land in the southern part of Central Anatolia (the Kenya province) are subjected to desertification. The total area of the eroded land is 466 thousand hectares. In 1960 shifting sands occupied 430 thousand hectares in central regions. Their formation is attributed to the deflation of lacustrine deposits.

Works on shifting sands reclamation started in 1960. By 1962, reed fences had been set up over the entire territory. They reached 1.5 m in height with spacings of 30–50 m between them.

Sand stabilization with reed fences was the first stage followed by the sowing of herbs. Planting of trees well adapted to severe local conditions constituted the second stage. Afforestation by setting up plantations of trees was the final stage of shifting sands fixation. By 1981 the territory of the reclaimed lands reached 300 thousand hectares.

The reclaimed lands are widely used in agriculture, in particular for the development of dry farming and for an intensive management of irrigated farming with the use of ground waters. About 3,000 wells have already been dug for that purpose (Blooming desert, 1981).

Large-scale reclamation of desertified areas and shifting sands is being planned and carried out in **China**.

The total area of desert territories in China is 1,095 thousand sq. km, with sandy deserts taking up 647 thousand sq. km and the rest being stony deserts.

The main sandy deserts and tracts are given in Table 3.

The most frequently occurring form of aeolian and erosion reliefs in the Chinese deserts are sand dune chains. The biggest chains are found in Takla-Makan and Kurbantongut. Shifting sands occupy about 65 per cent of the sand dune territory. They move mainly to the southeast because of northwestern winds. These areas include the southwestern part of Takla-Makan, the southeastern part of Kumtag, and the desert of the Tsidam depression, the Kurbatongut, Badan-Jhareng, Tengeri, Ulanpuho and Kuzupchi deserts, the Maouso, Hoyshangtag and Hulunber sand tracts, and the northwestern part of the Kersing sand tract.

Table 3

Territories of the Sandy Deserts in China

Sandy deserts and tracts	Area, of the total desert area, including Gobi, %	Sandy deserts and tracts	Area, of the total desert area, including Gobi, %
Takla-Makan	47.3	Maouso sandy tract	4.5
Kurbantongut	6.8	Kumtag	3.2
Badan-Jhareng	6.2	Hoyshangtang sandy tract	3.0
Tengeri	6.0	Kuzupchi	2.3
Kersing tract	5.9	Ulanpuho	1.4
Deserts of Tsidam depression	4.9	Hulunber sand tract	0.7

Dunes exposed to northeastern winds migrate to the southwest. Such migration is observed on the greater part of the Tarim depression, and in the areas to the west of the Huangho river. The northeast drift is characteristic of the eastern part of the Kersing sand tract and of southeast China. Phytoreclamation methods are extensively used in China to combat sand drifts and deflation. Besides, various covers are used for sand stabilization.

Sand stabilization is carried out along the three main directions:

1. Stabilization and agricultural use of sands around oases and villages.
2. Sand stabilization along motorways and railroads.
3. Prevention of the frontal sand drift.

At the edges of oases where dunes do not exceed 10 m and there are spacings between them forest-belts and separate patches of trees are established. Populus cupidata is planted on dunes and Eleagnus angustifolia between them. Their growth is assured by ground waters or by irrigation. Sometimes mechanical guards such as mulch from clay, straw, gravel, etc. are used on shifting sands between separate tree patches.

Planting of trees together with Tamarix ramosissima is employed for sand stabilization in oases situated in marginal desert areas. Data obtained in the southwestern part of Takla-Makan show that shrubs of Tamarix chinensis-type stabilize about 80 per cent of sand at mean wind velocities. Shrub belts may reach 300 to 500 m in width.

Different sand-fixator plants are used in various deserts. Thus, in oases along the border of Hinguang Populus bolleana, Eleagnus angustifolia and Ulmus pumila, as well as Tamarix chinensis among shrubs, are most suitable.

Solix matsudana, Populus simonii and Eleagnus angustifolia prevail in Ulanpuho desert; Populus cupidata and Eleagnus angustifolia, along with Haloxylon ammodendron shrub, are used in the Heksi corridor.

Prolonged experiments have shown that the employment of several species rather than the only one is more effective for sand stabilization.

The afforestation effort in Maouso sands has indicated that plantings of Salix cheilophila and Salix matsudana in the interdune depressions which form forest plots on leeward slopes of sand dune chains prevent forward sand movement. Salix cheilophila or Artensia ordosica are planted on the lower third of windward slopes. These plantations "draw up" dunes, decreasing the sand migration rate at the ground level and thus decreasing the amount of reblown sand. This method is called "running after the wind and chasing away the sand with plants".

Of special note is the work on sand fixation by afforestation of areas irrigated by the waters of the Yellow river in Shabodon. Trees there are planted together with shrubs: Robini pseudoacacia, Eleagnus angustifolia, Populus cupidata, Hedyseoparium, Caragana Korshinskii, Salix cheilo-phila. Considerable amount of sediment discharge represented by silt, being brought by the river at irrigation forms a crust on the sand surface facilitating its fixation.

Particular attention is paid in China to protection of motorways and railroads from sand. Phytoreclamation methods worked out in accordance with litho-edaphic conditions of various zones have been employed. They are listed in Table 4.

Prevention of sand transport caused by construction is achieved by protective belts. They are established by planting Salix mongolica and Tamarix juniperina along the dune contours. In sites where sand fixation is required mechanical guards are employed. Plant material is placed in bands at 1 m spacings or in 1x1 m checkers. Then seeds of Artemisia ordosica are sown on fixed areas (500 g per hectare).

Sand fixation measures carried out in Singzyan may serve as an example. Deserts here take up about 321 thousand sq. km. Two thirds of this area are covered with

Table 4

Sand Fixation Methods Used in Road and Railway Construction

Landscape type	Sand fixation techniques
	Railways
Steppes with shifting sands and semi-fixed and fixed dunes	Planting of Artemisia halodendron, Caragana microphylla on dune ridges, of Lespedeza dahurica on leeward slopes, and of Salix flavida on windward slopes. This protective system is known as "A tree you need in a place it should be".
Deserts with shifting sand dunes of great length	Straw checkers 500 m wide as mechanical guards with plantings of Hadysarum Sciparium, Calligonum mongolicum, and Salix flavind
Arid zones and Gobi where sand transport presents serious threat	Forest-belts of Populus cupidata, Eleagnus angustifolia, Salix cheilophila (often irrigated)
	Motorways
Deserts	Forest-belts of Artemisia ordosica and Salix cheilophila. Rock debris of salt slabs covers. Mechanical guards in the form of checkers.

sand dune ridges. To combat land erosion, forest plantations 300 km long and 500 m wide were set up. They protect 450 thousand hectares.

Large-scale reclamation works have been undertaken in Inner Mongolia where shifting sands occupy 34 per cent of the territory. 240 thousand hectares have been stabilized, with 210 thousand hectares made into pastures.

No data are available on the use of chemicals for sand stabilization in China [China . . . , 1977, Combating . . . , 1981] .

The total area under sand dunes in **Israel** is 130 thousand hectares. Coastal dunes are stabilized through formation and stabilization of the frontal dune. In some cases two or more frontal dunes are formed, spaced at 50 to 100 m. Frontal dunes are stabilized with Ammophyla arenaria. Spacings are fixed by herbs Ammophyla arenaria, Agropyron jumeum, Oenophera drummond etc. and by spraying a water-soluble emulsion.

Sowing takes place in October–November during the period of winter rainfall. Often rye and barley are sown in bands and they are later replaced by slow-vegetating perennial plants. Agropyron junsum allows for controlled grazing. Protective forest belt planting is represented by Sacehrum biflorum and Acacia cyanophylla. Acacia is planted in sites where it cannot be affected by salt water.

Inland dunes are stabilized by planting Calligonum Jucla and Agave. Binding substances are used whenever the need arises.

Sand stabilization as one of the effective means to combat desertification is also employed in a number of North Africa countries and those situated in the Sudano-Sahelian zone. It should be noted that problems of coastal and inland dune reclamation are specific in character.

Though there exist a uniform methodology of sand fixation, technical means and phytoreclamation agents may vary in different countries.

Measures on sand fixation and shelter belt establishment to prevent soil erosion on the oceanic coast in **Senegal** are preceeded by a detailed survey of local ecological conditions and climatic factors, the study of the infrastructure and establishment of nurseries.

Then a forward coastal dune is established, at a distance of 60–70 m from the maximum tide height line, 5–8 months before the next stage of fixation.

Shelterbelts from 260 to 3,000 m in length are set up at a distance of 20–25 m from the forward dune with the number of rows depending on the steepness of slopes. The rows in the first zone are placed at 42–45^{o} angle with prevailing latitudinal winds. The preliminary protection of areas from deflational processes is achieved by placing covers or 2.5x2.5 m checkers made of plant material. Sometimes upright synthetic materials are used, normally, this takes place in October–November. The vegetation cover is produced by planting seedlings of Eucalypt Anacardium with a covered root system (Fixation . . . , 1981).

In **Libya** shifting sand dunes occupy quite large areas both on the coast and in the interior (250 thousand hectares). They stretch in a strip from the Tunisia border on the west through the region of Misurat to Ajdabia in the east. By now, the coastal dune area has been mostly stabilized.

Two methods of sand fixation in the coastal and inland areas of the country are used:

1) The sand surface is stabilized by mechanical guards made of plant material.

2) Sand is fixed by binding substances such as raw oil, bytumen emulsion, and emulsion from synthetic rubber, oil, and water. "Biological" fixation by trees and shrubs is employed after the sand has been pre-stabilized. Mechanical means are arranged manually. Dried plant material is dug into the soil in rows to a depth of 15 cm with an aboveground part 35 cm high. 5 sq. m checkered guards are used on steep dune slopes composed of coarse sand and 4x4 m checkers, on flat slopes and fine sands. To fix sand further, Artemisia herba-alba, Retama raetam and Palm fronds are planted.

Imperata cylindrica, Aristida pugens, Retama raetam and palm branches or fronds are used as plant material.

With the growing scale of sand fixation activities in the country, a certain lack of plant material made itself felt which prompted the search of other methods of their protection, namely physico-chemical methods. Since 1961, sand fixation by oil products has been extensively used.

This technique is relatively simple. Oil products are sprayed by a special device which is made up of a 12 m^3 tank on a sled, engine and sprayers. The device is pulled by a caterpillar tractor. Binding agents, including high resinous oils, are heated to 45 ^{o}C before spraying. Agents are sprayed using special sprayers over 20 m bands at a rate of 4 tons per hectare. 25 hectares may be treated daily. Spraying from an aircraft was also employed.

A crust of 0.5 cm thick which stays on the sand surface for three years is formed when spraying raw oil.

Only non-toxic oil products which do not affect vegetation adversely, are used. Oil products were also sprayed from an aircraft.

The plant cover in areas fixed by binding agents is set up by planting 6–10 month-old seedlings or plantings with a covered root system. Planting is done in November–December when the rainfall moisture penetrates into soil down to 40 cm. Besides, roots of seedlings are kept in water in individual containers before planting, and thus a store of moisture necessary for a normal survival of plants during the early period is created.

In such conditions seeding is not considered to be effective.

Plants used for the inland dunes fixation include Acacia cyanophylla, A. cyclops, Eucalyptus Camaldulensis, E. gomphocephala, and Tamarix articulata. 40 per cent Acacia and 60 per cent Eucalyptus is considered to be the most effective combination of plantings.

The number of plants per hectare depends on the locality, forest-growing conditions and tree species and varies between 500 and 1,000 [Desertification . . . , 1977] .

Large-scale reclamation works with similar sand fixation techniques and agricultural methods of creating shelter belts are used in coastal sand areas in **Egypt, Tunisia, Morocco,** and **Algeria.**

The following tree, shrub and herb species are recommended for plant cover restoration in the mainland sands of North Africa:

a) trees – Tamarix aphylla, T. stricta T. articulata, T. gallica, T. africana, Eucalyptus woddwardis, E. oleosa, E. occidentalis, E. astringens, E. troguata etc., Calligonum arel, C. arich, C. arbores census, Haloxylon persicum, H. aphyllum, Ricinus communis, Saccharum spontanum, Casuarine equestivolia;

b) xerophyte grasses -- Panicum antidotale, P. turgidum, Aristida pennata, A. kareliana;

c) xerophyte shrubs -- Retama raetam, Atriplex halinus, Leptanis peprotechnica, Ochradenus baccatus, Salvadora persica, Genita saharae, etc.

In Egypt a sand stabilization works are carried out in the "New Valley" known as Wadi-El-Gedid. It is made up of a number of oases-depressions to the west of the Nile valley – Harga, Dahla, Farafra and Baharia. These oases are threatened by the northeast sand drifts. Sand encroaches upon the oases as wind sand flow and dune formations at a rate of up to 15 m a year. Considerable orchard areas in Dahla and Harga have thus been lost to sand [Meckelein, 1980]. Combating shifting sands in the New Valley by traditional methods (mechanical means, setting up shelter belts on pre-fixed sand) is impossible owing to inadequate plant-growing conditions while mechanical guards in the form of fences are quickly destroyed [Lychagin, 1975]. Even irrigated Casuarina equisetifolia shelter belts are completely buried by sand in the course of several years.

In the opinion of experts Hagedorn (1977), the only way of controlling the sand movement is not to place habitation and installations in its path.

The search for effective means of combating sand drifts in the New Valley is under way. The pilot projects envisages sand fixation by irrigated Casuarina belts which must not exceed 3 rows with 50 to 75 m spacings between them. Lower branches must be cut up to a height of 1.5 m to allow the passage of the wind flow, to prevent trees covering by sand and to ensure sand precipitation from the flow outside the belt due to a drop in the wind velocity. It is expected that the burial by sand of canals and irrigation furrows in the belt itself will be slackened for at least 60 years.

With a Casuarina belt 10 m high, its reclamation effect is expected to extent to 50–75 m (the experience gained in Central Asia shows that the reclamation effect of wind-swept open planted forest belts is observed at a distance equalling to 10–12 trees height).

A sand layer of 3–4 m accumulated between belts is to be fixed by a vegetation cover of, say, Tamarix which grows thanks to ground water formed by lateral infiltration from irrigation ditches.

For the overall protection of the pilot project, 8 shelter belts are planned to be set up to ensure the protection of oases from sand drifts and also of possible further agricultural reclamation of the land between the forest belts.

The transnational "Green Belt in North Africa" project [Transnational . . . , 1977] and the one in the Sahel region [Sahel . . . , 1977] was considered at the UN Conference on Desertification Control in 1977. The first belt will go through the territories of Egypt, Libya, Algeria, Tunisia and Morocco along the boundary of the regions with a mean annual rainfall of 150–250 mm. The green belt is an area where an integrated project is implemented to prevent further degradation of ecosystems. The measures include shifting sand fixation, moisture retention, afforestation, improvement of rangeland, and the development of crop farming, livestock breeding and dry farming. The width of the green belt may vary between 2–3 and tens of kilometers depending on climatic conditions and the relief. Shelter belts are recommended to set up by seeding and planting Amophyla sp., Haloxylon sp., Ricinus communic, Acadia cyanophylla, A. cenegal, A. longifolis, Eucalypt gemphocefalia, E. Camaldulensis, Eleagnus angustifolis, Tamarix sp., and Zizyphus spinachresti. In areas with a mean annual rainfall of 300 mm drought-resisting species of pines are recommended.

The second "Green Belt" will be set up along the southern boundary of Sahara. This belt, 150 to 400 km wide, will stretch from the Atlantic Ocean to the Red Sea through the territories of Senegal, Mauritania, Mali, Upper Volta, Nigeria, Chad and Sudan, the countries of extensive cattle breeding. Ecological, economic and social conditions in these countries are similar and they all face the same problems in desertification control.

The "Green Belt" project is aimed at the conservation, reclamation and proper use of fodder resources in the zone.

In the deserts of the Arabian peninsula viewed as a "buffer zone" bridging the vast African and Asian deserts, dune formations are fairly wide-spread. They are moving from sandy deserts (ergs) which take up more than 1 million sq. km.

Sand drifts threaten agriculture, roads, trees, cities, and such infrastructure elements as airports. Combating sand drifts may be well illustrated by the El-Hassa oasis, the largest in Saudi Arabia and one of the most ancient oases in the Middle East. It is situated 60 km to the west of the Persian Gulf and 300 km to the east of the country's capital El-Riad; its width – 20 km and it stretches for 30 km from north to south. Sand dunes move from the El-Gafur desert. The situation is particularly grave in the eastern part of the oasis where dunes move along a 8 km front at a rate of 10 m a year due to the predominant northern winds called shemal.

To fix shifting sands, mechanical guards such as fences made from date palm leaves are employed. After two years they are buried under a 2 m layer of sand.

The biological method involves setting up hedges of Tamarix up to 10 m high. Other trees and shrubs grow in their shadow. The method is more effective but labour and time consuming.

To protect roads, roadbeds are made of bound ground which is lavishly watered and coated with a sand-fixator. The roadside dune crests are levelled and fixed wherever possible with a layer of ground or fences, made from palm leaves and spaced at 10 times the height of the trees. Later a 400 m-wide roadside strip is fenced off with barbed wire to prevent grazing by camels and goats.

Planting of sand-fixator plants usually starts in winter, after the first rain. A rainfall of several millimetres is sufficient to moisturize dunes. One millimetre rainfall was found to moisten sand to a depth of 2 cm.

Planting material is represented by 5–10 year-old tamarix trees. Finger-thick cuttings 1 m long are defoliated and placed in water for 24 hours. When planted into moistened sand, they are 5 cm above the ground. It is important that plants take root in moist sand with roots reaching ground water. The plants are spaced at 4 to 6 m. To ensure survival, cuttings are planted in pairs. In wind-protected sites almost all plants take root while in open spaces on the dunes they are subjected to wind and may dry up.

Some other fast-growing trees may be used in setting up shelter belts as well. As a rule they are seeded between the belts but require additional irrigation (Table 5).

Large-scale sand fixation projects are implemented in the south of the Arabian Peninsula in the People's Democratic Republic of Yemen.

Table 5

Tree Genera Used for Sand Fixation in El-Hassa Project
[Achtnich, Homeyer, 1980]

Tree genera	Maximum height, m	Annual growth, cm
Acacia cyanophylla	8–10	75–100
Albizzia lebbek	9–12	80–120
Casuarina equisetifolia	10–15	75–100
Enealyptus camaldulensis	15–20	150–200
Parkinsonia amleata	5–8	80–120
Prosopis juliflora	8–12	150–200
Tamarix aphylla	8–12	80–150
Tamarix amplexicanlis	5–8	75–100

Reclamation of shifting sands is mainly undertaken in the coastal areas where a dune belt stretches for 1,000 km. Checkered mechanical guards 10x30 m in size rising 0.5 m above the ground are widely used. They are set up on windward slopes in 4–6 rows with the first two rows facing predominant winds spaced at 5 m.

Mechanical means are expected to last 2–3 years until plantings take root and take over a protective function.

Chemical agents are not used because of their unavailability and high cost. Afforestation of stabilized sand surfaces in Yemen is performed according to an agricultural pattern designed for planting in sands with insufficiently moist upper layers. It provides for the root system or butts to be placed only in moistened layers. The procedure is as follows. The dry sand layer is removed and a hole for a plant is dug in the moist sand. If the dry layer is very thick, it is removed by a drill. After planting, holes are filled with dry sand. In interdune depressions planting is done at a depth of 50 cm, on windward slopes at depth of 80–120 cm, and on dune crests, at 150 cm. Up to 10 l of water per plant are required, with another 10 l in the first 2–3 months if necessary.

The above technique ensures 90 per cent survival rate of plants in depressions and 65 per cent survival rate on dune crests.

Planting material is used selectively. On tops of medium-height dunes, Tamarix articulata, Acacia tortilos, and Calligonum comosum are planted. On slopes good results are obtained with Prosopis juliflora, Acacia cyanophylla, A. cyclops, and Parkinsonia aculesta, besides Tamarix. Parkinsonia aculeata, Tamarix aphylla, Aradorachta indica, Acacia arabica, Salvadora persica, and Vernonia sp. grow well in depressions.

In the last decade, much attention has been paid in the People's Democratic Republic of Yemen to the establishment of shelter belts. Research has shown that narrow tree belts of 1–3 rows spaced at 3–4 m are most effective. The species used are as follows: Conacarpus lancifolius, Casuarina equisetifolia, Dalbergia sissoo, Azadirachta indica, Eucalyptus camaldulensis, Terminalia catapa, Parkinsonia amleata, Zizyphus spinachristi, Tamarix articulata.

Le Werre (1976) gave the list of tree and shrub species used for shifting sands fixation in North Africa, and the Central and Middle East.

North Africa, Middle East	Middle East, Central Asia (Irano-Turanian region)	North Africa
Rainfall		
100–250 mm/year		200–400 mm/year
Calligonum arich C. azel	Calligonum arborescens	Eucalyptus oleosa
C. comosum	C. caput medusae	E. sargentii
Acacia aneura	C. polygonoides	E. endesmioides
A. ligulata	C. eriophorum	E. gongylocarpa
A. salinica A. sowdeni	C. comosum Salsola Richteri	E. kingsmillii E. woodwardii
A. pence	S. Paletskiana	E. gillii
A. victoriae	Ammondendron connollyii	E. intertexta
	Caragana microphylla	E. stricklandi
	C. Korshinskii	E. lesoueffii
	Haloxylon persicum	E. gracilis
	Haloxylon persicum	Acacia cyanophylla
	H. ammodendron	A. cyclops
	H. ophyllum	

Academician M.P. Petrov gives a more detailed list of species of plants (see Appendix), used for shifting sands stabilization and afforestation [Petrov, 1973] .

Arid zones in southern Africa are threatened by coastal and continental dunes.

To combat coastal dunes the technique of forward dune creation is employed to cut off sand moving from the ocean and to block it. Several dune chains 10–12 m in height are created parallel to the coast and perpendicular to winds. Usually dunesare formed 100 m away from the highest tide point [Heathland . . . , 1974] .

Forward coastal dunes are formed by setting up 2 m-high fences made of poles, woodboards, and plant material. When an obstacle is buried by the sand, a new fence around which the sand accumulates is set up until the necessary height is reached.

Lately, dunes have been formed by acacia planting, which is done in 30 to 60 m wide rows running parallel to the dune central axis. Sand is accumulated by grass which grows along with the sand accumulation.

Various mulching solutions are used for sand surface stabilization. The newly formed dunes are fixed by Psamma arenaria, Ammophylla arenaria and Ehrharta gigantea herb species. Psamma arenaria is seeded in loose sand and Ehrharta gigantea, between the dunes where it is protected from the wind. Ammophylla arenaria is seeded 1x1 m at a depth of 40–45 cm. Ehrharta gigantea is usually seeded together with Acacia cyclops and A. saligna. Seeds are mixed in the ratio 3 kg herb to 2 kg acacia. Under favourable conditions they are sprouting in 2 or 3 weeks.

Having fixed the dunes Ammophylla arenania dies off and the protective functions are assumed by trees planted expressly for this purpose.

Shifting sands occupy large areas in Australia. They are situated along temporary watercourses and on the coast.

The techniques of sand fixation are largely similar to those employed in South Africa. They include the formation of the forward dune and its further fixation and afforestation under its protection near by shifting sands.

A forward dune may be arranged by creating such obstacles as fences, various mechanical guards, or by bulldozers. After its pre-fixation by chemical mulching substances, such perennial plants as Acacia sorphorae and Osteopermum monoliferum are planted.

Reclamation of inland dunes is aimed at increasing rangeland productivity. To achieve this, Trifolim subterrameum is sown, and rabbit and kenguru populations are controlled [Heathland . . . , 1974] .

In the USA the desertification threat is represented by coastal dunes on the Atlantic and Pacific coasts. To combat sand transport and dune drifts artificial dunes are arranged perpendicular to prevailing winds. They are stabilized by checkered guards and herb sowing. Important installations are protected by gravel mulching. On the Pacific coast sand is stabilized by Ammophylla arenaria. It serves as a means of fixation before it dies off, while Cytisus scaparius and Pinus contortus sown simultaneously with it take over. On the Atlantic coast Ammophylla, Elymus giganteus, and Panicum amarum are used.

At second sand-breaking, complex fertilizers are used to ensure sustained growth of the established vegetation. In sites of intensive sand transport surface is prefixed with herb and various chemical agents.

An area of 4 million hectares was levelled and reclaimed in Michigan where the screening method was applied. A screen made of a thin layer of bytumen was set 60 cm below the surface which made it possible to conserve moisture in the rooting layer and ensured transformation of sandy soils into highly productive ones.

Inland dunes occur in Arizona, Colorado, Nevada, Kansas, Uta, and New Mexico. Part of these territories is in temporary agricultural use. Some cases were recorded when the use of these lands led to the emergence of shifting sands (Kansas, Nebraska) which buried neighbouring farms. Application of special techniques developed by the US Soil Conservation Service made it possible to reclaim the majority of these areas.

On non-arable lands granulated seeds of Angropogon hallii and Eragrostis tricodis are used for primary fixation. Then Elymus giganteus, Sorghrastum nutans, Panicum virgatum, etc., are sown.

Shifting sands in South America are encountered in the Peruvian-Chilean deserts (Sechura-Atacama) and the Monte-Patagonian desert in Argentina. They occupy quite small territories and thus do not pose a problem of a large-scale works to combat them.

The biggest sand fixation projects are undertaken in **Argentina** where 75 per cent of the territory in the northern and western regions are affected by the climate's aridity which increases from east to west.

All arid and semiarid lands are to a certain extent subjected to wind erosion. In the western part of Argentinian Panama wind erosion is typically manifested in the formation of sand dunes. There are two distinct kinds of dunes in Argentina: coastal dunes and inland dunes termed "medanos".

Medanos vary from 50 cm to 15–20 m in height and from 1 to 100 hectares in area. The first efforts to stabilize medanos started in 1959.

Sand fixation techniques are as follows:

1. **Levelling.** Levelling is carried out in three different ways: 1) by aerodynamic tubes (sand sprayers); 2) by graders; 3) by moving sand to a leeward slope by levelling dune ridges with wooden beams so that a leeward slope loses its cliff-like configuration. Graders and beams are pulled by caterpillar tractors, or draught animals, since tractors mounted on wheels cannot operate on high dunes.

2. **Seeding fodder cultures mixtures** with a sowing machine:

1) 60 kg of rye, 5 kg of Agropyrum elongatum and 5 kg of Vromus brevis per hectare are sown in spring (March–April) though rye would suffice to fix sand;

2) maize, Panicum miliaceum, Sorghum caffrorum, S. sudanense, and S. almun 5 kg each per hectare is sown in autumn (October–November); 1 kg of Eragrostis curvula should be added. Some kinds of seeds may be exluded from the mixture if unavailable (the most important are P. miliaceum, Sorghum and E. curvula).

3) The dune is covered by a thin mulch layer (in spring) while sowing or sorghum straw (in autumn).

4) To prevent mulch from being carried away by the wind a furrow is cut by a disk harrow.

The method is effective and turns a shifting sand dune into a stable pasture in 3–6 months.

Application of asphalt bytumen instead of grassy mulch has yielded good results, yet this method has not gained wide currency, as the necessary equipment is often unavailable in rural localities, besides it is more costly than the mulch technique.

In **Chile** an important contribution to combating desertification, which caused considerable damage in some regions of the country, was made by the National Forestry Corporation. Sand dune fixation was performed by both mechanical and biological means, the latter being more widely used as a more effective and less expensive method. Once dunes are stabilized such tree species as Pinus radiata, P. pinaster, Acacia cranophilia, A. lophanta, A. melanoxylon, Robinia pseudoacacia and Populus are planted [Milas, 1981].

The above survey shows that combating shifting sands is fairly costly and labour-consuming activity. Yet, the existing methods of desertification control, elaborated and tested in various countries of the world, allow us to view the future with optimism.

2.2. INDICATORS OF STABILITY OF SANDS

Aerial and space monitoring of shifting sands includes a complex of ground, aerial and space survey of composition, geography and dynamics of sands stability and also ecological conditions for their phyto-reclamation and development. Aerial and space survey was used to study shifting sands topography in different regions of the world [Fedorovitch, 1948; Petrov, 1973; McKee, Breed, 1974; Mainguet, 1976] . Ecological interpretation of sands is much more difficult.

Let us analyse the experience of investigations of shifting sands and degree of their stability by means of remote sensing methods. Recording of optical radiation effects of shifting sands serves as a theoretical background. Interpretation indicators of sands with different degree of stability are developed on the basis of this knowledge and interpretation experience. Interpretation indicators are used for the study of surface structures at different levels and for mapping of sand desert ecosystems in different scales.

Optical and Radiation Properties of Shifting Sands.

The nature of shifting sands picture on aerial and space photographs depends upon their reflection and radiation properties and interpretation possibilities – upon their optical and radiational contrast with fixed sands. In optical range spectral reflecting characteristics of sands with different stability are mostly informative. In the visible spectral zone 0.4–0.7 mkm sand areas with vegetation cover less than 5 % in dry season give high brightness factor up to 0.3–0.5 depending on the origin of mineral composition. Typical eolian sands of alluvial origin have smooth curve of brightness factor, gradually increasing with the increase of the wavelength. The curve has typical logistic shape and is described by four typical values of brightness factor: ρ_1 at wave-length 0.44 mkm in blue zone, ρ_2 at 0.54 mkm in green zone, ρ_3 at 0.68 mkm in red zone and ρ_4 at 0.8 mkm in near infra-red zone. The curve has a "table" of relatively low values of brightness factor in green-blue spectral zone 0.40–0.54 mkm with ρ = 0.17–0.26; a "table" of relatively high value of brightness factor in red zone 0.6–0.8 mkm with ρ 0.4–0.5 and relatively steep rise of brightness factor in yellow-orange zone $(\rho_1-\rho_3)/(\rho_1+\rho_3)$ 0.44–0.50.

However, sand spectral brightness factor considerably depends upon covering vegetation, mineral composition, microrelief, sunlight intensity, humidity and other environmental conditions.

The main controlling factor determining optical properties of sands ecosystems is vegetation. Overgrown sands with full cover of green vegetation give the lowest brightness factor 0.10–0.12. Overgrown sands with normal vegetation cover over 60 % during vegetative season also give low brightness factor in orange-red spectral zone 0.6–0.7 mkm, 0.12–0.15. That is why in spring when ephemerals vegetate, shifting sands give very high optical contrast with sands overgrown with vegetation, sometimes reaching 0.6–0.7. Besides that overgrown sands with mezomorphic vegetation cover over 60 % give clearly higher brightness factor in green spectral zone 0.52–0.58 mkm and in near infra-red spectral zone 0.8 mkm. Slight-medium fixed sands during vegetative season give intermediate brightness factors around 0.28–0.30 and 0.20–0.22 correspondingly. Optical contrast of shifting sands with medium fixed sands lowers down to 0.35–0.50, and with slightly fixed sands to 0.12–0.25. Optical contrast between shifting sands and sands overgrown with vegetation in the near infra-red spectral zone lowers down to 0.3–0.4, and in green spectral zone to 0.1–0.2. Due to such optical contrast on panchromatic photographs with orange light filter shifting sands are well defined by light colour on the dark-grey background of fixed sands. Since the transition between them goes through the stages of slightly and moderately fixed sands – the borders between shifting sands and sands overgrown with vegetation are diffusive or mosaic, especially on small scale photographs.

Optical characteristics of alluvial eolian sands give mentioned above mean values of brightness factor. Sands of eluvial origin (marine or proluvial) are characterized depending on their mineral composition by high variety of brightness factor. In orange-red spectrum zone 0.6–0.7 mkm brightness factor of typical grey-yellow eolian sands in Lower Karakum makes 0.32–0.36, on quartz and carbonate sands it rises to 0.42–0.50, gypsiferrous sands 0.65–0.70, on mica and graywacke sands it lowers down to 0.18–0.25.

The other abiotic controlling factor of the optical properties of sandy areas is their humidity. Even at low values of humidity sandy soils have high optical gradient, especially in orange-red spectrum zone 0.6–0.7 mkm. In humidity interval from maximum 1–2 % to minimum field moisture capacity 6–8 % brightness factor is rapidly reducing to 0.18–0.22 which gives high optical contrast between dry and wet soils 0.45–0.50. However in sands, referring to the small optical width of soils transfer from dry to wet conditions and to high mobility of soil moisture, there can be distinguished only three humidity ranges: 0–1 %, 2–6 %, over 6 %.

Humus content in sandy soils does not exceed 1.0–1.5 % except for depressions with dense vegetation and places where domestic animals are kept, thus it can hardly be a reliable controlling factor. So that fully developed typical desert-sandy soils have low brightness factor in orange-red spectrum zone 0.6–0.7 mkm, 0.25–0.28. Optical contrast of sands depending on humus content varies within 0.20–0.35.

Finally, brightness factor of sands depends upon dissection of their surface. With all other conditions equal, dissected sand surface has lower brightness factor than the smooth one. Differences in brightness factor values of dissected and smooth sands are increasing with the decrease of sun altitude. Indicatrix of light diffusion by sands with visible nanorelief and with sun altitude less than 45° and observation angle over 45° (from horizontal surface) are clearly asymmetric: they are more light from the side of the light source and more dark at the opposite side.

Radiation properties of dissected sands which determine their picture on infrared photographs in the first 3–5 mkm and second 8–14 mkm windows of atmospheric transparence are very complicated and non-stationary [Vinogradov et al. 1972, Hovis et al., 1968]. Radiation temperatures of dissected sands measured from airplanes and satellites are highly changeable depending on the season, weather, day time. As a rule in summer at daytime with calm cloudness weather bare sands without vegetation are "warmer" than stabilized sands with more or less dense vegetation; and the more dense vegetation, the more "cooler" the sands.

The greatest radiation contrast of shifting and overgrown sands occurs at noon or before noon, reaching 30–40 °C.

Wind causes considerable effect on the sands radiation temperatures. Under equal conditions it is often that the "warmest", i.e. the most light on infra-red aerial photos and most dark on space infra-red photographs appear to be not the slopes exposed to sun, but slopes exposed to winds with velocities over 5–7 m/sec.

Cloudiness considerably reduces radiation contrasts in sandy areas, and rain redistributes them depending on soil humidity: wet sands are "cooler" during warm season, and dry are "warmer".

In radiowarm spectral zone 0.3–30 cm sand areas with the same physical temperature differ from fixed sands by lower radio-brightness temperatures.

Besides the surface of sandy areas themselves, aerial and space photographs of sandy areas are also affected by the concentration of lithometeors in the atmosphere. Sand storms and flows in the atmosphere and dust mists are very common for the regions with shifting sands. Dust and sand in the atmosphere magnifies the brightness of the dark colours and reduces brightness of the light colours. Since sandy areas have light grey background the influence of mist on their brightness is not considerable. Small concentrations of lithometeors in the atmosphere do not change the brightness factor of dissected sands, but reduce the sharpness of the picture. Dust-sand accumulations of medium concentration increase brightness factor of sands in the visible spectrum zone by 0.05–0.09. Surface objects still remain visible, but their optical contrasts considerably degrade. Dust-sand flows give high superimposed brightness of 0.1 and more. Turbid atmosphere fully "marks", sometimes on light-grey sand background one can see shadows of lithometeor clouds.

In the infra-red spectrum zone 3–30 mkm dust-sand accumulations in the atmosphere above sandy areas reduce their radiation temperatures. That is why the surface of sands masked by dust-sand flows in the atmosphere, appears to be more "cool" on space photographs, i.e. more light, that sands when atmosphere is transparent.

Interpretation of the Degree of Sands Stability

Tracts of shifting sands can be seen on aerial and space photographs not only in the deserts but also in the steppe and even forest zone [Rasmussen, 1962; Fryrear, Wiegand, 1974; Parshikov, 1968; Kulik et al., 1980] . Secondary man-made shifting sands are found on light-texture soils under plough in different geographical zones and are interpreted on aerial photos of large and medium scales 1:10000–1:30000, and some areas are detected on small scale aerial photos and space photographs 1:100,000–1:300,000. In the deserts such "post-agrarian" shifting sands are located to the suburbs of abandoned ancient irrigation areas and areas with secondary salinization with the same features described for dissected sands of Lower Karakum. Shifting sands are also found on sandy loams of abandoned fields in the steppe zone, where they form small areas. Due to the absence of psammophytes in the steppe these areas at first remain bare and when sand material moves away they overgrow with xerophilous weeds and then with loose-bunch and rootstock grasses. They are indicated as light spots contrast to the surrounding background of square field network. Shifting sands can also be found on fields under long term cultivation on fluvioglacial and outwash sands in the forest zone, where one can clearly detect light spots of sands stretched along the direction of the dominating winds against the background of field network.

Secondary man-made shifting sands can be found in forest glades, where they make very sharp contrast with the surrounding forest. In one case these are modern coastal or alluvial sands where primary progressive succession was disturbed by cutting. Such tracts of shifting sands are found at the coasts of the Baltic Sea and at the US Atlantic coast. Secondary man-made shifting sands in forest glades are also located on ancient glacial and alluvial sands, they are the most impressive. Due to the absence of psammophytes these sands are practically bare and are identified as light spots on dark-grey background of forests which enables their identification not only on aerial photos but also on space photographs. One of the most well known examples of shifting sands among the taiga forests are Zabaikalskie sands in Buriat ASSR.

Study of the structure of large sandy areas involves the use of space photographs with different ground resolution, from 30–100 m to 3,000–5,000 m and with different surface coverage, from 100,000 sq. km to 10,000,000 sq. km [Vinogradov, Grigoriev, 1970, 1971; Kravtsova et al., 1976; McKee, Breed, 1974; Breed et al., 1979, Verstappen, Zuidam, 1970; Kolm, 1973; Mainguet et al., 1974] . At these scales elementary forms of eolian relief are not defined (deflation hollows, sand dunes, etc.), but macro- and megaforms of eolian relief are defined well. Space imagery interpretation gave very good results in defining of large sand ridges stretched along the direction of the dominating winds. These ridges were traced on space photographs for dozens and hundreds kilometres, and reflected not only direction of modern winds but also directions of paleowinds of the former climatic epochs. The second class of major eolian landforms, defined on space photographs, includes different kinds of cancellate sands, large sand dunes, cuesta sands perpendicular to the direction of dominating winds. Space photographs were also used for description of several peculiar macro- and megaforms of eolian relief, such as pyramidal dunes.

Elementary biogeocenosis units with different stability and correspondingly different optical density are not visible separately on the space photographs, but they form numerous combinations, each having its colour pattern, depending upon combination of photoisomorphic units. For example, five degrees of sands stability – overgrown with vegetation semi-fixed, medium-fixed, moderately fixed, poorly fixed and dissected with gradations of relative area in combination of 10 % give 1.5×10^5 of possible combinations.

This figure is frightening. However, calculation of occurrence frequency of different combinations of sands stability, revealed only 7–10 combinations in each type of sands with reliable frequency, i.e. 0.05 and more. Combinations give on the photographs intermediate values of colour saturation between sands fully overgrown with vegetation and fully dissected sands. For example, assuming colour saturation of sands overgrown with vegetation and semi-fixed sands as 0.6–0.8, moderately fixed sands 0.9–1.0, medium fixed sands 1.1–1.2, weakly-fixed sands 1.3–1.5, broken sands 1.6–2.0 and relative area ration respectively 0.5:0.5:2:3:4 combination gives on space photographs mean saturation of 1.325–1.575, and area ratio 2:6:1:0.5:0.5 lower 0.915–1.035. So that on space photographs made in late spring areas with domination of shifting and poorly fixed sands give grey colour; with domination of moderately and medium fixed sands–grey colour; with domination of semi-fixed sands and sands overgrown with vegetation cover – dark grey.

Optical contrast of combinative units is decreasing comparing to elementary units from 1.0–1.2 to 0.4–0.6 in relation to the reduction of scale and spatial generalization.

Mapping of Shifting Sands and Study of Their Structure.

Ecosystems of shifting sands can be studied by remote sensing methods at all spatial levels: at subelementary level – showing separate plants and forms of nanorelief at scales 1:1000 and more; at elementary level showing plants associations and landforms at a scale near 1:10000 and on multi-in-tegration levels showing combinations of plants associations, combinations of areas with different sand stability levels and forms of macro- and megarelief at scales 1:30000 and smaller.

Detailed study of shifting sands ecosystems is performed on photos 1:1000 and more taken from low-altitude airplanes, balloons and towers. Processing of 1:3000–1:5000 scale aerial photos involves the use of stereoinstruments with medium accuracy equipped with mechanical drawing devices capable of drawing separate eolian forms of nano- and microrelief, with 0.5–1.0 m contours, separate shrubs, semishrubs and herbs (stereoprojector СПР-2, stereograph СД-2, Zeiss stereotop, Santony stereomicrometer).

In lower Karakum at the experimental plot of 500 sq. m on poorly fixed and shifting sands using 1:2000 aerial survey magnified to 1:250–1:500 scale photos there were determined psammophytic shrubs Ammodendron conollyi, Calligonum caputmedusae, C. setosum, Haloxylon persicum, Salsola richteri; semishrubs Mausolea eriocarpa, Astragalus unifolialatus; herbs Stipagrostis pennata. Species diversity was determined with reliability over 0.95. Location of the plants was determined with the error less than 10–20 cm.

Study of shifting sands ecosystems at elementary biogeocenotic level gives best results when 1:10,000 (1:6000–1:15,000) scale aerial photographs are used. As an example, let us analyze interpretation of ecological facies with different stability of sands located around the well using aerial photo of 1:10,000 scale. The center of the area is occupied by water collecting takyr, water well and "tyrlo" – i.e. the area where herdsmen keep cattle and place their yurts. Takyr is shown as even light grey spot, "tyrlo" – even dark grey spot, well – a dot with 2–4 mm long (scale of the photo) path made by camels used for lifting water from the well. Then comes narrow transition belt of poorly fixed sands with semi-shrubs and herbs Artemisia Kemrudila, Stipagrostis pennata, which has grey colour with fine texture. This area is surrounded by belt of destructed major and medium sand dunes, so called "aklang" with separate species of psammophytic herbs (Stipagrostis pennata) and shrubs (Calligonum caputmedusae) which has light grey colour with clear pattern of sand dunes and separate dots of psammophytes. Next comes the belt of poor and medium fixed sand dunes and hillock sands with associations of psammophytic shrubs, semi-shrubs, herbs and ephemerals which has light grey and grey colour with smooth sand dune pattern and more dense dots of plants. This belt changes for background combination of moderate and semi-fixed honeycomb relief with association Haloxylon Persicum + Carex Physodes + Herbal ephemerae which give on the photographs grey, dark grey colour with honeycomb pattern of relief and dense dots of vegetation.

At the integration levels these round-the-well structures of shifting and semi-fixed sands are generalized into one contour and are interpreted on space photographs of 1:300,000–1:1,000,000 scales with resolution 30–100 m. On these photographs the whole described round-the-well complex of different stability sands with diameter 2–3 (from 1 to 6) km gives light grey spot with 2–3 (1–6) mkm in diameter at the scale of space photographs. Such scattered small round spots (light grey) with white dot of the well in the center and diffusive borders against dark grey background of fixed sands are seen on space photographs received in spring in Karakum, Kyzylkum, Karabil, Pribalkhashie. In SE Karakum with groundwater table at 15–40 m mean density of round-the-well spots is about 3 per 10 sq. km with mean distance between them around 9 km. Their distribution is uneven and density depends upon the pasture capacity. Relative area of shifting and semi-fixed sands among the areas of sandy landscapes is less than 10 % which does not interfere with functioning of geosystem of a sand track in general.

Mapping of shifting sands and sands with different degree of stability is very complicated due to extreme variability of surface structure in sandy deserts. Elementary units of sands stability can be mapped only at large scales of 1:10,000 and more. Smaller scales, beginning from 1:30,000 and less do not suit the purpose of showing simple contours of sand stability, they are good only for showing combinations of areas with different sand stability with indication of the relative area occupied by sands with this or that degree of stability.

Monitoring of Shifting Sands Dynamics.

Monitoring of shifting sands dynamics by means of remote sensing includes multiaspect use of aerial survey and space images for the study of sands stability: determination of desertification indicators, tracing of dust-sand flows in the atmosphere, registration of translational and oscillatory movements of sand dunes, registration of the changes in the area of shifting sands, registration of progressive succession on sands under reserve regime, assessment of the shifting sands phytoreclamation efficiency, and finally, forecast of dynamics of shifting sands stability in terms of their geophysical effects.

Static indicators of desertification and indicators of the degree of sands stability are used most widely for mapping of sands dynamics. Interpretation indicators of sands with different degree of stability have been already described. Here the assumption is that sands initially, at least from Bronze Age, have been semi-fixed. However, it's not the general rule: many tracts of dissected sands initially have been poorly fixed. So that, static interpretation indicators on separate photographs do not ensure reliable conclusions about dynamics and which is more important do not give quantitative characteristics of speed and direction of sands dynamics [Vinogradov, 1964; Kolm, 1973; Clos-Arceduc, 1969] .

The main static indicator of shifting sands dynamics is determination of so-called "relic" landscape elements, characterizing recent condition of the ecosystem. Indicators of sands destruction are exposure of eolian landforms on the slopes, exposure in between them of soddy desert sandy soil horizons, takyrs, solonchaks, traces of channel migrations, shoe-lines of water bodies, network of canals, dying and dead species of shrubs and trees, remains of desertified tugai landscapes and so on. Indicators of overgrowing of shifting sands are so-called fixed sand dunes that have preserved their shape, but currently are covered with dense herbs and shrubs. Such fixed dunes are interpreted on aerial photos of Black Lands in Caspian lowland, which experienced heavy grazing burden in the Middle Ages during the rise of Nogai and Zolotaya Orda (Golden Horde) – medieval states of nomads. Overgrowing of shifting sands started in 17th – 18th centuries when nomads (Kalmyks) have returned to their pramotherland. Similar fixed eolian landforms were detected by aerial survey in Nebraska (USA), New South Wales (Australia), where vegetation is restoring alongwith the improvement of climatic and hydrological conditions.

Specific indicator of modern eolian landforms dynamics is tracing of dust-sand storms and flows in the atmosphere on space photographs that cover large areas. It was observed that direction of dust-sand flows corresponded to the direction of ridge landforms. These flows skirt the obstacles and correspond to meteorological circulation, which is reflected in the pattern of ridge landforms. Discrepancy of this pattern and modern dust-sand flows can be explained by the impact of paleo-winds. Numerous zones of transfer of lithometeors in the atmosphere have been described on the basis of space photographs: trade wind tropical zone of Harmattan in the south-west Sahara, subtropical zone of Syrocco in the north of Africa, monsoon zone of Habood in the NE Africa, subtropical zone of Khamsin in the Middle East. It's observed that aximuth of lithometeors transfer in the northern hemisphere is deflecting from the direction of eolian ridges by 10–20^{o} to the left under the influence of the Earth rotation.

Space photographs are used to detect light cloud-like spots of deflation, dust-sand storms and whirls, where dust-sand particles are deflated from the surface. Such areas of high atmospheric turbidity correspond to the critical zones of desertification, for example in the south Sahara (Warran, Erg-In-Sakan, Kewir) in Central Asia (western Turkmenian lowland).

The most sound technique of shifting sands dynamics monitoring is comparison of repetitive aerial survey and space photographs of one and the same area. Comparison of repetitive photographs is performed for two main purposes: registration of translational and oscillatory movements of sand dunes and changes of the shifting sands area against the whole track of sand.

Tracing of shifting sands motion on the basis of repetitive aerial survey was carried out in many countries. Comparison of repetitive 1:5000 scale aerial photos of coastal shifting sands in the Wisla delta in 1952, 1958, 1968 and 1973 permitted determination of mean and maximum speeds of sands migration (Miszalski, 1974). It was calculated that 58 % of sands are moving at a speed less than 2 m/year, 23 % at a speed of 2–5 m/year, 18 % at a speed over 5 m/year, maximum speed reaching 10 m/year. Besides that quantities of the transfered sand material, influence of slopes and vegetation on the speed of transfer and other conditions of shifting sands movement are calculated.

One of the most interesting technique is monitoring of shifting sand areas through comparison of repetitive photos received in considerable time intervals 5–8 years. Study methods of shifting sands dynamics through comparison of repetative photos are subdivided into visual techniques and techniques with the employment of instruments.

Visual comparison begins with transformation of repetative photographs into the same scale, the same interval of optical density and contrast. Then comes successive interpretation of repetative photographs according to the uniform legend. It was shown on many examples that the increase in shifting sand areas occurred mainly due to the industrial development of deserts. Analysis of repetative aerial photographs has also revealed overgrowth of sands under conservation regime. In Sussex country (England) comparison of repetative aerial photographs of 1950, 1962, 1967 and 1971 was used for monitoring of reduction of dissected sand areas after implementation of conservation measures.

In spite of the high efficiency of visual comparison of repetative photographs an increase of remote sensing data, increase of survey frequency, expand of variety of multispectral and multiscale photographs require development of instrument-aided interpretation technology. One more advantage of this technology is that it excludes subjective mistakes and makes conclusions of different authors more comparable. Instrument-aided technology is subdivided into optical-mechanical and optical-electronical methods. The latter in its turn is subdivided into methods of instrument-aided interpretation of photographs with the following comparison of the results and methods of instrument-aided calculation of the images with the following interpretation of the received differences.

Determination of differences through comparison of two photographs firstly requires photoelectronic transfer of each partial photograph into digital form in which the object is classified by the level of this or that optical feature (optical density, amplitude, frequency-contrast characteristics, luminence chart, etc.). These data are entered into memory, or represented on alfanumeric display, or colour display. The results of classification according to these characteristics are successively compared line-by-line and point-by-point. The results are represented on the resulting display where symbols classify all visible changes in the ecosystem [Vinogradov, 1980] .

Monitoring of shifting sands includes supervision over the efficiency of phytoreclamation. Large-scale aerial survey is used at different levels of shifting sands phyto-reclamation. First of all it is used for preliminary investigations and assessment of sands suitability for this or that kind of phyto-reclamation. Then comes the working stage and registration of the carried-out phyto-reclamation programme. Finally comes the most important stage of monitoring maintenance, determination of the efficiency of phytoreclamation, condition of the planted vegetation and sands stabilization. All phytoreclamation measures are well seen on large-scale aerial photos. In 10–15 year period after planting efficiency of phytoreclamation is interpreted through the increase of density of dark points of shrubs, smoothing of the contrast eolian relief pattern, disappearance of glittering triangle-shaped dots of Stipagrostis, their substitution by dense points of semi-shrubs and growing shrubs and changing of the sand colour pattern from light grey to grey due to the growth of ephemeroids. Absence of these features on aerial photos and invariability of the image indicates poor phytoreclamation management.

2.3. PHYTO-RECLAMATION AND AFFORESTATION IN SANDY DESERT AND THEIR ORGANIZATION

Protective afforestation at low-productive pastures in Central Asia is performed according to the recommendations developed by different scientific-research institutions. Sometimes preference is given to wide shelterbelts sometimes to narrow ones. All-Union Institute of karakul sheep breeding (Ministry of Agriculture, Uzbek SSR) has developed widebelt method of protective afforestation at the pastures [Shamsutdinov, 1975] . According to this method seeds of black Haloxilon are sown into ploughed 25 meter wide belts with a spacing of 150–200 m. It is recommended to use this method in areas with good conditions for forest growing in piedmont plains with well developed slightly gypsum soils and where annual rainfall is not less than 180–200 mm.

It is also proposed to make protective forest belts on the pastures using another technology [Leontiev, 1962, 1973] . It is recommended to make 25 m wide belts not by ploughing, but make five 1.5 wide belts with in-line sowing of Haloxylon seeds. The recommended spacing between narrow belts being 5–8 m. Belts of this type carry out the same functions of pasture protection as ploughed-through 25 m wide ones. The use of narrow shelter belts ensures conservation of natural vegetation within the belt, while in wide belts recovery of natural vegetation will take 6–7 years. The use of narrow belt method is recommended in typical sandy desert conditions (80–120 mm of annual rainfall, ground-water, unavailable for vegetation).

The main method of making pasture protective belts in Karakum – is a method of echelons. Echelons are systems of three 1–1,5 m wide belts with 5–6 m spacings between them. On lands under reclamation echelons are made with spacings of 30–50 m between them. This method appeared as a result of transformation of recommendations made by the Institute of Deserts [Ovezliev et al., 1972] and SredazNIILH (Central Asian Research Institute of Forest Management) with regard to traditional Turkmenian methods of low-productive pastures reclamation.

On rich loess soils with mean annual rainfall within the range 170–250 mm pasture improvement and creation of pasture protection belts is recommended on preliminary treated soils – i.e. ploughing of 10–15 m wide echelons with the spacings of untreated soils between them of the same width or twice wider [Nechaeva et al., 1958] . Sowing is followed by seeds closing up.

Improvement of pastures with unfavourable forest growing conditions (compact grey-brown soils or takyrs and takyr-like soils) is proposed respectively after sand and water accumulation furrows were made [Muhammedov, 1979] . Furrows are made by trenchers or special plows. Agrotechnology of growing fodder plants includes preliminary in-furrow sand application, pre-irrigation of surface runoff and then seed sowing of the plants to be introduced as crops.

In sand deserts of Central Asia pasture protective belts increase yield of fodder plants at the interstrip areas by 14–16 %, and pasture capability increases by 30–40 %. Pasture protective belts cause beneficial effect mainly on halophytes and ephemerals. These plants being under protection of forest belts can remain even in dry condition and are less subjected to breaking and fall. By 1979 in Turkmenia afforestation by making protective belts reached 298.1 thousand ha in Uzbekistan -- 357.3 thousand ha, which helped to improve pastures at the area of 1.4 million ha in Turkmenia and 1.6 million ha in Uzbekistan. Systems of protective forest belts at the pastures carry out not only reclamation functions, but also protect sheep in bad weather, in winter and in summer. Areas with forest plantations can transform to optimum conditions any critical meteorological conditions affecting normal physiological functions [Vinogradov, 1967]. This ensures soaring of meat yields by 10--18 %, survival and preservation of young animals (sheep) by 8--15 %, wool clip by 7--12 %.

Reclamation of shifting sands is a series of measures including stabilization of sand surface and following overgrowing of fixed areas by sand-fixator plants.

In Central Asia traditional method of sand fixation is application of different kinds of mechanical protection guards made of local vegetation, including: standing in-row and checkered guards 0.3--0.7 m high; semi-buried standing-in-row guards (20 cm high); protective in-row matting (row width 60--70 cm) and matting longitudinal guards (row width 25--35 cm).

Sand stabilization properties of these mechanical protection guards are different. Standing in-row and checkered structures are used for general stabilization of shifting sands. They accumulate all sand coming from the outside. Matting in-row and longitudinal guards are used only for fixation of sand surface. All kinds of mechanical protection guards create favourable conditions for forest shelter belts.

Sand-fixator plants at the stabilized areas are introduced by seed sowing, by planting seedlings and cuttings.

Traditional methodology of shifting sands fixation and afforestation is used differentially, depending on the local conditions, intensity of wind regime and nature of the unit protected. Solving general tasks of reclamation such as restoration of shrubs on sand dunes, to stabilize sands in the areas with favourable conditions in-row matting or longitudinal mechanical protection guards are used, after that seeds of plants are sown. In the areas with rigid local conditions (saline sands, deep ground waters, intensive wind regime) checkered standing mechanical protection guards are used and seedlings are planted.

Traditional reclamation of shifting sands is based on manual labour, which makes it low effective. Construction of checkered mechanical protection guards at 1 ha requires around 40 man-hours.

Mechanization of shifting sand fixation and afforestation became possible with application of chemical substances forming stable cover which prevented deflation of sand. There have been developed various types of technology of binding substances application on sand surface [Gabai et al., 1971] and full mechanization of labour consuming processes as well as possibility to perform sand fixing in combination with afforestation [Svintsov, 1981].

New method of reclamation of the barkhan sands increases labour efficiency in sand fixation works by 15--20 times and afforestation works by 5 times.

It appeared that in Turkmenia the use of scientific achievements and advanced experience in reclamation became possible under the following organizational pattern (Fig. 2).

In the pattern of land reclamation much attention is devoted to organizational and preventive measures and forest conservation (planning of forestry works,

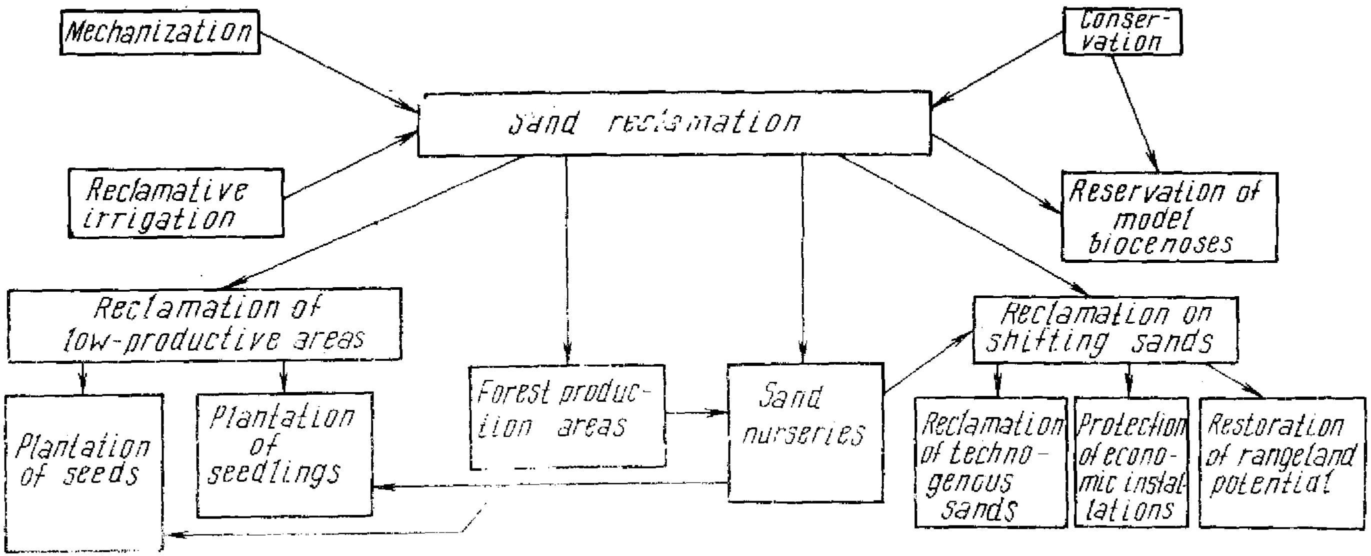

Fig. 12 Reclamation management structure

fire control, pest control, supply of documentation for forest improvement works with the indication of their priority, improvement of forest conservation, etc.). These measures ensure preservation of vegetation on sands during earth-moving works, especially during construction of pipe-lines, transportation of equipment, pasture management.

Preventive and conservation measures contribute to stabilization of natural processes and in some cases help to restore herbs and shrubs.

Reclamation works are planned and carried out on the basis of wide use of machinery. Great attention is devoted to the use of machinery complexes and implementation of afforestation on the basis of new technology.

Very promising future has introduction of new irrigation methods based on the use of local water sources (surface runoff, groundwater, artesian wells).

Conservation of natural model (standard) biocenoses with different degrees of degradation is planned through establishment of natural reserves. The regularities of biocenoses development discovered in these natural reserves are used for the forecasting of natural processes in sand deserts during realization of different projects.

Reclamation object (sandy desert) is defined not as a single whole, but as a combination of numerous natural components with qualitatively different features. For practical purposes the area is classified into sand dunes and low-productive sand territories. When dealing with a particular project area, selection of reclamation techniques is based on its productivity, which depends on type of underlying rocks, sand drifts of eolian origin, degree and character of the upper sand layers overgrowing, ground-water depth, moisture conditions of the upper sand layers, depth and thickness of drying layer, landforms and their dissections, intensity of deflation processes, sands destruction and overgrowing, origin of eolian sands, land use pattern of sand tract [Petrov, 1973] .

Scientific approach to the assessment of the area productivity incorporated into feasibility studies and detailed designing of reclamation works ensures scientifically-based planning, selection of the areas for reclamation and also selection of plants for phytoreclamation depending on the local ecological conditions.

Methods of the sand dunes reclamation depend upon the final aim. Reclamation techniques are subdivided into reclamation of industrial sands, protection of economic units from sand drifts, recovery of pasture potential. Mechanization of labour consuming processes (sand fixation with binding substances, sand fixation in combination with afforestation) is planned for all reclamation works irrespective of their aim.

On sand pastures subjected to desertification, reclamation techniques (afforestation by sowing and tree planting) are planned with reference to forest growing conditions. Sowing is used for the areas with favourable ecological conditions, tree planting is used for the areas with rigid conditions. Increasing of the area productivity is also planned through the introduction of new more valuable species of plants.

Requirements in high quality seed material are met by its production at special farms with permanent forest seed production plots (PFSPP) and nurseries for the growing of planting material.

One of the most promising trends in forest-seed production is establishment of forest-seed plots at the newly afforested areas through planting of seedlings with certain heritage. Disadvantage of this method is that first seed material will be received only several years after the beginning of the works.

Key questions in the PFSPP establishment are choosing the areas, selective assessment of the plantations planned for PFSPP and planting material.

Soil conditions of sand plots chosen for PFSPP can be of wide variety: from sandy desert soils to buried with eolian deposits wet solonchaks. The necessary condition for all cases is shallow groundwater.

Topography of the areas chosen for PFSPP should be slightly cut, passable for tractors in every season and for automobile transport in autumn–winter–spring period. The advisable size of PFSPP area in around 1000 ha and more in order to have a possibility in future to organize PFSPP complex for a certain soil-climatic zone. Establishment of PFSPP on the basis of plantation with different aged trees is reasonable in case when not less than 50 % of trees (shrubs) have valuable genetic features, high seed productivity, resistance to pests and diseases. Quality of separate species trees is determined with high accuracy during selectional assessment. Criterion for determination of possible seed productivity of different species is fructification capacity depending on edaphic conditions.

It is reasonable to perform selectional assessment of plants twice a year: in spring and in autumn. For example, during spring assessment of black Haloxylon the most stable and vivid feature – colour of flower petal and another – is used for determination of species deversity, and blossoming intensity – for assessment of possible general seed productivity. Autumn assessment during maturation season permits determination of general yields and susceptibility of trees to diseases and pests. The results of the observations serve as a basis for final conclusion about seed productivity of the whole plantation and its suitability for PFSPP establishment.

Referring to biological properties of black Haloxylon, 10–12 year old plantations with density of 0.5 are most suitable for establishment of PFSPP [Koksharova et al., 1977] . Plantations should be of the first or in extreme cases of the second quality classes slightly infected by meally dew gallfly and other deseases and pests. Haloxylon should dominate among other species, its ecoform being the most productive for the given edaphic conditions.

Establishment of forest seed production plantations at newly afforestated areas with the use of selected planting material is much more difficult. It requires preliminary investigations for identification of the "plus" trees, growing selected planting material and then growing of plants. Selection of the could-be-"plus" species* of black Haloxylon is performed with reference to existing interrelationship of ecoforms fructification depending on edaphic conditions. Trees awarded with candidate to "plus" status are those having high yields (and good quality seeds) as permanent feature. It is desirable that these trees stand-at-ease and their taxation features belong to the first quality class.

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*Plus species – trees with considerably wider complex of valuable features and properties than other trees of the same conditions.

Selected candidates to "plus" trees are numbered, measured and described according to the existing form and are submitted together with selection deed to a forestry farm. Documents are submitted to a forestry farm and to the Republican forest seed production station.

Could-be-"plus" species gain the actual "plus" status only if their posterity grown from seeds inherits the main features of the parent ecoform, crown shape, yield.

One of the main requirements to planting material grown from elite seeds – is their accordance to the standard. Standard seedlings are those inherited parent features, good for mechanical planting and having high survival rate at the reclamation areas.

Irrigated nurseries on sands in the system of land reclamation are intended for growing of seedlings of the sand-fixator plants. Unlike the usual forest nurseries these nurseries consist of the only one seedling section. During vegetative season seedlings reach standard size and do not require additional growing. Seedlings grown up under irrigation have good vital capacity hardiness and high survival rate in sands.

For planting there are used I and II class seeds collected from "plus" trees (shrubs) or from highly productive plantations with soil-climatic conditions similar to the areas planned for reclamation.

The area of the nursery is determined by the output of planning production and yield per 1 ha. For an irrigated nursery the latter usually makes 200–220 thousand pcs/ha. Nurseries are located on non-saline or slightly saline soils. Thickness of sand horizon should not be less than 50 cm, and groundwater table not higher than 1.5–2 m. Areas with non-saline loamy sand and loess soils with a groundwater table at depth of 3–4 m can also be used for nurseries. Land should be free from weeds, especially those giving rhizomes.

The following works are carried out at the areas selected for sand nurseries: a) capital levelling; b) digging of the irrigation network; c) presowing soil treatment (ploughing to the depth of 25–28 cm, soil compactness aimed at reduction of evaporation losses); d) application of organic and mineral fertilizers; e) treatment with chemicals (in case of soil pests presence); f) subdivision of seedling section area to seedling plots; g) preliminary irrigation and water spreading.

Seeds sowing techniques differ depending of seed and soil types.

Sowing rates and depth of seed closing up for different shrubs-psammophytes are the following (Table 6).

Optimum terms of seed sowing in the irrigated nurseries – are periods when temperatures steadily overcome 5 °C. In southern Turkmenia this is second half of February, beginning of March, in the north – first half of April.

Good germination is achieved through necessary preparation of seeds for sowing. For this purpose calligonum seeds are either stratified during 30–50 days or kept in running water for 4–6 days.

For Haloxylon and Salsola seeds 3–4 day sanding is practicable or they may be kept in running water for a day.

Crops maintenance works include the following: irrigation, application of mineral fertilizers (if not applied during presowing soil treatment), weed control, pest control soil pest and disease control, control of damage caused by animals.

Table 6

Sowing Rates and Depth of Seeds Closing Up At the Irrigated Nursery

Species of Plants	Sowing rate, kg/ha	Closing up depth, cm	
		sandy soils	loamy sand soils, loess soils
Haloxylon aphyllum	100	2–3	1.5–2
Haloxylon persicum	80	2–3	1.5–2
Salsola Paletzkiana	60	2–3	2
Calligonum arborescens	200	5–7	5
Calligonum elatum	75	4–5	3–5

Irrigation and application of fertilizers are the main agrotechnical measures aimed at growing standard planting material. Water-charging irrigation is necessary to ensure good upswelling and germination of seeds. It is performed right after sowing-in-furrow method.

Weed control in spacings between the rows is performed mechanically through soil ripping by cultivator. Inside the rows weeds are removed manually. Number of treatments depends on the presence of weeds and their growth within the nursery area.

Implementation of pest control is recommended in stages.

Soil abounds in pests can be treated with hexachlorine rate of 60 kg/ha during presowing soil treatment. Disease caused by mealy dew can be controlled through spraying of milled sulphur at a rate of 30 kg/ha.

Digging out of seedlings from an irrigated nursery is performed just before the beginning of afforestation. Roots are cut at a depth of 35–40 cm. Quality of seedlings is determined by the height of the overground part (Table 7).

Table 7

Plants	Height of the Overground Part, cm		
	I grade	II grade	III grade
Calligonum arborescens	80	60	40
Salsola Paletzkiana	60	50	35
Haloxylon aphyllum	75	50–75	40–50
Haloxylon persicum	51–60	41–50	30–40

Sand Detaining Structures. In the USSR and abroad protection of different objects against sand drifts and prevention of sand deflation is achieved by means of different sand detaining structures. The most popular are mechanical protection guards, subdivided into the following two main types (Fig. 3).

Impervious: standing high-row single and multi-row guards; semi-buried and buried single and multi-row guards; chechered, matting in-row and continuous guards.

Pervious: high-row single guards made of grasses; high-row single wooden guards, high-row guards made of wooden strips and prefabricated reinforced concrete shields.

High-row single and multi-row guards pervious and impervious (Fig. 3 a, b) 75–100 cm high and 10 cm thick are placed normally to sand transfer resultant. These protections are used to stop oscillatory and translational sand movement. Usually they are made of straight-stalk grasses, consumption of material is 1.5 m^3 per 10 m of a guard.

Pervious guards made of wooden strips are used for sand accumulation in the form of banks, which prevents sand drifts to the units in the regions with oscillatory sand migration. This also can be achieved by construction of several rows of guards. After the sand covered the first protective row, the second row is placed on this bank or first row can be shifted to new position. In such a way it is possible during several years to accumulate 15–20 m high bank. Speed of bank accumulation depends upon the quantity of coming sand.

Impervious semi-buried and buried single-or multi-row guards (Fig. 3 c, d) 25–30 cm high and 4–5 cm thick are placed normally to sand transfer resultant. Semi-buried guards are used for partial trapping of the passing sand and for prevention of sand deflation. Buried guards do not detain sand carried by wind, they are used to prevent sand deflation and seeds blow-out. Such guards are widely used in Central Asia for combating shifting sands and also for reinforcement of the road edges and canal banks. These guards are made of shrub and grass material, with consumption rate of about 0.20 m^3 per 10 m of a guard.

Sand detaining capacity of the guards is characterized by the cross-section of the accumulating sand bank S (m^2), which, if guards are placed on horizontal surface, is determined by the following formula:

$$S = 0.5\,(m + n)\,h_3^2\,, \qquad (1)$$

where m, n – gradients of the steepness of a sand bank slopes from the side of transfer resultant and from the opposite side.
h_3 – guard height.

Semi-buried in-row guards are used also for levelling of sand dunes. For this purpose several rows of semi-buried and buried longitudinal guards are placed at the lower one-third of the windward slope of a sand dune or a sand dune chain. In this case fixed lower part of the sand dune remains stable, the inflowing sand is detained by the guard, and the upper part is blown down by the wind. So the height of the sand dune is decreasing and its length is growing up. After installation of the second

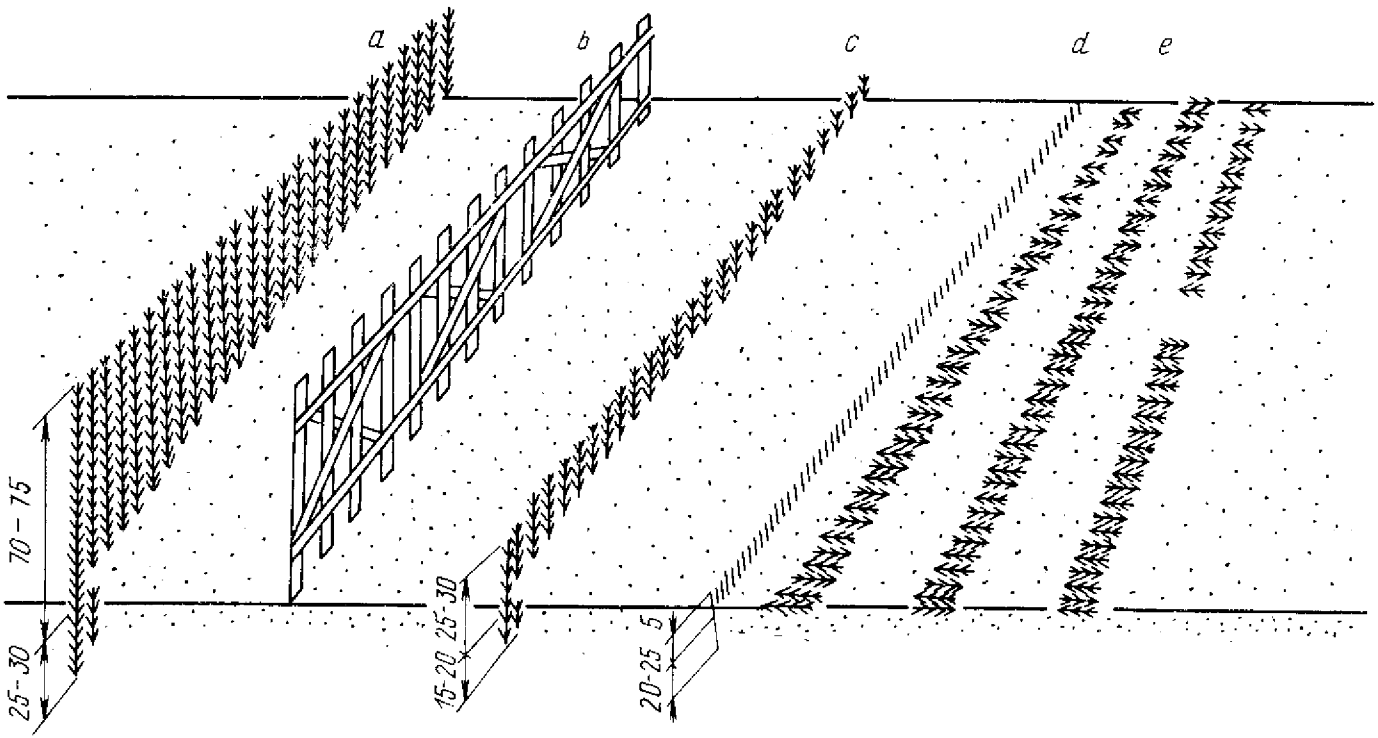


Fig. 3. Types of mechanical guards, aimed at protection from sand drifts and deflation:
a – impervious high-row; b – pervious high-row; c – semi-buried; d – buried; e – matting in-row

system of guards sand inflow progressively decreases and the sand levels taking the shape of a flat hill, which can be fixed by in-row guards and vegetation.

Semi-buried checkered mechanical guards with the area of 4–16 sq. m are installed at the areas with oscillatory type of sand movement. Semi-buried guards usually cover the whole area to be protected. Checkered guards are usually placed at the areas planned for afforestation or improvement of existing vegetation. Checkered guards protect young plantings from sand drifts and hacking.

Consumption of material for construction of semi-buried checkered guards is about 160 m^3 per 1 ha.

In-row matting impervious guards (Fig. 3, e) – are parallel rows made of branched grasses, placed like a dense, 60 wide and 5–10 cm thick billow, used for sand detention. It is made of branched seasonal and perennial shrubs and grasses, consumption of material is around 300 m^3 per 1 ha.

Continuous matting mechanical guards cover the entire surface of sand by 5–10 cm thick cover made of grass or reeds. They are used along with grass sowing at highly movable sands. Material consumption is about 500 m^3 per 1 ha.

Matting mechanical protection guards are rarely used for protection of vegetation and plantations at large areas because of their high cost. They are effective for an isolated sand dunes and sand hillocks control and for fixing sand slopes. Most widely they are used in sand nurseries where they protect sensitive sprouts from blowouts and cutting by sand particles. Matting mechanical protection guards require careful maintenance. Portable impervious guards are used for changing sand relief. Here power of wind is used for disintegration of the sand dune chains and driving sands away from the objects.

The main disadvantage of all guards is high manual labour consumption, since their installation practically involves no machinery. Recently there have been several proposals for using machinery in manufacturing of guards, specifically pervious mechanical protection guards made of reinforced concrete. However, their installation also requires manual labour.

Protections made of sand are also used. Mechanically made sandy protections can have the form of ditches, ditch-banks, banks, etc. To prevent blowout of banks and ditch slopes they are fixed by aggregating agents. Field observations showed that a ditch-bank has the best sand-detention properties. Aerodynamic properties of protection structures are not permanent and changing in the course of sand detention. Fig. 4 shows the nature of sand accumulation and the length of the windward and the leeward slopes formed by sand accumulation, depending on the height of a bank over the sand surface.

The amount of sand m^3, detained by 1 m of a mechanical protection guard, can be calculated according to the formulas:

for a sand bank – $W_b = 2.5h_b^2 + w_c h_o - 3h_o h_b - 3h_o^2$ (2)

for a ditch – $W_d = w_m h_d (1 - \beta) + (L_o + w_d + 2w_o)\sqrt{0.5 w_m h_d \beta / \alpha}$ (3)

for a ditch-bank – $W_{db} = 5h_b^2 = 5h_d^2$ (4)

for a bank-ditch – $W_{bd} = 4.5h_b^2 = 4.5h_d^2$, (5)

where

w_c stands for claw width;

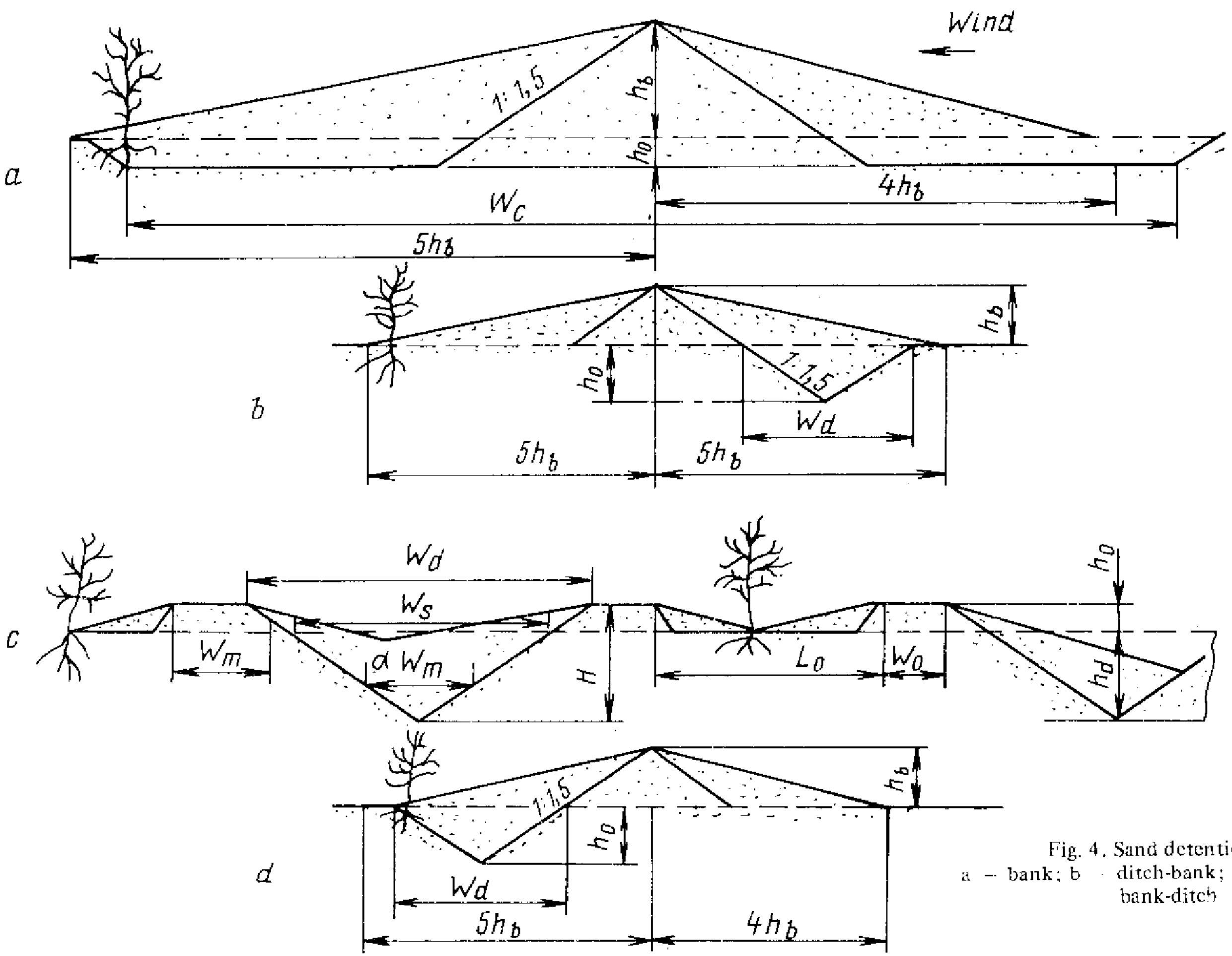


Fig. 4. Sand detention by:
a – bank; b – ditch-bank; c – ditch; d – bank-ditch

w_m - for ditch mean width;
h_d - for ditch depth;
β – is a factor, taking into account ground loosening and losses of sand dug out of a ditch and spilled over the slopes and the bottom;
L_o - distance between sand dumps edges of the adjacent ditches;
w_d – width of ditch together with dumps;
α - bank slopes declivity factor;
h_o – cut out sand layer ;
w_o – dump width ;
h_b – height of bank above sand surface

According to the observation data ditch-banks, placed at an angle of 75^o to the resultant of sand transfer, detain sand best of all. At an angle of 22.5^o sand is almost not detained.

Overall dimensions of protection structures depend upon the technical characteristics of the machines. Spacing between protection guards is taken not less than 3 m with regard to future possibility of machine treatment of spacings between plantations.

Number of rows in the system of protection guards (N) required for annual sand transport control is determined by the following formula:

$$N = \frac{G_p}{W}, \qquad (6)$$

where G_p - annual sand transport of the design probability, m^3/m.

The total width of a guard required for controlling annual sand transport of the design probability is determined by formula :

$$L = (n - 1) l , \qquad (7)$$

where "l" is spacing between rows of guards, determined by formula:

$$l = h_3 \ (m + n) \qquad (8)$$

For example,

$G_p = 10 \ m^3/m, W = 1.5 \ m^3/m, m = 5, n = 4, h_3 = 0.4$ m

It is required to determine N, l, L.

$$N = \frac{G_p}{W} = \frac{10}{1.5} = 6.66;$$

$$l = h_3 \ (m + n) = 0.4 \ (5 + 4) = 3.6 \text{ m};$$

$$L = (n - 1) l = (6.66 - 1) \ 3.6 = 20.4 \text{ m}$$

2.5. PHYSICO-CHEMICAL METHODS OF SAND FIXATION

In spite of the sufficient efficiency of mechanical shields, they have a considerable disadvantage: the impossibility to mechanize their placing makes the process costly and time-consuming.

Hence appeared the necessity of search for new methods of sand fixation, allowing to mechanize labour-consuming works. One of the suggested methods has been that of using binding substances.

The Soviet Union started research into application of binding substances, aimed at creating artificial soil structure and erosion control back in the 1930s on the initiative of academicians A.F. Ioffe and D.L. Talmud. Pioneering research in the field was carried out by P.V. Vershinin, F.E. Kolyasev, I.B. Revut and others. A variety of organic compounds were tested as structure formers: viscose, cellulose, hemicellulose, lignine, humic acids, peat glue, etc. [Vershinin, 1958] .

In the mid-30s the Agrophysical Research Institute in Leningrad started elaboration of a principally new method of sand fixation – the cementation of the surface layer with bitumen emulsion. The field tests were carried out in the southeastern part of the Karakum Desert and in the Lower-Dnieper Sands [Zakharov, Revut, 1954] . The emulsion was a 1:1 mixture of bitumen and water; to obtain a working solution, another 9 parts of water were added. The total consumption rate of emulsion and water was 20 tons per hectare. The emulsion was prepared in a specially equipped workshop and was applied by sprinkling. The bitument emulsion binds a 8–10 mm layer of sand for a period of two years. Higher humidity and temperatures higher by 3–4 degrees were observed under the crust thus formed. The crust is readily penetrated by sprouts of tcherkez and kandym (local plants), as well as of barley, millet, water melon and other crops. On the whole the bitumen cover contributed to an accelerated overgrowing of sands with psammophytes.

Experiments with bitumen emulsion were reactivated in the 70s at the Tashkent Institute of Railroad Engineers. The composition of the emulsion was: BN-IV Bitumen – 50 per cent, OP-7 Emulsifier – 4.5 per cent, caustic soda – 0.3 per cent, water – 45.2 per cent. Before application the emulsion was diluted with water in the 1:7 ration.

The post-war years saw the appearance of synthetic high molecular combinations whose rate of consumption is only a fraction of that of organic combinations. Below is a short description of some of them.

Polyacrilamid – PAA, PAA and SP – PAA. The first was obtained by synthesis from acrylnitric acid by M.N. Savitskaya at the Institute of High Molecular Combinations of the USSR Academy of Sciences (Leningrad) [Nerpin, Revut, 1964] . The other two were obtained at the Colloid Chemistry Chair of the Tashkent University, also by synthesis on the basis of acrylic acid [Kadyrov, Akhmedov, 1964] . These polymers are produced in the form of solutions and powder.

SP-8 is a co-polymer of metacrylic acid and metacrylamid. It is produced in the form of a powder well solüble in water.

To elaborate sand fixation techniques initial experiments on the use of PAA as a sand fixator were carried out in sands near Volgograd and Astrakhan regions on sites ranging from 1–3 m^2 to 300–500 m^2 in size. [Gabay, 1965] . It was found that, depending on the PAA concentration, the crusts preserve their binding properties within the period of 6 months to 2 years, the crust thickness ranging from 4 to 9 cm and their break-resistance 10 months later was 0.8 kg/cm^2. The crusts were permeable for atmospheric precipitation and did not prevent seeds of wheatgrass, quack grass (Agropyrum repens), brome grass (Bromus inermis) and alfalfa from germination.

In 1960–1965 the Institute of Desert Research of the Turkmenian Academy of Sciences carried out experiments using PAA to protect power-transmission lines' support from wind erosion in western Turkmenia [Nuryev, 1967] and also on the Central Asian Railroad [Gorbacheva, 1964]. The rate of consumption of the 1–3 per cent aqueous solution of PAA was 3 litres per m^2. Depending on the PAA concentration and rate of consumption, the 2–5 cm-thick crusts were preserved for a year, and up to four years. Kandym (Calligonum) cuttings took root well on fixed sand. Higher humidity was observed under the crusts in comparison with the control sites. In comparison with an open sand surface, bound sands had lower temperatures under the crust at daytime in summer.

"K" Series Substances. In 1958 the Chemistry Institute of the Uzbek Academy of Sciences used a synthetic polymer of poliacrylonitril and acrylic acid to obtain active soil structure formators which received a collective designation of "K" group – K-3, K-4, K-5, K-6, K_2-6, K-9, AKS, AKM, etc.

Along with soil structure formators, polymers of "K" group were tested as sand fixators to combat deflation of sands. In 1964 the Institute of Desert Research of the Turkmenian Academy of Sciences launched a series of field and laboratory experiments with K-4, K-6 and K-9 for the fixation of shifting sands [Nuryev, 1967]. The working solution concentration is 1–2 per cent and lower and the consumption rate is from 1.5 to 3 litres per 1 m^2 of sand surface. Field tests at the Karakum Canal and in western Turkmenia (for the protection of pylon foundations) showed that the 20 mm-thick protective crust as a heightened break-resistance rate (up to 10–12 kg/cm^2), is not eroded even by high winds, does not prevent sprouting of seeds, is permeable for atmospheric precipitation and also reduces ranges of temperature under the crust in summer and winter seasons.

K-4 and K-6 polymers were tested on Central Asian cotton fields to combat erosion caused by irrigation [Mirzazhanov, Mailibaev, 1974]. Prior to watering, bottoms of irrigation furrows were treated with K-4 or K-6 in the amounts of 30–40 kg/ha. That prevented soil erosion and increased cotton yields by 5–6 centners per hectare.

K-4 is a product of polyacrylnitrile saponification with alkali solutions under soft conditions.

K-6 is a product of polyacrilnitril saponification with sodium monosilicate with the reagents' ration of 1 to 5.

K-9 is a product of the saponification of waste of "Nitron" synthetic fibre with sodium hydroxide. These polymers are readily soluble in water. They were studied by the Laboratory of Shifting Sands of the Institute of Desert Research of the Turkmenian Academy of Sciences and found to have good sand-binding properties: mechanical strength, resistance to wind erosion, filtration rate, the depth of polymer penetration into sand, etc. K-6 and K-9 do not differ significantly from K-4 in these properties.

The Institute of Desert Research of the Turkmenian Academy of Sciences is developing a method of sand fixation with clay suspensions treated with "K" Series polymers, PAA and latex [Nuryev, 1969] . The mode of application is irrigation at the rate of 4 litres/m^2. Field experimental tests showed that the polymers completely prevent cracking of the clay crust upon drying, and that the crust does not prevent sprouting of seeds and increases sand's resistance to deflation. The mechanical strength of a clay crust treated with polymers is 7–8 times higher than that of untreated one. Humidity and temperatures under the crust are always more favourable. All this provides for normal growth of vegetation.

Sand fixation and combating wind erosion on light soils is carried out with synthetic latexes – aqueous dispersions of polymers, obtained through emulsion polymerization of monomers. The most commonly used latexes are ARM-15 and SKS-30 produced by the Sumgait Synthetic Rubber Factory.

Divinyl-styrene latex ARM-15 is a product of co-polymerization of divinyl and styrene, it is manufactured in the form of a 16–22 per cent aqueous emulsion. Application of a 2–16 per cent concentration of the solution at a rate of 3 litres/m^2 produces a 7–18 mm-thick impregnated sand layer. The break resistance rate of the crust thus produced is 2–3.6 kg/cm^2. In summer time the temperature under the crust was somewhat lower than that of the control site.

The best results have been obtained when latexes were diluted with spindle or vaseline oil at a ratio of 1:5 or 1:10. Surfaces treated with a 1.2–3.0 per cent concentration of the mixture at a rate of 100–150 kg/hectare can withstand 20 m/sec winds [Revut et al., 1969] .

The Kulundinskaya Agricultural Experimental Station has studied anti-deflation properties of SKS-65 GP latex produced by the Omsk Synthetic Rubber Factory. Soil treated with a 2.5–5 per cent concentration of the latex at a rate of 75–150 kg/hectare is protected against wind erosion for 3–4 months. The experiments have also revealed a diminution of the soil water loss on evaporation.

Several improved types of lignine preparations to be used as sand fixators and soil binders have been suggested. Designated as ALS preparations (acrylatelignosulphonates), they are obtained by chemical modification of nitrolignine – a byproduct of hydrolysis plants – using a method of grafted co-polymerization of metacrylate and other ethers of acrylic and metacrylic acids.

Laboratory tests of ALS preparations have shown their good sand fixating properties: small doses produce a thin wind- and water-resistant crust. Research into ALS is going on.

Water-Soluble Polymers (WSPs). These were synthesized in the late 1960s from petroleum waste and represent light-coloured pastes with 2–6 per cent of dry matter. Ionomer "VO", that is a sodium salt of hydrolyzed polizcrylonitrile, and ionomer "L" have been tested on the sands of the Apsheron Peninsula. Ionomer "VO" proved to be the more efficient as a soil binder [Amiraslanov et al., 1974] . The crust produced has sufficient mechanical strength. The recommended doses are: 100–200 kg of dry matter per hectare for ionomer "VO", and 75–150 kg/hectare for ionomer "L".

To be able to spray the "VO" and "L" ionomers, they have to be diluted by water to a concentration of 0.4–0.6 per cent, which corresponds to 15–40 tons of solution. The experiments have shown that such doses produce a wind-resistant, but fragile and non-water-resistant sand crust. Only 40–50 mm of precipitation destroyed it completely [Podgornov, 1980] .

Also worth mentioning is a method of sand fixation with an emulsion of indeno-alkylaromatic resin. It has been found that in terms of pure resin the emulsion concentration should not be less than 25 per cent at doses of 300 grammes/m^2, which corresponds to a rate of 12 tons of working solution per hectare. This concentration and dosage produce an 8 mm-thick bound layer whose break resistance rate 4 months later is 18 kg/cm^2 and which lifetime is more than three years.

Crude oils rank first among sand binders both in the USSR and abroad. High-resinous types of oil are the most efficient.

Oil from the Arlansk deposit in the northwest of Bashkiria contains up to 3.6 per cent of sulphur. In 1971 Arlansk oil was used for sand fixation in the Astrakhan Region and the Stavropol Territory. The total area of the stabilized surface is about 50 hectares. Oil was applied by a tractor-driven sprinkler of the OVT-1 type at a rate of 4–6 tons per hectare. Air temperature at the time of application should not be below 2^{0}. The optimal dose for the sandy areas near the Caspian Sea which ensures the preservation of the crust for two years is 5 tons per hectare. The experimental tests included sowing and planting of psammophytes: sand oats, djooztchook (Calligonum), tamarisk, Haloxylon aphyllum, etc.

Three years after the beginning of the experiment the movement of sands treated with Arlansk oil was practically halted and the danger of farm buildings being drifted over by sand eliminated. 1.2–1.4 metre-high bushes planted in rows reduced sand movement in comparison with control sites by 90 per cent.

Mangyshlak oil is a heavy, high-resin one. In 1974 it was used to fix sands along the Usen-Guryev oil pipe-line. The experiment involved a 1.3 km stretch of the pipe-line. It revealed that Mangyshlak oil can be extensively used for sand fixation along linear installations, for it has no herbicidal effect on seeds planted below the impregnated level [T.I. Fazilov, 1972] .

Nebitdag Fields Oils. In the early 1960s Nebitdag Oil Fields management jointly with the Institute of Desert Research of the Turkmenian Academy of Sciences used local oil for shifting sand fixation along power transmission lines and communications lines. They fixed supports of the Jebel-Koturdepe and Koturdepe-Barsa-Gelmes power transmission lines. The radius of the fixed surface ranged from 6 to 9 meters and the rate of consumption was 3 litres/m^2.

Already during the first year after the treatment sand movement around the supports was practically halted. The crust was preserved for 10 years.

In 1962–1963 waste remaining at the bottom and on the walls of oil tanks was experimentally used to fix sands in the Ferghana region. The consumption rate was 600–800 grames per m^2. The protective layer thus obtained withstood 30 m/sec winds and was easily penetrated by psammophytes. The crust was preserved for 6 years [Mirzazhanov, Mailibaev, 1974] .

Laboratory and field experiments on the fixation of sands with the help of oils and their mixtures with oil products were initiated in the 1960s. It was found that protective crusts were most resistant to erosion when multi-component binders were used, such as hot mixtures of bitumen and mazut with oil, tar with oil, or mazut with oil. Surfaces obtained with mixtures of mazut and bitumen with diesel fuel, and those of bitumen with benzine or kerosene have the disadvantage of quickly aging and cracking.

Resin-asphaltene compounds represent the most valuable binding component of oil products. Bitumen, mazut and oil contain certain amounts of oils which act as plactifier for resins and asphaltenes. The study of different types of protective covers revealed different types of bond between sand particles, depending on the chemical nature of the binder: rigid, flexible and elastic.

Rigid type of bond. Under the impact of external loads these bonds are broken beyond recovery even after the external load has been removed.

Flexible type of bond. Particles can move with respect to one another without breaking the bonds between them and recover easily the once-disturbed bonds.

Elastic bonding. No great external loads are required to break these bonds. After the loads are removed, the bonds are readily recovered.

Oil and mixtures of oil products create flexible type of bond between sand particles – the most favourable one for binding.

Field experiments were carried out along power transmission lines in the vicinity of Nebitdag. 3 litres/m^2 of oil product mixtures can be used to bind roadsides of roads built in shifting sands [Ivanov, 1975] . The recommended mixture compositions are:

oil – 50–60 per cent, mazut – 30–40 per cent; road bitumen – 5–10 per cent;

oil – 50–70 per cent, mazut – 30–50 per cent;

oil – 60 per cent, mazut – 20 per cent, nerozine – 20 per cent;

oil – 80–90 per cent, bitumen – 10–20 per cent;

oil – 90 per cent, mazut – 8 per cent, bitumen – 2 per cent.

The last few years saw the introduction of Nerozene, a shale resin, as a sand binder, which can be applied in the form in which it has been manufactured.

The preparation Nerozene (or SSP – semicoking shale resin) is produced by enterprises of the shale-chemical industry. It is a mixture of intermediate and heavy fractions of generator shale oil obtained by thermal decomposition of shales under soft conditions. It has a complex chemical composition: nitrous bases – 0.3 %, carbolic acids – 0.3 %, phenols – 21.4 %, acid asphaltenes – 13 %, nitral oils, hydrocarbons and nitrile acid compounds – 64 %.

In 1967 Nerozene was used in the Astrakhan Region for fixing deflation foci on pastures and along the Guryev-Astrakhan Railroad. In 1968 Nerozene was used to protect from deflation the Bukhara–Urals and Central Asia – Centre gas pipelines [Gabay et al., 1971] . Under the conditions of the Kyzylkum and Karakum Deserts the application of 2.5–3.0 tons per hectare of Nerozene produced a good sand-protective crust.

In 1971 Nerozene was tested in western Turkmenia to protect support bases of power transmission lines. The results of many years of laboratory experiments and field tests showed that to produce a good wind-resistant crust, no less than 2–3 litres/m^2 of Nerozene is required under the conditions of western Turkmenia.

As a fixator of deflated surfaces Nerozene has binding properties superior to those of crude oil. It produces protective crusts with satisfactory break resistance and with a durable upper layer. The best results are obtained when the preparation is sprayed at a high pressure. However, in view of its toxicity and specific smell, Nerozene should be handled with special care; in addition, it is twice as expensive as oil products.

Since 1973 the Institute of Desert Research of the Turkmenian Academy of

Sciences has been conducting a series of laboratory and field experimental works using a solution of bitumen in used motor oil and transformer oil to produce wind resistant crusts. After repeated regeneration the oils become unsuitable for any other uses.

The oil itself does not contain resins and thus it cannot produce a crust with good wind-erosion stability. That is why resin and asphaltene-containing substances, for example, bitumen and mazut, must be added to it. The levelling-up effect of the crust on the ranges of temperature under it in field conditions in summer time was found to be much lower than in the case of polymer and clay crusts, and higher than under Nerozene and crude oil crusts. These crusts are non-toxic.

The Sixth International Petroleum Conference which took place in Frankfurt-on-Main in June 1963 discussed interesting reports on the sand dunes fixation with the help of petroleum processing by products, as well as a method of directly producing waterproof films on soil with the help of resin-containing petroleum products.

A group of British researchers conducted a series of experiments in sand dunes in England and in the Negev Desert, using a mixture of mineral oil to produce a granulated structure of sandy soil.

Bitumen emulsions were thoroughly studied in the German Democratic Republic and the Federal Republic of Germany where they are primarily used in agriculture when cultivating different crops. To a lesser extent they are used for the fixation of industrial sand dumps, whose slopes are sprayed with 1.2–1.5 kg/m^2 of emulsion with the simultaneous sowing of herbaceous plants and planting of arboreous plants (Bielfeldt H., Gaenbner K., 1976).

In the United States of America bitumen emulsion is used in many states to combat wind erosion on light soils; with the application of 11 tones of solution per hectare.

In the early 1960s the US chemical industry produced preparations designated as WX-889, CR-239, Soil-Saver and Soil-Set. Aqueous solutions of these preparations were tested on 10x10 feet sand microplots. The optimum rate of censumption for CR-239 and WX-889 was found to be 2.3 gal/100 ft^2 (1.0 litre/m^2). CR-239 was found to be the most effective of the preparations tested.

The preparations high cost (450–870 dollars per 1 hectare) prevented their large-scale application.

In addition to the abovementioned preparations, in the state of Kansas to combat deflation they tested the following substances on highly eroded soils:

1. Swift's anti-erosion synthetic resin in the form of aqueous emulsion at a rate of 200, 400 and 800 litres/hectare.

2. Coherex (a synthetic resin emulsion) at a rate of 282, 565 and 1130 litres/hectare.

3. Anion-asphaltene emulsion at a rate of 282, 565 and 1130 litres/ha.

4. Oil-latex emulsion at a rate of 380, 760 and 1130 litres/hectare.

The preparations were applied in bands of 20 and 60 centimetres width and by overall spraying. After 24 hours the treated plots were subjected to 56 km/hour winds in an aerodynamic tunnel. The best results were obtained with overall spraying, which, even at minimum application rates, produced a highly wind-resistant cover lasting for 7 weeks. The oil-latex emulsion was found to have the best binding properties. On all treated plots accelerated germination of seeds was observed. The cost of fixation using the preparations was rather high – 570 dollars per hectare and more [Letey et al., 1963] .

The Federal Republic of Germany has been extensively using hygromull, an urea-formaldehyde foam, to improve the waterphysical properties of light soils and, to a lesser extent, for the fixation of sand. The preparation which has the form of white flakes contains up to 30 per cent of nitrogen which upon application becomes partially transformed for uptake by plants. After application to soil the hygromull is ploughed under, and when used as a sand binder, it is simply spread over the surface forming an anti-deflation cover. The preparation is biologically clean and causes no environmental pollution. Application rate for the fixation of sand ranges between 200 and 400 m^3 per hectare.

More than 300 hectares of sand banks in the vicinity of Antwerp were fixed and turned into meadowland with the help of hygromull. Hygromull was also used to fix coastal dunes in the Shelde mouth [Fazilov T.I., 1976] .

Curasol – an emulsion of polivinylacetate and dibutylmaleate is produced in the form of a thick cream-like mass. It is readily dissolved in water. After application to the surface of sand the crust becomes almost waterproof.

In microplot tests in the Federal Republic of Germany they used modifications of Curasol – Curasol AE and Curasol AN – with a view to determining water resistance of crusts and the impact of the surface layer's initial moisture to the degree of their structure formation. Doses of 35 to 67 g/m^2 were tested. It was found that when the initial moisture of the top sand layer is 0–10 % and concentration of curasol is 1 %, the total moisture of the layer being treated must not be more than 20 %.

Research undertaken in the USSR and elsewhere indicates that at present there exist various binding substances used for shifting sands fixation. The mechanical strength of the crusts obtained as well as of other dispersion systems is determined by physico-chemical phenomena and processes that develop across the junction of their solid, liquid and gaseous components. The essential processes include those of adsorption, hydration and ion exchange. Of great importance for these processes are also such factors as the rate of mineral particles dispersion, their mineralogical composition and moisture content. These factors are not constant for sands, loamy sands, loams, heavy loams and clays.

2.6. PHYTO-RECLAMATION OF SHIFTING SANDS

When reclamation of large areas is involved, the principal requirement of combating shifting sands is that all operations should be planned. In all cases phytoreclamation of sands should be conducted in accordance with detailed projects elaborated on the basis of preliminary studies of sandy areas to be fixated [Petrov, 1950] .

Phyto-reclamation of shifting sands involves the following operations:

1. Preventive measures designed to halt the expansion of areas under shifting sands and exclude the formation of the new tracts of shifting sands.

2. Reclamation of shifting sands, aimed at turning them into pastures or forests.

3. Reclamation of shifting sands with a view to protecting economic units from sand drifts and deflation.

Preventive measures firstly include organizational efforts aimed at the proper use of sand vegetation cover. On badly damaged sands it is necessary to strictly regulate or completely prohibit the grazing of cattle and the use of trees and shrubs for firewood especially on sand tracts bordering on cultivated lands, industrial enterprises and settlements.

Preventive measures aimed at protection of vegetation acquire particular importance during large-scale earth-moving operations, construction of gas and oil pipelines, as well as transportation of heavy equipment. Experience shows that these operations frequently result in the appearance of new areas under sand dunes which subsequently deal vast damage to the national economy.

Sand dunes are reclaimed by sowing seeds or planting seedlings of sand-fixator plants and also by planting seedlings of coniferous and broad-leaved species of arboreous over mechanical guards or chemical covers or without them. The choice of vegetation species used for the afforestation of sands is determined by the certain soil and climatic conditions and the intensity of deflation processes. For example, in the European part of the USSR large pine-tree plantations are initiated on sandy soils (with the exception of overmoistened ones) in the regions with the annual amount of precipitation more than 300–350 mm.

Curtain plantations on sandy soils in the regions with the annual precipitation not less than 250–300 mm, in depressions between hillocks, where the use of ground water is possible.

Echelon plantations from deciduous trees are created on sand dunes with additional supply of water from ground water, snow retention and local runoff. The width of echelons is 25–50 metres, with spacings between them of 100–150 m.

In the Baltic republics large plantations of pine-tree, birch and alder are being grown.

In the forest-steppe and steppe zones pine-tree is used to create plantations on sands, and poplar – in the areas with sufficiently shallow (not deeper than 3–4 metres) ground water. In southern and southwestern regions of the European part of the USSR white acacia may be planted on sands with buried soils and interlayers of clay.

In the Don, Naryn, Ural–Enba, Central and Eastern Kazakhstan sands Pinus vulgaris is used, and at ground-water levels of 0.5–1 m – poplar, black alder and sea-buckthorn; on Tersko-Kumski, Astrakhan, Daghestan and Kalmyk sands – poplar, white acacia, and elm.

In Central Asia reclamation of sand dunes relies mainly on psammophytic plants.

Protection of economic installations from sand drifts and deflation proved to be necessary mainly in the desert zone as a result of construction of large projects such as railways, oil fields, oil and gas pipelines, in sand dunes areas, as well as the result of the agricultural development of the sandy desert.

Protection of economic installations is possible if certain requirements are observed. Canals, collectors, rail-roads, agricultural lands and industrial facilities are considered to be protected if no blowout processes occur, if the arrival of sand to them is blocked out, no matter in the form of a sand dune, or in the wind-sand flow.

On gas, oil and water pipelines accumulation of sand is considered to be a positive factor, providing their protection.

Phyto-reclamation of sand dunes will be more effective and the expected results will be achieved if habitat conditions of plants on various types of sands and modes of economic activities in the region subjected to reclamation are fully taken into account. This means that any sand fixation and afforestation projects must be preceded by a phyto-reclamation survey. Such a survey involves the collection of exhaustive data on the natural conditions and economic uses of the sandy areas which will provide a basis for the phyto-reclamation project. The following points should be duly elucidated [Petrov, 1974] :

1. Typology of plant habitat conditions in the areas planned for sand fixation and afforestation. The habitat conditions of plants in shifting sands present the total of all evnironmental factors determining the growth and development of sand-fixator plants.

2. Elaboration of phyto-reclamation measures suitable for the revealed types of plant habitat conditions.

3. Phyto-reclamation assessment of tree and shrub species and herbs recommended for shelter belt plantations and for stabilization and afforestation of sands.

4. Management issues, linked with the implementation of the planned phyto-reclamation measures (protection of vegetation on sands, establishment of nurseries, mechanization of jobs, allotment of plots for supply of seeds and cuttings, etc.).

5. Study of the experience of phyto-reclamation programmes being carried out in the areas to be investigated.

Proper attention to these matters will contribute to the correct choice of phyto-reclamation methods of shifting sands and to the specification of goals, facing the phyto-reclamation personnel.

The following main types of plant habitat conditions can be distinguished in the world's arid zones:

1. Sands with sufficient atmospheric moistening (precipitation in excess of 250 mm with evaporation of about 1600 mm) which provides for natural overgrowth of sands with mesophyllic psammophytes.

2. Sands of the deserts with atmospheric moistening providing for natural overgrowth of sands with xerophyllic psammophytes – grasses and shrubs (precipitation from 100 to 250 mm, with evaporation of about 2300 mm).

3. Sands of the deserts with insufficient atmospheric moistening, not providing for the natural overgrowth of sands even with grasses (precipitation under 100 mm with evaporation of 2800 mm).

The types enumerated can be found both within one and the same natural zone in different zones, depending on the atmospheric moistening regime. These main types can further be subdivided into lower taxonomic stages according to the character of underlying rocks, thickness of eolian sediments, depth of ground water and the degree of its salinity.

For example, the following types of habitat conditions of plants can be identified in sandy deserts and semi-deserts:

1. Shifting sands of different thickness overlying water-permeable hard metamorphic and sedimentary rocks of low mountain ridges. They are usually sedimentary in origin. There is no ground water.

Table 2

Comparison of the World Deserts (acc. to M.P. Petrov, 1977)

Continent	Asia				Africa		Australia	America	
	Central	Middle	Iranian Plateau	Arabian Peninsula	North	South		North	South
Latitude height above the mean sea level	36–45° N lat about 1000 m	36–42° N lat about 200 m	28–36° N lat about 600 m	15–35° N about 500 m	15–30° N lat about 250 m	6–33° S lat 600–900 and 0–300 m	20–34° S lat about 500 m	22–44° N lat about 1000 m	5–50° S lat about 100 m
Geological features	Chinese platform Cr, Tr, Q	Turanian plate Tr, Q	Iranian massif from I to Q	Arabian platform from Cr to Q	African platform from Cm to Q	South-African platform from P_2 to Q	Australian platform from Pz to Q	Intermontane depression Tr, Q	Cordilleras foothill trough, Q
Topography	Ancient alluvial accumulative valleys, dry lake depressions and dry watercourses, blind-faced deltas. Denuded structural valleys and their residues, isolated mountains and ridges. Eolian forms. Similarity of relief-forming processes								
Surface deposits	Alluvial, proluvial, deluvial and alluvial quaternary and young, rocky, gravelly, pebbly, sandy, sandy loamy, loamy, clayey loess. Frequent outcrops of barren pre-quaternary rocks as isolated mountains and ridges. Similarity of the processes of weathering deflation, aeolian and water accumulation								
Climatic zones and sectors	Temperate continental	Temperate and subtropical continental		Subtropical and tropical continental and oceanic			Subtropical continental	Temperate continental	Oceanic
Maximum mean monthly temperature of the warmest month (°C)	27	32	33	34	37	28	31	33	26
Minimum annual rainfall (mm)	9	82	76	16	0.3	10	27	48	3 and 162
Aridity index (Meigs, 1953)	Ab 03 Eb 03	Ac 03	Ac 13	Aa 23, Ab 24 Ea 24	Ea 24	Ac 23, Ac 24, Ea 22	Aa 23, Ea 24.	Aa 23, Ea 24	Ea 23, Ac 23
Transit water	Transit rivers, local river network is greatly reduced, lakes are mainly salty, seldom temporary fresh. Local temporary runoff predominates								
Groundwater	Fissure, stratal, local, pore water of foothill valleys, river-valley-channel pore water. Distinct groundwater flow Sulphate and chloride. Salt water prevails								
Soil and saline crust	Abiogenic immature soils predominate. Gypseous, chloride, carbonate, gravelly, ferrous and solonchak saline crusts are common								
	Grey-brown	Grey-brown sierozem		Grey-brown sierozem subtropical and red-brown tropical		Sierozem red-brown tropical	Sierozem red-brown tropical	Subtropical and tropical red-brown	Abiogenic immature desert
Vegetation: Subregion	Saharo-Sind					South-African	Central-Australian (Eremei)	North-Mexican (Sonoran)	Andan
Province	Asian	Irano-Turanian		North-African		–	–	–	–
Ecological type	Sclerophytes, halophytes	Sclerophytes, halophytes, ephemerides, ephemeroids	Sclerophytes, succulents, halophytes, ephemeroids, ephemerides			Succulents, halophytes	Sclerophytes, succulents, halophytes	Sclerophytes, succulents, halophytes	Succulents, halophytes
Fauna: Subregion	Central-Asian		Mediterranean			Capean	Australian	Sonoran	Chile-Patagonian
Province	Gobi-Kashgarian	Irano-Turanian	Saharo-Arabian			Sonoran	–	–	Andan
Landscape	Stony, gravelly, gravelly-pebbly foothill deserts, pebbly and sandy-pebbly on structural plateaus, sandy ridgy hummocky, etc. Fixed with vegetation, barkhan sands of all types, non-stabilized by vegetation sandy solonchak, loamy, clayey, takyr, clayey badland, clayey, loess								

2. Shifting sands of different thickness overlying sandy-clayey plains. The ground water is deep and inaccessible to plants. Sands of this type are rather widespread.

3. Shifting sand of different thickness overlying water-permeable hard, mainly Cretaceous sandstones with very deep ground water, inaccessible to plants.

4. Shifting sands of different thickness overlying the slopes of loess-like hills with very deep ground water inaccessible to plants.

5. Shifting sands of different thickness overlying proluvial sediments of foothills with deep ground water inaccessible to plants, but with additional moistening from mud flows.

6. Shifting sands of different thickness overlying loose sandy lacustrine-alluvial sediments with shallow saline ground water accessible to plants.

7. Shifting sands of different thickness overlying loose sandy lacustrine-alluvial sediments in all deserts with shallow fresh ground water accessible to plants.

8. Shifting sands of different thickness overlying abadoned but formerly cultivated and old-irrigated lands in the river valleys and deltas of arid regions with good soils and shallow, frequently fresh, ground water, accessible to plants.

Every group can further be subdivided in terms of sand accumulations thickness into: a) small sand dunes up to 1 metre in height; b) medium sand dunes up to 3 metres in height; c) large sand dunes over 3 metres in height.

It is normally native shrubs, perennial and annual grasses that are used as sand fixators in phyto-reclamation. All of them are heat- and drought-resistant and can grow on atmospheric moistening, using ground water wherever available.

3. ORGANIZATION OF SCIENTIFIC RESEARCH AND PRACTICAL PHYTO-RECLAMATION OF SHIFTING SANDS

3.1. STUDY OF DEFLATION AND SAND TRANSPORT PROCESSES

The main relief-forming factor in a sandy desert is the wind activity which results in blowout, transport and accumulation of sand. Transport and accumulation of sand result in the formation of sand drifts, while blowout bares the foundations of various structures. That is why it is very important to know the direction and intensity of the above-mentioned processes.

Eolian processes in sandy deserts reblew and dissected the initial loose-sand layer and formed the contemporary eolian relief, which over large areas has become wind-resistant to a certain extent and is presently in a state of dynamic equilibrium. This has been facilitated by a number of natural factors which favoured overgrowing and compacting of the surface of eolian forms.

The desert's rather stable system can be disrupted. Its natural equilibrium can be destroyed by a change in environmental factors or man's economic activity. Bared of its protective soil and vegetation cover, the mass of loose sand becomes to be affected by the wind setting off a process of an active deflation. The process can have catastrophic consequences for economic facilities and installations.

Under natural conditions (without the influence of anthropogenic factors) the surface of overgrown eolian forms is subject to varying degrees of deflation but is rather resistant to this process owing to its vegetation cover. Undissected eolian relief is little affected by natural deflation. For example, rolling and enveloping sandy areas as a rule display no pronounced evidence of deflation, transport and accumulation of eolian material. The susceptibility of strongly cut relief to deflation differs from feature to feature. For example, lower part of slopes of sand ridges and depressions between them are little affected by the wind: the slopes – owing to their rather dense grass cover, and depressions – also owing to a high content of power particles in the sand, shallow occurrence of weak primary sediments and ground water which represent the local base level of deflation. Ridge summits and upper part of slopes can display evidence of deflation in the form of deflation hollows, enveloping accumulations of sand and even sand dunes. The greater intensity of deflation on ridge summits is due to the greater dryness of ground and wind impact.

The planning of effective and economical measures of protecting facilities and installations against sand drifts and blowout is impossible without reliable information about the wind resistance of the sand surface.

The required degree of detail of such information will change with progress in design work on the project.

For example, at the feasibility study stage of the unit construction, when primary attention is paid to the choice of site or route, the description of wind resistance of sandy surface should cover a large area, being at the same time rather schematic, without too much detail. The map scale will naturally be small.

As soon as the site or the route has been chosen (the technical project stage), a detailed mapping of the surrounding territory will be necessary, with the large-scale map or scheme showing the entire diversity of physical features and the intensity of deflation process.

Experience of actual construction in sands shows that large-scale protection measures can start only after the completion of the construction, when the initial sand surface has been changed.

The most commonly used approach is the study of erosion resistance of sandy surface and the drawing up of a map (scheme) on the already completed installation. In this case the classification and the map's legend must include, in addition to the natural types of sand resulting from natural processes of eolian relief-formation, anthropogenic or "technogenic" forms (types) of sand surfaces which appeared as a result of construction work.

The classification of wind erosion processes is an important element of the mapping of wind-erosion resistance of sands.

In classifying sand desert relief for purposes of mapping, most researchers subdivide all eolian forms into two (overgrown and denuded) or three (overgrown, semi-overgrown and denuded) categories depending on the stability of their surfaces. In the second case the category of semi-overgrown sands usually includes so-called sand dune-hummoky complex which is a transitional stage from overgrown to denuded sands or vice versa. However, in sandy deserts, in addition to the above-mentioned three categories, there are a number of eolian forms whose surface is eroded or overgrown in a manner precluding their inclusion in either of the three categories. In the meantime, it is very important to know the degree of the substrate's mobility both for forecasting the eolian process and for developing measures of combating it and then going ahead with economic development of the territory.

Classifications based on geobotanical features alone do not provide a sufficiently complete picture of the wind-erosion susceptibility of a sandy surface. As a consequence, **the geobotanical method** should go along with a geomorphological one which makes it possible to study the form and amount of accumulating sand as a measure of deflation intensity [Orlov, 1928] .

Since sand accumulation is a result of blowout and transport, the amount of accumulated sand can serve as an indication of the process' intensity: the greater the amount, the higher the deflation intensity. For example, small enveloping accumulations of sand on overgrown surfaces of eolian forms are evidence of weak deflation, whereas isolated small sand dunes are evidence of a stronger degree of deflation. One should bear in mind in this connection that in deserts sand accumulation as a rule takes place in the immediate proximity of the source of deflation. Exceptions are cases when eolian sands are blown over solid or compacted surfaces (takyrs, plateaus, solonchaks, etc.) where their mobility increases. Sand can be transported over large distances also in conditions of prolonged predominant winds. Such cases, however, should be discussed separately.

Unmistakable evidence of sand transport over denuded overgrown sand surfaces is the presence of sand ripple. Only well sodded sandy surface with dense shrub or grass cover does not display clear traces of ripple. However, this does not mean that there is absolutely no sand transport over overgrown eolian forms, because the upper 5 cm of the dry surface horizon are devoid of consolidating sod, and strong winds do shift the sand substrate. This transport does not pose danger for economic facilities and installations, however.

The authors suggest the following classification of sand surfaces as a function of their susceptibility to deflation:

1. **There is no deflation** – the surface is overgrown without evidence of ripple;
2. **Deflation is weak** – there is evidence of ripple and enveloping sand accumulations without a typical ridge;
3. **Deflation is moderate** – sand ripple, enveloping surfaces, ridges on them and isolated small (0.5–1.0 m) sand dunes;
4. **Considerable deflation** – a combination of sand dunes and sand dune chains with overgrown (mostly hillock) forms;
5. **Strong overall deflation** – a bared field of sand dunes with isolated individual plants in depressions between sand dunes.

The first type (absence of deflation) is to be found on overgrown weakly dissected eolian forms which usually constitute smooth rolling sands or fixed sand mounds as well as enveloping sandy surfaces. The first and the third are normally observed along the periphery of sand tracts, and the second in the outskirts of irrigated areas, shores of lakes and solonchaks. In natural conditions the overgrown sandy surface is not subject to deflation. However, mechanical destruction of the upper sod layer may produce deflation hollows on smooth rolling sands as well as enveloping accumulations and even small sand dunes.

The second type (weak deflation) is the most common in a sandy desert. It is typical of overgrown (slopes and depressions) and weakly overgrown (summits) sand ridges with different degrees of dissection and their combinations. The degree of susceptibility to deflation differs from feature to feature. The least eroded are lower parts of slopes and depressions between eolian forms, the most deflated features are summits.

The third type (moderate deflation) is characterized of weakly overgrown strongly dissected sand ridges. Inter-ridge depressions and lower parts of slopes are not susceptible to deflation, while the summits and upper parts of slopes are affected by it.

The fourth type (considerable deflation) is most frequently found in sands with an intermediate degree of dissection and on sand dune-hillock complexes. Susceptibility to deflation differs from feature to feature: sand dunes are subject to overall deflation, hillock forms are subject to partial (weak) deflation. The depressions between sand dunes are mostly overgrown, the speed of movement of sand dunes is low. Commonly observed is only the restructuring of ridges and intensive sand transport in the form of wind-sand flow.

The fifth type (strong overall deflation) is to be found on sand dune tracts. Sand transport takes place in the form of wind-sand flow and the movement of eolian forms. Two subtypes may be differentiated: sand dunes on a loose sandy substrate and sand dunes on dense rock (takyrs, sors, outcrops of bedrock, etc.). The second subtype has greater mobility and as a rule offers poorer conditions for vegetation.

When studying and mapping the types of sandy surfaces this method provides a sufficiently complete picture of the intensity and direction of deflation processes in the area in question. This will make it possible to elaborate grounded recommendations on the siting of installations and to make a preliminary assessment of the scale and place of protective measures, i.e. to obtain information obligatorily included in a feasibility study of an economic unit.

Aerial photography can provide valuable material for a comprehensive study of deflation processes in deserts and compiling of maps which would accurately show the distribution of different types of sand surfaces. Aerial photography can considerably reduce the volume and the time of costly land surveys, at the same time producing cartographic material of a better quality.

The regional study and mapping of wind-erosion resistance of large areas prior to their economic development should concentrate on the identification of areas potentially resistant to deflation owing to their mechanical strength which in turn is determined by the lythology of initial sediments. These are favourable locations for the siting of installations and facilities.

In terms of the suggested classification such areas should be classified as not subjected to deflation.

In the Karakum desert these areas include the outcrops of kyrs, fragments of clayey delta plains and plateaus.

The elaboration of protective measures on the site should be based on the findings of the study and mapping of wind-erosion stability of sands on a larger scale, with greater degree of detail. Thus, in addition to the five types of sand surfaces described above, all sorts of their combinations, transitional types and subtypes can be differentiated. Such maps distinguish between the following two categories of sandy surfaces: 1) sands which do not call for fixation; 2) sands which require fixation. The first category includes sands with a dense well preserved sod layer, with few deflation hollows and practical absence of sand transport. The second category includes surfaces with the sod layer damaged in different degrees and with enveloping sand accumulations and sand dunes. The number of subtypes of sandy surfaces which can be distinguished here may be as high as 8 or 9.

Proper choice of scale and area to be covered by the survey is an important element in the wind-erosion stability mapping for purposes of a feasibility study and the elaboration of protective measures. Experience shows that for the former the map scale should not be more than 1:500,000 while the surface area to be covered is determined depending on the tasks set and the programme of research. For the elaboration of protective measures of a certain economic unit the scale should not be smaller than 1:20 for linear installations (pipelines, motor roads, power transmission lines) and not smaller than 1:2,000 for square installations. Whenever possible, the scale of mapping of a square installation should be the largest possible one, in the optimal case approaching to that of a technical project blueprints. This would enable to represent all the planned protection guards (their types and parametres) in that very scale.

The length of the strip to be mapped in the case of linear installations will coincide with the length of the installation in question, while its width is determined by the area affected by wind erosion which may vary between tens and hundreds of metres depending on the state of the sandy surface. The more homogeneous is the sand surface, the narrower can be the strip to be mapped.

Area to be mapped in the vicinity of square installations is determined also by the area of sandy surface damaged by construction work.

The results of studies of wind-erosion stability of sands and the maps compiled must be updated in 5 years.

The information presented on maps of wind-erosion condition of sands permits reliable planning of protective measures required. However, maps do not offer information about the quantitative aspect of the processes involved, which complicates the task of determining the width of a protective zone near the units, situated on the leeward and windward sides.

The intensity of deflation processes, their quantitative characteristics, is determined in the course of laboratory processing of data on wind regime, as well as with the help of field instrumental observations on stationary plots of 1–2 hectares or fixed profiles, and quantitative registration of sand transport in the wind-sand flow.

Since the wind is the main relief-formator factor, office work concentrates on the study of wind regime. The study of wind regime of deserts is important for the understanding of heliomorphological processes taking place there and especially for the study of movement and accumulation of sand.

There are several methods of processing wind regime data.

The simplest and the most commonly used method was suggested by Drozdov in 1957. It uses direction recurrence of winds, blowing at 8 or 16 magnetic bearings and average wind velocities at that very magnetic bearings. Usually observation periods of 10–20 years are required to obtain reliable data. Average wind velocities and registration of their directions give a good idea of the wind regime in a certain locality, identifying the predominant winds, i.e. those which may cause sand drifts and blowouts.

Similarly to wind-erosion maps, the method described does not provide for a quantitative characteristic of the processes involved. The latter problem can partly be resolved by using not average wind velocities or recurrence of winds, blowing at various magnetic bearings, but sums of velocities of winds blowing at certain magnetic bearings which cause transport of sand. In this case it is necessary to take into account the fact that sand particles of different size become involved in movement only when a wind velocity reaches a certain threshold value (Table 8).

Table 8

Beginning of Sand Movement with Respect to Grain Size

Type of sand	Grain diameter, mm	Wind velocity, m/sec
Fine	0.1–0.25	4.5–6.7
Medium	0.25–0.5	6,7–8.7

Continued

Type of sand	Grain diameter, mm	Wind velocity, m/sec
Large	0.5–1.0	9.8–11.4
Coarse	1.0–2.0	11.4–13.0

We usually have data on wind velocities and directions measured 8 or 16 times in 24 hours with the help of vanes at a height of 10 metres. Since the wind velocities measured by the vane are not equal to the wind velocities near the surface (where the velocity is much lower), the threshold near-surface velocity is usually determined by calculations. It is suggested [Gvozdikov, 1966] that wind velocity at a height of 10 cm should be determined over sand dune surfaces by the formula $U_{10} = 0.475\ U_{1000}$; over takyr-like depressions between sand dunes covered with sand dy the formula $U_{10} = 0.333\ U_{1000}$; over sandy pebble plain by the formula $U_{10} = 0.375\ U_{1000}$. Here U_{1000} is wind velocity at a vane height of 10 m.

For practical purposes vane wind velocities over 5–6 m/sec are used as threshold velocity, because at these wind velocities the roll over of sand particles starts the actual wind velocity at a height of 10 cm being 3.5–4 m/sec.

It has already been mentioned that threshold wind velocities can be used to draw hodographs according to the sum of wind recurrences or the sum of their velocities.

Hodographs, drawn for a visual graphic representation of the wind's annual resultant effect; are a vector sum total of certain wind direction recurrences, plotted at a scale corresponding to the velocity of each observed case or to the sum of velocities for a period of observation. The method is now in practical use. However, hodographs or wind roses drawn using sums of active wind velocities or using the wind resultant at a certain period give only a general idea about wind regime in a region. With their help one can only get the idea about the direction of prevailing winds.

The procedure used in drawing a hodograph is simple and consists of the following stages: 1) it is drawn from an arbitrary point corresponding to the 1st of January; 2) the direction and velocity of the wind are represented as a vector drawn from the point in the direction where the wind is blowing to the length of the vector being proportionate to the observed wind velocity at a chosen scale; 3) every subsequent (in the order of observation) case of sufficiently strong wind is also represented as a vector whose beginning matches the end of the preceeding one. The result is a broken line sometimes of a highly irregular shape which reflects the sequence of changes in wind directions and velocities.

A hodograph of this type is a visual representation of the peculiarities of the wind regime: the longer it is, the more active is the wind; the straighter its line, the more pronounced the predominant wind. A broken line is an evidence of the inconstancy of the wind regime. Strong winds and storms are clearly visible on a hodograph as longer segments.

The following example can be used to illustrate the method. Table 9 contains initial wind regime data measured by the Repetek meteorological station over a period of two months. Table 10 gives the number of recurrences of winds, blowing at 16 magnetic bearings, the number of active winds recurrences, average annual velocities of all active winds and an average velocity of a certain wind.

Figure 5 represents a wind rose drawn on the basis of total annual number of wind recurrences. A peculiarity of drawing a wind rose is that the number of recurrences of winds, blowing at a certain magnetic bearings are plotted from the initial point at a certain scale (in our example 1 cm stands for 50 cases of wind recurrences). For a better visual effect the ends of lines coming from the initial point can be connected by straight segments. The wind rose drawn for Repetek (1956) shows that the majority of the winds blow at the north magnetic bearings. Similar wind roses can be drawn for active winds recurrency, etc.

Fig. 6 is a hodograph of the resultant of active winds for two months (Table 9). The active winds on the hodograph drawn by the method described above constituted a curve showing that in January–February the predominant southerly winds may bring about northward movement of sand.

Wind regime data can also be processed taking into account wind energy. Most researchers agree that energy is proportionate to the velocity in the third power.

To facilitate the use of the wind energy index, Dobrin L.G. (1965) suggested to involve the following factors which reflect energy potentials of winds of various velocities, where a 4 m/sec wind velocity in the third power was taken for a unity (Table 11).

Further processing of data (the drawing of a hodograph) uses the methodology mentioned above. Although hodographs give no indication of the amounts of sand transported (in m^3 per meter), they provide reliable evidence about the general direction of sand transport and its seasonal distribution.

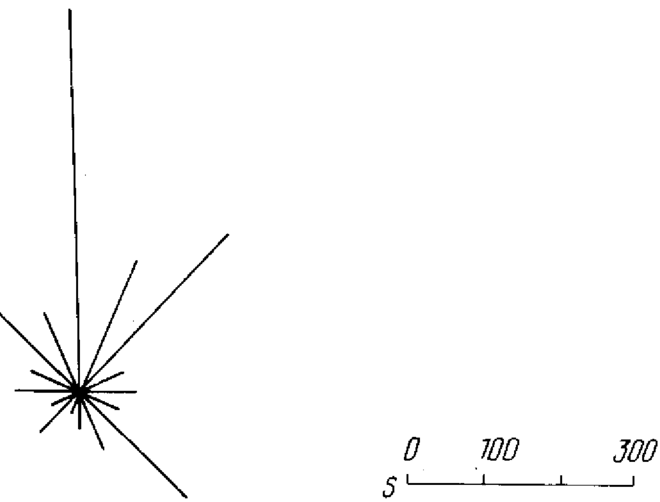


Fig. 5. Wind rose

Table 9

Wind Regime at Repetek Meteorological Station in January – February 1956

Date	Wind direction and velocity, m/sec							
	January				February			
	1 h	7 h	13 h	19 h	1 h	7 h	13 h	19 h
1	–	–	W-3	NW-6	SSE-8	WNW-8	W-7	NW-4
2	NW-5	NW-3	NW-1	–	NW-1	–	NW-5	NW-4
3	N-1	E-2	NE-3	ENE-1	SSE-7	SSE-4	S-9	S-9
4	–	–	N-1	NE-1	SSE-6	S-1	SSW-2	–
5	NNE-1	NE-1	N-1	–	SE-1	SE-1	SE-4	–
6	–	–	NNE-2	–	–	–	NW-3	–
7	–	–	W-1	–	E-6	SE-3	SE-9	SE-8
8	–	–	N-1	N-2	SE-10	SE-4	SE-8	S-1
9	NE-1	E-1	E-5	–	SE-1	SSW-3	NW-3	–
10	NE-1	NE-1	SE-2	–	–	ESE-1	ESE-3	NE-1
11	SE-3	ESE-3	S-3	–	SE-1	SE-1	SE-1	SW-1
12	–	–	E-1	–	W-5	NW-4	NW-5	NW-6
13	–	W-1	SW-1	–	W-5	W-3	W-2	SW-3
14	–	NE-1	NE-1	–	SW-1	SSW-2	SSE-3	SE-1
15	SW-7	W-3	W-1	N-2	N-5	W-2	SW-1	–
16	W-1	N-1	SW-4	W-5	–	–	SSE	N-4
17	W-5	–	SW	–	N-4	NW-3	N-2	N-2
18	NE-2	NNE	N-1	NE-1	N-2	N-2	N-4	N-3
19	–	–	SE-1	SE-1	NNE-1	N-1	ENE-3	NE-3
20	–	SE-3	S-3	–	NE-1	NE-1	N-1	N-1
21	E-2	–	W-1	–	NE-2	NE-3	E-3	N-5
22	–	–	NNW-1	NNW-2	N-5	NW-5	NNW-3	NE-1
23	N-2	N-2	N-1	N-1	–	N-1	ENE	ENE-1
24	–	–	W-1	NE-1	NE-3	ENE-4	NE-1	SE-5
25	N-2	W-1	SW-2	W-1	W-2	SW-3	WSW-1	NE-2
26	–	–	SW-1	–	NE-1	NW-5	NW-3	NW-1
27	E-1	E-2	SE-7	SE-3	–	–	WSW-1	N-4
28	SE-6	SSE-8	S-6	–	–	–	ESE-6	ESE-6
29	–	SE	SW-2	–	SE-9	SE-9	SE-14	SE-12
30	–	–	SE-7	SE-5				
31	SE-8	SE-4	NW-5	SE-5				

Table 10

Wind Activity at Repetek Meteorological Station in 1956

Wind direction	Frequency of winds with velocities, m/sec													Total		Average velocity, m/sec	
	1	2	3	4	5	6	7	8	9	10	12	14	17	Total	Active	Total	Active
N	59	41	47	33	33	7	17	7	11	1	1		1	258	78	3.4	6.1
NNE	14	16	21	12	11	5	8	2	1					90	27	3.3	6.1
NE	38	23	26	17	16	6	7		2		1			136	32	3.2	6.4
ENE	6	4	5	4	3									22	3	2.7	5.
E	14	5	7	3	2									31	2	2.1	5.
ESE	5	4	3	3	3	2			1					21	6	3.3	6.
SE	20	14	15	8	8	9	9		3	2	2	1		91	34	4.0	7.0
SSE	2	3	16	1	4	3	2		2	2				35	13	4.2	6.9
S	10	1	3	2	4	2			3	1				26	10	3.7	6.9
SSW	2	5		2	2									11	2	2.9	5.
SW	10	6	13	1			2			1				33	3	2.7	8.
WSW	3		3	4	1		1							12	2	3.3	6.
W	10	6	5	2	4	3	2	1	2	1				36	13	3.7	6.7
WNW	4	1	8	5	1	3	4	2	1					29	11	4.4	7.0
NW	13	13	28	8	12	8	7	1	5					95	33	5.6	6.3
NNW	3	8	11	6	6	8	4	1					1	48	20	4.3	6.5

Table 11

Wind Energy Increase Factor (K) at Various Velocities (U)

U, m/sec	K	U, m/sec	K
5	2	13	34.4
6	3.4	14	43.0
7	5.4	15	53.0
8	8.0	16	64.0
9	11.4	17	77.0
10	15.6	18	91.0
11	21.0	19	113.0
12	27.0	20	125.0

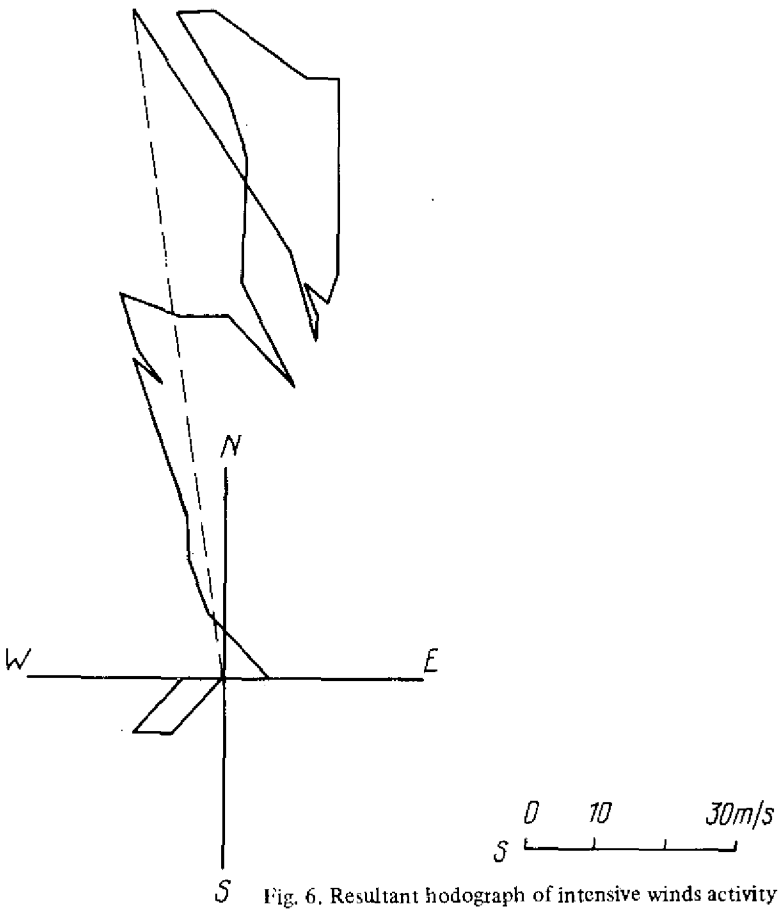


Fig. 6. Resultant hodograph of intensive winds activity

The valuable information thus obtained is used at preliminary stages of planning of the protective measures, carrying out feasibility studies, determining the extent of the protective zone and the direction of ground displacement from a unit, etc.

Several methods of using the results of wind regime data processing have been suggested to obtain quantitative assessments of sand transport. They will be discussed in detail below.

These are several methods of deflation processes study. Out of them the geodetic method becomes increasingly widespread. The essence of the method is the use of geodetic instruments to observe the relief dynamics in the immediate vicinity of sites to be protected and on sites themselves.

Depending on the objective (the study of general deflation processes, dynamics of blowout and accumulation, or the movement of eolian forms alone), surveys with a transit or a level are carried out once a year, once a season, or once a month. In case of transit survey a specific plot with an area of 1–2 hectares is chosen. The corners of the plot are marked with permanent bench-marks. The survey's results are the basis of the plot's plan compiling. Particularly suited to a comparative study of sand transport are large-scale plans in which contours are spaced at 50 cm. Levelling marks only some points of profiles drawn according to the survey data from one and the same initial point, which are a visual illustration of the changes in the relief structure.

Out of the two geodetic methods of observing changes in the relief of sands the planimetric survey provides the most complete information. Areal plans reflect general mode of displacement, of chains, the impact of lateral drift on the ridge's frontal movement, as well as the influence of vegetation on the general process of relief formation. Transversal profiles are less informative. They give an idea only of the general trend in the eolian relief displacement. It may be profitable to combine the two methods when intervals between planimetric surveys are covered by measurements along profiles.

With the help of simple calculations the two methods make it possible to determine the amount of sand moving towards the site.

Under field conditions the amount of sand transported by wind-sand flow can also be determined with the help of such simple devices as "accumulating fences", "trap trenches" and other sand trapping devices.

An accumulating fence is a solid shield erected in the way of the wind-sand flow. The amounts of sand accumulated on both sides of the shield provides a measure of the intensity of sand transport in the wind-sand flow. Shields of different penetrability produce different patterns of sand accumulation. The greater the penetrability, the smaller the amount of sand accumulating in front of the shield and the greater the accumulation behind it. Solid shields accumulate a bank of sand whose width is twice the shield's height. Shields with a penetrability of 50 per cent hold up accumulations whose width is 12–13 times the shield's height.

The amount of sand accumulated by the shields is to be measured at least once a month and in any case immediately after strong winds. As shields become drifted over, new shields are erected and observations continue.

Trap trenches are simple devices for measuring the amount of sand moving near the surface. Trenches are dug across prevailing winds. In loose ground (sands) the edges and bottom of a trench are strengthened with boards, the upper part of the trench is also partially covered to prevent the blowout of sand by whirl-like flows. The amount of accumulated sand is periodically measured, and for normal operation the trenches should be periodically cleaned of sand.

The most accurate data on sand transport in a wind-sand flow is provided by sand traps. Since the major amount of sand is transported near the surface (Table 12), observations with the help of above-mentioned devices are reasonable to carry out within the 50 cm layer.

In the USSR, sand traps designed by A.I. Znamensky (1950) are used on a large scale.

The early designs of sand traps are a metal cylinder, whose receiving section is in the form of a truncated cone, the area of the inlet hole being 10 cm^2. The latest designs of sand traps make it possible to register sand transport in the flow at every other centimeter.

Table 12

Sand Transport in a Wind-Sand Flow at 5 m/sec. Wind Velocity

Height, cm	Amount of sand, %
0–5	58
5–10	30
10–15	10
15–30	2

3.2. MATHEMATIC METHODS FOR QUANTITATIVE STUDIES OF SAND TRANSPORT

Initial Meteorological Conditions and Data. The principal weather conditions determining sand travel are a wind regime, the air and sand temperature and humidity and precipitation.

Initial data for mathematical calculations of sand transport are taken from the nearest meteorological station's observation register (Table 13). To obtain more reliable data, meteorological phenomena over a period of at least 10 years are analyzed. The more years are covered by observations, the higher is the accuracy of the results. On the basis of the initial meteorological data (Table 13) the direction and velocity of prevailing sand-moving winds are determined. It is preferable to do the same on the monthly basis.

The calculations are made without considering winds at temperatures below zero after and during precipitation, because in such cases there is no sand transport in a wind-sand flow.

The duration of each wind is considered to be six or three hours, which corresponds to the interval between two observations following one another.

Monthly observations of sand moving winds make it possible to determine sand transport for every month. In certan cases this information is very important. This

Table 13

Initial Data Register for Mathematic Calculation of Sand Transport

Meteorological Station ____________ Month ____________ Year ______

Date	Air temperature, °C				Wind direction and velocity, m/sec				Soil surface temperature, °C				Snow cover depth, cm	Rainfall, mm	
	0 p.m.	6 a.m.	12 a.m.	6 p.m.	0 p.m.	6 a.m.	12 a.m.	6 p.m.	0 p.m.	6 a.m.	12 a.m.	6 p.m.		6 a.m.	6 p.m.
1	−10.2	−10.5	−9.1	−11.0	E–6	E–7	SE–8	SE–8	−8.6	−10.0	−4.3	−9.4	–	–	–
2	−15.5	−14.3	−7.0	−9.1	SE–7	SE–8	SE–10	SE–8	−15.4	−13.4	−3.1	−10.3	–	–	–
3	−12.3	−13.7	−5.4	−8.1	SE–10	SE–10	SE–10	E–12	−11.3	−13.6	−2.3	−9.4	–	–	–
4	−10.3	−11.8	−4.8	−8.1	SE–12	SE–8	SE–16	SE–12	−12.2	−12.9	−2.3	−8.9	–	–	–
5	−9.9	−11.1	−2.1	−7.8	SE–12	SE–12	SE–14	E–14	−11.4	−12.3	−0.8	−8.9	–	–	–

kind of differentiated data permits correct planning of sand-removal operations, protection of economic units against sand drifts, etc.

Following a thorough study of the initial meteorological conditions and data, sand transport can be calculated monthly or annualy, depending on the requirements. It is necessary to study sand transport for a number of years in order to calculate it with a given probability.

Determination of Sand Transport at Magnetic Bearings And Sectors of the Horizon. The amount of transported sand G (g/m for the period of wind activity t) is presented by the formula:

$$G = 0.10\,(U_W - 5.4)^3\,t, \tag{9}$$

where U_W is the wind speed according to the wind vane of a meteorological station fixed at a height of 10 metres.

In order to obtain the value of the transported sand amount the above expression (10) is to be divided by the density of sand ρ_m in natural conditions.

The per-second and hourly sand transport for the wind velocities in the range from 6 to 39 m/sec. is taken from Table 14, which makes calculations more simple.

Table 14

Per-Second and Hourly Sand Transport at Different Wind Velocities

Wind velocity, m/sec	Sand transport calculated by the formula	
	$0.1\,(U_W-5.4)^3$, g/m · sec	$0.1\,(U_W-5.4)^3 3600$, kg/m · h
6	0.022	0.078
7	0.407	1.465
8	1.765	6.353
9	4.661	16.778
10	9.728	35.023
11	17.602	63.366
12	28.869	103.927
13	43.846	157.846
14	63.575	228.868
15	88.416	318.298
16	119.004	428.416
17	155.973	561.507
18	199.969	716.890
19	251.403	905.049
20	311.041	1119.746
21	379.412	1365.882
22	457.104	1645.574
23	$0.545 \cdot 10^3$	$1.961 \cdot 10^3$
24	$0.643 \cdot 10^3$	$2.315 \cdot 10^3$

Continued

Wind velocity, m/sec	Sand transport calculated by the formula	
	$0.1\,(U_w-5.4)^3$, g/m · sec	$0.1\,(U_w-5.4)^3\,3600$, kg/m · h
25	$0.752 \cdot 10^3$	$2.315 \cdot 10^3$
26	$0.874 \cdot 10^3$	$3.145 \cdot 10^3$
27	$1.007 \cdot 10^3$	$3.626 \cdot 10^3$
28	$1.154 \cdot 10^3$	$4.153 \cdot 10^3$
29	$1.313 \cdot 10^3$	$4.729 \cdot 10^3$
30	$1.488 \cdot 10^3$	$6.036 \cdot 10^3$
31	$1.677 \cdot 10^3$	$6.036 \cdot 10^3$
32	$1.881 \cdot 10^3$	$6.771 \cdot 10^3$
33	$2.101 \cdot 10^3$	$7.564 \cdot 10^3$
34	$2.338 \cdot 10^3$	$8.416 \cdot 10^3$
35	$2.592 \cdot 10^3$	$9.330 \cdot 10^3$
36	$2.863 \cdot 10^3$	$10.308 \cdot 10^3$
37	$3.153 \cdot 10^3$	$11.352 \cdot 10^3$
38	$3.463 \cdot 10^3$	$12.465 \cdot 10^3$
39	$3.791 \cdot 10^3$	$13.647 \cdot 10^3$

The amount of sand transported monthly (or annualy, G_t) along some given direction by the winds of all velocities U_{wi} is equal to the sum of sand drifts by the winds of each speed G_{vi}, that is

$$G_t = \sum_{i}^{t} G_{vi} \tag{10}$$

Sand transport at the speeds and directions of sand transporting winds monthly (or annualy), can be determined by matrix integration. The method for calculating of annual sand transport by all the winds blowing at 8 magnetic bearings can be seen from Table 15. The vertical column represents wind velocities, the horizontal one – their duration and the corresponding sand transport at the cardinal points. Summing up the values of sand transport given in the vertical column, the total sand transport per month (or per year) along the corresponding directions can be obtained. The sum of total sand transport at all the magnetic bearings represents the overall transport per month or per year in the area in question. Volumes of transported sand, thus calculated, correspond to the conditions of an open lowland area.

The direction of sand transport for calculations is taken to be perpendicular to the transport front. However, the wind does not always blow at an angle of 90° to the line considered. Winds are usually oblique, blowing at an angle less than

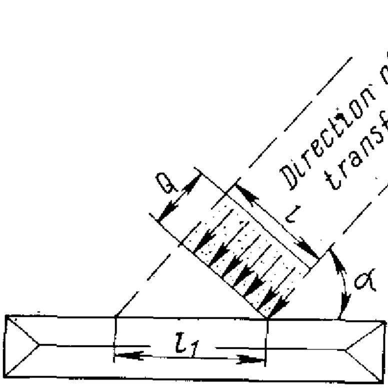


Fig. 7. Sand transport over a mechanical protection guard, caused by oblique winds

90°. In this case (Fig. 7), the sand transport over the length unit of a protection guard in less than that in case of the perpendicular wind. In case of oblique winds this phenomenon is taken into account by reducing the sine of the angle at which the wind is blowing.

When the angle at which the wind is blowing is α^{o}, the sand transport per unit of length is presented by the formula:

$$Q_1 = \frac{Ql}{l_1} = \frac{QL}{L\csc\alpha} = Q\sin\alpha , \qquad (11)$$

where l is the width of the sand transport area;

l_1 is the length of the protection guard section;

Q is the total sand transport.

A short section of the line which can serve as a drift front or a means of sand detention is assumed to be a straight line dividing the field of wind directions into two parts – the right and the left ones along the line. These parts form the maximum sectors of sand transport, and each of them is equal to two right angles.

Let us assume that the guard line AB is attacked by the winds of the northern sector (Fig. 8). Let the values of sand transport at the magnetic bearings for these attack angles be equal to G_W, G_{NW}, G_N, G_{NE}, the indices show the direction of the wind. Then the total sand transport over the line AB is presented by formula;

$$R_o = G_W \sin\alpha_1 + G_{NW}\sin\alpha_2 + G_N \sin\alpha_3 + G_{NE}\sin\alpha_4 \qquad (12)$$

In other words the total annual (or monthly) sand transport along each of the vectors G_{calc} is multiplied by the sine of the corresponding angle. Taking into account this correction the quantity of sand drifted to an object $G_{specified}$ can be determined (Table 16).

Consequently, the sand detention capacity of a guard for instance, of the one set along the line with the magnetic bearing of NE-90° (see Table 16) will be equal to

$$R_o = 11.49 + (0.49 + 0.15)\,0.707 = 11.95\ m^3/m.$$

Table 15

Matrix for Calculating Sand Transport in the Meteorological Station Area ______________ for the month (year) ________________

Wind velocity, (U_w), m/sec	Sand transport Q, $m^3/(m/h)$	Wind direction																
		N		NE		E		SE		S		SW		W		NW		
		Wind duration, t (h)	Sand transport, G, (m^3/m)	Wind duration, t (h)	Sand transport, G, (m^3/m)	Wind duration, t (h)	Sand transport, G, (m^3/m)	Wind duration, t (h)	Sand transport, G, (m^3/m)	Wind duration, t (h)	Sand transport, G, (m^3/m)	Wind duration, t (h)	Sand transport, G, (m^3/m)	Wind duration, t (h)	Sand transport, G, (m^3/m)	Wind duration, t (h)	Sand transport, G, (m^3/m)	Total
6	–	36	–	–	–	3	–	9	–	30	–	–	–	6	–	18	–	102/–
7	0.0011	42	0.044	–	–	6	0.006	9	0.010	3	0.003	3	0.003	18	0.019	12	0.013	93/0.1
8	0.0045	54	0.243	–	–	9	0.040	24	0.108	3	0.014	–	–	18	0.081	9	0.041	117/0.51
9	0.0120	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10	0.0250	54	1.352	2	0.050	–	–	–	–	3	0.075	3	0.075	9	0.225	4	0.100	75/1.88
11	0.0452	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
12	0.0739	33	2.440	6	0.444	–	–	–	–	–	–	–	–	3	0.222	–	–	42/3.10
13	0.1129	–	–	–	–	–	–	–	–	–	–	–	–	–	0.677	–	–	6/0.68
14	0.1636	6	0.982	–	–	–	–	–	–	3	0.491	–	–	3	0.491	–	–	12/1.96
15	0.2275	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
16	0.3063	21	6.432	–	–	–	–	–	–	3	0.919	3	0.919	–	–	–	–	27/8.27
Month (year), total		246	11.49	8	0.49	18	0.05	42	0.12	45	1.50	9	1.00	63	1.71	43	0.15	$\frac{474}{16.51}$

Notes: 1. When calculating sand transport the factor of proportionality in formula (9) which takes into account time in hours and sand weight in kilograms $\rho_m = 1400\ kg/m^3$, is assumed to be equal to $2.57 \cdot 10^{-4}$.

2. In the graph "Total" the wind duration is given in the numerator and the total sand transport (m^3/m) in the denominator.

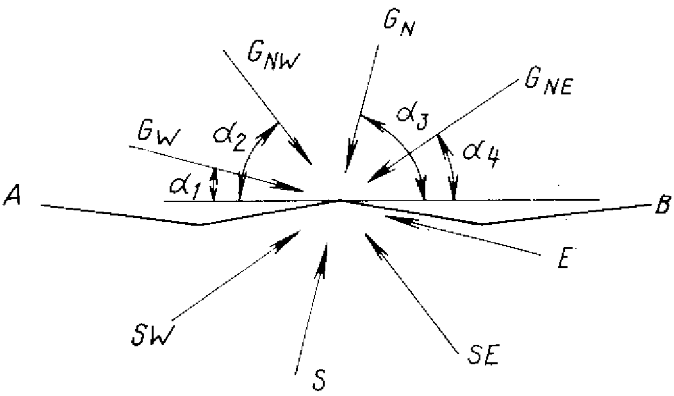


Fig. 8. Angles at which northern winds attack rows of mechanical protection guards

The total value of sand transport is the resultant of all types of transport is the given sector.

The resultant of sand transport can be determined graphically.

For this purpose the parallelogram similar to the parallelogram of forces is plotted on the vectors of the neighbouring types of sand transport. The diagonal of the parallelogram is the a b s o l u t e r e s u l t a n t of the considered types of sand transport.

Table 16

Quantity of Sand Drifted to an Object

Side of an object									
Left					Right				
Wind direction	Attack angle α_i	Sin α	$G_{calc.}$	$G_{specified}$	Wind direction	Attack angle α_i	Sin α	$G_{calc.}$	$G_{specified}$
N	90	1	11.49	11.49	N	–	–	–	–
NE	45	0.707	0.49	0.350	NE	–			–
E	0	0	0.05	–	E	–	–	–	–
SE	–	–	–	–	SE	45	0.707	0.12	0.08
S	–	–		–	S	90	1	1.5	1.5
SW	–	–	–	–	SW	45	0.707	1.0	0.71
W	–	–	–	–	W	0	0	0	–
NW	45	0.707	0.15	0.11	NW	–	–	0.15	–
			Total:	11.95				Total:	2.29

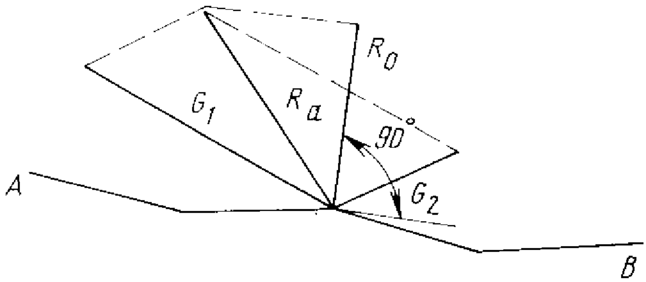


Fig. 9. Absolute and relative sand transport resultants

The total sand transport over the given line is equal to the projection of the absolute resultant onto the vertical perpendicular to this line. It is called the relative resultant of the sand transport onto the given line (Fig. 9).

To determine the resultant of sand transport for several vectors, it is first plotted for two vectors, then the third vector to the found resultant is drawn and the second resultant plotted, the fourth vector to it is drawn and so on till all the vectors of the initial transports will be replaced by one resultant.

This method of calculation shows that the meteorological observations data are very important for determining the volumes of transported sand.

The results of the analytical calculations of sand transport are in good correlation with the volumes of sand transport obtained by observation and can be used for finding a tentative solution to a number of applied tasks, for instance, for choosing the route for automobile or railway roads.

Statistic Characteristics of Sand Drifts. The annual sand transport along one and the same direction is the total quantity of sand (in cubic metres) transported by a wind-sand flow during a year along this direction within a 1 metre-wide stretch.

The value of annual sand transport is presented by the formula:

$$G = \frac{0.10}{\rho_m} \sum \sum_{k=1}^{n} (V_w - 5.4)^3 t_k , \quad (13)$$

where ρ_m is the sand density in the given area.

The maximum annual sand transport to be detained is the total quantity of sand in cubic metres transported by a wind-sand flow during a year along all the directions of the wind toward the guard line within a 1 m-wide stretch.

The maximum annual sand transport is presented by the formula:

$$G = \frac{0.10}{\rho_m} \sum \sum_{k=1}^{n} (V_w - 5.4)^3 t_k \sin\alpha , \quad (14)$$

where α is the angle formed by the direction of wind with the longitudinal axis of a protection guard.

The design of guards for sand drifts prevention with regard to the maximum sand transport observed in a given area, is a vague task, because the quantity of transported sand exhibits annual variations. The observed maximum value grows with the growth of the number of years of observations, therefore it is reasonable to design mechanical protection guards to prevent sand drifts on the basis of the calculated maximum volume of transported sand for a given area which is substantiated by technical and economical calculations, rather than on the observed one.

The quantity of the transported sand determined by the wind regime data for randomly chosen year, may turn out to be a value of different probability, compared with the data obtained during a many-year period of monitoring. Besides, for the first-priority units the reliability of calculations of transported sand should be higher than that for the units of lower priority. Therefore, the calculated sand transport is determined on the basis of accumulated data. Sand transport is therefore calculated on the basis of the wind regime data obtained during the period of no less than 10 years, processed by the method given above. For a comparatively short period of observations calculated sand transport is determined by the Student's distribution law. The data obtained are entered into registers. They provide a basis for calculating the average statistic sand transport and the mean square deviation for every side of the unit (Table 17).

Table 17

Register for Processing Sand Transport Data

Years of observation	Right side of the unit			Left side of the unit		
	G_i	$G_i - G_m$	$(G_i - G_m)^2$	G_i	$G_i - G_m$	$(G_i - G_m)^2$
1	11.95	. . .	. . .	2.29	. . .	. . .
2 etc.	. . .	. . .	. . .	. . .	. . .	. . .
Total	. . .	. . .	. . .	. . .	. . .	. . .

The mean statistical value of sand transport during the observation period is presented by the formula:

$$G_m = \frac{\sum_{i=1}^{n} G_i}{n}, \qquad (15)$$

where n is the number of observation years.

The mean square deviation for each side of the unit if the number of years of observation is $n > 30$, is as follows:

$$\sigma = \pm \sqrt{\frac{\sum_{i=1}^{n} (G_i - G_m)^2}{n}} \qquad (16)$$

The variation factor is $C_v = \dfrac{\sigma}{G_m}$ (17)

The mean error of the mean statistic value (in per cent) is

$$E = \pm\, 100 \frac{C_v}{\sqrt{n}} \tag{18}$$

Table 18

Data for Checking the Sufficiency of Observation Years Over Sand Transport for Processing

Variation factor C_v	Needed number of the years of observation depending on the mean error of the mean statistic value E, %							
	±4	±5	±6	±7	±8	±9	±10	±20
0.15	14	9	6	5	4	3	2	1
0.20	25	16	11	8	6	5	4	1
0.25	39	25	17	13	10	8	6	2
0.30	56	36	25	19	14	11	9	2
0.35	76	49	33	25	19	15	12	3
0.40	100	64	44	33	25	20	16	4
0.45	126	81	55	42	32	25	20	5
0.50	156	100	69	50	39	31	25	6
0.55	189	121	83	62	47	38	30	8
0.60	225	144	99	74	56	45	36	9

When C_v and E are determined, Table 18 is used to check if the taken number of years of observations over sand transport is sufficient for data processing.

The calculated sand transport on the basis of available data is

$$G_{calculated} = G_{mean} + \sigma \cdot \tau\,, \tag{19}$$

where τ is a rated deviation for the Student's Distribution Law, determined depending on the probability of surpassing and the number of years of observations (Table 19).

Sand Transport Roses. Untill recently, the applied meteorology has operated only with a notion of a wind rose, which expressed the number of wind recurrences at the main magnetic bearings. This kind of the wind rose does not characterize the dynamic parameters of a wind flow and, therefore, can only be of limited use while solving the applied technical tasks. It can serve only for the reliable determination of the duration of a factory smoke spreading and that of other hazardous air pollutants at the magnetic bearings. Any attempts to use wind roses for the orientation of the objects' protection means, designed to combat sand drifts were not effective enough, because the number of wind recurrences is not proportional to sand transport.

To effectively prevent sand drifts, it is necessary to know the quantity of sand and the direction of its transport to the unit to be protected.

Only on the basis of these data, one can rationally design protection guards. For this purpose the notion of the rose of sand transport was introduced into engineering.

Table 19

Rated Deviations for the Students' Distribution Law

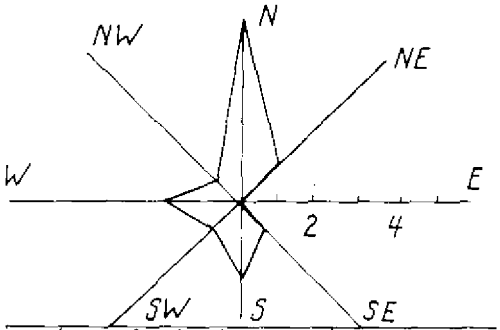
n – 1	Probability of surpassing, %		n – 1	Probability of surpassing, %	
	5	10		5	10
1	12.7	6.31	9	2.26	1.83
2	4.3	2.92	10	2.23	1.81
3	3.18	2.35	11	2.20	1.80
4	2.78	2.13	12	2.18	1.78
5	2.57	2.02	13	2.16	1.77
6	2.45	1.94	14	2.14	1.76
7	2.36	1.90	15	2.13	1.75
8	2.31	1.86	16	2.12	1.74

The rose of sand transport for a certain year or month is plotted based on the data of Table 15. For this purpose along the specific directions the corresponding total sand transport values (in m^3/m) are plotted (in scale) from the central point. These values are given in the horizontal column for a month (year) at the bottom of Table 15. Straight lines connecting the obtained points form a multiangular resembling of a rose. The graph of the rose is supplemented with a certificate containing the numerical characteristics and the information on the location and time of sand transport, on the meteorological station providing the data according to which the rose is plotted as well as the date (the year or month) and the amount of sand transport at magnetic bearings (m^3/m). The certificate of the rose (see the example) shows that the maximum sand transport took place at the magnetic bearing N, and the minimum one at the magnetic bearing E (Fig. 10). The direction of the transport is taken to the centre of the rose.

Evidently, any design of protection means of economic units cannot be based on the sand transport data obtained during any randomly selected year. These data may either give very low values, if they correspond to a year with low rate of sand transport, or excessively high if the year was characterized by an intensive sand transport.

Means of protection against sand drifts and their location in the plan should correspond to the calculated rose of sand transport. This is the rose which reflects sand transport of a given reliability at all the magnetic bearings. The certificate of a calculated rose should contain information on the meteostation providing the data, on the base of which the rose is plotted, and the years of observations.

The calculated rose of sand transport gives a clear idea as to the quantities and the directions of sand movement in a wind-sand flow. For all practical purposes, and, above all, for the rational design of protection means, it is necessary to know exactly these primary parameters of the wind-sand flow.



Meteorological station	. . . year . . . . month						
N	NE	E	SE	S	SW	W	NW
11,49	0,4	0,05	0,12	1,5	1,0	1,71	0,15

Fig. 10. Sand transport rose

If we project the calculated rose of sand transport onto the plan of an area affected by a sand drifts, it is easy to determine the resultant of the transport for each side of the line for which we need to calculate the parameters of protection guards (the number of rows, the height of a guard). The rose is superimposed onto the unit plan according to the geodetic magnetic bearings. Geodetic magnetic bearings are counted from the nearest pole and measured from 0 to 90°. Consequently, geodetic bearings may be northeastern and northwestern from the northern side, and southeastern and southwestern from the southern side.

For example, we need to apply the rose of sand-drifts to the front side of a unit with the bearing of NE-50°. For this purpose, the rose centre is matched with

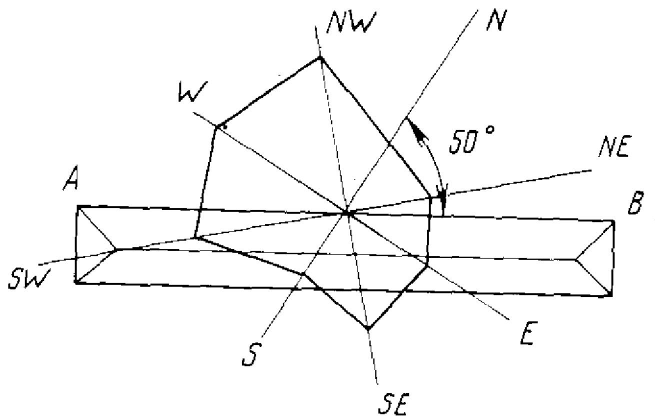


Fig. 11. Correlation of the sand transport rose with the plan of an economic unit

any point on the object's front side. Then the rose is turned till the angle between the northern direction of the rose (the northern pole) and the vector of the given sector along the longitudinal meridian becomes equal to 50° (Fig. 11). The same method is used to apply the roses to the sides of objects at other bearings.

Sand transport rose is also used for choosing the type of a protection guard, aimed at protection from sand drifts not only linear installations but square units, such as settlements, as well. The units, situated in the open area, subjected to sand drifts, suffer from sand transport along all directions.

The total amount of sand transported monthly (annualy) to the territory of the unit is determined with the help of sand transport rose by the formula:

$$G = G_1 l_1 + G_2 l_2 + \ldots + G_n l_n , \quad (20)$$

where G_1 stands for annual (monthly) sand transport at a corresponding magnetic bearings of the rose, m^3/m;

l_1 stands for linear projection of the unit's area contour on the line, perpendicular to the corresponding magnetic bearings of the rose, m.

3.3. STUDIES OF THE WATER REGIME DYNAMICS

Studies of water regime of the soil root zone are essential for the right assessment of habitat conditions in shifting sands and the correct selection of sand-fixator plants.

Certain conditions must be observed while studying the water regime of soils [Rode, 1969] :

1) Moisture content should be determined through the entire vertical cross-section of the root zone since, as a rule, the soil is heterogeneous by its mechanical and chemical composition and structure and therefore different soil layers may vary by the amount of moisture accumulation and debit.

2) Observations must be conducted in such periods which would provide ample information about the changes in moisture content over a period of time.

3) Tests should be repeated to obtain reliable results.

The water regime of soils is usually tested layer by layer with an interval of 10 cm. Moisture content is determined 3–4 times a month.

At present, two fundamentally different methods of soil moisture content determination are employed, namely those involving the extraction of soil samples as opposite to the determination of moisture content in field conditions, without samples' extraction.

In accordance with the first method, samples of soil are extracted from each soil layer either by boring holes or from specially-prepared soil diggings and then part of these samples is put into special soil pots provided with tightly fitting covers. The pots containing the moist soil are weighed on a technical balance with an accuracy of 0.01 g. Then these samples are dried in a thermostat at a temperature of 100–105 °C until they acquire a constant weight (the moisture evaporates completely from the samples in six hours). After that the pots are again weighed. The difference in the weight between the dry and moist soil pots (in gramms) gives the information on the moisture content in the tested samples. The percentage of moisture content in the soil is calculated in reference to a dry soil sample, by using the following formula:

$$\frac{W_1 - W_2}{W_2 - W_0} \times 100, \qquad (21)$$

where W_1 is the weight of a pot with moist soil;
W_2 is the weight of a pot with dry soil;
W_0 is the weight of a pot itself.

A special table below (see Table 20) is suggested for a better recording of data obtained in weight method tests either in the laboratory or in field conditions.

A possibility to measure the soil moisture content in field conditions and without the extraction of soil samples is based on different physical properties of the soil solution. There have been developed four fundamentally different methods of measuring the soil moisture content directly in the ground:

1) The tensiometric method or the one based on the sucking soil pressure.

2) The electrometric method, based on electroconductivity and electrocapacity of soils.

Table 20

Moisture Content of Sand, Extracted from a Depression Between Sand Dunes in the Karakum Desert on February 12, 1980

Depth of sampling, cm	Pot's serial number	Empty pot weight, g	Weight of moist soil pot, g	Weight of dry soil pot, g	Moisture weight, g	Dry soil weight, g	Soil moisture content, %	Note
0–10	1	21.50	67.85	65.92	1.93	44.42	4.34	No vegetation present
10–20	2	20.83	74.53	72.33	2.20	51.50	4.27	
20–30	3	22.14	70.31	68.81	1.50	46.67	3.23	

Table 21

Annual Changes in the Moisture Content of Sand Between Sand Dunes in the Karakum Desert

Layer depth, cm	Periods							
	Jan. 10		Feb. 12		March 9		April 10 etc.	
	%	mm	%	mm	%	mm	%	mm
0–10	4.34	6.51	4.01	6.01	3.97	5.95		
10–20	4.22	6.40	3.75	5.62	3.85	5.77		
20–30	3.23	4.84	3.04	4.56	3.00	4.50		

3) The method of thermal probes recording the soil heat conductivity.

4) Radio-active methods using gammaspectrometry or neutron indicators [Kulik, 1979].

These methods of measuring the soil moisture content have not become very popular since it turned out that in cases of low moisture content, as is the case in areas covered with sand dunes, great deviations in findings are observed.

The combined tables give a general idea about the moisture content of soils and grounds. The information on soil moisture content may be presented either as the percentage to the dry weight and, at the same time, in the form of moisture reserves in mm of a water layer (Table 21).

Reserves of moisture in millimetres of a water column per one hectare may be calculated by the formula:

$$M_r = M_l \times \frac{SW \times h}{10}, \qquad (22)$$

where M_r is moisture reserves in mm of a water layer;

M_l is the moisture content of a layer in percentage to the dry soil weight;

SW is the specific weight in g/cm^3 of the tested layer;

h is the thickness of the tested layer.

When measuring the moisture reserves in a 10 cm-thick layer the formula assumes the form:

$$M_r = M_l \times SW \qquad (23)$$

For the sand tracts of the Karakum desert the specific weight of sands ranges within 1.37–1.67 g/cm^3. In demonstration Table 21 the specific weight for all layers is assumed to be 1.50 g/cm^3.

The moisture content of a tested layer of soil may be graphically illustrated. Chronoisopleths of moisture content are most graphically vivid. This method allows to describe the peculiarities of dynamic changes in moisture content within the tested layer at any period of observations.

At the same time this graph may provide information on the intensity of precipitation, air temperature changes and changes in the temperature of the upper soil layers, the relative humidity of the air and other climatic factors.

The soil moisture may be represented graphically by a system of coordinates. In the initial period of drawing a graph, time (month, year) is plotted on the X-coordinate while the depth of layers tested for their moisture content on a regular basis is plotted on the Y-coordinate (Fig. 12a). Then the values of soil moisture content in percentage to its dry weight are plotted on the corresponding coordinate for each observation period (Fig. 12b). After that the intermediate values of the moisture content are interpolated (when drawing the graph changes in the moisture content are reflected within the range of 0.5; 1; 2, etc. %). For sandy soils the moisture interval is usually taken as 0.5 %. Points with an equal moisture content are connected by curves which form chronoisopleths of moisture content (Fig. 12c). The space between the neighbouring lines represents a soil layer whose moisture corresponds to a certain value. Depending on the season, layers change their position within the ground thickness and may sometimes totally disappear from it [Rode, 1969].

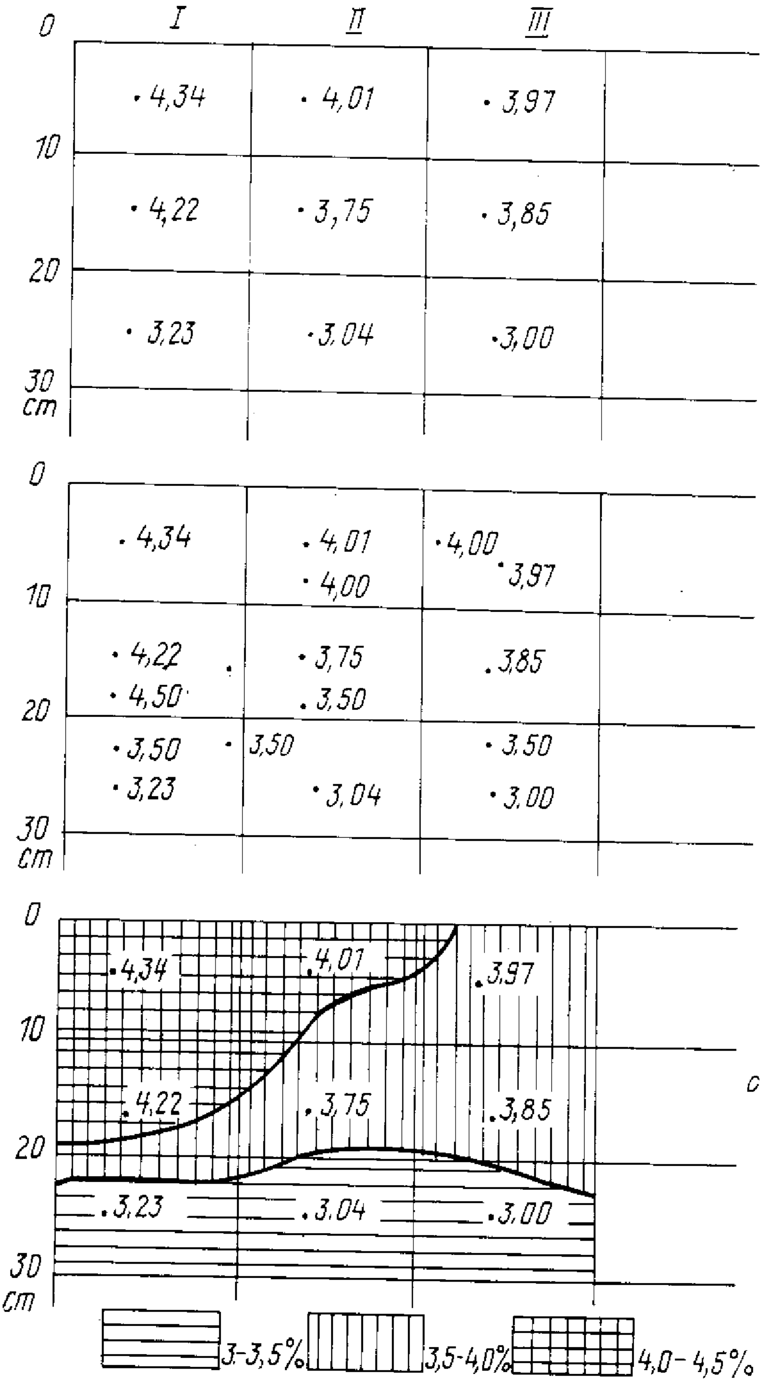


Fig. 12. Chronoisopleths of moisture content

To determine the main pathways of moisture entering into the soil and its debit it is reasonable to calculate water balances. The total water balance of soil may be calculated by using the equation:

$$V_r - V_l = (P_s + GWI + SR_i + SWI + C) - (E + D + OGW + SO_{tt} + GWO_{tt}), \quad (24)$$

where V_f is the final amount of moisture in the soil;

V_i is the initial amount of moisture in the soil;

P_s is total precipitation reaching the soil surface;

GWI is the amount of moisture coming to the soil from ground-water;

SR_i is the amount of surface water coming into the area, covered by this type of soil;

SWI is the amount of intersoil water coming into the given soil;

C is the amount of vaporous moisture coming into the soil from the atmosphere and condensing in it;

E is the value of physical evaporation of moisture from the soil;

D is the amount of soil moisture sucked out by vegetation;

OGW is the value of moisture outflow from the soil into ground-water.

SO_{tt} is the value of the surface moisture outflow;

GWO_{tt} is the value of the intersoil outflow.

The income of a water balance consists of precipitation, the surface water coming into the area, the intersoil water, coming into the soil through the thermogradient transport of vaporous moisture, the ground water afflux and the condensation of vaporous moisture from the atmosphere; while the expenditure is made up of the losses for physical evaporation and transpiration, the surface and intersoil water outflow and the moisture outflow into the ground-water.

According to the experimental and field tests data [Kulik, 1979] some of the factors can be excluded from the water balance equation because of their negligible effect. These are the intersoil moisture afflux, the afflux of moisture from ground-water and, in case of sandy soils, the surface runoff and, correspondingly, the surface outflow. In the areas under sand dunes moisture desuction from the soil is also excluded. At the same time more attention should be paid to precipitation as a component affecting the moisture afflux from the atmosphere.

Thus, after adjusting the main water-balance equation in case of shifting sands, it may look as follows :

$$V_f - V_i = (P_v + P_h + C) - (E_{ph} + GFR_t), \quad (25)$$

where V_f is the final amount of moisture in the sand;

V_i is the initial amount of moisture in the sand;

P_v is the vertical precipitation (rain, snow);

P_h is the horizontal precipitation, i.e. hydrometeors (mist, dew, soft rime, hoarfrost);

C is the condensation of atmospheric vapours on the sand surface;

E_{ph} is the physical evaporation from the sand surface;
and

GFR_t is the gravity film moisture runoff into ground-water.

The data, characterizing the vertical precipitation over the test period, are taken from the observations of the nearest meteorological station.

The amount of moisture coming with hydrometeors is calculated by multiplying the number of days with hydrometeors (the data provided by the nearest meteorological station) by 0.2 mm, for the last figure is considered to be the average amount moisture coming into the soil [Kulik, 1979].

The amount of moisture obtained by condensation is determined by using condensometres. These are soil pots put inside waterproof paper cups. Condensometres are filled with sand whose moisture content is close to MG and fixed in a sandy soil. Condensometres are weighed at sunrise and sunset. Then the absolute condensation value is recalculated into mm of a water column. Recalculations are done by dividing the moisture content value into area of an inlet of the pot.

Condensation may also be measured by using the method of heat balance [Kuvtinova, 1963]. The total physical evaporation from the surface of the soil and the physical evaporation are calculated by using the empirical formulas suggested by N.F. Kulik in 1979.

Table 22

Rate of the Vertical Gravity Runoff in Power-like Fine Sands [Kulik, 1979]

Moisture content, %	Runoff rate under natural conditions, mm/h of water column
10	46
8	10
7	2.5
6	0.1
5.5	0.04
5	0.02
4.5	0.01
4.0	0.005
3.5	0.003
3.0	0.002
2.5	0.001
2.0	0.0006
1.5	0.0003
1.0	0.0001
0.9	0.0001
0.4	0

For denuded shifting sands:

a) in March and November

$$E_{ph} = P_{r \leqslant 3} + 2^{n>3} + 0.2 \text{ (days without precipitation } - n > 3) \quad (26)$$

Table 23

Water Balance of Sand Dunes in the Lowland Karakum, mm

October 1964 – September 1965

Periods	Soil moisture content in the beginning of the test period	Income				Soil moisture content in the end of the test period	Expenditure			Changes in soil moisture content
		Rainfall	Condensation	Hydrometeors	Total		Evaporation	Gravitational runoff	Total	
October–February	148.99	81.8	3.83	16.4	102.03	202.57	8.0	40.45	48.45	+ 53.58
March–September	202.57	64.7	19.92	3.1	87.72	153.00	80.40	46.89	127.29	– 39.57
Annual	148.99	146.5	23.75	19.5	189.75	153.0	88.40	87.34	175.74	+ 14.01

b) in April to October

$$E_{ph} = P_{r \leqslant 3} + 3^{n>3} + 0.3 \text{ (days without rainfall)}, \qquad (27)$$

where E_{ph} is the physical evaporation, mm of a water column;
$P_{r \leqslant 3}$ is precipitation equal to or below 3 mm;
$n > 3$ is the number of days with rainfall above 3 mm;

The gravity film runoff is calculated according to the formula suggested by N.F. Kulik in 1979. This value depends on the rate of runoff (Table 22), the time (in hours) and the ground moisture content on the lower boundary of the tested layer.

It is most useful to present water-balance calculations in the form of a matrix (see Table 23).

To illustrate the point, list the water-balance calculations for 3.5 m layer in sand dunes. During the test period (October 1964 to September 1965) rainfall amounted to 81.8 mm during the cold season and to 64.7 mm during the warm season. Besides, there were 98 cases of hydrometeors (such as fog, dew, soft rime, hoarfrost) which ensured an additional moisture income of 16.4 and 3.1 mm during the cold and warm seasons, correspondingly. Moisture, obtained by condensation that is the one which enters the soil as a result of molecular sorption of water vapours, ensured an additional moisture income of 3.83 and 19.92 mm throughout the seasons correspondingly.

The moisture expenditure for physical evaporation and gravitational runoff was correspondingly 8.0; 40.45 mm and 80.40; 46.89 mm during the cold and warm periods.

3.4. STUDIES OF SUITABILITY OF SOILS FOR AFFORESTATION

Afforestation requires knowledge of a whole range of soil properties, such as the mechanical composition, the degree and nature of salinization, the physico-chemical properties, availability of nutrients, etc. However, before commencing any studies of a soil profile, it is necessary to obtain a description of natural phenomena genetically interrelated with the given type of soil. Among the basic natural factors which have a direct impact on the soil cover formation are the following:

1) Geomorphological description of the land area.
2) Its geological structure including the underlying and soil formating rocks.
3) Hydrogeological conditions.
4) Vegetation as a soil-formating factor.
5) The role of the animals in soil formation.

Each of these factors are first studied by literature and then during soil tests in field conditions. All the research data on natural factors are entered into a special field register with markings for those data which require further verification.

After studies of the soil-formating factors are over, a soil digging is laid. Such soil diggings are usually two metres deep or even much deeper when needed.

To extract samples of soil for chemical and other analysis from the depth of more than two metres, special soil borers are used.

A soil profile is bared so, that the vertical side of the digging, which is to be used for morphological description of the soil, should be well sunlit. Then, using a measuring tape, soil horizons are identified and described from bottom to top.

Below there is the description of a soil profile of the typical sandy desert soil of Central Karakum. The digging was laid in a depression between hillocky sand ridges.

0–3 cm	Dark grey loose, dry fine-grain sand without inclusions, transition to the next horizon is determined by the structure.
3–14 cm	Greyish damp sod horizon compact due to the presence of the root systems; transition is distinguished by the colour, structure and by the accumulation of roots.
14–23 cm	Yellow-grey medium-compact horizon; occasional roots of ilak, occasional insect conduits; slightly damp (fresh); transition to the next layer is determined by the structure and colour which is darker.
23–45 cm	Grey-yellow damp and slightly compact transitional horizon of homogeneous fine-grain sand; transition to the next horizon is gradual.
45–75 cm	Grey-yellowish soil-formating rock with an underlaying layer of homogeneous damp finegrain sand; occasional living roots and occasional semidecomposed remnants of root systems.
260–270 cm	A transition to bed rocks, first signs of interlayers of light grey micaceous sand which is damp and slightly compact; there is almost no yellow sand in the low part; a gradual transition.
270 cm and deeper	Bed rocks of grey micaceous sand which is damp and contains isolated spots of iron accumulation, gypsum and iron oxides inclusions.

The description of this soil profile was undertaken at the end of March (on March 24) and therefore the entire profile contains moisture brought about by precipitations.

In other seasons the moisture content will be different and the soil may be even absolutely dry. Thus, one has to pay attention to the saturation of soils with moisture.

After studying the morphological properties of soils determination of the presence of salts and carbonates in the soil layers is carried out. To test the soil salinization in field conditions, one has to have a set of test tubes and two reagents: silver nitrate ($AgNO_3$), barium chloride ($BaCl_2$) and distilled water. The presence of salts is tested in the following way:

– two small samples of soil are taken from each soil horizon, put into test tubes to which distilled water is added;

– then the test tubes are shaken and left to settle;

– then the sediment is decanted into clean test tubes to which the reagents, $AgNO_3$ and $BaCl_2$, are added correspondingly. If either chlorides or sulfates are present in the soil, then the researcher will see a milky substance in his test tubes.

The chemical reactions involved are as follows

$$AgNO_3 + Cl^- = AgCl + NO_3^-$$

$$BaCl_2 + SO_4^{2-} = BaSO_4 + 2Cl^-$$

By the intensity of sedimentation one can judge about the degree of salinization.

In this respect soils may be subdivided into the following groups:

	Depth of saline Horizons occurrence, cm
1. Saline	150 and deeper
2. Strongly saline	100–150
3. Strongly saline solonchak-like	70–100
4. Solonchak-like	30–70
5. Solonchak	5–30

Depending on the salts content the degree of soil salinization is determined on the basis of the results of laboratory analyses, and is subdivided into the following groups:

	Salt content (dry residue), %
1. Slight	0.25–0.50
2. Medium	0.50–0.70
3. Strong	over 0.70

To detect the presence of carbonates in the tested soil profile one has to use 10 % solution of hydrochloric acid. If carbonates are present in the soil, then when a drop of hydrochloric acid is applied to it bubbles of gas appear on its surface.

One can judge, at least roughly, about the amount of carbonates present in the soil by the intensity of gas bubbles appearance. As it is known, alkalinity is one of the adverse soil properties. Classification of soils by the degree of their alkalinity in field conditions is based either on the study of morphological characteristics (brownish colour, strong compactness in a dry state, fissuring, etc.) or on the analysis of a qualitative reaction. The most simple reaction of this kind is a reaction between a water extract and phenolphthalein when the former becomes tinted pink.

As for the presence of gypsum in the soil profile, then its content is usually detected visually by using a magnifying-glass. Gypsum particles may occur either in the form of crystals, nodules or nests of finely-grained powder (newly-formed gypsum).

A study of the hydrophysical properties of soils is a rather complex labour-consuming operation and is usually conducted on a limited scale. Hence, the selection of a testing site requires definite attention, for the site should be most typical of the given area.

Depending on the aims of soil studies a certain set of hydrophysical properties may be tested. However, in field conditions it is mostly the following physical and water properties of soils that are determined:

1. Specific weight.
2. Field capacity.
3. Permeability (vertical percolation rate).
4. Vertical percolation factor.
5. Capillary uplift.
6. Ground-water critical depth.

In addition to field tests, laboratory tests are undertaken to de. mine:

1. Specific gravity (to determine porosity).
2. Maximum moisture capacity.
3. Wilting factor.

Various specific methods exist for determining these characteristics.

While describing the soil profile, some samples are taken for chemical test in the stationary analytical laboratory. Samples are taken from all genetic horizons, from the bottom to the top, thus obtaining an average sample.

Methods of Determination of the Basic Hydro-Physical Properties of Soils

I. **Specific weight.** Usually 4–8 cm-long metal cylinders with a 3–5 cm diameter and a short cutting edge are used for determining the specific weight of soils in field conditions in a soil digging.

Test procedure:

1) A cylinder is carefully pushed into the soil horizon so that no to destroy the sample structure.

2) The cylinder is removed and cleaned. Extra soil is cut into a cup, prepared in advanced, and weighed.

3) The sample is then dried out to a permanent weight.

The specific weight is calculated by the formula:

$$d = \frac{A}{V}, \quad (28)$$

where d is the specific weight, g/cm^3;
A is the weight of the absolutely dry soil, g;
V is the cylinder volume, cm^3.

II. Testing of Water Permeability by Flooding the Site

Test Procedure

1) A metal frame of 25x25 cm is fixed into the ground at the depth of 5–10 cm on a site representative of the given kind of soil. Another frame, of 50 by 50 cm in size and of equal height, is fixed around the first one. The ground near these frames is compacted and a measuring ruler is put inside each frame. The ruler is used to follow the water level.

2) At the beginning of the test a measure of water (5 cm deep) is poured simultaneously into the two frames, and this water level is maintained by adding water from measuring cylinders.

3) Water expenditure is recorded at definite time intervals: 2 min., 3 min., 5 – 10 min. With the decrease of water expenditure, the intervals are increased from 30 min. to one hour. Observations are carried out from three to six hours, depending on the soil properties.

4) For each time interval water permeability is determined by the formula:

$$V = \frac{Q \cdot 10}{S \cdot t}, \qquad (29)$$

where Q is the water expenditure, cm^3;
S is the area of the percolating column, cm^2;
t is the test time, min.;
V is the permeability and percolation rate, cm/min.

All the results obtained at different water temperatures, V_t, are reduced to 10 °C in accordance with Hasen's formula:

$$V_{10} = \frac{V_t}{0.7 + 0.03} t^o \qquad (30)$$

and then a graph is drawn. Determinations are repeated two or three times.

3.5. TECHNOLOGY OF SAND FIXATION

The survival rate of any plants grown in sand dunes depends on the intensity of deflation. Both the sand accumulation and blowout produce a negative impact. Deflation of sand in the areas under sand dunes can be stopped by using either mechanical means of protection or by applying binding substances.

Mechanical protection guards have been used by experts in afforestation and agroreclamation for a long time in Central Asian deserts. Lacking any analogues Soviet experts engaged in agroreclamation and afforestation have developed a number of types and constructions of mechanical protection guards which are widely used in sand drifts control in all desert regions of the Soviet Union.

The technology of erecting the standing mechanical guards is as follows: a 20 cm-deep ditch is dug along the line marked in advance. Then the protective material is applied to one side of the ditch and is put into a vertical position, covered by sand and packed.

The protection rows are oriented across prevailing winds.

Plant material of various sizes is used for constructing standing (30–70 cm high) or semi-buried standing mechanical guards.

A system of checkered standing or semi-buried standing guards consists of the main rows, oriented across prevailing winds, and of the transverse ones. The checker may be 2 by 2 m, 3 by 3 m or 4 by 4 m in size.

The matting in-row guards are made by placing the plant material (5 to 7 cm thick) across the row. The stability is ensured by putting some sand on the central part of the row.

Matting longitudinal guards are usually made up of straight-stalk plant material (reed, cat-tail) placed in layer 10–15 cm thick and 25 cm wide. When placing the plant material along the line of the guards the bundles of stalks should overlap each other and the places of juncture should be covered with sand. The stability of matting longitudinal guards is also assured with the use of pegs put in pairs at every 4–5 m on both sides of the guard.

In sand dunes mechanical protection guards are erected manually from November to late January. This time is considered to be the most favourable because a sand dune, fixed with the mechanical protection guards will have assumed stability by the sowing or planting date, thus preventing any excessive burial or blowout of seeds and cuttings. Substrate moistening greatly facilitates the installation of the guards during that period.

Matting guards can be raised at any season of the year, still the period before sowing or planting is preferable. If they are placed earlier, they would not protect the sown seeds since by the time of spring sowing the guards themselves have been buried by sand.

The optimum spacing between the rows of mechanical protection guards are as follows (Table 24).

All the types of mechanical guards are recommended to be placed in the lower half of the windward slope of a sand dune where the plant habitat conditions are better and where the mechanical guards are less subjected to destructive winds. Mechanical guards can also be placed throughout the entire surface of a sand dune.

Table 24

Spacing Between the Rows of Mechanical Guards, Their Height Being 30 cm (after A.M. Stepanov, 1963)

Wind velocity, m/sec	Spacing between the rows at a slope steepness, deg.		
	5	10	15
up to 17–18	4.2	3.0	2.1
over 18	3.3	2.1	1.2
	Matting guards		
up to 17–18	4	3	2
over 18	3	2	1

The reclamation properties of mechanical guards are also revealed in their positive impact on moisture conservation in the sand and in reducing the heating of the upper sand horizons.

The use of mechanical guards alone allowed to fix and afforestate sands on the area of 640,000 hectares in Turkmenia and Uzbekistan over the period of 1945–1965. In recent years (1968–1978) this area increased by 180,000 hectares [Petrov, 1977] . Thanks to this, a danger of sand drifts affecting oases, human settlements, economic units, irrigation facilities, motor- and railroads has been completely eliminated.

In the last ten years serious efforts have been undertaken in the Soviet Union in search of ways to mechanize sand-fixation and afforestation operations. Certain progress has been scored in this respect. Thus, it has been possible to mechanize sand fixation operations by using various sand-binding substances which can form either flexible or rigid crusts on a sandy surface. As it was mentioned in the previous chapter various chemicals such as raw oil, Nerozin, polymers of the K series, latexes, used lubricants, resins, etc., can be used as sand-binding substances.

The mechanical strength and the wind-erosion resistance of such sand crusts primarily depend on the application rate and on the even distribution of a binding substance over the area, that is on the technology of application of such substances.

As the experience testifies the best method of applying such binding substances to the sand surface is spraying. This is achieved by using various spraying machanisms ensuring an even spread of the preparation over a sand surface. In the Soviet Union for the purpose they use the OVT-1 sprayers driven by DT-75 tractor. The sprayer OVT-1 leaves a track of treated sand surface from 6 to 8 m wide. In addition to the devices mentioned above, a wheeled bitumen-carrier (BKP-1) with a modified spraying nozzle, is also used. The latter is mainly used for fixing sands around pipe-lines, rail- and motor roads and in conditions of not too complex sand relief.

There is also a machine which ensures either a strip or overall application of binding substances over the windward slopes of sand dunes. The technology of application is as follows: the machine moves across the slopes of sand dune ridges along a horizontal line, parallel to the crest. The windward slopes are treated either from top to bottom or in the reverse order. In case of an overall stabilization the next strip of the binding substance sprayed should overlap the previous one. The strips of a binding substance can be applied in the form of checkers.

In terms of labour productivity and total costs, sand-fixation operations performed by one machine operator or tractor driver is higher by an order of 25–30 and three to four-fold, lower correspondingly.

To fix sands in the vicinity of railway tracks, two types of engine-driven cars for spraying were designed by researchers from the Tashkent Railroad engineers Institute. The use of these cars allows to fix 50–70 m wide strips of sand along the railway track.

Sand fixation around some isolated objects such as posts of electric transmission lines or communication lines which are to be erected in sand dunes and around banks of water canals and reservoirs, may be carried out by using portable sprayers providing a forceful spraying of the fixing agent.

3.6. THE TECHNOLOGY OF AFFORESTATION

Any phyto-reclamation programmes in the areas of shifting sands should be carried out by taking into account the degree of their mobility, the depth of the ground-water table, the salinity of sands and underlying deposits, the nature and peculiarities of distribution of vegetation.

Knowledge of the ecological conditions allows to choose correctly the species of plants used for reclamation and to ensure efficiency of agroreclamation and afforestation.

Since sandy soils are loose enough, no special preparation of the ground before planting or sowing is required. On the contrary, efforts should be taken to fix the sand surface by using diverse types of mechanical protection guards.

Trees and bushes are considered to be the best sand-fixing plants used for afforestation of sands for apart from sand fixation they also provide firewood. Herbaceous are of secondary importance and they are sown only whenever it is impossible to cultivate some bushes or whenever there is an economic necessity to increase the amount of fodder grasses.

Shelter belts are established either by sowing seeds or planting seedlings. A combination of bushes and grasses yields an especially good result in sandy areas with good conditions for the plants' growth. These may occur, for instance, within irrigated oases or on their border with shifting sands where ground-waters are relatively fresh and close to the surface. It is preferable to plant seedlings on shifting sands since seeds would be easily blown out and their shoots would be either destroyed by erosion or covered with sand.

Usually *sand-fixing plants* are planted by seedlings or cuttings, grown either in special nurseries or in natural plantations. The manual planting of seedlings is done in this way: two workers walk along a marked line with one of them making 40–50 cm-deep holes in the sand either using a sharpened stick-shovel or a special Kolesov planting tool. The second worker places either seedlings or cuttings into the holes in such a way that the root neck of a seedling is buried below the sand surface or a cutting buried to the surface level. Then the first worker again plunges its tool 10–15 cm away from the freshly planted seedling and compresses the soil around it.

The quality of planting is checked by pulling random seedlings or cuttings: if they are loosely planted, they can be easily retracted from the sand. A correctly planted and well-buried seedling or cutting is difficult to pull out from the sand.

In southern deserts of the USSR the best time for planting of seedlings or cuttings is January or February (but not later than March) if the soil is moist down to 40 cm. In case of dry sand, the planting can be transferred to late March and carried out in shortened periods.

In northern deserts of the USSR the planting session is held in March and April, that is as soon as the soil thaws and it can be pierced with a stick-shovel.

Whenever seedlings are planted within checkered guards they should be placed not in the centre of a checker but closer to its corners and edges.

The quality of seedlings determines their survival rate, growth and resistance to adverse factors.

Seedlings take root only till May or June. In summer part of seedlings wilter because of lack of moisture in the upper soil horizons. To increase the survival rate of seedlings they are treated with special growth-stimulating substances.

The sowing of sand-fixing plants may be conducted as the main type of afforestation works or as an additional measure.

The manual sowing is usually done by using a shovel: one worker sticks a shovel into moist sand, opening a 3–5 cm-deep cleft into which another worker throws seeds mixed with sand.

Another method of sowing is scattering of seeds riding a horse or a camel. It is recommended to let a horde of sheep follow the sower to tram the seeds into the soil.

The sowing of sand-fixing grasses. Such grasses as wild rye or lyme grass, Aristida, Agriaphyllum are widely used.

To sow one hectare (2.47 acres) with wild rye by using a shovel some 4–5 kg of seeds are needed. The nest method of sowing (10,000 nests) is preferable. The best time for sowing wild rye is the autumn from September onward till cold season. It is better to sow this grass into damp sand after the first autumn rains. In spring time one should sow wild rye right after the melting of snow before the sand dried out. Compared to the autumn sowing the spring one is less effective.

The methods of Aristida cultivation are simple enough for no special preparation of soil is required, especially in shifting sands. Still, seeds are to be protected against wind erosion by fixing the sand surface. Otherwise, the greater part of the seeds would be blown out. Aristida is to be sown either in winter or in spring, either by scattering the seeds or using the nest method. When using a nest method, a cleft is made by sticking a shovel 5–10 cm deep into which several seeds are put. The sowing rate is 4 kg of seeds per one hectare. Shoots of this grass may also be planted. In this case the survival rate reaches 90 per cent.

Mechanization of afforestation and sowing operations. To reclaim and afforestate large areas of shifting sands by planting seedlings and cuttings, some special machinery like LPA-1, LMB-1 and others, which are usually driven by a cater-pillar tractor of DT-75 -type, are used.

Trees are usually planted in lines running parallel to the dune ridge on windward slopes. Depending on the type of the relief (small, medium, high and large chains of dunes) trees may be planted in different places. In depressions between sand dunes trees are planted over the entire area and over lower parts of the sand dune ridges. Among medium-high sand dunes seedlings are planted in depressions and up to two thirds from the bottom of a windward slope of a sand dune. In the areas of large and high sand dunes seedlings are planted on windward slopes to cover two thirds of them only.

A tree-planting machine is serviced by a tractor-driver and two workers. During a 7-hour working shift they can plant some 5,000 seedlings or cuttings in shifting sands.

Mechanized sowing is achieved by using sowers or special devices.

An aerial scattering of seeds of sand-fixing plants, in particular of wild rye and saxaul (Haloxylon) ensures a high survival rate.

According to L.A. Leontiev (1949) the method of aerial sowing of saxaul seeds is the following: an aircraft flies at an altitude of 25 m above the ground, scattering seeds onto a land strip 20 m wide. The spread, however, is not even for there are more seeds in the centre of the strip than to the sides.

Usually the pilot is assigned a rather prolonged sector for aerial treatment so that he can dump all the seeds in one run. Aerial sowing is done in strips with a spacing of 20 m between them.

The experience of aerial sowing in different conditions existing in southern deserts of the Soviet Central Asia demonstrates that the best results are achieved on semi-overgrown sands with shallow ground-water (such as areas of formerly cultivated lans covered by sand). The best time for aerial sowing is from December till February.

In the remote areas of deserts where the living conditions are harsher, especially on denuded sand dunes, the efficiency of aerial sowing is lower due to the wind blowing the seeds out into depressions and covering seedlings with sand.

Expenditure rates of seeds and seedlings. It is considered that for all species of plants sown manually the number of planting spots should not be less than 3000 in case of overall sowing.

Whenever planting is done in 3 m wide rows and with the spacing of 1 m between planting spots in a row, the total number of such spots may amount to 3300.

At present, due to the mechanization of afforestation and the use of standard planting materials the efficiency of afforestation works has sharply increased. This permits to reduce the total number of planting spots per one hectare to 1000–1100. This recommended number of planting spots ensures the survival of 600–800 plants per one hectare – a figure close to the natural biocenosis of plants.

The sowing rate of seeds (both for manual and mechanized sowing) is as follows: 10–12 kg of dzuzgun (Calligonum), 7–8 kg of Salsola paletriana and saxaul (Haloxylon), 4 kg of Aristida, 8 kg of Aellenia and 4–6 kg of Agriophyllum.

Afforestation of shifting sands by trees in the European part of the Soviet Union.

On sandy soils forests are planted for various agricultural and reclamation purposes, such as a stock of wood, to protect crops, to fix shifting sands and for various special purposes. Depending on the natural and economic conditions echelon, curtain and overall plantations of trees are set up.

Forests grown on sands are of economic and protective value and they belong to the group 1 of forests.

Sandy areas in the European part of the Soviet Union are located in the zone of unstable humidification. Adverse natural phenomena are droughts and wind erosion and they are neutralized thanks to modern agrotechnology.

In the Ukraine they developed a method of planting pine trees on sandy soils in the steppe zone where the upper 3–4 m-deep layer is moistured annually.

All the afforestation operations are mechanized. The technology is as follows:

– first, the area to be afforestated is marked by narrow rows with a spacing of 2.5–3 m;

– the grass cover inside the rows is removed by running disc harrows;

– then they do subsoiling within the marked rows to a depth of 50–60 cm and simultaneously treat soil with hexachloran to kill the root-eating pests; the subsoiling is executed by RN-60 mounted cultivators, driven by tractors T-74, DT-75 and DT-54.

Following the subsoiling, marking out and mechanical treatment of soil comes, the row is widened to 150 cm. Thus, a strip of land, overgrown with natural grasses, is left in the spacing between the cultivated rows. The grass strip may be as wide as 100 cm in case of a 2.5 m spacing and 150 cm in case of a 3 m-wide spacing. This width of a grass strip is quite sufficient to protect the soil and plants from wind erosion.

It is usually the common species of pine trees (Pinus vulgaris) that are used to fix sand dunes in the steppe and forest-steppe zones. Some 5000–6000 one-year-old seedlings are planted per one hectare. They are planted in rows with a spacing of 2.5–3 m between the rows and of 0.7–0.8 m within a row.

A method of mechanized deep planting of big seedlings of trees and bushes (which do not require any mechanical protection) became widespread in the semi-arid areas and on sandy soils, subjected to intensive deflation, in the European part of the Soviet Union. The idea is to plant 120–250 cm tall seedlings with a developed root system to a depth of 60–70 cm. Such deep plantings allow trees to grow in places where deflation normally results in sand drifts which cover the cultivated areas with a layer of 40 cm thick. The use of big seedlings sharply reduces the damage to plant germination since crowns of seedlings are raised above the space where a wind-sand flow is the strongest.

The roots of such seedlings, 60 to 70 cm deep in soil, are not blown out during the entire vegetation period, thus ensuring their proper development and growth of root system.

A relief of shifting sands may thus be stabilized by seedlings 3–4 years after their planting. Provided the survival rate of new seedlings is 40–80 %, the remaining number of trees is then enough to fix sands.

Using this method it is sufficient to plant 2000 seedlings per one hectare. Here is a description of the most rational technology of afforestation by using this method: rows of trees running parallel to the ridges of sand dunes spacing between them being of 3–4 m. Within each row the trees are planted at a spacing of 1.5 m.

Depending of the amount of rainfall, the depth of a ground-water table and the presence of nutrients in the sand, the following selection of tree species is suggested. In the western Caspian lowlands where there is over 300 mm of rainfall, poplar trees (Topulus alba) are mainly planted on powder-like fine-grain sands with a ground-water table of 6–8 m. Here, Acacia (A. pseudoacacia) and elm trees (Ulmus pumila) are also grown.

On saline sands it is recommended to grow tamarisk (Tamarix) trees.

In the northern Caspian lowlands where the conditions for afforestation are much more rigid, Calligonum Caspian willow (Salix caspica), sharpleaf willow (Claeagnum augustifolia) and oleaster (Claeagnus augustifolia) are recommended for planting by the deep method.

In the arid areas of the Soviet Union afforestation of sand dunes by deep planting of big seedlings have not become widespread since deflation processes there result in covering the seedlings with a 70–100 cm-thick layer of sand which whithers away the planted seedlings.

Treatment of seedlings and their exploitation. All the seedlings require a careful treatment in the first few years after planting. It is necessary to pay special attention to safeguard them against cattle grasing and to protect mechanical guards from destruction.

In case seedlings, cuttings or shoots are blown out buried by strong winds they must be fixed in their places by throwing some sand to their sides or by placing some dry grass around which would accumulate sand. Buried plants should be freed from the sand.

Some sand-fixing plants (Calligonum, sharpleaf willow) form a well-developed single shoot after the first year. It is undesirable to keep such crowns in the years to come since such crowns are poor in breaking winds and very often they themselves break down. To avoid this, thin shoots must be clipped to a stump to form a bushy crown. The cut branches may be further used as cuttings.

Since some of the seedlings and cuttings whither away as a result of deflation and lack of moisture, it is necessary to replace them after a first year. In southern deserts of the USSR this replacement must amount to 30 % of planting and to

50 % of sowing in terms of afforestation works of the first year. On the third year the replacement must be as high as 15 % of planting and 25 % of sowing of the initial afforestation effort.

In northern desert areas of the USSR the forest replacement is more limited in scale and its volume is to be determined in autumn after the seedlings are checked and counted.

The further forest maintenance consists of regular sanitary cuttings. Unless such cuttings are done, trees grow weaker, they whither away and loose their primary purpose. Such cuttings not only prolong the life of trees but produce sizable amount of firewood.

Places of planned cuttings are choosen annually in such a way as not to affect the entire afforestation area but just some rows located across the predominant winds. Unsystematic cuttings must not be allowed. Planned cuttings must be done late in autumn after the trees shed the leaves.

The first cutting of erythronium and Salsola poletriana stands must be done 7–9 years after planting. Cuttings may be repeated 4–6 years afterwards since the cut trees develop much faster, compared to shoots and planted cuttings.

Calligonum and Salsola poletriana grow normally after winter cuttings, reaching 100 % and 70 % of annual growth correspondingly.

An important moment in preserving forest belts is to avoid self-seedling and the appearance of aftergrowth especially in years with a high rainfall when many new shoots appear. Forests subjected to sanitary cuttings are excluded from any exploitation for 3–5 years depending on the rate of forest growth.

Soil should be tilled and sanitary cuttings done in shelterbelts of pine, poplar and other trees grown on sands.

Soil tillage should be started right after the planting of trees. The first subsoiling should be done by light toothed harrows and the further soil tillage should be undertaken along the rows of trees as need may be till the crown closure is achieved.

Sanitary cuttings of trees are done for the trees benefit thus ensuring their long life and avoiding possible damage by natural forces such as heavy snow. They also help in keeping trees in a proper sanitary condition.

3.7. PROTECTION OF ECONOMIC UNITS FROM SAND DRIFTS AND DEFLATION

The USSR's efforts on combating shifting sands were aimed at protecting economic facilities, construction sites and installations from sand drifts and deflation.

The choice of protection method depends on the type of a unit and its design features. For example, a motor road or a construction site should be proofed against sand drifts, pylon foundations of power transmission lines – against blowout, and canals – from sand drifts and wind erosion of dams.

Square installations erected in deserts include industrial sites of oil and gas fields, as well as workers' and service personnel's settlements.

The experience of construction and operation of square installations in the Karakum Desert shows that their erection involves an inevitable dustruction of the sand-fixing sod and vegetation cover over large areas. The width of an area involved in levelling and other earth-moving operations around the site may vary between 100 and 500 metres, which is quite sufficient for the development of a steady wind-sand flow and even eolian forms (envelops, ridges, small sand dunes) at high wind velocities.

Recommended measures for the protection of sites include three stages: the choice of site location, construction (mainly earth-moving) work and erection of mechanical protection guards.

Technological conditions permitting, sites should be chosen in least dissected eolian which are most fixed by vegetation. Maximum advantage should be taken of local stretches of dense ground, not covered with eolian deposits (takyrs, kyrs, parts of plateaus, etc.) Denuded shifting sands should be avoided.

The conditions of construction work in the desert depend on the thickness of the eolian cover.

In the Karakum Desert eolian sands rest on clayey surfaces or takyrs (Karakum Lowlands) and on compacted rocks or kyrs (Transunguz Karakum). In such cases it is best to use so-called negative levelling, i.e. removing the entire eolian cover, baring the underlying kyr surface. Sites built in such a manner will be free of sand and, consequently, not affected by sand drifts. This implies that the whole of sand layer must be moved leeward from the site. If left on the windward side, sand banks will gradually be blown out to the site.

In areas where the eolian cover is very thick or strongly dissected negative levelling is impossible. However, here too all excess ground should be removed leeward.

Technological conditions permitting, all communication lines should come from the leeward side so as to preserve a maximum of vegetation of the windward side.

Third-stage measures include the construction of mechanical protection guards in the form of checkers or sand banks treated with binding substances with subsequent planting sand-fixing plants.

Let us discuss these measures in greater detail. An important part of the sand fixation programme is the determination of the optimal width of the protective belt or zone. Since square installations in the desert are mostly built on sand with a sod cover and the existing legislation calls for obligatory recultivation (involving in this case the restoration of the sod and vegetation cover), the entire sand area disturbed by earth-moving operations will be subject to fixation. This means that the width of the protective zone will be determined by the earth-moving technology and the efficiency of preventive conservation measures.

The experience of the construction of gas extraction sites in the Karakum Desert shows that the total area of sod cover destroyed by construction work varies from 1.5–3 hectares to 70–100 hectares. As a consequence the entire surface of technogeneous sands, those under technological equipment and artificial surfaces is subject to fixation.

The protection of industrial installations should be done in accordance with the following pattern (Fig. 13).

1) On the site (the fenced-in area) the area free from construction work is fixed by narrow in-row guards (1 metre wide with a spacing of 2 metres between the rows) with subsequent sowing and planting of sand-fixing plants. Permanent walkways are marked for the service personnel.

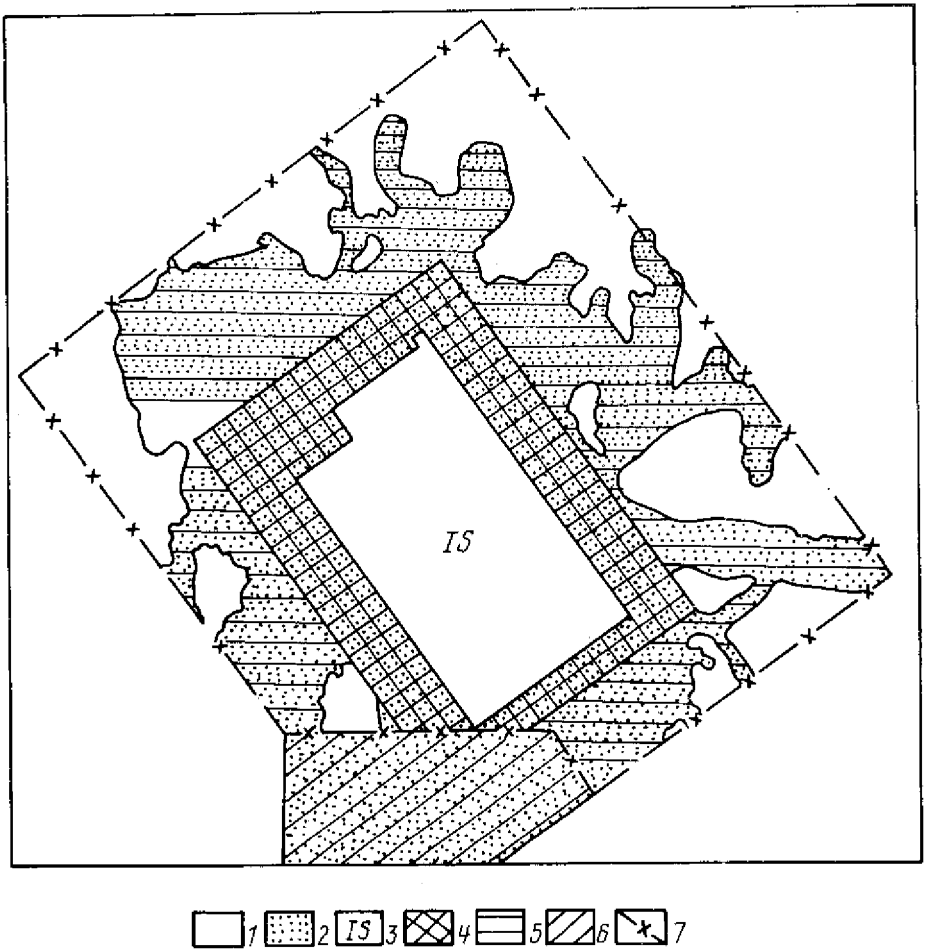


Fig. 13. Plan of protection of gas-extraction industrial site:
1 – sodded sands; 2 – "technogeneous" sands; 3 – industrial site; 4 – checkered mechanical guards or fixed banks; 5 – narrow-strip mechanical guards; 6 – auxiliary facilities' location; 7 – barrier

2) Checkered guards and fixed sand banks are arranged outside the fence.

3) Beyond checkered guards and banks narrow in-row guards are arranged throughout the entire breadth of sands destroyed by construction with the subsequent sowing of sand-fixing plants. The rows should be oriented across the predominant winds so as to prevent intensive blowout of sand between the rows.

4) Auxiliary services as well as the access roads are set up on the leeward side of the site.

5) The entire area under protection guards and plantations as well as the adjoining area of sodded sand within a 500 m radius should be protected from destruction.

Sometimes technological conditions make it impossible to avoid siting of projects on denuded shifting sands. In this case site protection becomes a costly and complex undertaking. The determination of the size and shape of the protective zone will depend on the rate and direction of sand drifts. The width of the protective zone is calculated on the basis of sand transport volume moving over a distance of 1 metre. The checkered guards and sand banks should hold the whole amount of sand brought by the wind-sand flow in the form of small sand dunes. Along the guards psammophytes are sown. In areas adjacent to the mechanical guards it is recommended to "block" the movement of sand dunes by planting psammophytes in depressions between them. The measure, which should cover as large an area as possible, is designed to reduce the sand transport toward the guards.

The protection of workers' and service personnel's settlements should include:

1. Paving the entire damaged area which is not built up with an inert material such as gravel or rock debris.

2. The arrangement of a protected zone on the windward side of a settlement where movement of transport, machinery and people is prohibited. This involves fencing in of an area of sodded sand adjoining the site with a width ranging between 100 and 500 metres, depending on the sands' susceptibility to deflation. With a view to achieving a denser vegetation cover, during the first 2 or 3 years sand-fixing plants are sown and planted (in deflation hollows). Before the beginning of construction the protected zone is duly marked and subsequently fenced in. Access roads are built from the leeward side.

The main problem of building a pipe-line in sands is its protection against blowout. In this case sand transport does not cause negative impact, and the formation of sand accumulations can be even regarded as a positive phenomenon. Thus protection of pipe-lines in a sandy desert comes to the elaboration of methods, aimed at preventing blowout.

In the desert eolian forms of relief have varying degrees of dissection depending on the local deflation baselevel. Consequently, a pipe-line buried below the local, deflation baselevel will not be subject to blowout, and, conversely, its shallow burial or laying it on an embankment will result in blowout.

Three principal techniques of laying pipe-line in sandy regions have been sketched: into an embankment (western Turkmenia), into an embankment and ditches (Bukhara – Urals gasmain) and into ditches (Central Asia – Centre gas-main).

Experience has shown that in absence of mechanical guards or in case of their destruction it is pipe-lines built by the first method that are subject to greatest blowout. The second method also results in considerable blowout, while the third one leads to least blowout. Cases of pipe-lines blowout placed in a ditch have been mainly due to non-compliance with the design or the use of earth-moving techniques unsuitable to the pipe-line installation method. As a consequence, it has been recommended to bury the pipe-line at a maximum possible depth (1.5–2 metres) below the sand surface levelled along the profile of minimum route transit heights.

The recommended method of deep burial of the pipe-line along the profile of negative elevations will be effective only if the following requirements are met in its design and construction:

– In denuded sand dunes levelling should follow the line of minimum elevations.

– In overgrown sands with large height drops and steep slopes when an embankment has to be built, it should be stabilized immediately after filling the ditch.

– Whenever a ditch is built in sand dunes, the angle of its walls should be as close as possible to 35° – the angle of natural slip of sand. In overgrown sands the ditch walls must have a concave transverse profile, gradually flattening downward. This will prevent slipping of sand from the ditch walls.

– In levelling operations all overgrown eolian forms found within the route transit range and which are classified as small ones (up to 3 metres high) must be removed until their underlying rock is bared. In the case of medium and large eolian forms (from 3 m upwards) only sharp curvatures of the elements of the relief (slope feet, summits) are to be levelled so as the ditch profile should not exceed the angle of the pipe's natural bending, i.e. 5–6°, a pipe should be placed along the "enveloping" profile. All mobile forms of eolian relief should be cut down to their base levels.

– During earth-moving operations (levelling the strip and working out the ditch) loose sand is to be moved only to the leeward side. Ground for filling the ditch should be taken only from the leeward side, taking maximum care not to damage the ditch walls. The above-ditch bank of loose sand which is formed after filling the ditch must be compacted, because in extremely dry conditions there is no sagging and the bank will be subjected to blowout.

In order to prevent ditches from filling with sand, the time between their digging and the laying of pipes should be reduced to a minimum, especially when crossing sand dunes. Otherwise, it may become necessary to deepen the ditch – an operation which, as the experience of the Central Asia – Centre gas-main has shown, involves considerable problems.

Constant geodetic supervision over the levelling and pipe-laying operations is required, and the entire project should be monitored by the design agency.

Recommendations of the installation and blowout protection of a pipe-line in a specified area should be worked out in stages. Stage one involves recommendations on the choice of route in an eolian relief system. Stage two involves recommendations on earth-work technology, taking into account the relief and the wind regime, and the third stage consists of recommendations on protecting the pipeline against blowout. The first two stages are carried out during the survey and design operations, and the last one – after the completion of construction work.

Under the recommended method of laying a pipe-line, sand-fixation operations are practicable to start 1.5–3 years after the pipe was layed and buried, with the obvious exception of emergencies. This is determined by the fact that during the period, the eolian relief damaged by the earthworks will have undergone certain changes, and the sections of the pipe-line most susceptible to blowout will have become clearly visible. Therefore, the design documentation for the pipe-line should include only recommendations on routing the line in eolian relief system and on earth-work technology, while specific recommendations on the protection of the pipe-line should be made already during its actual operation after its additional detailed examination. Sand-fixation costs may be included, for example, in repair and maintenance costs. Strict observation of these recommendations on the routing and earth-work technology will ensure a maximum reduction of blowout.

Local seats of blowout may be combated with the help of binding materials, that set up a cover on the sand surface.

Construction of a main pipe-line in sands, particularly of several threads, frequently results in disturbance of the soil and vegetation cover by the earth-work, there appear masses of loose-sand ground, deflation of which leads to the formation of shifting sands. Although the phenomenon does not occur very often, it should be taken into account when constructing in sands.

Construction of gas mains entails building of numerous industrial units, main and access roads, pumping stations, workers' settlements, etc. Care should be taken not to locate these installations in the shifting sands area, formed along the pipeline. Consequently, they should be situated on the windward side of the pipe-line route (for example, installations along main roads).

It should be pointed out that the recommended method does not preclude phyto-reclamation for the fixation of sand along the pipe-line route. After the construction of the pipe-line has been completed, one can undertake phyto-reclamation in the sandy areas with favourable plant habitat conditions.

In conclusion, a few words might be added about the economic expediency of the recommended method. Calculations have shown that maximum burial of pipe-lines results in approximately the doubling of levelling earth-work required by the design (especially in sand dunes). The cost of that kind of earth-work is equal to that of ordinary levelling using the average profile method plus the cost of sand-fixation by phyto-reclamation. This means that the recommended method involves no increase in the total cost of construction. If one takes into account that the method does not require labour-consuming and organizationally complex sand-fixation operations (especially in sand dunes) and, as a consequence, eliminates the risk of accidents due to blowout of unsecured pipe-lines, the overall advantage of the method becomes obvious.

The principles guiding the siting and protection of the bases of towers of **power transmission lines** are largely similar to those concerning pipe-lines. In this case, too, objective number one is to prevent blowout.

The choice of route should be dictated by the same considerations: the least dissected eolian relief with the thickest sod cover should be chosen. Maximum advantage should be taken of the local spots of deflation-resistant surfaces. Earth-work should be guided by the same requirements as in case of pipe-lines: excess earth should be moved leeward.

When towers are erected in sodded eolian sands, the area around the bases damaged in the process should be fixed. In sand dunes, banks near the bases are to be fixed, their radii being determined by the intensity of wind activity.

A variety of materials can be used for fixation of towers' bases. In addition to binding substances, local materials, such as plant stems, gravel, pebbles, clay, etc., can be used.

On motor roads the pattern of protective measures will vary broadly as a function of local conditions, especially geomorphological ones (features of eolian relief, intensity of relief-forming processes such as deflation, etc.).

Motor roads can be built: over ground with a sod layer or over eolian terrain subject to different degrees of deflation.

In the first case principal attention is paid to the choice of route in the eolian relief system. Here it is important to "follow the accidents" of the terrain – that is to map out the route along the least dissected profile of zero data, and along linearly extending relief features, primarily depressions between ridges and other hollows.

This is the case when the route is submeridionally oriented, for it is precisely the orientation of linear eolian forms in the greater part of western Turkmenia's desert. This is also the direction of major depressions in the native rock underlying the eolian sands. Such depressions are characterized by the least dissection of eolian forms, and a dense grass and brush cover.

When the route is traced sublatitudinally, the geomorphological features and, consequently, the choice of protective measures will be largely determined by the terrain along the route whose degree of vertical and horizontal dissection may change after several tens or hundreds of metres of the route.

Wind protection is to be primarily provided on the windward side of the road for it is only from this direction that sand transport is possible. All the sand accumulated on the lee side of the road as a result of natural wind erosion or earth work will be transported away from it.

As a consequence, the road's protection will be selective, mainly in the places where it crosses ridges, watersheds, etc., and is built in deep depressions. Stretches of the road which cross depressions between ridges or pass over bottoms of hollows do not require protection.

Whenever ridges have to be crossed without accompanying protective measures, there will always exist a danger of sand drifts. The causes are as follows. Cutting a road through ridges and watersheds produces piles of excess ground which are moved toward the nearest depression between ridges (which is the optimum case, in the worst case it is spread on both sides of the cutting). The slope of the cut creates a so-called aerodynamic shadow in which sand is accumulated slipping from the ground dumps and ridge summits subject to various degrees of deflation. The sand "train" thus formed gradually encroaches on the paved part of the road.

Consequently, in planning earth-work, it is very important to take into account the wind regime and the direction of the transport of sand. It is also recommended to move ground only to the leeward side, unless it is impossible to use it in profiling the road. Lateral cutting of ground should be prohibited. Earth-moving machinery should move only along the longitudinal profile.

The choice of protective measures for a sublatitudinally oriented motor road passing through eolian relief subject to different degrees of deflation will be dictated by geomorphological conditions.

Preventive measures acquire particular importance when motor roads are built in sodded sands. The main requirement in this case is to preserve the vegetation cover to a maximum possible extent, particularly on the leeward side. For this purpose, protective zones are to be set up at the roadsides and in the adjacent windward area. Grazing and driving of cattle, as well as the cutting down of vegetation are to be prohibited there. All types of earth-moving operations should they be carried out in the road's immediate vicinity, are to be confined to the leeward side. If technological considerations make it imperative that earth-moving operations should be performed on the windward side, they are to be accompanied by the fixation of the damaged sand surface. In addition, movement of construction machinery and transport along latitudinal stretches of the road should also be confined to the leeward side.

It would seem that when a road is built in **shifting sands** the choice of route is of no importance, for conditions are equal in all directions. But this is at first glance only. In this case it is paramount to determine whether the route follows the direction of final sand transport and the movement of eolian forms, or goes at any angle to it. Upon the result will depend the scale of sand-fixation work and the siting of the system of protection guards.

When the route coincides with the direction of sand dunes forms' movement, the danger of the road being drifted over is minimal: the dunes will move parallel to the road or slightly overlapping with it. In this case the protection of the road will consist of streamlining the roadsides with the help of binding or inert substances. Fig. 14 shows a schematic diagram of this mode of protection. The optimal dimensions of defences (row width and the total width of the protection zone) follow the pattern: the smaller the angle between the directions of the route and the eolian forms' movement, the narrower the protective zone, and vice versa. At large angles, when the windward side becomes pronounced, it accounts for the bulk of protective measures, and at angles approaching 90°, organization of guards from the leeward side becomes meaningless.

The most unfavourable case is when the road cuts across denuded features of eolian relief at angles close to 90 degrees. It calls for maximum efforts to create a complex of protection guards from the windward side (Fig. 14 b).

The design of defences in sand dunes must meet the following main requirement – to prevent movement of sand (eolian forms) over the road bed. Consequently, the guards must have sufficient "capacity" to absorb the moving sand mass to halt it, and to let vegetation take root. In this respect the existing methods of highways' protection by means of overall or in-row application of binding substances to the roadsides are not effective, since sand dunes are easily moving over them.

Protection of **railways** against sand drifts has a long history in Central Asia. It was in 1880, with the beginning of Trans Caspian railroad construction, when the problem of shifting sands control on engineering installations manifested itself. Methods of railways protection are largely similar to those of highways protection. But the requirements to railways protection are more strict. For instance, if in case of a highway sand transport across the road in a wind-sand flow having non-accumulative regime is permissible, in case of a railway such transport is out of the question. It's related to the fact that rails form an aerodynamic shade for the wind-sand flow and sand accumulation takes place and formation of sand drifts. That's why on railways they always used capacious protection guards, mainly in-row or checkered, that totally halt sand transport either in the form of a wind-sand flow and in the form of sand dunes. At first they were mechanical protection guards made of wooden shields, boards, sleepers, then of bushes and herbs. Mechanical protection guards were installed on a narrow roadside. Mechanical guards made of cane and reed were the most widely used. Sometimes along such guards they sown or planted psammophytes. All the work was done mannualy, so it was labour-consuming and costly.

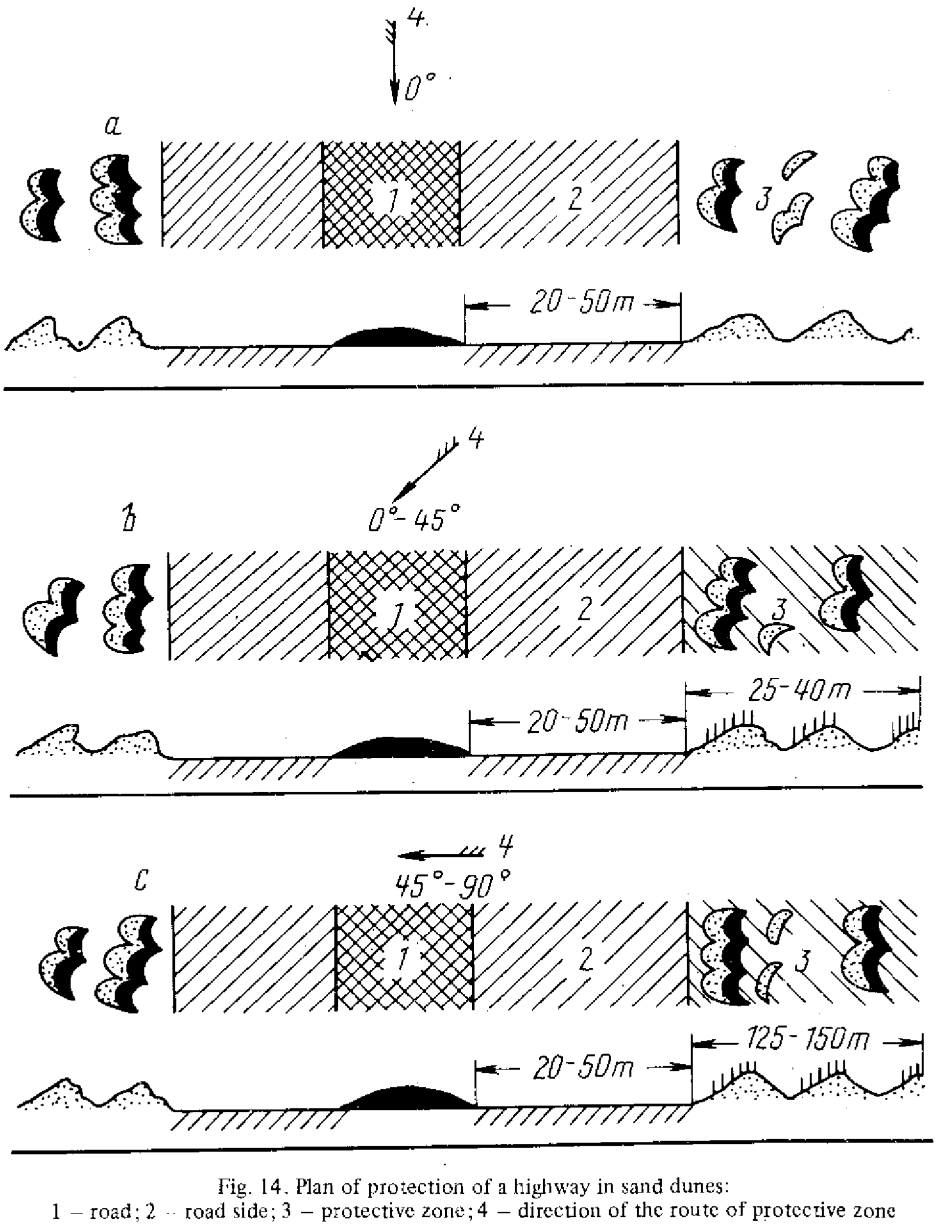


Fig. 14. Plan of protection of a highway in sand dunes:
1 – road; 2 – road side; 3 – protective zone; 4 – direction of the route of protective zone

At present an integrated method of railways protection from sand drifts is made use of. In consists of 1) shifting sands fixation by chemical fixators, trenches, ditch-banks, banks and others on a roadside, the width of which may vary, depending on the degree of wind erosion resistance of the sand surface; 2) psammophytes are sown and planted over the guards; 3) forest shelter belts are planted in areas adjacent to the roadside; 4) guarding of defences, artificial and natural plantations on the roadside. The width of fixed and protected area along the railway may vary between several hundred metres and one kilometre, depending on the natural conditions.

The use of the integrated method implies a maximum degree of mechanization. Besides, it is best suited to the requirements of environmental protection and reproduction of natural resources in a desert.

Combating shifting sands on **irrigation canals** mainly consists in the prevention of the bed being drifted over with sand and of the deflation of dams. The methods used are similar to those employed on motor roads and railways. However, taking into account better conditions for silviculture owing to a heightened moistening of sand with filtration water and the availability of water for irrigation, the most effective method to combat shifting sands in this case is phyto-reclamation. In addition, it has been shown experimentally that watering of plantations on the canal dams two or three times a year makes it possible to do without sand fixation using mechanical or other protection guards. Additional moistening alone prevents deflation on dams, stimulates growth of psammophytes and spontaneous overgrowing of shifting sands. However, on adjacent territories, where it is difficult to organize watering of plantations shifting sands, sand fixation measures should be used.

Besides sand deflation along canals, there is a problem of water erosion which may result in the breaking of dams and the constant siltation of a bed. This means that hydrophytic trees and shrubs should be planted on the windward slopes of the dams to secure them. In addition, with a view to reducing the negative effects of filtration through sand, so-called biological drainage is to be used, consisting in planting forest shelter belts on the dams of trees with good transpiration properties.

The successful completion of this complex of operations (phyto-reclamation, securing of banks, biological drainage) in combination with obligatory nature conservation measures in the canal zone will create a peculiar landscape with favourable ecological conditions.

CONCLUSION

Under conditions of scientific and technological revolution development of deserts is a difficult and challenging task. What is needed, on the one hand, is big capital investments, a special approach and the use of certain methods and engineering facilities, while on the other hand, there should be a close back-feed connection with environmental protection, improvements in the ecological situation as well as scientific forecasts of adverse consequences of man's interference into the natural equilibrium. The maintenance of arid biogeocenoses in conditions of an increased economic pressure calls for steady improvements in the organization and technology of rational land use and in an application of a complex of specific measures.

Any violations of ecological balance in arid areas result in desertification. These may trigger salinity on irrigated lands and overstocking of desert pastures and indiscriminated felling down of trees and bushes may form foci of deflation and tracts of shifting sands.

To combat desertification of desert pastures, certain measures are taken in the Soviet Union to irrigate and afforest them. Thus, during the period of 1976–1980 some 37.6 million hectares of pastures were irrigated in desert, semi-desert and mountainous areas. In 1981–85 some 23.9 million hectares of desert areas (including 15 million in Kazakhstan and 6.9 million hectares in Turkmenia) are to be irrigated.

Development of new lands and building of large irrigation systems triggers water and wind erosion in certain soil-climatic conditions. Such areas require a restructuring of their irrigation networks, planting of protective forest belts, fixation and afforestation of gullies, banks of canals and water reservoirs.

In recent years some 1480 km of bank-protective forest belts, 6800 hectares of tree groves and 1260 hectares of orchards and vine plantation were planted in Uzbekistan. Forest belts along the banks of the Karakum canal amounted to 12,300 hectares.

Crops-protecting belts are planted in areas affected by a strong wind erosion. Their areas exceeded 6000 hectares in Turkmenia and 28,000 hectares in Uzbekistan, mainly in the central part of the Ferhgana valley, in the Golodnaya ("Hungry") and Karshinskaya Steppes.

While carrying out afforestation projects in the sandy deserts of the Soviet Union much attention is paid to grow forests to improve land, obtain timber and other forest products as well as use these lands as pastures.

The developed methods of shifting sands fixation allowed to successfully protect economic facilities from sand drifts. These methods are used selectively depending on the existing conditions of forest growth, the intensity of wind regime and the nature of protected objects.

The afforestation and land-improvement methods used in sandy areas of the Soviet Union presuppose afforestation and fixation of sands with the help of local sand-fixing plants. However, under the most difficult conditions for afforestation provisions are made to use various mechanical protection guards as well as physico-chemical methods of amelioration, such as protective films made of bitumen, polyacrylamide and other polymers.

Afforestation, as the most ecologically stable method of shifting sands fixation, is carried out to fulfil the following goals:

– planting of forest protective belts on the outskirts of oases, field boundaries and along canal banks, consisting of the local and introduced species of trees and bushes, grown on irrigated areas. An example of such a protective belt is a forest of black saxaul (Haloxylon aphyllum), 120 km long and up to 4 km wide, on the northern border of the Bukhara oasis;

– planting of forest belts in the cattle-breeding desert areas to protect the cattle from strong winds and increase the fodder supplies;

– restoration of the natural vegetation cover on the areas where it has been destroyed as a result of strip mining, building of roads, pipe-lines, etc.;

– afforestation, shifting sands fixation and control of sand drifts. Here the most important problems are: the development of methods of afforestation of near-oasis sand areas to protect irrigated fields, canals, human settlements and roads from sand drifts.

At present, afforestation and sand-fixation projects are carried out on the total area of 608,000 hectares in Uzbekistan and 300,000 hectares in Turkmenia. From 1976 to 1980 forests occupying a total area of 367,300 hectares were planted on sands, mountainous and irrigated lands. During the 1981–85 period it is planned to afforest 455,000 hectares, including 450,000 hectares on sands.

Planting of forest belts consisting of saxaul (Haloxylon) trees is a good example of the rational use of afforestation to raise the fodder yield of desert pastures for trees and bushes there bolster up fooder reserves available on winter pastures. Such man-made pastures may be used as soon as 2–3 years after planting. Besides, they are durable and can be used as long as 30 years. The organization of such long-lasting range lands allows to break the seasonal limits of natural grazing facilities, provide cattle with fodder on the round-the-year basis and increase their yield by over three-fold.

In an experiment, run by the Institute of Deserts of the Turkmen Academy of Sciences, a possibility to grow fodder on shifting sands by using sprinkler irrigation was proved. After applying the usual rates of organic and mineral fertilizers and using the irrigation rate of 5500–6500 m^3/hectare, the desert can yield as much as 0.5–0.8 tons of green mass of corn and sorghum per hectare (2.47 acres). Such land-improvement operations allow to bring the formerly barren lands under cultivation, fix shifting sands, avoid salinization of soils and use economically irrigation water.

However, in spite of all successes scored the problem of sand fixation and development of shifting sands is still rather difficult and acute, requiring concerted efforts by scientists and experts from many countries of the world.

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Major Sand-Fixating Plants of Foreign Deserts and Semi-Deserts

Central Asia	India and Pakistan	North Africa and Middle East	South Africa	Australia	North America and Mexico	South America
			Trees			
Populus simonii	Prosopis spicigera	Pinus pinaster	Eucalyptus gomphocephala	Acacia aneuara	Prosopis juliflora	Prosopis argentina
P. cupidata	P. juliflora	P. halepensis	Casuarina equisetifolia	Eucalyptus gomphocephala		P. strombulifera
P. bolleana	P. glandulosa	P. pinea	Pinus pinaster	Casuarina equisetifolia		P. tamarugo
Elaeagnus moorcroftii	Acacia senegal	P. brutia		Banksia integrifolia		P. chilensis
E. angustipolia	A. mollissima	Acacia arabica				
Ulmus pumila	A. tortilis	A. senegal				
	A. arabica	A. horrida				
	Salvadora oleoides	Eucalyptus gomphocephala				
	Zizyphus nummularia	E. camaldulensis				
	Balanites roxburghii	Tamarix articulata				
	Gymnospora montana	T. aphylla				
	Casuarina equisetifolia	Casuarina equisetifolia				
	Calophyllum inophyllum	Cupressas sempervirens				
	Tamarix articulata	C. arizonica				
	T. aphylla	Conocarpus lancipllins				
		Haloxylon ammodendron				

Continued

Central-Asia	India and Pakistan	North Africa and Middle East	South Africa	Australia	North America and Mexico	South America
			Shrubs			
Haloxylon ammodendron	Tamarix ramosissima	Tamarix ramosissima	Acacia cyanophylla	Acacia cyanophylla	Atriplex canescens	Atriplex canescens
Tamarix ramosissima	Capparis aphylla	T. pseudopallasii	A. cyclops	A. aneura	Poliomintha incana	A. nummularia
T. laxa	Calligonum polygonoides	Retama raetam	A. saligna	A. sophorae		A. semibaccata
T. chinensis	Ricinus communis	Acacia cyanophylla	Myoporum insulare	Osteosphermum monoliferum		Plectocarpa tetracantha
Salix flavida S. matsudana S. mongolica S. cheilophila S. cheilophila Calligonum mongolicum	Leptadenia spartium	A. cyclops Nitraria retusa Calligonum comosum C. arich C. azel	Leptosphermum haevigatum Myrica cordifolia Metalasia muricata Stoebe vulgaris Branshylaena discolor	Atriplex vesicaria		
C. roborobskii		Ricinus communis	Osteospermum species			
C. caput-medusae			Acanthosicyos horrida			
Hedysarum scoparium H. mongolicum Caragana microphylla C. korshinskii Nitraria schoberi N. sibirica Robinia pseusdoacacia						

Semi-shrubs						
Artemisia sphaerocephala A. ordosica A. halodendron		Artemisia monosperma			Artemisia filifolia	Kochia brevifolia
Perennial grasses						
Psammochloa villosa	Cenchrus ciliaris	Ammophila arenaria	Arthraerua leubnitziae	Spinifex hirsutus	Agropyron smithi	Panicum urvilleanum
	C. biflorus	Aristida obtusa	Aygophyllum stapfii	Pennisetum clandestinum	Ammophila reanaria	
	Arundo donax	A. pennata	Aristida kalaharien-sis	Senecio crassiflorus	A. brevilegulata	Pennisetum chinese
	Agropyron elongatum	A. pungens	A. brevifolia	Carpobrotus aequilatorus	Andropogon scoparius	Hyalis argentea
	Ehrhartia brevifolia	Arundo donax	Ammophila arenaria	Arctotis stoehadifolia	A. gerardi	
	Saccharum spontaneum	Agropyron junceum	Ehrharta gigantea	Ammophila arenaria	Bouteloua curtipendula	
	S. munja Citrullus colocynthus Panicum antidotale	Lotus creticus Imperata cylindrica Pennisetum dichotomum	Sporobolus pungens	Triodia basediwii	B. gracilis Calamovitfa gigantea C. longifolia	
	Elionurus hirsutus	Polygonum equisetiforme			Elymus giganteus	
					E. canadensis Panicum virgatum P. havardii Redfieldia flexuosa Sporobolus flexuosus	
Annual grasses						
Agriophyllum arenarium Pugionium cornutum Stiopnolepis centiflora Salsola praecox	Kochia indica	Salsola praecox	Digitaria sanguinalis	Canavalia maritima		

CONTENTS

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