Chapter 3
Geography and Geomorphological and Lithological Characteristics of the Aralkum

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3.1 Introduction

The geomorphological and lithological features of the Aralkum today are characterized by the vast plains stretching on the very flat, intercontinental seafloor, which is now predominantly desiccated. The sediment layers, mainly clay, silt and sand, which came from the main tributaries within the last few millennia are rather heterogenic according to the dynamics of the river discharges. The desiccated seafloor exhibits new changes by wind erosion, causing sand and dust transport, and thus forming sand dune landscapes on the older seafloor.

3.2 Geology and Tectonic Processes

The geological and geomorphological factors play an important role in the formation and differentiation of the landscapes in the desiccated Aral Sea basin. This basin is the center of an eroded tectonic depression of the northern part of the Turanian plate (epihercynic platform). From a geomorphological point of view, the Aral Sea can be called a very flat, innercontinental lake, and the Aralkum can be called a very flat plain.

The structural basement of the relief is the tectonic elements of the northwestern Turanian platform. These are mainly the Chelkar syneclise, the Syr Darya syneclise and the Kyzylkum depression. These syneclises are large depressed structures of a continental platform crystalline basement. There are usually no distinct topographical depressions on the syneclises because they are covered by rather thick sediment layers (see Chap. 2). These elements were formed during the hercynic Ural mountain development (in the whole region north of the Aral Sea) und during the Caledonian Turgay–Kyzylkum mountain development (the region east of the Aral Sea). The basement of the platform exhibits strong dislocations and metamorphic changes. The tectonic ruptures dismember it to strata which are oriented in

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submeridional directions. The west Aralian stratum corresponds mainly with the position and size of Ustyurt Plateau, including the western deep furrow of the Aral Sea with a depth of about 50–60 m. The eastern lower Syr Darya stratum forms the lower layers along the eastern coast of the Aral Sea (Bubnoff 1924; Leuchs 1935).

The Aral Sea basin with its variety of relief forms makes contact with deep faults and transregional lineament zones. Two tectonic anticlines divide the Aral Sea depression into four structural units. The first stretches from west to east (along the former island of Kokaral to the Syr Darya's mouth). This is the division between the northern, Small Aral Sea and the southern, former Large Aral Sea (now the Aralkum). The second stretches along the Kulandy peninsula, the former island of Vozrozhdeniya and the southern small islands. This is the division between the western deep furrow (western basin of the former Large Aral Sea) and the dry flat eastern basin (now the Aralkum). The submeridional deep furrow of the Aral Sea (between Vozrozhdeniya and the western coast) is the continuation of the Chelkar syneclise. The delta of the Amu Darya (the fourth structural unit) is located at the continuation of this huge deep furrow from the Palaeozoic period. Nowadays, it is filled up deeply with alluvial deposits.

For the region of the Aral Sea, the basis surface of the Aralsk layer trains of the Lower Miocene and the thickness of the layer trains of the Andasai from the Upper Oligocene/Lower Miocene was used to define the recent tectonic movements and their amplitude. For most parts of the area there have been only changes of level between 0 and 300 m since post-Miocene times. The characteristics of the tectonic structure became apparent only during the neotectonic epoch. The differentiation of the various directions of the tectonic movements is distinctly marked. In contrast, the Syr Darya syneclise and the East Aralsk depression are more characteristic. Knowledge of those tectonic movements was gained by precise nivellement measurements of the railway lines. For the Aralsk–Dzhusaly–Kyzyl-Orda section during recent decades a rather constant tectonic sinking speed of about 8 mm/year was found.

The smooth transition from the flats hills of Mugodzhary to the slight basin of Kyzyl-Orda is interrupted by the Malye Barsuki anticlinal and the sharp changes in height on the upper plain which correspond to the north Aralian lineaments. The neotectonic disjunctive disturbances without displacements or with very slight displacements only are typical for this region. They have a huge spatial size, and are clearly defined by their depth and tectonic age.

3.3 Sedimental Deposits on the Dry Desiccated Seafloor

The tectonic characteristics of the whole area are governed by the spatial distribution of the deposits from the Mesozoic and the Cenozoic periods. The lithological-stratigraphical complexes of the Aralkum region comprise deposits from the Upper Cretaceous, the Palaeogene, the Neogene and the Quaternary. These are former unique sea sediments and some continental deposits of very differing constitution

and thickness. The thickness of the sediment layers is about 500 m on the anticlinal parts and 2,000–4,000 m in the synclinal basins. The basis of the platform at the northeastern coast of the Aral Sea is about 500 m deep and increases to about 3,000–4,000 m at the western coast. The sediments on the platform are mainly terrestrial sediments, which started during the Late Triassic (T_3) until almost the recent late Quaternary (Q_{IV}). The sediments from the Late Cretaceous until the Miocene (K_2-N_1) are dominated by marine sediments.

The various types of lithological basis of landscape are defined according to the genesis and composition of sediments, to mineral content of underground water and to the effective time of the exogenous processes. The oldest sediments are limestones from the Upper Cretaceous, but also marl, sandstones and reddish-brown clay layers are known from that period. They are rather common all around and are uncovered by denudation on top of the anticlinal vaults and other arches (e.g. on the former islands of Vozrozhdeniya and Lazarev, on the Kulandy and Muinak peninsulas and along the eastern edge of Ustyurt Plateau, and on the southeastern banks of the Syr Darya adjacent to the Dzhusaly vault). The thickness of the Upper Cretaceous layers is between 220 and 270 m. The groundwater is slightly to strongly brackish (0.3–13%).

Most sediments are from the Lower and Middle Palaeogene – the Saksaulski and Cheganski stratification sequence of the Eocene and Lower and Middle Oligocene. The main rocks are sandstone, clay, pebbles and gravel. Those sediments are often strongly transformed by aeolian processes. The groundwater is saline (0.5–8.5%). The Eocene–Oligocene–Pliocene sediments on the former northern and western coasts of the Aral Sea form a typical unit of the lithological landscape basis, the denudation plateaus. In some parts also the Lower Miocene sediments belong to this type (carbonatic, colored clay of the montmorillonite type, aleuritic layers, quartzite stones and limestones). These sediment layers are rather resistant against denudation; they are responsible for the formation and stability of the flat plateaus and tables in the north and west.

In the wide valleys of the ancient rivers and in some of the furrows of the northern edges of the tableland, the formation of deluvial and proluvial sediments is prominent. Those landscapes and ecosystems in these dissected reliefs are very dynamic.

During the middle Pliocene the sea retreated. All over a continental development started. The eastern Aral Sea region became strongly influenced by erosion and accumulation, which was the basis for the formation of the present lithological basis. The rocks from the Miocene to the Pleistocene are found all over except on the anticlinals and some other vaults. The middle Pliocene sediments are present as deluvial-proluvial lenses and as rock debris infiltrated with loam. Above them, the later sediments from the Pliocene are sand layers with alternate layers of clay and silt, with lenses of gravel and clayey sand. The sediments from the Pleistocene and the Holocene are mainly sands of fluviatile and aeolian origin.

The alluvial sediments of the middle Quaternary with mixed yellowish-brown quartzitic and feldspar sands, with interlayers of carbonatic clay and silt, are the lithological basis of most landscapes of the lower Syr Darya, Zhana Darya and Amu Darya (except the deltas). These layers are about 40–60 m thick. The mineralization

of the groundwater is only 1–3 g/L. This Quaternary alluvium is present also on the western edge of the sands of Malye Barsuki and reaches the Aral Sea coast west of the village of Akespe. The alluvial layers in Akbidaik Bay amount to only 2 m.

The younger alluvium of the Syr Darya and Amu Darya deltas (Late Quaternary) with carbonatic clay, loam, loamy sand and sand is the lithological basis of this delta type. These sediment layers are about 3–20 m thick in the Syr Darya delta and about 30–40 m thick in the Amu Darya delta. The total load of sediments of the Aral Sea and its water exceeds 15 kg/cm^2. This coincides with the load value of the whole sediments (Mörner 1980).

The present landscape is characterized by considerable aeolian sands close to the coastal areas, mainly the Malye and Bolshie Barsuki sands, the Priaralski Karakum sands, and the Zhuvankum Kyzylkum sands.

According to the present erosion catena, the lowest parts presently are characterized by chemical sediments of the desiccated salt lakes and by solonchak soils. Here, loam, sandy loam and silt are mixed with salts or salt layers are included. Sometimes salt covers the surface. These mixed layers may be up to 8 m thick. If the groundwater is rather shallow, less than 1.5 m, the formation of solonchak soils is prominent. If it is more than 1.5 m, then crusty-puffy solonchaks are formed.

The marine deposits of the old Aralian transgression (Chap. 2) form their own type of lithological basis with fine and medium granular sands of grayish-yellow color. They are derived from the early Holocene. They exhibit intermediate layers of loam, sandy loam and clay, but often also with layers of shells. They are about 5–6 m thick. This layer is quite often also indicated by a partly or almost dissolved gypsum layer of 1.5–2 m with extraordinarily rich accumulations of shells and other marine fossils. Below this gypsum layer there is grayish and yellow sand without shells.

The youngest development started in 1960. Since then a new lithological type of silty sea sands with intermediate layers of greenish-gray clay, gypsum and sea shells has formed. This desiccated area of the seafloor since 1960 is now actively overformed by strong aeolian processes.

The desiccated seafloor sediments can be defined according to their composition. Slightly higher parts are more subjected to wind erosion than lower parts or slight depressions. In those depressions, accumulation of dust and sands takes place and solonchaks form. The edaphic processes there are very dynamic and the substrates exhibit transformations to lithological attributes similar to those of the former coastal areas.

3.4 Geomorphological Structure

The huge basin of the Aral Sea depression is part of a geological platform regime with weak tectonic movements and with the predominance of a dry climate. These are the reasons for extant accumulative plains, denudation plains and flat eroded table plains which are only very slightly dissected. The relative height differences

are normally between 10 and 30 m, but in the northwest they may be up to 100–350 m. The absolute elevations of the former coastlines are between 400 m above sea level (asl) in the northwest on the plateaus and 70 m asl in the southwest in the sand deserts. The lowest point is now the dry seafloor, which is about 25–28 m asl. The elevation amplitude of the Aralkum is between 25 and 58 m asl, including the old and new Aral terraces.

Berg (1902) and Gorodezkaya and Kes (1986) studied the geomorphological features of the coasts of the Aral Sea. They distinguished four geomorphological districts: the northern (north Aralian plains), the eastern (sand deserts Priaralski Karakum and Kyzylkum and the Syr Darya delta), the southern (the Amu Darya delta and the Sarykamysh basin) and the western (Ustyurt Plateau) districts.

In the north and west the Aralkum is limited by high structural denudation plateaus. North of the Aralkum there starts a tableland plain which is dissected by some terraced steps. These steps indicate the various phases of the big Palaeogene sea, with phases of continental denudation of this territory and with the direction of erosion towards the Aral basin. The elevation of this tableland plain is about 200–300 m asl; some relict islands from a former trunk mountain reach 300–400 m asl. There is a distinct steep slope of about 30–60-m height which is the delimitation to the lower denudation plain at 100–200 m asl.

Ustyurt Plateau in the west is delimited from the Aral basin by steep slopes (chinks) from the adjacent plains and the Aral Sea. In northern Ustyurt there is a tableland plateau with incrustations armouring the surface. The elevation is about 120–170 m asl (rarely up to 220 m asl). The shallow Sam-Kosbulak basin has an elevation of 70–100 m asl.

The big basin of the Aral Sea is divided geologically into two depressions: the Small Aral Sea depression in the north and the Large Aral Sea depression in the south. The Large Aral Sea depression is situated south of the former island of Kokaral (see Chap. 2, Fig. 2.6). The delimitation of both is caused by the "River Rapid of Berg", which is a distinct submarine dike. This dike became dry in 1986–1990, and is now the southeastern border of the Small Aral Sea. Both depressions have their own undulating or delimiting slopes of the seafloor.

The Small Aral Sea is strongly dissected into four basins forming distinct bays: the Great Sarychaganak, Butakov and Shevchenko bays and the middle main part of the Small Aral Sea. The Small Aral Sea is a small and shallow water body, which until 1960 was about one ninth of the whole sea area. About 42% of the area of the Small Aral Sea has a water depth of 10–20 m. The maximal depth was 29.5 m, the mean 13.3 m. Within the submarine vaults between the basins, the depth was only 12–14 m. The basins of the Small Aral Sea exhibit an oval or roundish shape with a shallow, rather flat U-profile and a flat central part. The area of the rest of the Small Aral Sea is 3,200 km^2 and the dry seafloor in the small depression has an area of 2,400 km^2 (part of the Aralkum).

The Small Aral Sea has a dyke between the Shevchenko and Butakov bays. The Large Aral Sea is now divided into the deep western basin and the shallow eastern basin, separated by the former island of Vozrozhdeniya which is now part of the mainland.

Before 1960 the Small Aral Sea and Large Aral Sea were one water body, connected by two water channels west and east of the island of Kokaral. The main role in water exchange between the two parts was played by the eastern connection, the "Berg Crossbar", a connection between both basins, named after the famous geographer L.S. Berg. It was about 15 km wide and 10–15 m deep. The northwestern connection between the former island of Kokaral and the Auzy-Kokaral peninsula was very shallow, only up to 1.0–1.5 m deep, and very narrow (up to 0.6 km).

The Large Aral Sea had an area of 60,000 km^2. It consisted of two basins divided by the tectonic vault of the former island of Vozrozhdeniya. The eastern basin is rather shallow, almost plain to a vast extent. The western basin is rather deep with steep slopes. This western basin is a deep sea furrow originally with a surface area of 13,000 km^2 and a maximal water depth of 64 m. The eastern basin originally had a surface area of 47,000 km^2.

The eastern basin was very large but was very shallow. Before the regression the center had a depth of about 20–28 m, with a mean depth of 14.7 m. The relief of the seafloor still exhibits the traces of old riverbeds and other water discharges, and of old accumulations of sediments from sand spits, sand bars and terraces. The plain relief of the basin in some northern parts is dissected by flat vaults and small steep slopes; in the central part it is dissected by some meridionally oriented long but flat ridges or dikes (2–3 m high).

The seafloor of the Aral Sea, similar to that of other innercontinental big lakes, is divided morphologically into three parts: shelf, slopes and basin. The shelf of the western coast is very narrow and has a distinct edge where the steep slope starts. The western basin is about 150 km long from Cape Baigubekmurys to Cape Dzhidelibulak. Its width is about 15 km in the south and 5 km in the north. The eastern slope, with an absolute height of 35 m, is also characterized by a sharp edge to the shelf; this edge demarcates an old coastline. The relief of the shelf is not flat but has several island dykes and submarine bars.

The shelf of the eastern Large Aral Sea exhibits several terraces. They are 34–35, 38–39 and 41–43 m asl, which corresponds apparently with old coastlines from ancient regressions. Since the 1980s these old coastlines have been visible because of the present desiccation process.

The Small Aral Sea morphologically only exhibits a shelf with a rather shallow and flat basin and slight vaults. The eastern part also exhibits slight stepwise terraces from older regressions. The desiccated seafloor at the western coast is about 2–10 km wide. At the north coast it is only 1.5–2 km wide at the capes and 5–10 km wide within the bays.

Along most parts of the former coast at the shallow parts (53–48 m asl, corresponding to 0–5 m original water depth, isobates) the substrate sediments are well sorted by wave activity and consist of sand. The relief was and is almost plain and not dissected. Many relict relief forms such as bars, sand spits and tombolos are present there. A tombolo is a deposition landform such as a spit or bar which forms a narrow piece of land between an island and a mainland shore, or between two islands. Tombolos usually form because the island causes wave

refraction, depositing sand and shingle moved by longshore drift in each direction around the island where the waves meet. Those older surface areas are practically desalinized. They are now subject to the intensive action of aeolian processes, such as deflation, sand transport and accumulation and dune formation.

Within the 5–7-m isobate line, the shelf is often somewhat steeper, indicating the transition to the submarine slope of the former Aral Sea. This is often indicated by a stepwise terrace of 0.5–0.8 m in height. The seafloor is often dissected by dykes and furrows, mostly composed of sand, which now on the desiccated part are again subject to strong aeolian processes.

Within the 7–13-m isobate, the desiccated seafloor is a slightly oblique plain at the eastern coast and the northern coast. The sediments are a mixture of sand, silt, loam and predominantly clay. Around the bigger islands (Barsa-Kelmes, Vozrozhdeniya), sand predominates. The relict relief forms with small flat hills at the eastern coast and netlike sculptured reliefs at the northern coast were caused by submarine abrasion processes. The morphometric differences of these relief forms are maintained by the differing intensities of the hydrodynamic processes and the slope angles below the water surface. The desiccated plains are now subject to halogeochemical processes (salinization, desalinazation Sydykov et al. 1983) and to wind effects (deflation, accumulation Gel'dyeva and Budnikova 1985, 1987).

Within the substrate sediments of the 13–20-m isobate area of the desiccated seafloor, we find predominately aleuritic (soft siltstone) and pelitic depositions. Nowadays, these substrates are also influenced by wind erosion and halogeochemical processes.

The newly formed land surface still exhibits the morphological structure of the seafloor with its relief form and abrasion character. Only the sandy coasts on the older desiccated seafloor are almost totally transformed by wind erosion and new sand dune landscapes have been formed.

3.5 Formation of the New Continental Plain (Dry Seafloor: Aralkum)

The strong lowering of the seawater level of the Aral Sea during the last 50 years changed the coastal dynamics. The desiccated soil sediments along the coast and the forms of the relief play an important role in the formation and development of the present landscape structure on the older seafloor. Studies on the actual landscape morphology of the former submarine coastal slopes and the dynamics of the present coastal displacement can reveal basic facts of these drastic landscape changes.

The present situation of the coasts of the Aral Sea and the changes along the fluctuating coastline are influenced by several factors and conditions. This is mainly the geological and the geomorphological activity of the Aral Sea basin as well as the adjacent mainland and the hydrodynamics (including wave intensity) of the

remnant water body. The character and the influence of the waves and the related water currents depend on the wind regime along the coast and on the coastal configuration as well as on the decline of the actual coast and the type of coastal sediments. Because the Aral Sea had and has a very long and flat coastline, the combination of these factors leads to a highly diverse coastal landscape picture.

In accordance with the classification of the coast of the Aral Sea, we can distinguish the following coastal types: abrasion coast, steep abrasion coast, smooth abrasion coast, undulating coast, smooth accumulative coast, dissected accumulative coast, undulating accumulative coast, and arid denudation coast. The development of the coastal zones of the Aral Sea within the last few millennia was characterized by frequent changes of the sea level. This is again in accordance with the diversity of coastal structures seen today.

However, within the last 50 years the coasts of the Aral Sea were subject to a strong and rapid decline of the seawater level. The actual desiccated seafloor has strongly changed from a submarine coastal slope to a shallow water level and then to desiccation. Between 1960 and 1970 the annual decrease of the seawater level was about 0.09–0.50 m. Within the ever-fluctuating and ever-retreating new coastline new abrasion as well as accumulative terraces developped. They are often formed synchronously, but at different height: abrasive terraces were formed above the coastline, whereas accumulation terraces were formed below the coastline. Further retreating sea-level may cause erosion of the newly accumulated sediments again. Those complex retranslocation processes may result in a mosaic of various terraces according to changing wave-action. Then these terraces are often only shortly visible.

In general, abrasion of the lower coastal slopes is observed with transport of the sediment particles to the upper water level, which is the main process in the formation of beach lines by accumulation of submarine sediments from the coastal slopes.

The areas of the islands and of shallow underwater hills strongly increased as a result of the shrinking water level. The huge shallow ponds and plains close to the eastern coastline were enriched by accumulative sediments. Thus, underwater shelves were formed. During the 1970s (since 1972) the lowering of the sea level was about 0.6–0.8 m annually. Then accumulative relief forms of the sea came to light (underwater shelves, promontories, sand spits, tombolos), and these were partly preserved by the salt crusts, but later were changed by aeolian activity. Because of the very low slope angle at the eastern coast, huge seafloor areas became dry annually.

Since 1978, several abrasion terraces have become visible; they were formed earlier by submarine abrasion. Along the western coast as well as at the northern coast the disappearance of those terraces and cliffs was prominent. The ongoing desiccation and lowering of the water level brought those terraces to upper parts of the slopes, becoming inactive geomorphological structures. Now most of the newly formed coastal structures are accumulatively formed. Only small parts of the present retreating coastlines are still active abrasion coasts, mainly at the capes of the northwestern and western coasts.

The shrinking of the sea surface area led to a total change of the coastlines. This was the case especially along the flat eastern coast (Fig. 3.1). All the large bays such as Akkol, Bozkol, Dzhyltyrbas, Dzhyltyrbas and Muinaksky and many smaller bays became dry. All islands became part of the mainland (Vozrozhdeniya, Barsa-Kelmes, Kokaral). New islands were formed for short times where submarine bars or vaults were, but rather soon also became part of the new mainland. Also, in the Small Aral Sea (North Aral Sea) many small bays and lagoons became dry. Great Sarychaganak Bay in the northeast was completely dry. The big bays of Butakov and Shevchenko were connected with the main part of the Small Aral Sea only by small sea channels.

The recent coasts of the remnant water bodies of the divided Aral Sea are mainly of only one coastal type: they represent a typical smooth coastal border. This coastal border is characterized by a broad belt of recently desiccated flats and seafloors which are covered in the first few years by a dense halophytic, annual vegetation (Chaps. 9 and 10). The middle and upper parts of this coastal belt are regularly bare of vegetation and the loose sedimental substrates are subject to wind erosion, except at those sites where groundwater is leaking and new springs have developed (Zektzer et al. 1973). Of course, the formation and character of these coastal borders depends on the composition of the sea sediments and the actual processes forming the relief (aeolian, halogeochemical, pulverization). The seafloor

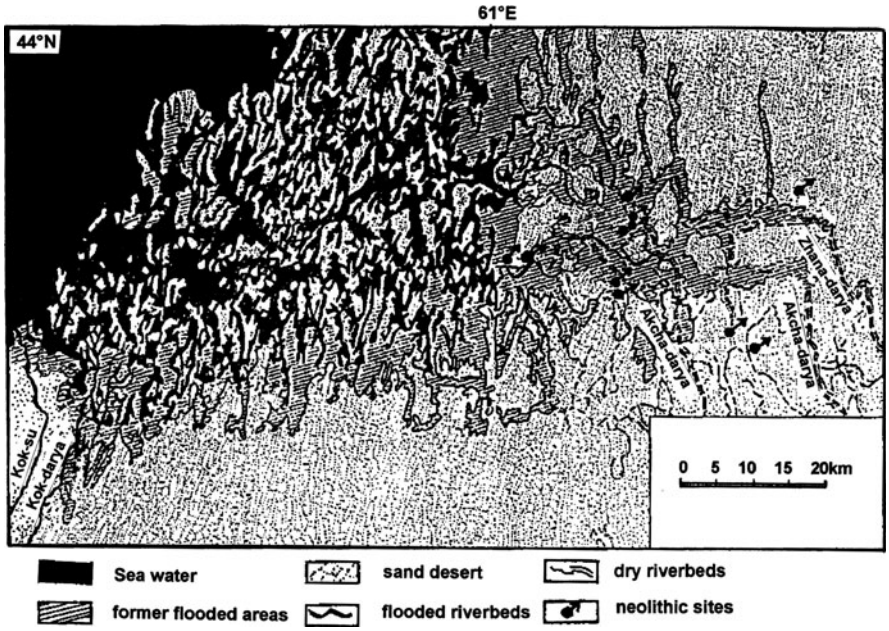

Fig. 3.1 Part of the southeastern coast of the Aral Sea around Akpekti formerly with numerous islands and bays, demonstrating the amphibiotic dynamics of a very flat coastline (Modified from Letolle and Mainguet (1996))

sediments exhibit a great variety of types: sands, aleurites, clays, shell limestones, shells, gravel, pebbles and other detritus (mainly near the abrasion capes at the northwestern and western coasts). Since 1984, mainly aulerite (rich in limestone and phosphorous), silt (at the eastern coast), clay and loam in most bay areas of the north became uncovered. Along some of the islands (Barsa-Kelmes) also sand deposits became desiccated. On all desiccated flats from the last 20–30 years, a thick crust of salts and salt powder developed on the deposits by water evaporation.

The sediments along the northern coast bays are composed of sand, silt and loam. It is remarkable that since the beginning of the 1980s a very rapid change of all the hydrodynamic and hydrochemical processes with continuing retreat of the water level has taken place and reduced the accumulative relief forms of the sea tremendously.

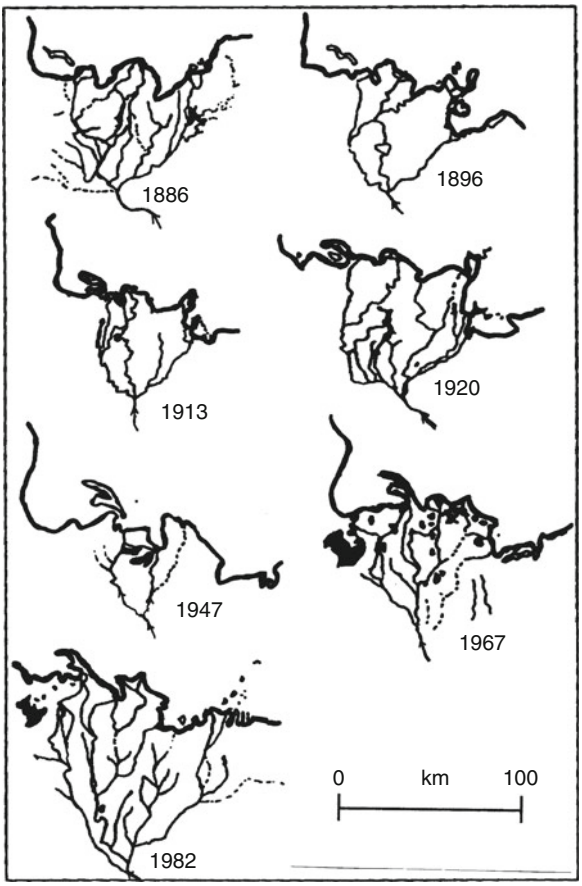

Fig. 3.2 The great variability of the delta of the Amu Darya between 1886 and 1982, indicating an increase in area caused by sedimentation but even more by the retreat of the coastline, land connections to former islands and the disappearance of delta lakes (Modified from Letolle and Mainguet (1996))

3.6 Delta Areas of the Dry Seafloor

The main tributaries to the Aral Sea, the Amu Darya and the Syr Darya, produced large delta areas on the flat plains. Their sand and silt sediment load is huge and thus those slowly growing deltas formed wide amphibiomes with always changing river courses (Fig. 3.2). During the desiccation process of the last few decades, on the one hand, the amount of water delivered to the Aral Sea was much lower than earlier and, on the other hand, the water courses became longer and longer and the old delta areas were partly channeled by river erosion. The lowering of the groundwater has led to a severe dieback of tugai vegetation. As long as water is flowing and reaching the remnants of the Aral Sea, new small deltas are formed again in lower parts. The Syr Darya has already formed a new delta in the North Aral Sea north of the new dam. Since those delta areas were formerly very important stands of extensive tugai shrub vegetation with very diverse wildlife, there is hope that the new deltas will be colonized by tugai species as well and that recovery of parts of the tugai areas may take place.

3.7 Conclusions

The geomorphological features of the new desiccated seafloor as a new continental area (Aralkum) are governed by geohalomorphic and aeolian processes. The vast-plain open sea bottom is not totally plain; it exhibits old submarine channels, hills, ridges, sand splits and tombolos, which are now overformed. Mainly the older seafloor, which became desiccated before the 1980s, is characterized by sandy substrates; the younger seafloor, which came to light after the 1980s, is sandy, silty or clayey, but is more or less strongly salinized. Ninety-seven percent of the Aralkum area is situated in the big Aral depression south of the former Kokaral peninsula (and including it) and 3% of it is situation in the small Aral depression around the Small Aral Sea.

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