Morphology & Evolution of the Subarnarekha Delta, India

By D. Niyogi

Abstract

A description of the Subarnarekha delta based on air photos and field-research. The development is analyzed and a hypothesis is given concerning the deltaic cycle. In the delta-formation marine forces have a dominating influence.

A detailed geomorphic investigation of the coastal areas of Orissa and West Bengal along with that of the lower reaches of some prominent river valleys was started in 1962. Since December, 1965, a grant from the Council of Scientific and Industrial Research was available for this purpose. The study of the Subarnarekha delta was undertaken as part of this regional geomorphic investigation. Though small in size as compared to the two adjoining deltas, viz. the Ganges and the Mahanadi-Brahmani-Baitarani deltas, the study of the Subarnarekha delta is particularly interesting for the clarity of the landform units composing the delta as well as for the completeness of the delta form. The purpose of the paper is to describe this deltaic association of landforms as well as to interpret the modes and stages of formation of this delta.

Location of the Subarnarekha delta: The delta of the Subarnarekha is situated about 150 km South-West of Calcutta, where the river Subarnarekha flows out into the Bay of Bengal (Fig. 1). The main portion of the delta is situated within the state of Orissa, only the eastern fringe falling within the adjoining state of West Bengal.

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Fig. 1. Localization of the Subarnarekha Delta on the east coast of India between the Ganges-Brahmaputra Delta and the Brahmani-Mahanadi Delta.

Fig. 1. Subarnarekha Deltaet på Indias østkyst mellem Ganges-Brahmaputra Deltaet og Brahmani-Mahanadi Deltaet.

The geomorphic study was initially undertaken on air photos which were available for the entire area on 1:30.000. The assembly and interrelationship of landform units were, in the first instance, studied on the air photos. Detailed morphologic study of each of the landform units was later on carried out in the field. Data interpreted from air photos which were thus checked in the ground were then transferred after necessary corrections, to a base map (scale 1:30.000 or 3.33 cm = 1 km) with the help of a sketchmaster. The Survey of India topographic sheets (scale 1 inch to 1 mile or 1.65 cm to one km) were of invaluable aid in preparation of this base map. This morphologic study of the delta was subsequently followed up by granulometric studies of sediments composing different geomorphic units, as well as by careful levelling along a radial profile along the east bank of the river Subarnarekha. In addition long stretches of the southwestern and northeastern shoreline beyond the delta have been studied to understand the regional geomorphic background of the delta.

Regional Setting of the Subarnarekha Delta

The nearest rock exposures are around Nilgiri, about 60 km west of the delta, which represent the farthest northeastward extension of the Eastern Ghats. Interspersed with recent alluvium and prac-

tically indistinguishable from it occur Upper Tertiary marine unconsolidated sediments between Nilgiri and Balasore, as well as on the western bank of the Subarnarekha about 30 km north of the delta. Tops of these sediments are lateritized in a patchy manner. The age of laterisation is generally believed to be Mio-Pliocene. The Upper Tertiary sediments appear to have a low dip towards the southeast, and are overlain by Pleistocene alluvial sediments which are in turn overlain by fluvial and marine sediments of recent age.

From a geomorphic point of view, the delta is situated along the sandy shoreline between the silty clayey fringes of the Ganges delta on the northeast and the clayey Mahanadi-Brahmani-Baitarani delta on the southwest.

The river Subarnarekha rises from the eastern slopes of the Ranchi plateau in the central portion of the state of Bihar at an altitude of about 675 m (2200 ft) above Mean Sea Level. Following the Tropic of Cancer roughly for about 80 km (50 miles) in an easterly direction, the river takes a southward turn and then flows approximately in a southeast direction until it meets the Bay of Bengal; the length of the river is approximately 385 km (240 miles). The climate of the entire basin is humid tropical, the average annual rainfall being 165 cm (53 inches). The average diurnal tidal range in the adjoining areas of the Bay of Bengal is about 4.31 m (14 ft).

Morphology of the Delta

The Subarnarekha delta is a nearly symmetrical delta with a width of about 17 km (11 miles) and a lateral extension of over 50 km (32 miles) stretching from Kalasimli in the west to well beyond Digha in the east. The approximate orientation of the delta is eastnortheast-westsouthwest. The solitary channel swings its way through the many sandy ridges.

South of Khanpur the river has progressively shortened its course, thereby casting off two meanders. The river is currently in the process of casting off the third meander near Nayabali. Southeast of Nayabali, another meander has been abandoned to the east. Further south the river has executed a sweeping bend and ultimately meets the Bay with an acute angle pointed southeast. On the eastern flank of the estuary a 3.3 km (2.1 mile) wide deltaic flat is present behind a number of barrier bars. West of this deltaic flat the talweg of the river is seen to take a southwesterly turn.

The delta of the Subarnarekha is primarily made up of a series of sandy ridges interpreted to be ancient beach ridges and barrier bars, situated on silty or clayey marine terraces which appear to represent ancient lagoons. At places where the terrace is sandy, it probably represents ancient beach. Most of these sandy ridges have since formation been activated by the wind and have been converted to dune ridges.

1. Beach ridges and swales: Beach ridges are comparatively low, nearly parallel ridges produced mainly by wave action parallel to present and ancient shore configurations. The height of these ridges is controlled by the height of the waves, the texture of the material as well as by the antiquity of the ridges. In the present area these ridges are 4-9 metres high. Older ridges are somewhat lower due to subsequent subaerial erosion.

These ridges are invariably wider near estuaries where the average width is 50 m (59 yds), and gradually narrow down as one proceeds away. Where beach ridges contain silt in addition to sand, rivers flowing in the interridge swales have deposited elongated bodies of silt which are visible on air photos as dark grey stripes alternating with light grey lines representing beach ridges.

Beach ridges being always parallel to the existing shoreline, are faithful recorders of previous shore configurations. The Subarnarekha estuary area shows a complicated attitude: on eastern and western banks of this river respectively seven and five belts of beach ridges are visible. The widest beach ridge belt is over 1.75 km (1.1 mile) in width and contains seven lines of beach ridges.

The tendency for formation of beach ridges is not visible anywhere along the present shoreline studied.

2. Barrier bars and spits: These are elongated bodies of sand deposited in offshore position mainly through the action of littoral current. At first these bars are under water; later on waves, perhaps, are responsible for pushing these above water. Some of the bars are connected to the land and are termed spit.

As soon as a submerged bar approaches the high tide level, it forms a barrier to the waves. Finer material are deposited in the lagoon formed behind the bar. Gradually the lagoon gets filled up and is converted to deltaic tidal flat, as is the case near the present mouth of the River Subarnarekha. At present one or more submerged barrier bars are visible in the deltaic zones within the present area.

The distinctive features of the bars and spits are the relatively coarse-grained (sandy) character, linear arrangement with reference

to the shoreline and the association with silt/clay deposits on the landward side. On the basis of these features may lines of barrier bars corresponding to previous shorelines have been interpreted in the Subarnarekha delta; these fully resemble barrier bars growing in the present day.

3. Coastal dunes: Sand bodies as beach ridges and emerged barrier bars have been activated by the prominent wind blowing from the southsouthwest with the production of hairpin and transverse dunes. Dunes along the present shoreline vary in heights from 1-2 metres up to 15 metres, and are more prominent in the eastern half of the delta.

Ancient dunes are also seen along previous shorelines. Practically all ancient beach ridges and some barrier bars have been partly or wholly converted into dunes. This is the reason of the crenulated landward margins of many of the beach ridges and bars which as a rule show a straight seaward margin.

Nearly constant orientation of the present-day and ancient dunes indicates a constant wind direction over the last 3000 years.

4. Marine terraces: The above mentioned landforms are situated on a number of marine terraces. These are either sandy or silty, or are a mixture of sand and silt. Initially these were formed as coastal plains by marine agencies alone or through a combination of marine and fluvial agencies. Uplift of the land relative to the sea finally gave rise to these terraces in successive phases.

Silt-clay materials shoreward of barrier bars are tidal flat deposits formed on the leeward side of the bars. Silty features shoreward of beach ridges evidently represent fluvial sediments: meander scars (as at Nayabali, on the east bank of the River Subarnarekha) and filled channels are often visible on marine terraces, particularly on air photos, and supply the tell-tale evidence of origin.

Some sandy portions of marine terraces which neither show ridged top nor are flanked by lagoonal clays on the landward side, have been interpreted as ancient beaches.

In absence of detailed survey the actual number of marine terraces can only be approximately stated. Preliminary survey indicates three terraces. The level of the lowest terrace is more or less accurately known. The undulating top of this terrace shows a thin, mildly lateritized, brown-spotted soil profile and is situated on an average 3.8 m above the M.S.L. There are probably two more terraces, one 4.7 m and the other 6.1 m above M.S.L.

5. Deltaic Flat: The present-day deltaic flat has advanced nearly 2 miles or 3.2 km into the bay and contains at least four visible barrier bars and at least one submerged bar which is visible during low waters. The flat has a major westerly inlet and a subsidiary inlet to the southeast. Remarkable is the fact that the deltaic flat has grown only on the eastern margin of the Subarnarekha estuary.

Littoral drift: The angle of meet of the Subarnarekha with the sea gives a misleading impression about the littoral drift. The shape and disposition of the barrier bars and the deltaic flat coupled with the attitude of the talweg of the river across the intertidal zone, which can be distinguished on air photos (marked by an arrow on Fig. 2), clearly indicate that the river has executed a right-angled bend here, and the littoral drift is in the opposite direction, viz. northeast to the southwest. Similar attitude of the estuary configuration is noticed in three other rivers situated to the west of the Subarnarekha, as well as in four rivers situated to the east, in each both estuary configuration and the attitude of talweg (marked by arrows on Fig. 2) clearly point to a southwesterly littoral current.

Recent shoreline changes: A comparison between the attitude of the shoreline in the Survey of India topographic map (1931), aerial photographs (1952) and the present-day attitude of the same reveals the recent trends of changes and also the rapidity with which such changes are brought about.

In the Subarnarekha estuary (Fig. 2) the bold line indicates the 1952 shoreline (high water line) as studied on air photos. In 1931, the shoreline was situated nearly 0.8 km (0.5 mile) inland, bordering the next inner bar. In 1968, on the other hand, the shoreline has moved a similar distance seaward and is currently bordered by the next seaward bar. Apparently the delta is advancing into the sea by depositing a succession of bars.

Landform sequence in the Subarnarekha estuary:

The series of beach ridges found between Khanpur and the river mouth have here been interpreted as marking successive positions of a receding shoreline. The sequence of events have been somewhat different on the two banks of the river: the eastern bank reveals as many as seven or eight lines of beach ridges alternating with bars, while the western bank shows five lines of beach ridges, bars being present only along the last line. Shorelines starting with the earliest that passes through Khanpur and Nangaleswar have been given sequential numbers (Fig. 2).

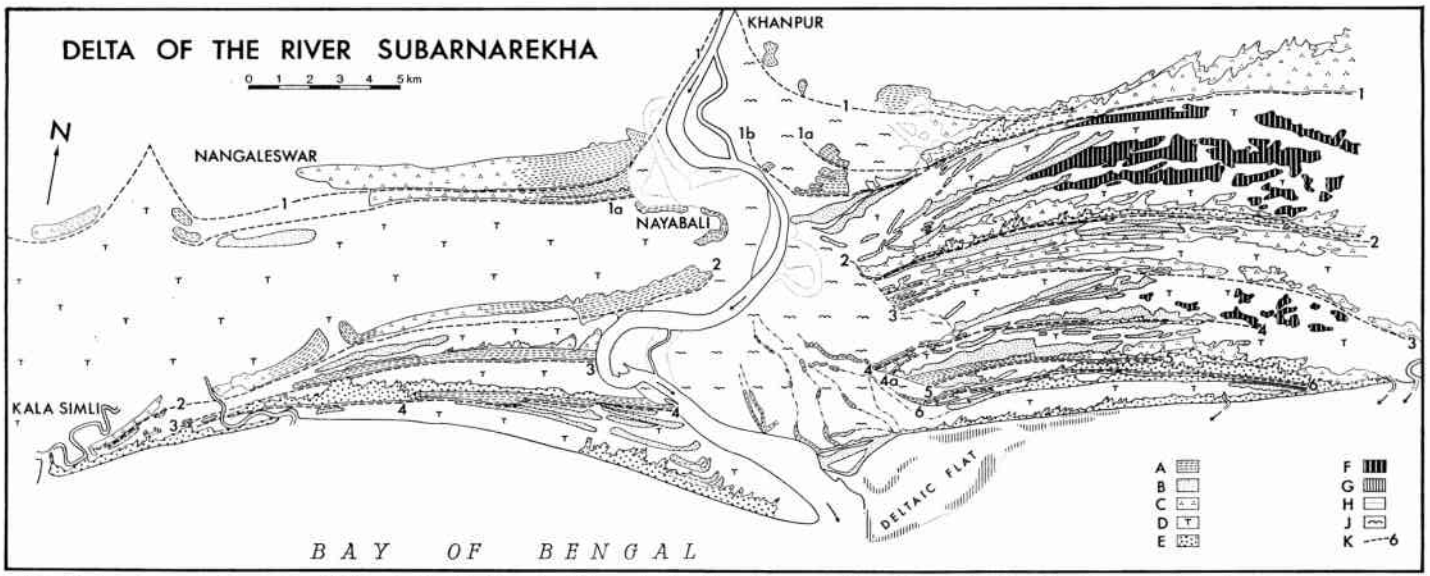

Fig. 2. Landscape elements of the delta. A. Beach ridges, indicating former shorelines. B. Barrier bars. C. Marine terrace, sandy. D. Marine terrace, silt-clay. E. Dune ridges. F. Irregular sand patches. G. Submerged bar. H. Natural levee. J. Fluvial terrace. K. Ancient shorelines. Figures indicating development stages.

Fig. 2. Subarnarekha Deltaet er et strandvoldsdelta, en type, der fremkommer, når deltadannelsen sker på en kyst, hvor stærke marine kræfter gør sig gældende. Deltaets landskabsformer: A. Strandvolde, vidnesbyrd om kystliniens tidligere beliggenhed. B. Barre-øer, udviklet af sandrevler på strandplanet. C. Strandplan af sandaflejringer. D. Strandplan af silt og ler, fremkommet ved udfyldning af strandsøer og senere relativ hævning af området. E. Klitrækker, nuværende og tidligere kystklitter med vindbrud og parabelklitter. F. Uregelmæssige ophobninger af revlesand. G. Revler. H. Naturligt floddige, levee. J. Delta-flade, opbygget af flod-aflejringer. Relieffet præget af levee-strukturer, der vidner om flodløbets ændringer som følge af mæandreringen. K. Tidligere kyst-linier. Numrene angiver udviklingsfølgen. Deltaic flat = Submarin deltaflade. D. Niyogi, del.

Character of the Subarnarekha Delta

A study of the geomorphic map of the Subarnarekha delta reveals the following features:

1. The delta is of an asymmetric nature for in the western half only beach ridges are seen running through the marine terrace; barrier bars are present only seaward of the last beach ridge (No. 4).
2. The eastern half of the Subarnarekha delta, on the other hand, shows a regular alternation of beach ridges and bars except in the case of the first shoreline (no. 1 and 1 A). Six regular cycles of beach ridges alternating with a variable number of bars are visible (Table 1).
3. The first shoreline (No. 1) along with the two adjoining shorelines (No. 1 A and 1 B) are typical ria type submergent shorelines with deep landward pointed inflections (as at Khanpur and Nangaleswar) controlled possibly by the size of the rivers. The estuaries were probably moderately deep and wave action appears to have been the dominant marine agent which may explain the absence of barrier bars.
4. The shorelines 1 A and 1 B come within a short distance seaward of the first. In fact the beach ridges corresponding to 1 A and 1 B are for long distances attached to those of the earlier series. Beach ridges of 1 A and 1 B are prominent only near the estuary, and indicate that the tendency was to gradually fill up the drowned valley and straighten the ria shoreline.
5. The nine series of barrier bars formed seaward of the shoreline 1 B bear distinct resemblance to the bars forming at the river mouth at the present moment. Filling up of the estuary might have been responsible for the formation of barrier bars.
6. The second shoreline (No. 2) is quite close to the shoreline 1 A in the eastern half of the delta; in the western half this shoreline is separated from the previous one by a gradually widening terrace.

   West of the river, this shoreline is represented by beach ridges, while to the east, due to the absence of ridged surface, the landform has been termed marine terrace. This shoreline has given rise to a very prominent line of fossil dunes.
7. Marine aggradation straightens the shoreline 2 and gives rise to shoreline 3. Delta building by the Subarnarekha starts in the real sense onwards from shoreline 3.

8. Shoreline 4 shows a distinct seaward bulge.
9. The present shoreline which is further bulged out has been shifted seaward in the recent years by accretion of a number of bars.
10. When shoreline 4 was in existence, the river used to flow in an easterly direction. Since then, keeping pace with the gradual seaward shift of the shoreline, the river mouth progressively shifted westwards by a total distance of 7 km (4 miles), all stages of this shift being faithfully recorded in a series of natural levees. This westward shift of the river mouth was probably brought about by a westerly littoral drift.

Growth of the Subarnarekha Delta

It is well known that a series of coastal and offshore investigations in a number of European and American centres has established that during the Pleistocene, the sea level was lowered by a variable amount during each glacial phase and was again restored in the following interglacial phase. Radio-carbon dating method has fixed the last lowering of the sea level at about 25.000 B.P. Since then the sea level started coming up, rapidly at first, up to about 8000 B.P. After this, the sea level appears to have risen slowly and to have become more or less stationary at the present level between 2000-5000 B.P. There is no concensus of opinion on this latter issue, probably because of other complicating factors as independent rise of the land surface and sinking of the offshore sea bed.

The submergent character of the shoreline 1 with a deep landward inflection indicates that this was evidently the post Pleistocene shoreline at which the sea level stabilized. This was the beginning of the Subarnarekha delta which appears to have grown in the following manner:

1. The first stage after the restoration of the sea level was the filling up of the drowned river valleys and formation of the beach ridges onshore (shoreline 1).
2. This led to a gradual straightening of the shoreline (shoreline 1 B), when by accretion of nine barrier bars the delta advanced seaward.
3. After this, a mild submergence again produced a subdued ria-type shoreline (No. 2) which is recorded by beach ridges followed by one barrier.

4. The next shoreline was again straightened when three lines of barriers were accreted.
5. At shoreline 4 the deltaic bulge is visible. Until now, the accretion of barriers had taken place only on the eastern side. At shoreline 4, two lines of barriers were formed on the eastern side and deposition of barriers start also on the western bank.
6. After this, two more lines of beach ridges (5 and 6) alternating with bars are seen on the eastern bank, which are followed at present by four more barriers, in course of which the total advance of the deltaic front on the eastern bank is nearly 5.3 km (3.3 miles). On the western bank, however, the total land accretion is only by 2.2 km (1.4 mile) which is entirely in the form of barriers.

Thus delta-building which evidently took place after the last rise of sea level, consisted mainly of a cyclic alternation of formation of beach ridges and formation of bars.

The deltaic cycle: This cyclic alternation is visible only on the eastern bank of the Subarnarekha; on the western side only five lines of beach ridges alternating with terraces are visible. Another remarkable feature is asymmetry of events after shoreline 4.

It thus appears that while conditions for formation of beach ridges (strong waves) and bars (littoral current) were alternately created on the eastern bank of the Subarnarekha, only the conditions for formation of beach ridges were generally present on the western bank.

In absence of detailed levelling it is not possible to fully interpret this asymmetric pattern of deltaic cycle exhibited here. Since the sea level has remained sensible constant during the growth of the delta, it is probable that both subsidence of offshore bed due to compaction of sediments and filling up by sedimentation may have been operative alternately and thus created conditions for formation of beach ridges and barriers respectively.

Conclusions and Comments

The Subarnarekha delta is thus a dominantly sandy complex developed in an environment controlled by waves and littoral drift when, respectively, beach ridges and barrier bars were formed. The exact causes of asymmetry on the two banks are unknown. The landform complex of the Subarnarekha delta is comparable to that of the Rhône delta, particularly of the little Rhône.

It may not be inappropriate at this point to compare the morphology of the Subarnarekha delta with that of the two adjoining deltas. The landform complex of the Ganges delta is quite different due to the fine size of the materials involved as well as due to a different energy set-up. The compound delta of the Mahanadi-Brahmani-Baitarani, on the other hand, reveals a number of beach ridges though the grain size of the materials is somewhat finer than in the case of the Subarnarekha.

Dansk sammendrag og kommentar

Subarnarekha-Deltaets landskabsformer og udviklingsforløb

Indias østkyst præges af de store deltaer. Fig. 1 viser Subarnarekha Deltaets beliggenhed. På grundlag af flyvebilleder har landskabselementernes mønster kunnet udtegnes i hovedtræk. Derefter har feltundersøgelser kunnet planlægges og observationer foretages vedrørende jordbundstyper, relieffets detaljer, niveauforhold og de recente faktorer af betydning for deltaets vækst: flodsedimenter, materialvandring, bølgekræfter, strømvirkninger og tidevandsforhold. Bortset fra selve flodløbet må dette tropiske sump- og klitområde betegnes som yderst vanskeligt tilgængeligt. Undersøgelsens resultat er det geomorfologiske kort, som gengives i fig. 2 og en forklaring på deltaets særprægede udvikling. Denne hypotese har betydning langt ud over den lokale, idet den belyser en række forhold af almindelig interesse for tolkning af deltaer af den type, der fremkommer, når deltadannelsen sker på en kyst, eksponeret mod et udstrakt havområde, hvor stærke marine kræfter gør sig gældende: strandvoldsdeltaet eller Tiber-typen (sml. Paraibaflodens delta i Brasilien, beskrevet i afhandlingen Baixade fluminense, G.T. bd. 57). Subarnarekha Deltaet afviger fra hovedtypen ved at være asymmetrisk på karakteristisk måde. Deltaets østlige del er således præget af de mange konformt orienterede strandvoldssystemer med klitrækker og mellemliggende smalle fladestriber, udfyldte laguner: en strandvoldsslette af ryg- og lavningstypen. Deltaets vestlige del afviger herfra ved dominansen af de udstrakte flader, udfyldte store strandsøer, afgrænset mod Det Bengalske Hav af et system af mod øst divergerende strandvoldssystemer: en strandvoldsvifte. Mellem disse to marint prægede terræntyper ligger det centrale, fluvialt udformede område, der helt igennem består af flodsedimenter, og hvis overfladerelief præges af de mange forlægninger af flodløbet, mæandreringen, og dennes konsekvenser i form af gennemskæringer med hesteskosøer som følge, forhold der ses af leveestrukturerne.

Den dominerende materialvandringsretning er øst mod vest, hvilket forklarer den store tilførsel af materiale med deraf betingede opbygning

af strandvoldssystemer øst for flodudløbet. Også revledannelserne på kanterne af det submarine delta øst for flodudløbet vidner om materialvandringens hovedtendens. Floden bryder materialvandringsstrømmen langs kysten, idet store dele af sandmaterialet, suspenderet i de udstrømmende vandmasser, føres bort fra kysten vest for udløbet.

Det er ejendommeligt, at flodens aktuelle udløbsretning ved første øjekast på kortet kunne tydes som en udløbsforlæggelse mod øst fremkaldt af en kraftig materialvandring vestfra. En sådan foregår også af og til, hvilket ses af de krumoddestrukturer, der forekommer i kystlandet umiddelbart vest for udløbet. Flodens udløbsretning har imidlertid skiftet mange gange som følge af mæandreringens dynamik, og det er denne, der alene er årsag til udløbets nuværende retning. Flyvebilleder viser også tydeligt, at flodvandet bøjer skarpt mod vest efter udløbet; det samme er tilfældet for de mindre vandløbs vedkommende i deltaets østlige del (angivet med pile).

Kystliniens udvikling viser en række stadier begyndende med en typisk rias-kyst, kystlinie 1, med tragtformede æstuarier ved Khanpur og vest for Nangaleswar, formentlig svarende til et højt havniveau i tertiær eller interglacial tid. Kystlinierne 1 a og 1 b vidner om rias-kysttypernes stadige eksistens, omend æstuariet er indsnævnet, medens de følgende kystlinier 2 til 6 alle antyder en udbygning af kystlinien på æstuariets tidligere plads som resultat af deltaets vækst. Disse strandliniers abrupte afskæring forklares ved floderosionen i mæandrenes ydersving og giver således dimensionerne af mæanderbuerne forsåvidt som maximale udsving her er registreret.

Det påpeges, at Subarnarekha-Deltaet i type afviger fuldstændig fra Ganges-Brahmaputra Deltaet, der har karakter af et æstuariedelta. Årsagen hertil er dels sidstnævnte deltas beskyttede beliggenhed inderst i havbugten, hvorved marine kræfter bliver uden større betydning for udviklingen, dels det langt mere finkornede materiale som de heromhandlede floder medfører. *Axel Schou.*