The Upper Quaternary Deposits
of the Changjiang Coastal Plain
-Shanghai area-

By Cecile BAETEMAN

with the collaboration of
Frieda Bogemans, Evelyn Govaert,
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under the direction of
Prof. Dr Roland PAEPE

Belgian Geological Survey - Earth Technology Institute,
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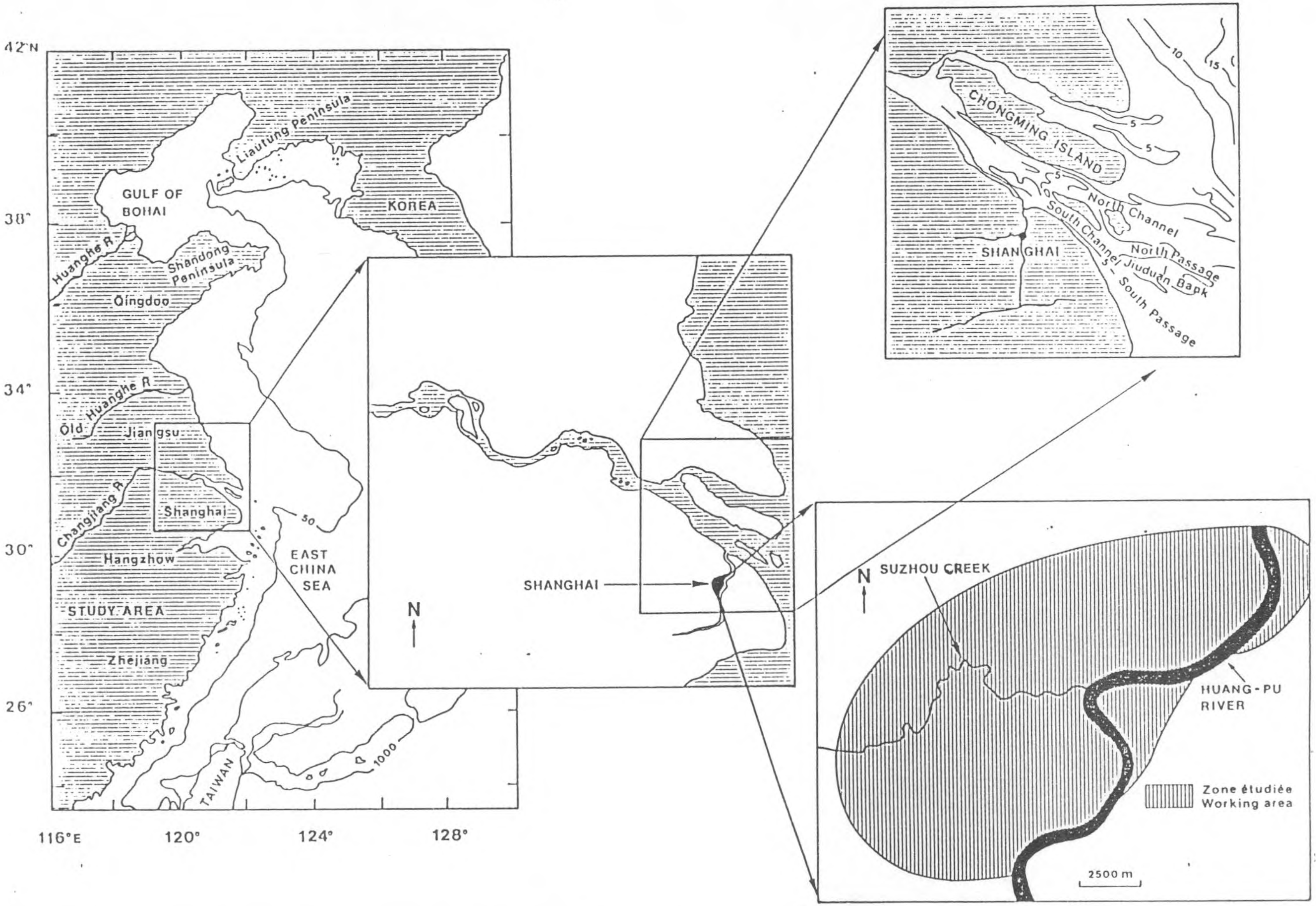


fig. 1. Location of the city of Shanghai and the Changjiang coastal plain

1. General introduction

The city of Shanghai is situated in the vast low lying coastal plain bordering the East China Sea in the East and characterized by the lower reach of the Changjiang (Yangtze) River (fig.1). The river debouches into the East China Sea just north-east of Shanghai.

The Changjiang represents an extreme within the context of present day rivers because of both its large size and high suspended load. The Changjiang is the fourth and fifth largest river in the world in terms of mean sediment and volume discharge, respectively (Table 1). It is also unique because it empties onto a comparatively wide, shallow and open continental shelf, characterized by a submerged relic river valley system (Milliman & Jin Qingming, 1985). The East China Sea is in general noted for strong tidal currents and low energy waves.

The Changjiang river is the largest river in China (about 6300 km long) and forms a primary source of sediments of the continental shelf of the East China Sea, especially the inner shelf. The fine-grained nature of the nearshore sediments results from the very high rate of influx of riverine sediment which overcompensates for reworking by storms and tides. In terms of its influence on the general hydrographic character of the estuary, tidal phase is as important as the amount of river runoff. However, river runoff is the dominant factor in controlling sediment transport to the ocean.

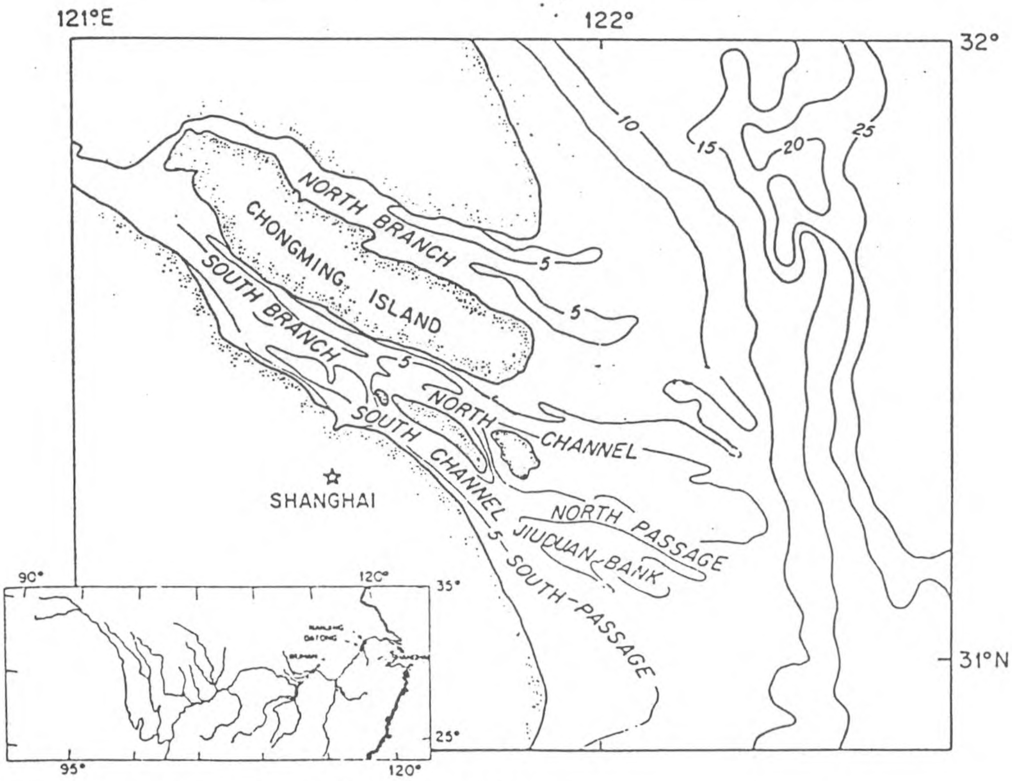
Because of the 2 to 4 m tidal range, the modern Changjiang estuary is a mesotidal estuary. The channelized flow is characterized by a triple bifurcation, branching first into North and South branches around Chongming Island; the South Branch dividing into North and South channels; and finally, the South Channel branching into North and South passages. At and near the river mouth, a broad bar system has developed (fig.2).

Ten largest rivers in the world (in terms of sediment discharge to the world oceans). Only the Changjiang, Amazon, and Mississippi rank among the world's top 10 rivers in sediment discharge, water discharge, and drainage area

River	Average sediment discharge (10^6t y^{-1})	Water discharge (km^3 y^{-1})	Drainage area ($\times 10^6$ km^2)
1. Ganges/Brahmaputra	1670	971	1.48
2. Huanghe (Yellow)	1640	56	0.75
3. Amazon	900	5519	6.15
4. Changjiang (Yangtze)	478	979	1.80
5. Irrawaddy	285	428	0.43
6. Magdalena	220	237	0.24
7. Mississippi	210	580	3.27
8. Orinoco	210	1007	0.99
9. Huanghe (Red)	160	123	0.12
10. Mekong	160	470	0.79
Totals	5373	10,331	16.02
World totals	13,505	37,400	102

(from Milliman & Jin Qingming, 1985)

Table 1



(from Milliman et al., 1985)

fig. 2 The Changjiang River mouth and its channels

The Changjiang transports its sediment to the ocean through the South Branch of the estuary. At present the North Channel of the South Branch is the major conduit of sediment. The South Passage of the South Channel is a site of rapid accumulation, in large part because of landward transport of sediment during much of the year. The North Channel has been the major conduit for the seaward flow of river water since 1966, whereas the South Channel is dominated by flood-tide flows.

In contrast to the prograding south bank, sand bars and islands along the north bank have showed a tendency towards lateral accretion. As a result of the growth of shoals along the south bank and merging of sand bars into the north bank, the estuary has narrowed considerably. The present width at the outfall of the estuary reaches about 90 km.

About 40 % of the Changjiang sediment is accumulating presently through seaward progradation of sand and mud banks in the outer estuary. Shoreline accretion appears to account for < 5 % of the total Changjiang load. In recent years most land accretion has occurred along the sand bank separating the North and South Passages of the South Channel; the north and south shores along the South Branch are presently eroding (Milliman & Jin Qingming, 1985).

Although the Changjiang's load is considerable, there is no classical offshore delta comparable to that e.g. off the Mississippi. The fine-grained material, with only about 30 % of the load coarser than 10 μ (Milliman,*et al,* 1985), extends in a plume-like pattern onto the shelf from the Changjiang.

According to the physiographic classification proposed by Fairbridge (1980) the Changjiang estuary belongs to a funnel shaped coastal plain type (fig.3), characterized by elongate, tidal sand ridges, oriented parallel to tidal currents and to the onshore-offshore directions (Hayes, 1975) (fig.4). Such sand ridges are often noted as *estuary mouth shoal* or *estuary entrance shoals.*

All these features of the river mouth clearly delineate the

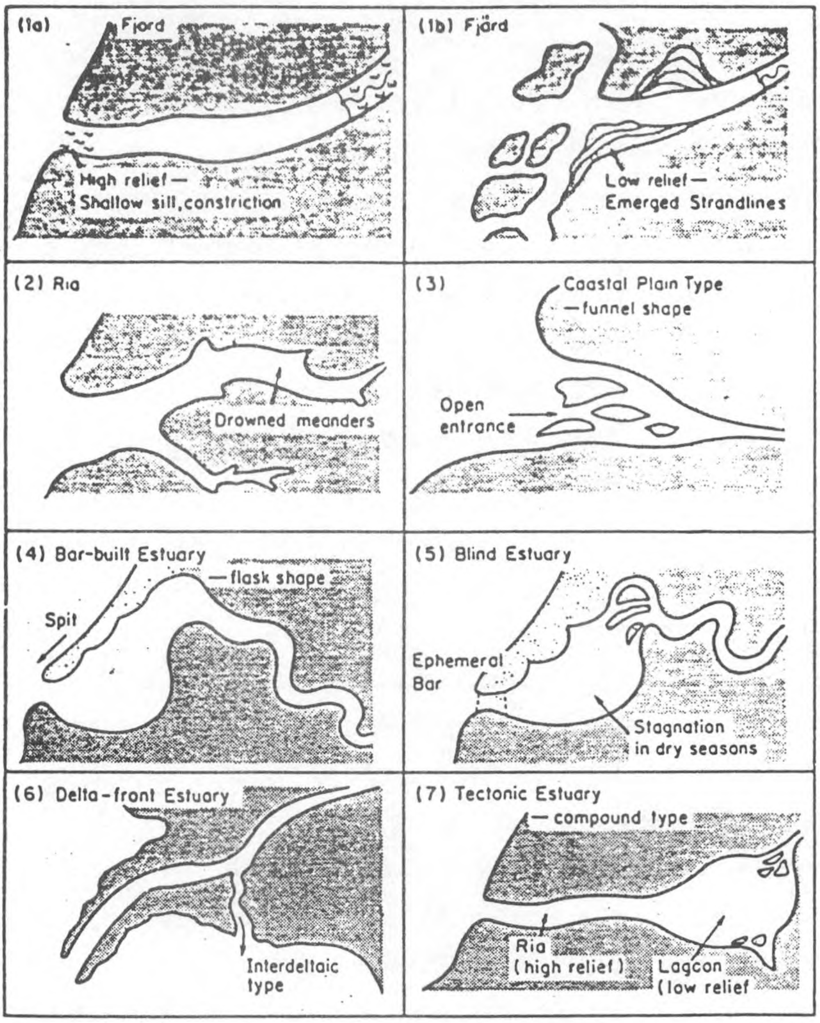


fig. 3 Basic estuarine physiographic types. Hydrodynamic characteristics are not considered here; discharge, tidal range, latitude (climate), and exposure all play important roles in modifying these examples, in addition to long-term secular processes such as tectonics and eustasy (schematic) (from Fairbridge, 1980).

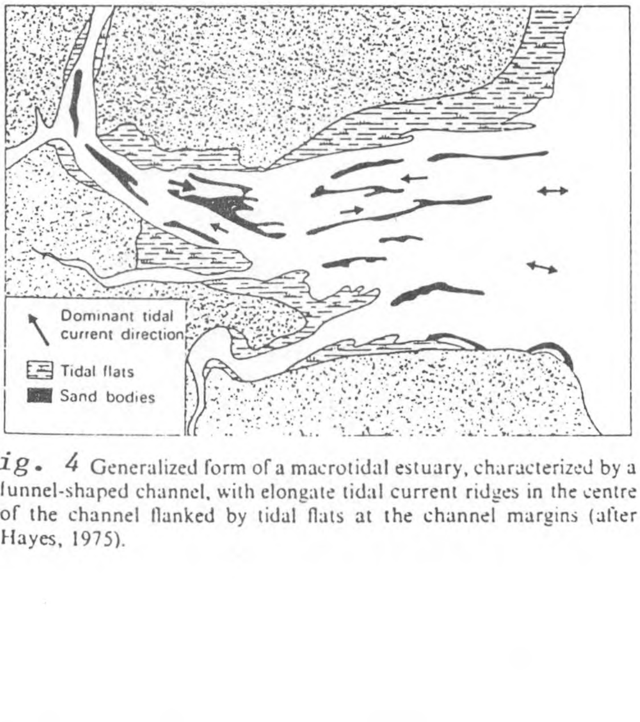


fig. 4 Generalized form of a macrotidal estuary, characterized by a funnel-shaped channel, with elongate tidal current ridges in the centre of the channel flanked by tidal flats at the channel margins (after Hayes, 1975).

characteristics of an estuarine system. The Changjiang does not show the typical characteristics of a deltaic system. It is important to make the distinction in order to better understand the development of the geological sequence of the area, at least for the last phase of filling up.

However, the area always has been designated as the **"Yangtze River Delta"** and it is even believed in general that the entire low lying plain is the proper delta of the river itself (Li Congxian, 1986). But it should be mentioned that already in 1939, J.S. Lee clearly stated : *"Before reaching the sea, the Yangtze River traverses an area which is sometimes called the Yangtze Delta. Although roughly triangular in shape, this area, essentially of lowland, is not a true delta. Its physiographic evolution clearly proves the erroneous nature of such a conception".* Since it is not clear whether the term "Yangtze Delta" stands for the triangular shape of the plain or for the deposits at the mouth of the river, the term will be replaced by a more correct description, *viz.* the **Changjiang coastal plain**.

The Changjiang coastal plain belongs to those plains which were formed and shaped during the Holocene under influence of the rising sea level, like the lowlands along the Mississippi, Brahmaputra, Indus, Chao Phyn, Mekong, Rhine-Meuse, etc.. These areas are known to be very vulnerable as they are situated very close to sea level. From a geological point of view these coastal lowlands consist of a considerable thick sequence of unconsolidated sediments, sensitive to compaction. Moreover the areas are all characterized by a very high density of population, which is burdering even more the critical situation because of the building constructions and, not at least, because of the supply of drinking-water.

Indeed, the city of Shanghai with a population of more than 10 million is known to be in a critical situation as it belongs to the problematic group of the sinking cities of the world. Due to ground-water withdrawal, land subsidence occurred drastically. Land subsidence was already noticed in

1921, but in 1965 it has reached a maximum of 2.63 m. The greatest subsidence happened between 1956 and 1959 with an annual rate of 98 mm (Shi Luxiang % Bao Manfang).

According to previous investigations, the compaction of the sediments due to ground-water withdrawal is mainly occurring in the upper 70 m (Su He-yuan). In order to control this very critical situation of land subsidence, the ground-water withdrawal is to be managed. Therefore a mathematical model will be elaborated. The knowledge of the Quaternary geology, and more particularly of the Upper Pleistocene and Holocene deposits will provide one of the basic elements for the design of the mathematical model.

2. Methodology

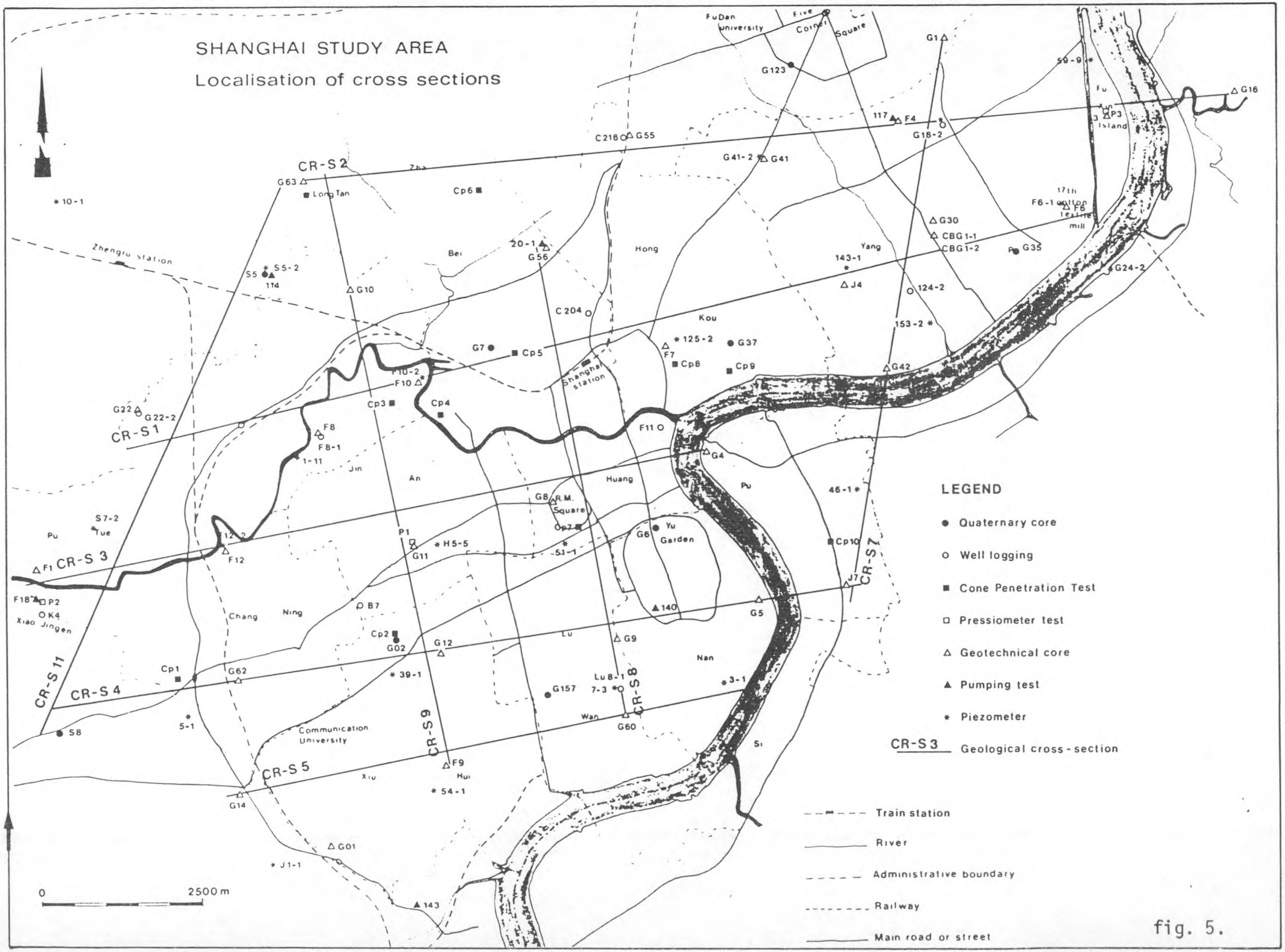
The Quaternary study was established on base of boreholes. 42 boreholes have been carried out previously, spread over the entire studied area, at a distance of about 1 km to 2.5 km from each other (fig. 5). From these boreholes a rather brief description could be used, giving, for each hydrogeological and geotechnical unit, colour, texture and some additional characteristics.

In the framework of this study, three additional boreholes have been carried out, viz. the CBG1-1 and CBG1-2, both located next to each other in the NE part, and the K4 boring located in the SW part of the studied area. These boreholes could be investigated more in detail, putting special emphasis on the sedimentary features and in consequence they form a basis for the interpretation of the description of the other borings.

The interpretation of the cone penetration tests (CPT) and well-loggings has been used to a lesser extent as complementary data.

Inherent in the filling up system of coastal and alluvial plains is the frequent lateral and vertical changes in the sedimentary sequence. In studying coastal and fluvial sedimentary bodies or stratigraphic sequences, an important perspective to maintain is that the unit being examined is the result of a depositional environment that is not fixed in time and space. Rather, this depositional environment will migrate laterally and vertically depending on the net effect of influential processes acting on the area (Kraft *et al.*, 1985). Hence it is impossible to interpret one single boring as such and to recognize the units and their succession, because one boring only represents an isolated spot in a complex entity.

It is true that nowadays Quaternary geology means a lot more than only establishing the boundary between units from subsurface data from one single spot. This approach does not



SHANGHAI STUDY AREA
Localisation of cross sections

fig. 5.

reveal any information about the spatial distribution of deposits, which is a necessity for a fuller understanding of the development and evolution of the area through space and time.

Hence it is imperative to establish the three-dimensional geometry of the deposits, i.e. the interrelationship between the different borings. Therefore cross-sections were established in detail and the correlations are based on the sedimentary characteristics, rather than on the premised hydrogeological and geotechnical units. These cross-sections have been used as a basis for the mathematical model.

The only possibility to correlate properly a series of boreholes, implies the knowledge of the processes and mechanism responsable for the deposition of the sediments and the formation of their facies, thus making an environmental interpretation. Although it is probably not true that each environment produces a unique sedimentary deposit, the basis of environmental interpretation rests on the assumption that particular environments generate deposits that bear the impress of environmental processes and conditions to a degree sufficient to allow discrimination of the environment (Boggs, 1987).

In order to interpret facies of a depositional system which consists of an assemblage of interrelated environments and their associated processes, it is necessary that facies be analysed in terms of their relationship in space. Coastal plain systems as well as rivers that feed them, form an excellent example of an interrelated depositional continuum. Furthermore, it is often impossible to make a unique environmental interpretation on the basis of a single depositional facies. Therefore facies associations and sequences must be studied rather than individual facies. Facies associations are groups of facies that occur together and are genetically or environmentally related. The sequence in which they occur thus contributes as much information as the facies themselves (Boggs, 1987).

It is true that a total understanding of changes in coastal and alluvial configurations, or rates of change in the position of coastal and fluvial sedimentary environments, must include an understanding of the vertical sequence for the area being studied. This third dimension to the sedimentary environments represents the element of time, and time is of overwhelming importance in understanding coastal and alluvial evolution (Kraft *et al.*,1985).

3. Regional Geological Setting

3.1. General introduction (by Huang Huanzhong)

The Yangtze River Delta is a tremendous delta. The river is 6380 km in total length. Its annual runoff and average sediment discharge is at 924 x 10^9 m^3 and 486 x 10^6 tons respectively. The mean tidal range of its estuary is 2.65 m, belonging to a mesotidal estuary with rich sediment supply. The development and formation of the Yangtze River Delta is evidently affected by the action of tidal current, runoff and the deposition of brackish water sediments.

The Yangtze River Delta is localized in the tectonic depression area, in which very thick Quaternary loose deposits overburden directly on Tertiary sandstone and mudstone in deceptive conformable or unconformable contacting form. According to the hydrodynamic conditions, sediment features and biogenic assemblage, the Yangtze River Delta can be divided into a main body deposition regime and an associated deposition regime. The main body consists of delta-plain, delta-front and pro-delta facies. The associated regime in sea area can be represented by Jingzang radiant sand bar and Qiantang River bar, while on the continent by the northern and southern coastal plain along the Yangtze River.

Shanghai working area is situated in the southern coastal plain of the Yangtze River Delta front (fig.6). The tectonic system, belonging to the end of the Yangtze peneplatform consists of Pre-Cambrian fold basement, Sinian, Early-Paleozoïc marine carbonates, Mesozoïc continent and Caenozoïc alternating marine and continental accumulation. Zengjing-Chuansha great fault (NE) divides Shanghai area into two tectonic units (Jinshan-Nanhuai bending fault belt and Qingpu-Baoshan downwarping fault belt).

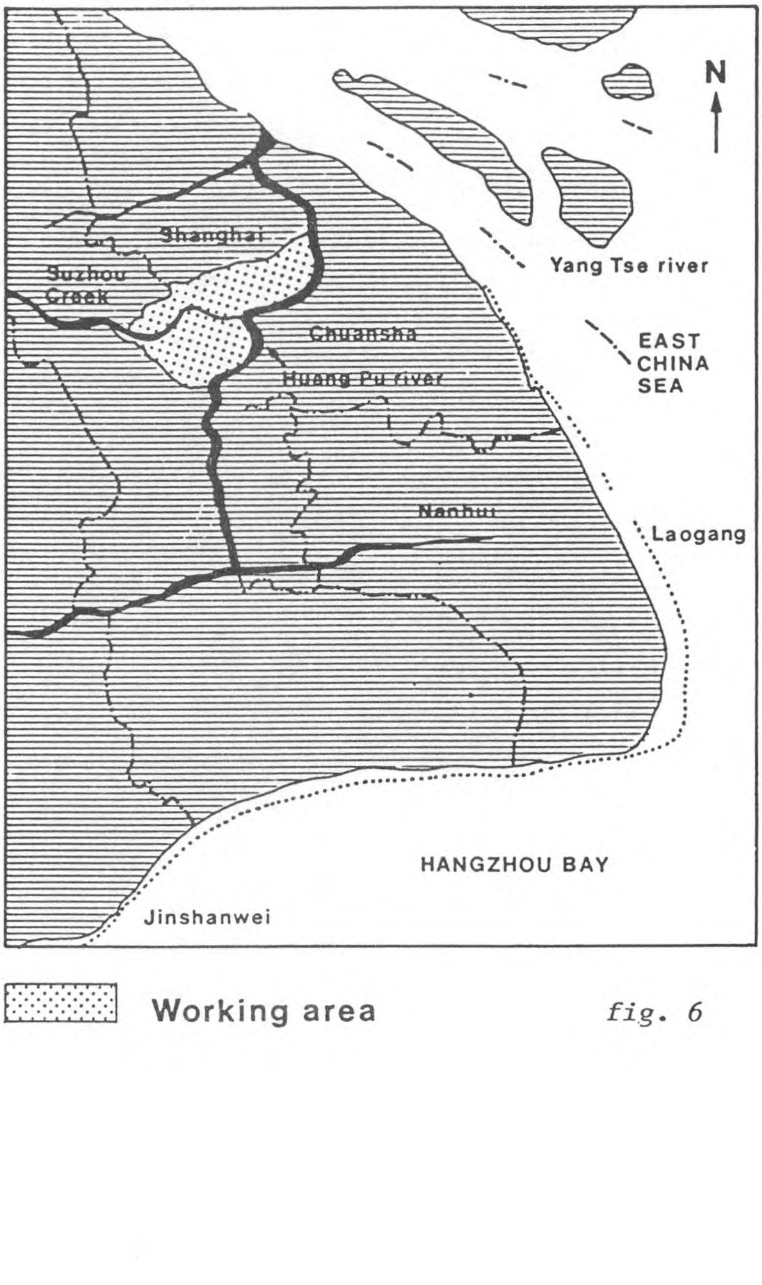

N
Yang Tse river
EAST CHINA SEA
Shanghai
Suzhou Creek
Chuansha
Huang Pu river
Nanhui
Laogang
HANGZHOU BAY
Jinshanwei
Working area

fig. 6

The Holocene sediments in the southern coastal plain are supplied by the Yangtze River discharge. After the diffusion of the littoral current and the action of tidal current and wave, the tidal flat in the estuarine coastal area has been developed and then silted up to be land. Modern Shanghai tidal flat has no deep and large tidal channel and its average slope is below 0.39 pro mille. The relief of this area is gentle and its elevation above mean sea-level is about 2.5 m - 4.5 m. The eastern part is 1 - 2 m higher than the western part. Mostly, it contains estuarine marine facies silty clay with silt and marine biofossils.

Since Neogene, Quaternary deposits in this area, ranging from 200 -350 meters, have been deposited by neotectonic movements and tends to thicken from the north bank of Hangzhou Bay to the river mouth of the Yangtze River. Based on all the data obtained from the boring in Shanghai Flour Mill, Quaternary deposits below 150 m are alternated sand and mottled clay, belonging to fluvial-lacustrine facies, while above 70 m lie gray clay intelayering with light gray sand and silt, belonging to marine or marine-continental facies. The deposits above 70 m belong to Late Pleistocene and to the Holocene strata. These sediments belong to marine - marine-continental facies deposits containing abundant microfossils, mollusca and spore-pollen, etc. , except the dark green or brownish yellow stiff clay at the top of Late Pleistocene, belonging to continental facies. The dark green stiff clay layer is the key bed between the Holocene and Late-Pleistocene.

During the Quaternary period, this area has experienced at least 8 cold to warm changes distinctively. Since the late stage of Early Pleistocene, 6 marine strata have been deposited with the warm climate accompanying transgression. In cold period, the continental facies strata with main fluvial-lacustrine deposits have been developed. For the extension of transgression, it tends to thicken and widen upwards.

3.2. Late Pleistocene and Holocene of the Shanghai area - A review of the literature.

Late Pleistocene

The Changjiang Estuary and its huge coastal plain fascinated since the last hundred years many geologists from China as well as from abroad. This unique area indeed is bearing a very interesting but complex Quaternary geologic history, generally indicated as alluvial and deltaic Pliocene-Quaternary sediments (fig.7).

In more recent times considerable research has been carried out, but mainly emphasized on the nearshore and offshore zones of the estuary.

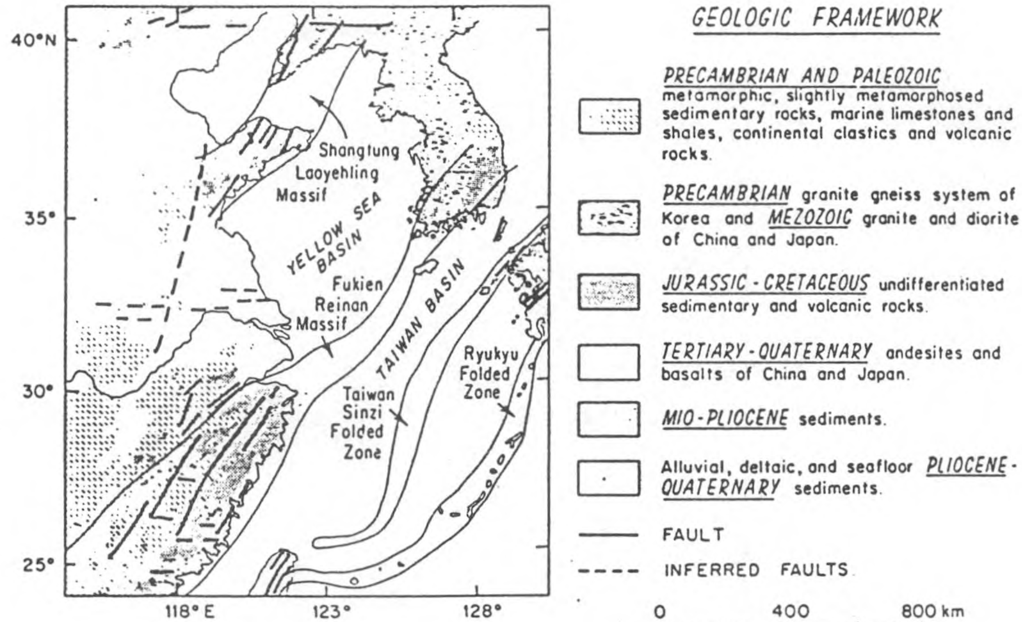


fig. 7 General geology of eastern China and Korea, showing structural highs and sedimentary basins. (from Butenko et al.,1985)

The review of the existing literature on the Quaternary of the Shanghai area is far from complete because of the difficulties concerning the accessibility (and not at least, the language) of the papers. Nevertheless a rather important amount of data and information could be gathered, depicting the Late Quaternary geologic history of the area.In this review the stratigraphic terms are mentioned such as they have been used by the authors.

In a general study about the Quaternary System of China, Zhou Mulin *et al.*(1982) proposed a subdivision of the Quaternary into 5 glacial stages and 4 interglacial stages, based on Quaternary Stratigraphical tables compiled by various geological institutions and stressing on biostratigraphy and climate changes (Zhou Mulin, *et al.*, 1982).

The stages this study is concerned with are the 4^{th} interglacial stage (Lushan-Dali interglacial stage), the 5^{th} glacial stage (Dali glacial stage) and the post-glacial stage (Holocene). The authors (Zhou Mulin, *et al.*, 1982) described them as follows.

The 4^{th} interglacial stage (Lushan-Dali interglacial stage) is represented by the Sjara-Osso Gol Formation, occurring in Hongniuhe, southern Ordos of the Nei Mongol Autonomous Region. This formation is composed of fluviolacustrine loess, yielding fossils of loess steppe. The "Xiazhu Loess" is extensively developed in South China where it is interbedded with many layers of fossil soils. Ingression of the sea took place in this stage with deposition of marine bed which pinches out near Wang-Zhendian, Qingxian, west of the Bohai Bay. According to the authors, the palaeo-magnetic dating of this marine bed gives an age of about 0.10 M.y.B.P.

The 5^{th} glacial stage (Dali glacial stage) was first observed on the Diancangshan of Dali, Yunnan. It is characterized by glacial features which are made by recent glaciers lying at an elevation ranging between 3000 to 1000 (sic) or more meters. During this stage East China was experiencing a cold periglacial climate.

A 14-C dating of periglacial vegetation from Beijing yielded an age of 29 300 ± 1350 y.B.P.. During the maximum Dali glaciation, the global sea level dropped tremendously and in China it was as low as -150 m. The shelf of China, Korea and Japan emerged and formed a great plain. In East China the Dali glacial stage was apparently separated by short interglacial stages (interstade): an early and a late sub-glacial stage. It was in this interstade that a global transgression took place, at 22 900 - 32 000 y.B.P.

In 1986 Zhou Mulin (1986) elaborated this glacial-interglacial classification emphasizing on the loess stratigraphy on the one hand and on the marine transgressions on the other hand.

About the trangressions he stated that they occur in interglacial, interstadial or post-glacial warm climate intervals. The sea-level fluctuations roughly correspond to glacio-eustatic climate cycles and are considered basically as eustatic transgressions.

The author added (and changed) some general information about these transgressions:

- the first Holocene marine transgression bed, deposited in a post-glacial interval, is composed of grey, sandy clay and puddly clay, and is widespread in beach zones. It usually yields abundant *Ammonia* foraminifera, is buried 20 to 50 m under the land surface, and is dated in the range 2500 to 8000 y.B.P.. It is termed the Ammonia Transgression and may be correlated with the Flandrian Transgression in Europe.

- the second marine transgression bed has been formed during the interstadial in the Dali glaciation, Late Pleistocene, and is composed of grey yellow clay and grey black silty, puddly soil. The bed contains *Pseudorotalia* fossils, buried at depths of 40 - 70 m under the land surface and is dated at 24 - 39 ka B.P.. This may be correlated with the Neotyrrhenian transgression in Europe.

- the Lushan-Dali interglacial transgression, Late Pleistocene, is marked by dark-grey silt, fine sand and puddly soil, forming the *Asterorotalia* Transgression bed. In general, the marine bed is buried at depths of 80 - 120 m under the

land surface. Paleomagnetically it is slightly younger than the Black Event, dated at about 70 - 100 ka and may be correlated with the Tyrrhenian Transgression.
The Dali glaciation was correlated with the Weichselian from Europe.

From the accessible literature it became clear that a lot of attention was paid to the Dali glaciation and more particularly to the sea-level stand during that period.

Zhu,*et al.* (19..A) concluded from investigations on the East China shelf that the Dali glaciation started about 70 000 y ago and that it was characterized by several fluctuations. The authors found out that the lowermost sea level of the Late Pleistocene must be situated about 15 000 y B.P. and its position was located at a level between 140 - 160 m. By that time the East China Shelf was emerged and formed a vast coastal plain.

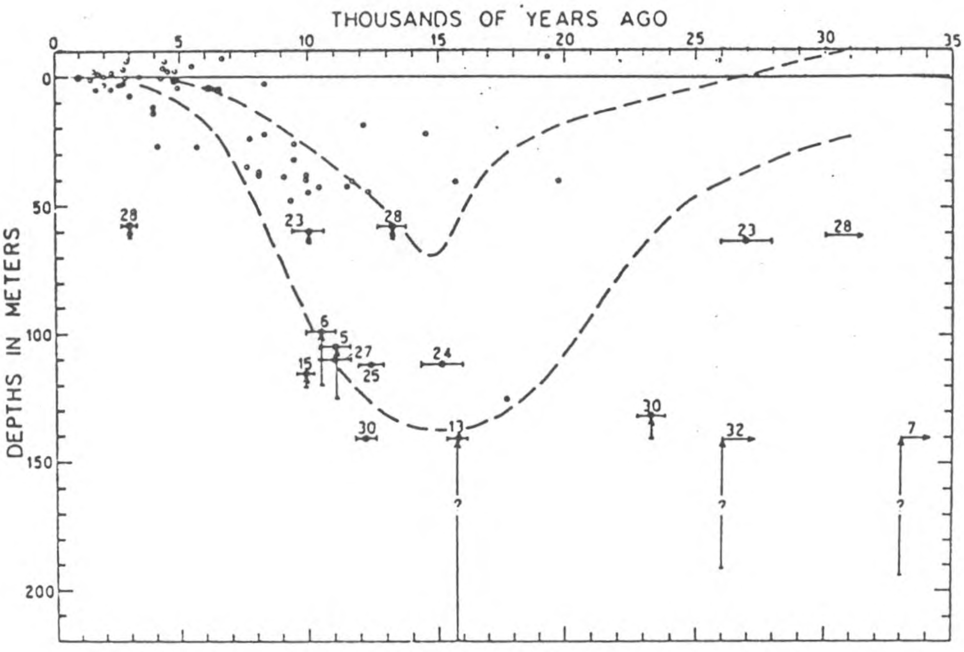
In 19..B, Zhu *et al.* investigated the effects of the sea-level changes in the Late Pleistocene on the East China Shelf and a subdivision for the Late Pleistocene was introduced as follows.

The period around 40 000 y B.P. (Early Stage of Late Pleistocene) was characterized by a stable low sea level which was situated at a depth about 70 - 100 m. A part of the shelf became emerged and developed into a river valley with lake basin bog.

In the Middle Stage of the Late Pleistocene, the ancient Yangtze Delta was much more influenced by the changes of the sea level and around 35 000 y.B.P. the area developed into an estuarine environment. The authors concluded that the ancient Yangtze Delta had experienced a larger transgression about 32 000 y.B.P. where the sea reached a level of 10 - 20 m. Therefore they believed that in this period the ancient Yangtze Delta was similar to the actual one, although its extension was much bigger.

Table 2. Radiocarbon-Dated Samples

Station no.	*Depth (m)*	*Species*	*Depth range (m)*	*Dated sea level below present (m)*	*Radio-carbon lab. no.*	*Radio-carbon age*
5	125	*Mytilus corscum*	10–30	105	W2214	11,050 ± 600
6	118	*Mytilus corscum*	10–30	98	W2215	10,520 ± 600
7	194	*Astarte* sp.	10–30	140?	W2340	> 33,000
		Macoma calcarea	10–30	140?	W2342	> 40,000
13	219	*Macoma calcarea*	10–30	140?	W2343	15,740 ± 400
15	120	*Mercenaria stimpsoni*	0–10	115	W2338	9,880 ± 350
23	64	*Mactra chinensis*	0–10	59	W2217	10,000 ± 600
		Corbicula japonica	brackish	64	W2216	27,000 ± 1000
24	112	*Ostrea gigas*	brackish	112	W2036	15,200 ± 850
25	112	*Ostrea gigas*	brackish	112	NTU-22	12,400 ± 500
27	110	*Ostrea gigas*	brackish	110	NTU-38	11,000 ± 700
28	62	*Mactra chinensis*	0–10	57	W2220	3,000 ± 300
		Anadara subcrenata	0–10	57	W2254	13,260 ± 600
		Corbicula japonica	brackish	64	W2219	> 30,000
30	140	*Ostrea gigas*	brackish	140	W2237	12,200 ± 400
		Mactra chinensis *Pecten albicans*	0–10 10–30	130	W2341	23,260 ± 600
32	190	*Arca inflata*	0–10	140?	W2360	> 26,000



Depths and ages of radiocarbon-dated shallow-water relict shells from the floor of the East China Sea (Table 2) and adjacent areas. The solid circles at the upper left indicate ages and depths of peat in salt marshes on the west coast of Korea (Park 1969). For comparison, the open circles are for samples from off Japan (Kagami 1962; Hoshino et al. 1967; Hattori 1967; Fujii 1967, 1969); because of known tectonic activity of Japan these points have a wide scatter. The dashed lines denote the envelope for most data points on the world's continental shelves

fig. 8 (from Emery, Niino and Sullivan, 1971)

The Late Stage of the Late Pleistocene showed a rather different picture according to Zhu *et al.*(19..B). After 26 000 y.B.P. the sea level dropped periodically, facilitating the development of a shelf margin abrasion terrace. Between 26 000 - 23 000 y.B.P. there was a first relatively stable sea level and an abrasion terrace at the level of 100 - 120 m* was formed. At that location distinct remains of an ancient coastline with evidence of river mouth bars and shell beaches were found. After 23 000 y.B.P. the sea level lowered continuously until a depth of 150 - 160 m and shaped the second and third abrasion terrace.

As from 15 000 y.B.P., a period which is considered to be the coldest one in the Late Glacial, the sea level started to rise rapidly until 12 000 y.B.P. .

The Late Stage of the Late Pleistocene was also investigated by Guo Xuemin (1988) in the Changjiang Estuary area. The author described this period as one characterized by a falling sea level and with mainly fluvial sediments. According to the author, the rivers intensified their erosional activity by the end of the period and an erosion surface was formed with a dark palaeosoil zone in the eastern part.

The sea-level changes of the East China Sea were investigated in particular by Emery, Niino and Sullivan (Emery *et al.*, 1971). Although the paper is mainly dealing with the Post-Pleistocene sea levels, some considerations on the Late Pleistocene were put forward as well. The continental shelf of the East China Sea was selected because it was indirectly influenced by Pleistocene glaciations, i.e. it belongs to those areas that were not covered by glaciers, but the lowering of sea level, caused by the locking of water in glaciers, exposed the shelf, converting it into extensions of the land.

Studies of rocks and sediments from the floor of the East China Sea revealed several samples that contained shallow-water shells from relatively great depth on this shelf (Table 2). These samples indicate that past sea levels were

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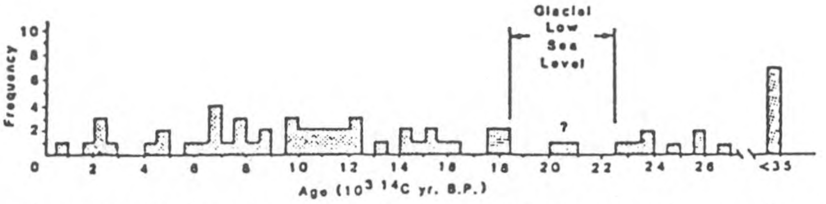
* waterdepth of the actual shelf.

lower than at present (fig. 8).

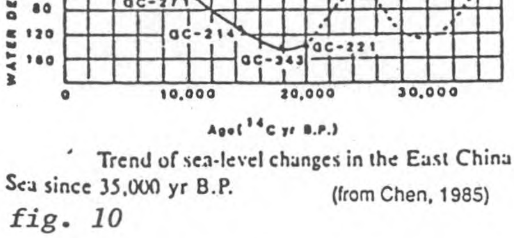
The authors concluded that it appears to be clear that the continental shelf between Japan, Korea and China was exposed subaerially when sea level was low during early Holocene time. However existing dated samples seem to favor a minimum sea level about 15 000 years ago.



Histogram of ^{14}C dates for marine sediments in the East China Sea. The gap in dates between about 22,000 and 19,000 yr B.P. may reflect a glacial low sea-level stand. (from Chen, 1985)

fig. 9

The low sea-level stand was also discussed by Chen *et al.*(1985). Based on a series of 14-C dates from marine sediments in the East China Sea, the author believed that the gap in dates between about 22 000 and 19 000 y.B.P. may reflect a glacial low sea-level stand (fig.9). Besides, the author collected and discussed the existing 14-C data and constructed a relative sea-level curve for the East China Sea (fig.10). The 14-C ages were coming from marine sediments, shells from cheniers, neolithic sites and finally from peat and wood. However, the stratigraphic position of the dated



Trend of sea-level changes in the East China Sea since 35,000 yr B.P. (from Chen, 1985)

fig. 10

samples is not very clear. To construct the sea-level curve, Chen *et al.* (1985) made the following assumptions: 1) because the total continental shelf was subaerially exposed during the last glacial maximum, relict shells of that age should be absent from surficial sediments of the continental shelf; 2) the chenier rampart extending inland is a result of a marine transgression; and 3) the gaps which occurred in the age sequence of Neolithic settlements are also the result of transgression.

Another aspect of the Late Pleistocene which was very often described in the accessible literature was the boundary between the Pleistocene and the Holocene.

Wang *et al.*(1981) described a dark green silty clay layer with a large extension in the Yangtze Delta area and considered it as a keybed between the Holocene and the Pleistocene. The clay layer, which is characterized by some Fe-Mn concretions, rust-orange spots, plant roots and vegetation remnants, but without foraminifera or marine fossils, is about 3 to 5 m thick and it is found at different depths according to the location. In Shanghai it is occurring at a depth ranging between 20 to 25 m. The clay layer is lacking in erosional areas of the Yangtze-Wuson River system, which then are filled with erosional alluvium from a later period.

Palynological investigation yielded evidence that the clay was deposited in a cold and dry period, most probably during the Dali glaciation. According to the authors, the sea level was low in that period and the continental shelf of the East China Sea was a vast extend of land, where the traces of the Ancient Yangtze River bed could be found till the shelf margin.

In 1983, (as well as in 1988) Guo Xuemin mentioned similar aspects of the Holocene-Pleistocene boundary in the Changjiang Estuary area. He described the palaeogeography of the Late Stage of the Pleistocene Regression, a period which included the late stage of erosion, characterized by a continental deposit with fluvial facies. The deposit consists of yellow silty fine sand in the lower part and yellow, yellowish green and dark green clay in the upper part, which he interpreted respectively as "small-scale point bar fluvial sandbar belonging to river-bed sediments" and "clay with floodplain fine sediments". Additional features of the deposits were: vegetation remains, humic material, lower content of $CaCO_3$, a lot of small and fine Fe/Mn concretions, oölitic siderite and yellow and yellowish-white stripes.

The author explained that, because of the lowering of the sea level and the intensified erosion of rivers during the Late Stage of the Late Pleistocene, the continental deposits along the valley were eroded and different erosional landforms were formed. The author also stated that the weathering was remarkable during the erosion, because a dark green clay layer with a well-developed dark ancient soil layer was widely distributed.

In 1986 Li Congxian carried out a rather elaborated study on the Changjiang Delta. He describes the underlying stratum of the post glacial sediments as a layer of dark green loam which is widely distributed in Changjiang Delta area. According to Li Congxian (1986), it belongs to the Late Pleistocene stratum which was deposited during the last low stand of the sea level since it distinctively differs from the overlying sediments in lithology, sedimentary facies and sporo-pollen assemblage. The loam is characterized by its compactness, the presence of yellowy brown spots, vertical white stripes, iron and manganese nodules, siderite, plant debris and root system and *Charophyta* and the absence of marine fossils, all of which undoubtly verify the continental origin of the loam.

The palynological investigation carried out on a boring from Shanghai (Flour Factory) yielded that during the period the dark green loam was formed, the climate was drier and colder (about 6 - 8° C lower than nowadays); a climate the author considered to be similar to that of the last glaciation in the area. Therefore he concluded that the dark green loam was deposited during the Dali glaciation of the Late Pleistocene.

The depth where the dark green loam occurs varies in different regions. It is about 20 - 25 m and locally as deep as 30 m in Shanghai, showing an eastward dipping. The dark green layer is absent in the valley where yellow and yellowy grey sand and gravelly sand layers are detected. In local areas near the mouth of the river there are only marine sediments which belong to one of the underlying units of the dark green loam. The disappearance of the loam layer in the area may be the result of local alluvial erosion and cutting.

However, when explaining the stratigraphical sequence of the Delta plain (in contrast with the Strand plain), the author described the underlying stratum of the post glacial sediments not any more as dark green loam, but as: "continental deposits made up of sandy gravel alluvial and erosion surface of bedrocks formed during the last lowstand in Late Pleistocene, only in local area being on the old marine layer of Late Pleistocene, and graduates into continental sediments of flood-plain and freshwater swamp".

A rather different picture of the Holocene-Pleistocene boundary was put forward by Zheng *et al.* (1988). The authors wrote that the stratum of the southern Changjiang delta in the later period of the Late Pleistocene consists of Xiashu Loess in the western hilly land, and of dark green or yellowish brown hard clay in the eastern plain. These deposits are regarded as the basement of the Holocene loose sediments and deposited during the "later Wurm glaciation" (from about 25 000 to 15 000 y.B.P.).

The article is mainly dealing with "the cause of formation" and "the relationship between the two strata" which was considered as one of the main unsolved problems. The authors concluded (among other things) that the windblown loess was distributed also in the eastern plain, even in the shelf of the East China Sea. In the plain region, it appears in the form of yellowish brown or dark green hard clay. The authors continue their explanation as follows: "Through weathering, leaching and pressing, loess in eastern plain formed yellowish brown hard clay. In evolution process of Holocene sedimentary environment surface water containing richly organic matters permeated into upper layer yellowish brown hard clay. Owing to resolving of solvable organic matters, it caused reduction of high-valence ions and change of colour, so the upper layer of the hard clay formed dark green or yellowish green hard clay." Such an explanation about the formation of the dark green compact clay is most remarkable and very hard to believe indeed.

But in the same book, Tao *et al.*(1988) did observe that the two kinds of deposits of the Late Pleistocene, i.e. the Xiashu Loess and the Tenacious-clay with a greyish colour, are found in different areas; the Xiashu Loess is occurring in the western hilly region and the Tenacious-clay in the eastern lower plain.

In studies which are more concerned with Holocene deposits, the dark green clay is nearly always mentioned. Yan Qinshang *et al.*(1988) described it as a tenacious-clay layer with a greyish or yellowish brown colour identified as river-lake-marsh deposits of Late Pleistocene. This layer can be used as a marker defining the boundary between Holocene and Pleistocene deposits.

Guo Xuemin *et al.* (1988) wrote that the Holocene series of the Yangtze region overlie the wide spread stiff dark green clay of terrigenous origin of the uppermost Pleistocene with disconformity contact.

In the research papers dealing with the offshore area of the East China Sea, the Holocene-Pleistocene boundary is very often mentioned as well.

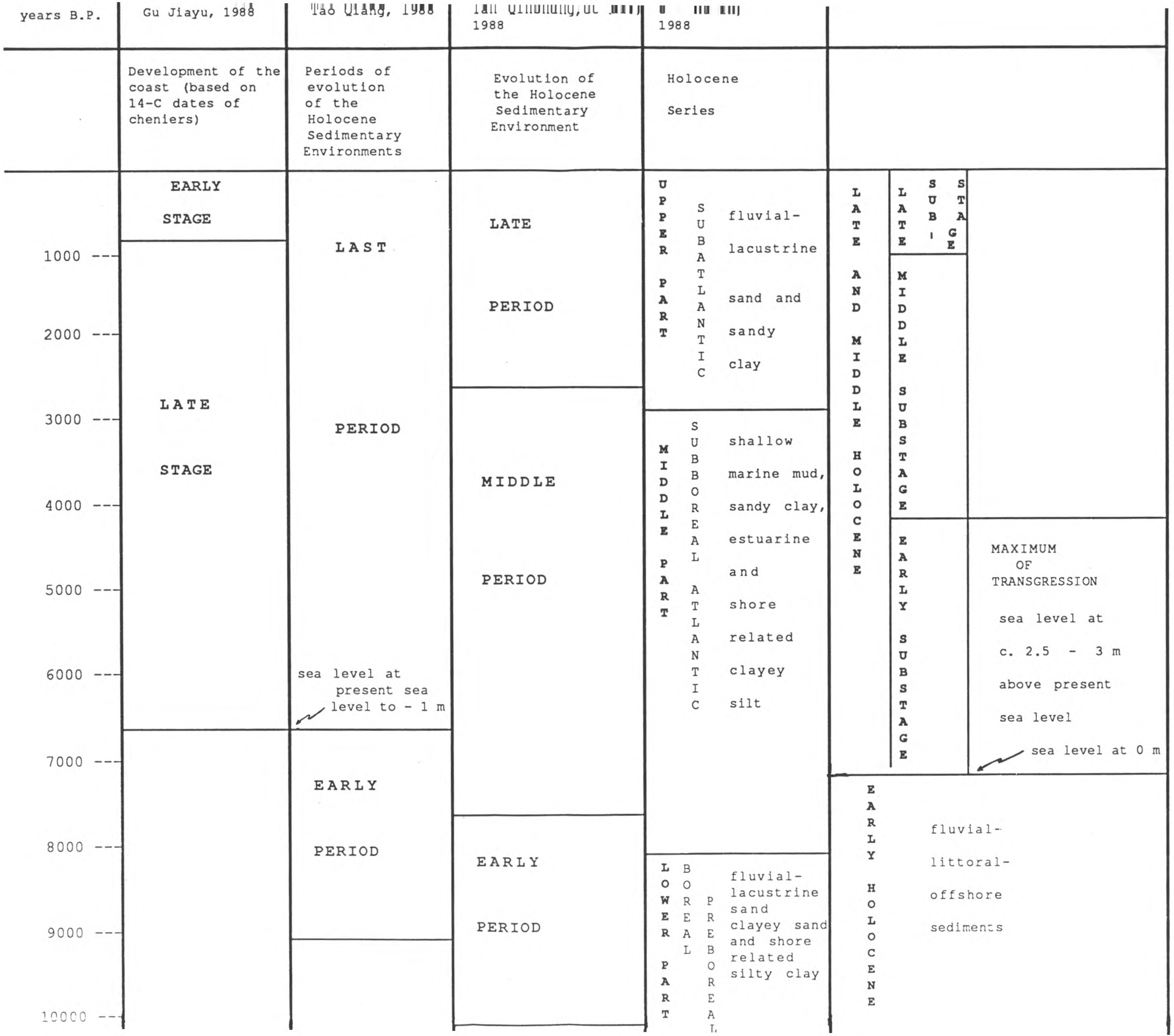
Keller *et al.* (1985) observed that on the innermost shelf the modern sediments blanket semi-consolidated clays representing earlier Changjiang deposits. These stiff gray silty clays are characterized by considerably higher bulk densities and shear strengths, and lower water contents than those sediments with a comparable texture found to the east on the midshelf. Examination of consolidation test data also reveals that this gray clay displays a preconsolidation pressure that is considerably greater than the preconsolidation pressures determined at similar depths in other cores. These data tend to support the supposition that this gray clay represents an older sediment, possibly deposited during a lower stand of the sea or a period of different dynamic conditions. Based on high resolution seismic profiles data, it appears that this semi-consolidated horizon extends over much of the innermost shelf as well as seaward for some distance under the adjacent sand deposits.

According to Butenko *et al.* (1985) shallow seismic profiles show that the Holocene sediments overlie an eroded Late Pleistocene surface, dominated by a number of well-defined burried river channels formed during the last low stand of sea level. Associated with the buried Changjiang channel are linear "ribbons" that, according to the authors, presumably represent relict river bank features (possible levees?). One core penetrated a very stiff clay near these features, supporting the concept of overconsolidated clays associated with subaerial exposure.

Holocene and the post-glacial transgression

In the accessible literature about the Holocene of the Changjiang coastal plain and the Shanghai area, it is clear that full consideration was given to the chronostratigraphical subdivision of the Holocene on the one hand, and to the evolution of the so-called "subdelta's", which are occurring at the river mouth, on the other hand.

The sedimentary sequence as such and its interpretation were looked upon in a rather general way, except for the research carried out on the offshore, adjacent to the estuary.


years B.P.
Gu Jiayu, 1988
Tao Qiang, 1988
1988
1988
Development of the coast (based on 14-C dates of cheniers)
Periods of evolution of the Holocene Sedimentary Environments
Evolution of the Holocene Sedimentary Environment
Holocene Series
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
EARLY STAGE
LATE STAGE
LAST PERIOD
sea level at present sea level to - 1 m
EARLY PERIOD
LATE PERIOD
MIDDLE PERIOD
EARLY PERIOD
UPPER PART
SUBATLANTIC
fluvial-lacustrine sand and sandy clay
MIDDLE PART
SUBBOREAL
ATLANTIC
shallow marine mud, sandy clay, estuarine and shore related clayey silt
LOWER PART
BOREAL
PREBOREAL
fluvial-lacustrine sand clayey sand and shore related silty clay
LATE AND MIDDLE HOLOCENE
LATE SUB-STAGE
MIDDLE SUBSTAGE
EARLY SUBSTAGE
MAXIMUM OF TRANSGRESSION
sea level at c. 2.5 - 3 m above present sea level
sea level at 0 m
EARLY HOLOCENE
fluvial-littoral-offshore sediments

The basis for establishing the stratigraphical subdivisions are very seldom mentioned or elaborated in detail. Most often it is generally described as being "the palaeoclimate, reflected by pollen spore assemblage and stratigraphical age as determined by the 14-C method".

In many cases palaeo-microfauna, grain size, and heavy mineral analyses are mentioned as additional basis.

A rather great number of stratigraphical subdivisions, concerned with the Shanghai area and surrounding, were found in the accessible literature. But it is most remarkable that only very few of them show any similarity; nomenclature and time boundaries do change a lot. Even a series of papers published in one and the same book (Yan Qinshang, 1988) exhibits important differences.

The best way to demonstrate these differences, without making any further confusion, was to assemble all the classifications in a table (Table 3 & 4).

It is critical to evaluate the validity of the different classifications as it was impossible to find out what evidence and/or arguments* have been used exactly to elaborate them (except some palynological data, giving however similar assemblages).

It is also very unfortunate that the authors themselves very seldom refer to the previous published papers or give comment on the result, so that the various opinions on the different classifications have not been explained nor argued.

In the publications about the Holocene, any attempt of lithostratigraphical classification or correlation is lacking.

On the other hand some ideas about the palaeogeographical implications of the coastal plain**, describing sedimentary environments and their evolution, most of the time related to sea-level changes, have been put forward by several authors.

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* it should be mentioned that from some publications only a summary was available.

** the evolution of the "subdelta's" occurring at the river mouth will be discussed later.

years B.P.	Gu Jiayu, 1988	Tao Qiang, 1988	Yan Qinshang,et al., 1988	Guo Xumin,et al., 1988			Guo Xumin,1988		
	Development of the coast (based on 14-C dates of cheniers)	Periods of evolution of the Holocene Sedimentary Environments	Evolution of the Holocene Sedimentary Environment	Holocene Series					
	EARLY STAGE	LAST PERIOD	LATE PERIOD	UPPER PART	SUBATLANTIC	fluvial-lacustrine sand and sandy clay	LATE AND MIDDLE HOLOCENE	LATE SUB-STAGE	
1000	LATE STAGE							MIDDLE SUBSTAGE	
2000									
3000			MIDDLE PERIOD	MIDDLE PART	SUBBOREAL ATLANTIC	shallow marine mud, sandy clay, estuarine and shore related clayey silt			
4000								EARLY SUBSTAGE	MAXIMUM OF TRANSGRESSION sea level at c. 2.5 - 3 m above present sea level
5000									
6000		sea level at present sea level to - 1 m							sea level at 0 m
7000		EARLY PERIOD					EARLY HOLOCENE		fluvial-littoral-offshore sediments
8000			EARLY PERIOD	LOWER PART	BOREAL PREBOREAL	fluvial-lacustrine sand clayey sand and shore related silty clay			
9000									
10000									

Wang Jingtai *et al.*(1981) provided a rather elaborated study on the Evolution of the Holocene where some distinct cyclicity was recognized. The deposits have been divided into a lower, middle and upper section and were described respectively as silty clay to silty sandy clay, muddy silty clay and silty clay with sandy lenses. The lower part was interpreted as littoral-lagoonal sediments deposited during Boreal and Subboreal times. The interpretation was based on the occurrence of *Ammonia confertitesta* and *Sinocytheridea* foraminifera, local thin peaty layers, $CaCO_3$ concretions and penetration of reedroots. The middle part, containing shallow-marine shells and ostracoda on the one hand and a humic and warm pollen-assemblage on the other hand, has been interpreted as shallow-marine to nearshore sediments deposited during Atlantic and Subboreal time. From the upper part only the decrease of foraminifera and ostracoda and the occurrence of some continental animals were mentioned together with the pollen-assemblage of *Pinus - Quercus - Gramineae* indicating that the sediments were deposited during the Subatlantic.

The authors concluded that the post-glacial transgression started about 15 000 years ago (after the Dali glaciation) and that the rise of the sea level was very fast, so that the remains of coastal sand and freshwater peat were well preserved. About 10 000 years ago the sea already invaded the Shanghai and Nantong area along the Changjiang river (for location, see fig.11) and at about 7500 years ago an estuary of the Changjiang was formed as far as Zhenjiang - Yangzhou (fig.11 & 16).

Still according to Wang Jingtai *et al.*(1981), the period after 7500 years ago was characterized by a slower sea-level rise and a great amount of sediments from the river was deposited at its mouth so that the development of the Changjiang "Delta" could start.

Because of the confusion in terminology about "Delta" already mentioned above (see chapter 1), it is not clear whether the coastal plain adjacent to the river on the one hand or the flood- and ebb- tidal delta's in the estuary on the other hand, were meant.

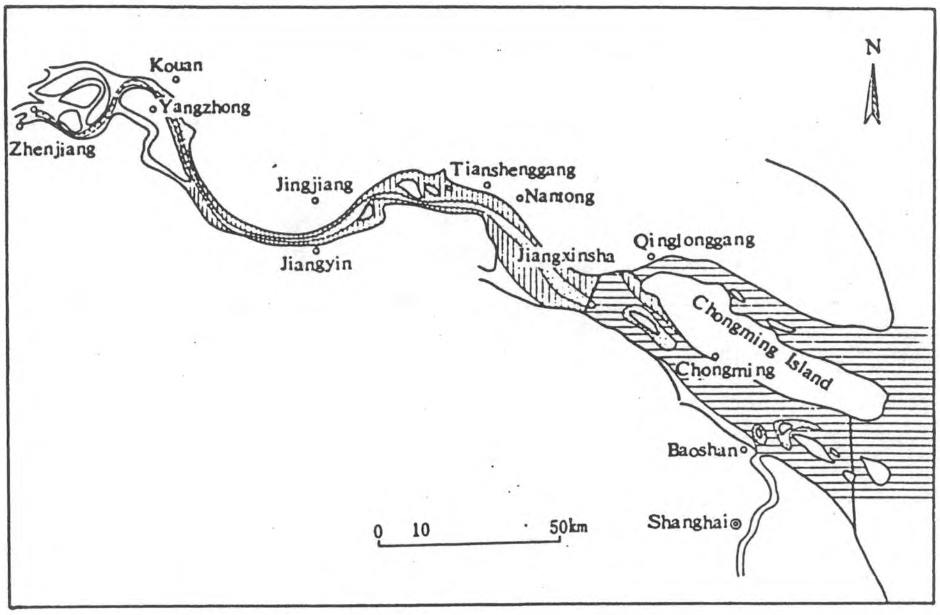
N
Kouan
Yangzhong
Zhenjiang
Jingjiang
Tianshenggang
Nantong
Jiangyin
Jiangxinsha
Qinglonggang
Chongming Island
Chongming
Baoshan
Shanghai
0 10 50km

fig. 11

The relationship between a rapid sea-level rise and the preservation of coastal sand and freshwater peat is not very evident neither. First of all it was not explained when exactly the peat developed. According to the text, the peat was already occurring before the influence of the post-glacial transgression as it was well preserved by the sediments overlying it. Anyhow in the accessible literature it is never mentioned that peat was formed during the Late Stage of the Dali glaciation.

In fact the occurrence of peat at the base of Holocene marine deposits in a coastal plain is a very well-known feature. It is the so-called *basal or basis peat*. The formation of a peat layer preceding the marine ingression proper, is commonly attributed to an assumed rise of the ground water table resulting, either directly or indirectly, from the rise of the sea level. Indeed in many cases the existence of a causal relationship between the commencement of peat formation and the position of the sea level is clear. The peat formation is related to the occurrence of diffuse upward seepage of ground water in a belt parallel to the coast.

As a result of the rising of the sea level, this belt shifts progressively inland and upward in the course of time. Occasionally, the peat development can result from other causes. Regular inundations by run-off water, particularly to be expected in valleys with a poor drainage, can result in peat formation. In such cases a certain relationship with the sea level may still be expected. However, in isolated depressions, or poorly drained areas, peat may have started growing fully independently of the (rising) sea level.

However the basal peat very seldom comes into being on a relatively impermeable formation (such as the dark green clay layer) which is able to prevent upward seepage from occurring.

On the other hand it is very unlikely to assign the peat to an intercalated peatlayer*. The development of peat namely requires, among other things, a rather protected environment, not affected by an important marine influence and certainly

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* peatlayer intercalated between sediments deposited during the post-glacial transgression, in contrast with the basal peat

without a high supply of sediments, otherwise the peat growth stops. This implies a.o. that a peat, when located adjacent to the area under marine influence, is very unlikely to develop with a rapid sea-level rise.

Taking these considerations into account it is most probable that the peat, which has been mentioned by Wang Jingtai *et al.* (1981), is to be assigned as basal peat. The basal peat could develop on the sandy sediments of the Late Pleistocene fluvial deposits (see below,4.1.2.) from these parts of the offshore which were emerged at that time.

But a contradiction still remains. According to the literature (a.o. Emery *et al.*, 1971 & Zhu *et al.*, 19 B, see above) the coldest period of the Dali glaciation and the lowest sea-level stand is situated at 15 000 years B.P. exactly the same period the post-glacial transgression started. So when did the peat have time to develop on these deeper lying parts of the emerged offshore? Moreover the transgression has been characterized by a very rapid sea-level rise. Indeed, according to Zhu *et al.* (19 A), the sea level rose from about 140 - 160 m to 1 - 2 m below present sea level in the time span between 15 000 to 7000 years ago. This is nearly 2 m per 100 year; about the same average was obtained by Chang-Shu (1985) who dated the sea-level stand of - 100 m at 13 500 years ago and the one at - 50 m at 11 000 years ago.

It is clear that until now in the research very general statements have been put forward; therefore these can only be accepted as being general ideas trying to unravel the geological history, and not yet as exact or precise data.

In his study on the Evolution of the Sedimentary Environments of the Changjiang Estuary Area, Guo Xuemin (1983) states that the lithological sequence of the entire Quaternary system was very complicated and that alternation of sedimentary environments happened very often. The author duly noticed that the Holocene sedimentary sequence of the area is characterized by many facies variations as well vertical as lateral.

In the palaeogeographical reconstruction Guo Xuemin (1983) concluded from the observation of a hiatus in the continental deposits (from the Late Stage of Late Pleistocene) that an erosion period occurred during the Late Pleistocene leading to disconformity between the Holocene and Late Pleistocene deposits. He described that during the lowering of the sea level and the intensified erosion of rivers during the Late Stage of Late Pleistocene, the continental deposits along the valley were eroded and different erosional landforms were formed. The author also writes that the weathering was very distinctly during that erosion period. However, the author does not explain how an erosion can occur during that period which is known to be cold and dry with a very low sea-level stand and which therefore he labelled as a regression. Moreover during that same period, fine-grained sediments (dark green stiff clay) were deposited in the flood plain in that area. The confusion about the situation in the Late Stage of Late Pleistocene is complete, because the author in fact tries to explain the absence of the dark green clay in certain areas as a result of erosion which occurred during the Last Stage of Late Pleistocene; an erosion which produced at the same time the deposition of the same dark green clay. It is obvious that in the evolution during the Late Stage the events have not been put in the right order.

The description of the Holocene deposits is rather similar to the one Wang Jingtai *et al.* (1981) put forward, but Guo Xuemin (1983) gives some ideas about the sea-level changes. At 10 000 years B.P. the sea-level stand is to be situated at -50 to -60 m. The author considered the Early Atlanticum as the period where the transgression was at its maximum with the largest lateral extension of marine sediments. Fig.12 depicts that situation on which the author comments that an important part of the area was below sea level. This situation did not last very long and the southern part very quickly evolved to "land" where a coastal plain (in the east) and a delta plain (in the north) came into being. The development of the coastal and deltaïc plain occurred in the Middle and Late Holocene. The coastal plain was characterized in particular by a sea ward progradation whereby a series of parallel shell bearing sand ridges were formed.

fig. 12 图 全新世最大海侵期古地理图

Holocene palaecgeographical map

1. muddy shallow sea bottom
2. sandy coast
3. muddy sandy coast
4. continent

Three distinct stages which were correlated with sea-level stands, were recognized in the formation of ridges. The sediments of the ridge from the Early Stage, overlying clayey sediments with a littoral facies, were dated at 6400 ± 100 y.B.P., so the author concluded that the maximum of transgression occurred in the period 7000 - 4000 years ago and reached a level of 2.5 m - 3 m above present sea level. The ridges from the Middle Stage apparently were not so well developed, but they are considered to be formed between 4000 and 1500 years ago; so the sea-level stand of that period was assigned to be at 0.5 m - 1.5 m above present sea level. The ridges from the Late Stages, with a "top level" at 1.5 m - 2.5 m were formed in the last 1500 years. Based on this altitude the author concluded that the sea level was higher in the Late Stage than in the Middle Stage and then lowered gradually to its actual stand.

It is to be mentioned here that the validity of shell bearing sand ridges as a sea-level indicator should be regarded critically from the point of view of their formation and altitude in relation to sea level as well as from the point of view of the relevant datable material.

Recent sea-level research yielded that shell middens are not the best tool for reconstructing, in space and time, the positions of former sea levels. In fact, in practice it is not possible to establish directly the vertical relationship between the base of a shell midden and sea level. The only thing which is more or less certain is that the base of the shell middens is above local high water spring tide level at the beginning of its construction (Martin *et al.*, 1986). Plainly, only one dating is insufficient, and one must have a statistically significant series of dates in order to interpret correctly the period of maximum transgression.

Moreover it is generally concluded that the most molluscan species can not be assigned a high indicative value. Considering all the fauna elements on the basis of quantitative investigations, it is possible to differentiate only between littoral, shallow- and deep- water environments. Furthermore, the few species that do occur within a (relatively) narrow range are often subject to *post-mortem* transport and are, therefore, only useful when it can be shown that they are autochtonous (Petersen, 1986).

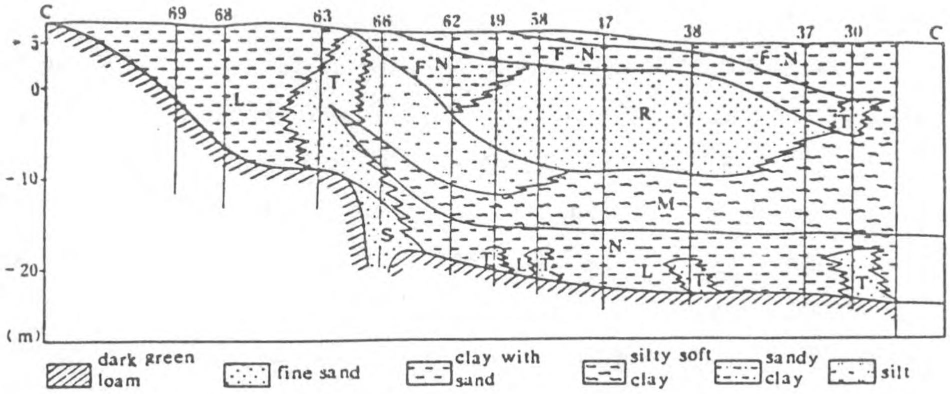
On the other hand palaeo-shorelines, as sea-level index points out, are more sensitive to individual sea-level fluctuations within a region than the long-term trends. These features also have limitations in interpreting local emergence and submergence histories and coastal evolution. They do not provide the absolute timing of events and may not even indicate the relative ages of changes in the system. Recognition of these events, however, can be used to augment longer-termed radiocarbon data and help resolve short-lived variations and their control on coastal evolution on short time scales not resolvable from existing radiocarbon data alone. The limitations of a single sea-level index to access local submergence/emergence histories are compounded by the fragmentary record of deposits recording minor changes in relative sea level (Gayes, 1988).

In 1986, Li Congxian elaborated a research on Sedimentary Characteristics of the Chinese Delta's whereby the Changjiang Delta was studied rather thoroughly. The author considered the post-glacial transgressive - regressive sequence of the *delta* on the one hand and the *strandplain* on the other hand. According to him, a boring drilled in the Shanghai Flour Factory is representative for the post-glacial sedimentation in the strandplain where two successive sequences were recognized, respectively a transgressive and a regressive sequence.

The sediments of the transgressive sequence, which in general is 7 - 8 m thick, were described as yellow grey and greyish brown loams in which calcium nodules are rich and siderite and pyrite are common. Vertical reed roots are also found. The author interprets the sediments as being deposited in a coastal swamp environment according to the presence of the microfossils (*Ammonia confertifesta* assemblage and *Sinocythere* with some other continental and marine transitional fossils). The palynological investigation (yielding a "*Castaneae - Quercus aliena - Pinus - Gramineae - Chenopodiaceae* assemblage") reflected that the climate was cool-warm. Furthermore, the author describes that: "fine sand lenses, 3 - 5 m thick, are often encountered in the transgressive sequence, which are remains of old littoral barriers, and peats deposited behind the barriers are locally occurring. Towards the top of the transgressive sequence, the barrier-lagoon and coastal swamp facies are gradually substituted by neritic facies".

The regressive sequence of the strandplain was divided into two parts. The author described it as follows: "The sediments of the lower part are homogeneous yellowy grey silty clay with a few siderite and relatively higher calcium content, amounting to 16.4 %. Foraminifera are found rich in species and number, mainly normal sized neritic species, and of *Ammonia beccarii - Elphidium advenum* assemblage. The rich ostracoda is *Echinocytheris bradyi - Sinocytheridea latiovata* assemblage. And other neritic fossils such as spines of echinoidea, bryozoans and triceratium etc. are common. Spores and Pollen of *Castanopsis - Quercus glauca - Polypodiaceae* assemblage reflects a warm and humid subtropic climate. Therefore, the lower part belongs to neritic facies. It should be noticed here that the author's subdivision into transgressive and regressive sequence, and the allocation of respectively coastal swamp and neritic facies, is contradictory. The superposition of neritic deposits on coastal swamp deposits involves a transgression. Therefore only the upper part is to be considered as regressive sequence.

The upper part is mainly grey silt containing rich foraminifera of *Epistominella naraensis, Ammonia convexidor* assemblage, which are small sized in majority, and ostracoda, mainly *Sinocytheridea latiovate, Neomonoceratina dongtaienses,* and some marine and continental fossils such as spines of echinoidea and Charophyta. The 3 - 4 m thick upper layer of the part is referred to littoral facies as it is composed of yellowy grey loam containing iron-manganese nodules and many plant roots and fragments, with some peat layers locally intercalated and the foraminifera in it become poorer with the relative increase in the euryhaline species. The upward decrease and disappearance of pollen *Chenopodiaceae* in the sporo-pollen analysis of the sediments from the depth 2 - 3 m reflects the weakening of sea water influence with time and freshwater intruding of coastal swamps. A relatively visible regional change of the upper part is shown by the dominance of



Profile of the strandplain north of the Changjiang River.

L – Lagoon; T – Littoral bar; N – Nearshore shallow water deposits; M – Littoral-neritic deposits; R – Radiating sand bar; F – Flood-tidal deposits; S – Channel-filling sand body.

fig. 13

(from Li Congxian, 1986)

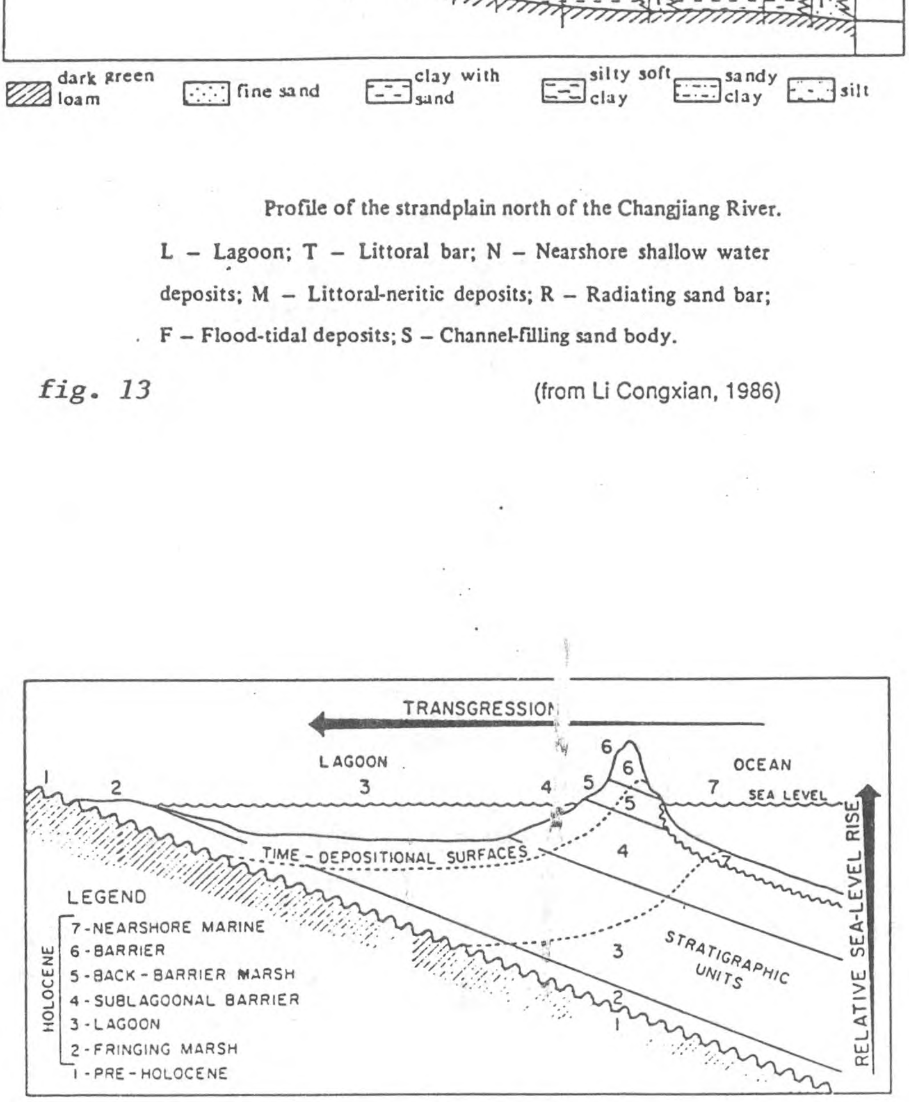


fig. 14 model of transgressive barrier stratigraphic sequence showing the difference in internal geometry of stratigraphic units and time lines (from Kraft and Chrastowski, 1985)

grey loam with sand lens south of the Changjiang and of fine and silty fine sand north of the Changjiang."

To demonstrate the transgressive sequence, Li Congxian (1986) refers to a cross-section north* of the Changjiang River (fig.13). However, the author does not give any further explanation about the sudden presence of the barriers and lagoons, which he quickly touched in his text, but which, according to the profile (fig.13), form the entire part of the transgressive sequence, together with the nearshore shallow water deposits on top of the barriers and lagoons.

The author's interpretation of barriers and lagoons as well as the cross-section require some comments. The littoral barriers are drawn as isolated patches, relatively high but rather narrow**, and with apparently no relationship between them. The most striking feature however, is the fact that the four different barriers are overlying directly the Pleistocene deposits on nearly the same level. This is a most remarkable situation for a transgressive sequence, where shorelines tend to migrate <u>landward</u> and <u>upward</u> in space and time. Moreover, the basal unit of a transgressive sequence in general consists of a marsh fringe organic mud overlain by lagoonal mud which in turn is then overlain by sand from the barrier (Kraft & Chrzastowski, 1985) (fig.14).

The gradual change from coastal swamp facies into neritic facies (according to the text of Li Congxian 1986) or the change from lagoonal facies to nearshore shallow water deposits (according to the cross-section) is very hard to believe as well.

First of all the neritic facies is to be excluded. The neritic zone is situated in the marine environment more particularly in the continental margin encompassing the shallow- water areas extending from the shoreline to the shelf break. The post-glacial transgression was characterized by a rapid sea-level rise indeed (2 m per 100 years, for the period until 7000 years ago), but a gradual change from a lagoonal environment behind coastal barriers directly to a neritic

* the precise location of the cross-section is not known

** the horizontal scale is not mentioned unfortunately environment (several tens of meters of water depth) in a time span of the Early Holocene period, seems to be exaggerated. Furthermore the vertical stratigraphical sequence at least should show deposits of the foreshore and shoreface on top of the barrier sand deposits.

On the other hand, coastal barriers develop as a result of a slowly rising sea level (Phleger, 1969 and Hoyt, 1967) and gradually develop into tidal flat (intertidal zone) environments (in tidal regions) if enough sediment is available (Reineck & Singh, 1986). Moreover it is very important that enough sand-size sediment is available and enough wave activity is present for the development of coastal barriers. The author did not mention whether these conditions were occurring at that time.

Last but not least, it should be noticed that in the vertical stratigraphic sequence no barriers are occurring anymore, except a great one (located at 63, fig.13) on top of a channel fill (!) and a small one (located at 30, fig.13) somewhere in the middle of nearshore shallow water deposits.

The confusion about the possible (and impossible) relationships between adjacent coastal depositional environments on the one hand, and the wrong correlations of horizontal and vertical facies, which were put forward by Li Congxian (1986) on the other hand, are most probably due to a misinterpreting and/or misunderstanding of the terminology of the concerned depositional environments. Indeed it is critical to make any conclusion about the transgressive as well as the regressive stage since the author does not explain exactly what is meant by "nearshore shallow water deposits (N)" and "Littoral-neritic deposits (M)".

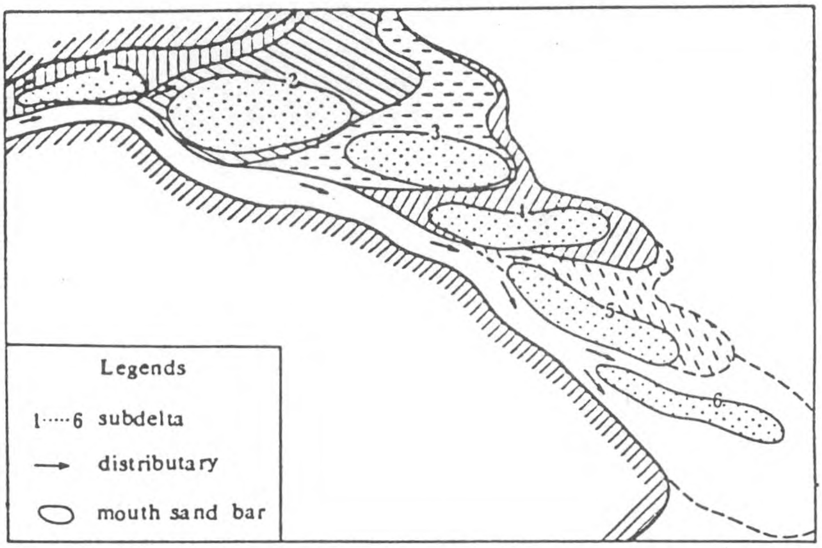
According to the current literature, this covers an area extending from the shoreline to the continental shelf break, an area that covers hundreds of kilometers and hundreds of meters in water depth. This obviously is a too great range to interpret the evolution of a coastal plain properly.

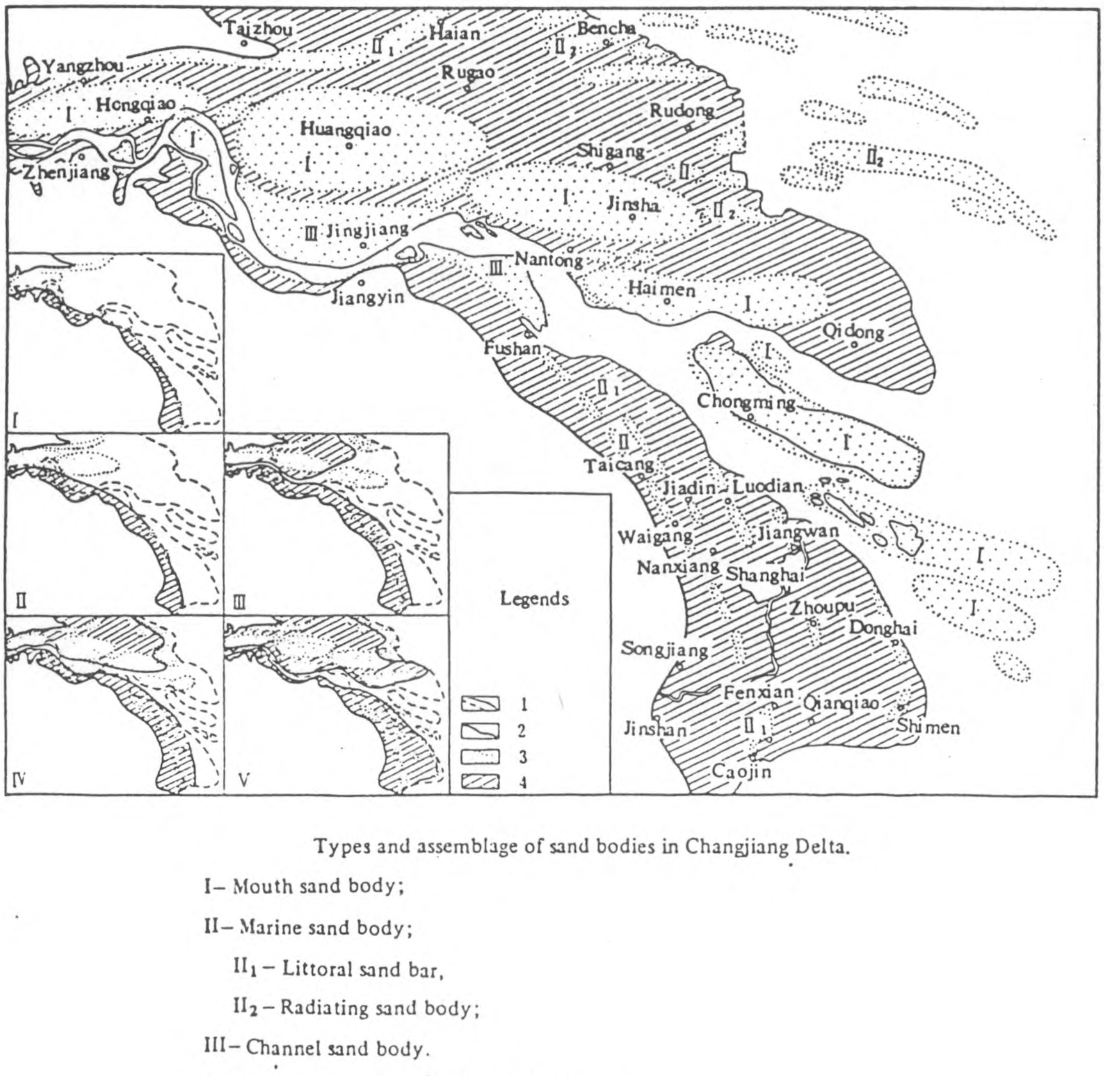
The one-sided use of foraminifera to determine depositional environments, especially in an evolving coastal plain, is very critical. The range of their occurrence is most of the time far too great and some foraminiferal assemblages are controlled by a series of parameters which often have no direct relationship with actual water depth (Scott & Medioli, 1986). Moreover, palaeo-environmental reconstructions based on the distribution of organic remains may be spoiled to a certain extent by *post-mortem* effects. The determination of foraminifera does provide a tool that can be used to obtain additional information for the reconstruction of sedimentary environments, but it is certainly not an exclusive one. It is to be incorporated in data from other sources.

The influence of the Holocene transgression on the development of the Changjiang coastal plain and its palaeo-geographical evolution have been also investigated recently.

Yang Qinshang & Hong Xueqing (1988) investigated the Southern Deltaic Plain and found out that the position of the Changjiang River Valley was situated below the surface of 50 - 60 m at the end of the Late Pleistocene. The authors considered that the area was characterized by relatively deep valleys which were rather quickly inundated by the Holocene transgression. Indeed, by the time of 8000 - 7500 years B.P. the shoreline is to be situated already at -7 m (of the palaeo-surface topography). During the period of 7000 - 6500 years ago the east Shanghai area changed into a shallow marine environment covered by about 20 m deep water and the Taihu hilly region into coastal marsh environment of shallow water. Enbayments and lagoons of relatively small size were formed on the Hangzhou-Jiaxing-Huzhou plain and Taogi plain. For the last 4000 years, the coastal plain east of Gangshen was characterized by a rapid seaward progradation, while the Taihu area became a freshwater lake.

Tao Qiang & Yan Qinshang (1988) presented rather different results for the area South of the Changjiang River. The authors concluded that about 6500 years ago the sea reached





Types and assemblage of sand bodies in Changjiang Delta.

I– Mouth sand body;

II– Marine sand body;

II_1 – Littoral sand bar,

II_2 – Radiating sand body;

III– Channel sand body.

1– Present coastline; 2– Boundary of delta;

3– Sand body; 4– Land.

fig. 15

the level of about 1 m below present sea level and in the period of about 9000 - 6500 years B.P.the eastern part of the investigated area (including a.o. the Tai Lake area) became a shallow bay while the marine influence had not yet reached the central and northern part. By the end of this period the shallow bay evolved to a tidal flat and low-salinity marsh. This is a sedimentary environment which differs considerably from a shallow marine environment with a waterdepth of about 20 m as was put forward by Yang Qinshang & Hong Xueqing (1988). Still according to Tao Qiang & Yan Qinshang (1988) the area silted up into land or freshwater lakes and marshes as from 6500 years B.P..

Another different opinion was found in an article from Li Jingan & Yan Qinshang (1988) who explained that before 7000 y.B.P.the sea level was situated close to the present one. In the western part of the Shanghai area freshwater marshes developed, while the eastern part was a shallow sea, in which a *recurved spits* began to develop in the offshore. However, the continuation of the authors' explanation is rather hard to understand as they write that: "during 7000 - 6500 years ago, the recurved spits began to emerge and a lagoon developed on its western side, so that the sequence of sedimentary environments eastward was freshwater marsh, lagoon, recurved spits, tidal flat and shallow sea. During the period 6500 - 3000 years ago, the ancient lagoon silted up and was replaced by a freshwater marsh which joined the western marsh. The sequence of sedimentary environments in the same direction was freshwater marsh, tidal flat and shallow sea."

All these different opinions make it difficult to put forward a general picture of the development and evolution of the Changjiang coastal plain during the Holocene.

A better similitude has been found in the description of the so-called "subdelta's", also called river mouth bar or sand bodies in the Changjiang Delta system , or sand islands and shoals, or mouth sand bodies. Six stages were recognized

Stages of the sand bodies in the Changjiang Delta system

Absolute age (BP)	International stage	Archaeological stage	Stage of sand bodies				
				Littoral sand barrier			
			River mouth sand bar	South of the lower reaches of the Changjiang River	North of the lower reaches of the Changjiang River	Radiating bar	River channel sand bank
	Subatlantic	Iron Age	Changxing stage 700	Donghai-wanxiang		Jianggang radiating bar	
−1000			Chongming stage 200–1700	Wangjianqiao-Jiangzhen Jiangwan-zhoupu		Sanyu radiating bar	Changyinsha
−2000			Haimen stage 1200–2500	Luodian-Qianqiao		Bencha radiating bar	Matousha
−3000	Subboreal	Bronze Age	Jinsha stage 2000–4500				
−4000				Jiading-Zhelin	Taizhou-Haian		
−5000		Neolithic Age	Huangqiao stage 4000–6500				
−6000	Atlantic			Waigang-Caojing			
−7000			Hongqiao stage 6000–7500				

Table 5

(from Li Congxian, 1986)

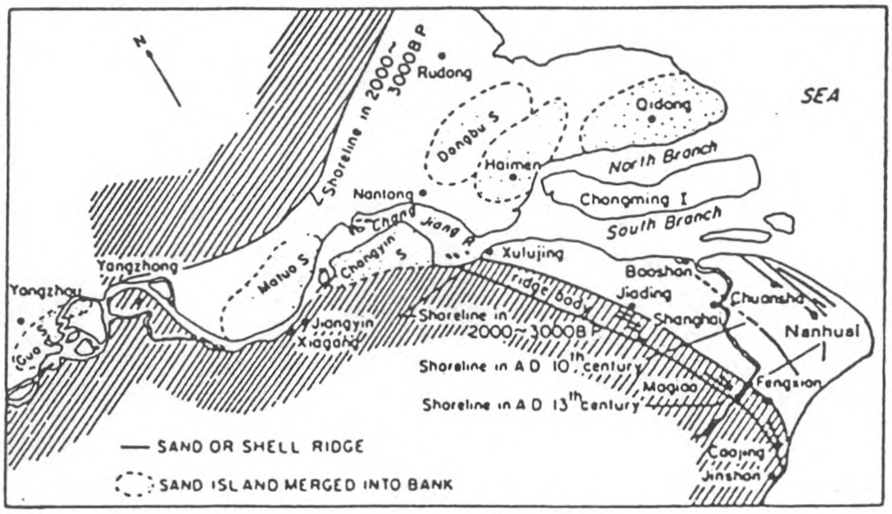
during which the successive subdelta's developed (Wang Jingtai *et al.*,1981, Guo Xuemin, 1983, Chen Jiyu *et al.*, 1985 and Li Congxian, 1986).

A brief but clear explanation about the *subdelta's* was given by Chen Jiyu *et al.*, (1985). The authors state that since the post-glacial transgression, the Changjiang estuary has undergone a progressive progradation seaward of shoals and tidal flats fringing the south bank, merging of linear sandbanks with the north bank, successive filling and narrowing of the estuarine enbayment, and a resultant seaward migration of the river mouth.

For the location of the "subdelta's" and their classification into six stages, see fig. 15 & Table 5.

A more historical development of the Changjiang estuary was elaborated by Chen Jiyu *et al.*, (1985) who concluded that after the post-glacial Holocene rise in sea level, the Changjiang estuary presumably was funnel-shaped, the head of the estuary being located at what is now Zhenjiang-Yangzhou Reach (fig.15). Judging from 14-C dates of mollusc shells from several sand ridges shoreward of the Tai Lake plain, the ridges accreted in a seaward direction at a very slow rate, implying that at this time, the Changjiang's sediment load was relatively low.

Sediments loads, however, increased immensely with developing human activity. Following initiation of massive reclamation in the mountainous areas of the drainage basin in the 3rd century A.D., the suspended load in the Changjiang began to increase substantially. By the 10th century, the shoreline had prograded to east of the Huangpu River (Shanghai, fig.6). During the 12th and 13th centuries, the shoreline was already near a line stretching from Chuansha to Nanhuai (fig.16). Since then, shoreline locations have been recorded by a succession of man-made dikes. The shoals along the south bank of the Changjiang estuary have been prograding seaward at approximately 1 km per 40 years, but recently, the rate has increased to 1 km per 23 years.



Changjiang estuary and historical changes in its configuration.

fig. 16

(from Chen Jiyu, *et al.*, 1985)

4. DESCRIPTION AND INTERPRETATION OF THE LITHOLOGIC UNITS.

4.1. Lithology and sedimentary facies

4.1.1. Introduction

The Upper Quaternary deposits of Shanghai which we are concerned with, has mainly been looked upon in function of the geotechnical and hydrogeological properties. That explains why the nomenclature of the Upper Quaternary of Shanghai is characterized by units identified as "Compressible Layer", "Aquifer" and "Dark Green Stiff Clay" (fig.17b). From a geological point of view the emphasis was restricted to the chronostratigraphy of some isolated borings (amongst others F10, Flour Mill) leading to the subdivision of the Quaternary in Q_4^3, Q_4^2, Q_4^1, Q_3^2, Q_3^1, etc.,..., (Q_4 for the Holocene, Q_3 for the Upper Pleistocene deposits). The identified "Compressible Layers" and "Aquifers" have been labelled with this chronostratigraphy.

However it is clear that the correlation of the borings and hence the lateral and vertical distribution of the units is not very well understood. This finds expression for example in the contradiction of two articles (Shi Luxiang & Bao Manfang) and Li Xiangling), both from the Shanghai Geological Department. In one article the Second Compressible Layer is occurring below the Dark Green Stiff Clay (fig.17), while in the second text and in the general Hydrogeological and Engineering Geological Profile of Shanghai (fig.18) the Second Compressible Layer is lying above the Dark Green Stiff Clay.

This study is based on 42 borings* until a depth of c.70 m which were carried out previously. The sediments, divided into broad units, have been described in a general way indicating colour, texture and some additional characteristics like the presence of shells and vegetation remnants. Some general

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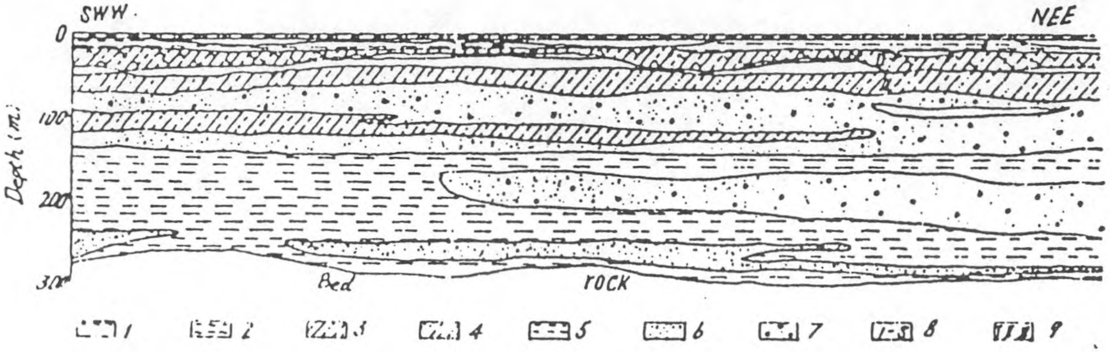
* the detailed boreholes logs are enclosured in the appendix



Geological profile of the urban area of Shanghai. 1, surface soil; 2, muddy clay; 3, muddy clayey loam; 4, clayey loam with sand; 5, stiff clay; 6, sand; 7, sand with gravel; 8, confined aquifer; 9, compressible layer.

fig. 17 a

(from Shi Luxiang and Bao Manfang)

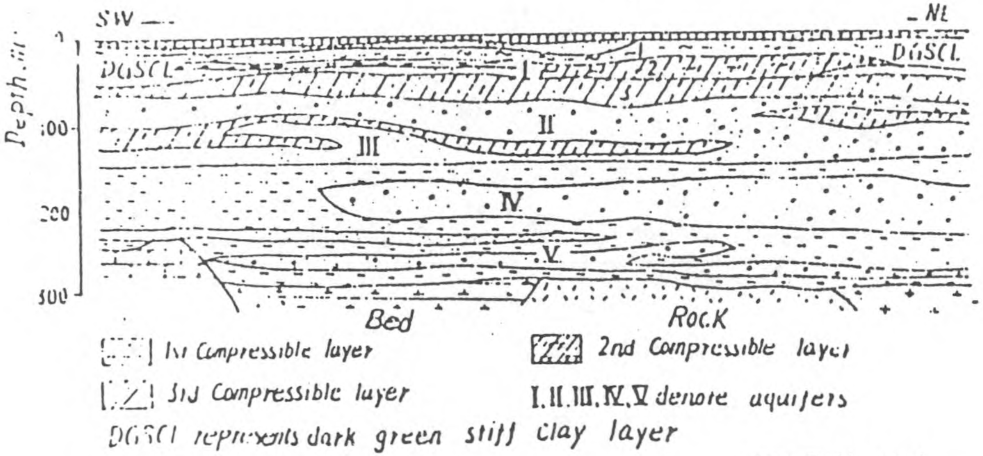
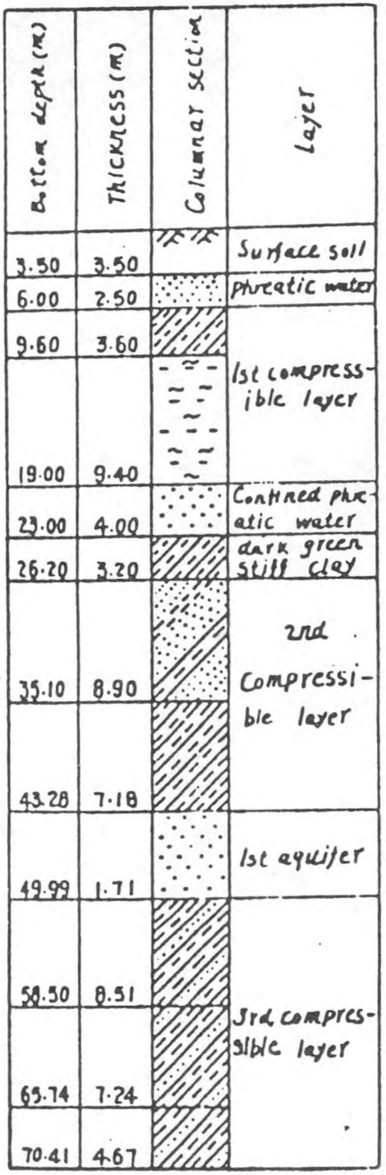


fig. 17b

(from Su He-yuan)

fig. 17 Hydrogeological profile of Shanghai urban area.



Bottom depth (m)	Thickness (m)	Columnar section	Layer
3.50	3.50		Surface soil
6.00	2.50		phreatic water
9.60	3.60		1st compressible layer
19.00	9.40		
23.00	4.00		Confined phreatic water
26.20	3.20		dark green stiff clay
35.10	8.90		2nd Compressible layer
43.28	7.18		
49.99	1.71		1st aquifer
58.50	8.51		3rd compressible layer
65.74	7.24		
70.41	4.67		

(from Shi Luxiang and Bao Manfang)

fig. 17c

sedimentary structures were sometimes mentioned as well. But the attention was especially focused on the so-called engineering properties which were noticed in the following way:

-for the compressible layers: soft and plastic
saturated butterlike
high cohesion
high moisture
-for the aquifers: saturated, wet and loose.

Some borings (most probably older ones, namely S5-2, G7, G37, G6, S8, G123, G02, G157) give very brief and summarized data, only mentioning colour and texture.

On the other hand, three borings, CBG1-1 and CBG1-2, both located at a very short distance from each other, and K4 have been carried out recently in the framework of this study. These borings were investigated in detail and consequently had to form the basis for all the other borings. Hereafter these three borings will be referred to as reference borings.

As the geological sequence considered in this study is only known and identified by means of the hydrogeological and engineering units, the same units will be used in this chapter as a provisional subdivision. The investigated sequence consists of, from top to bottom, the uppermost part, the First Compressible Layer and the Second Compressible Layer belonging to the Holocene , and the Dark Green Clay, the First Aquifer, the Third Compressible Layer and the Second Aquifer from the Late Pleistocene.

4.1.2. Description and interpretation

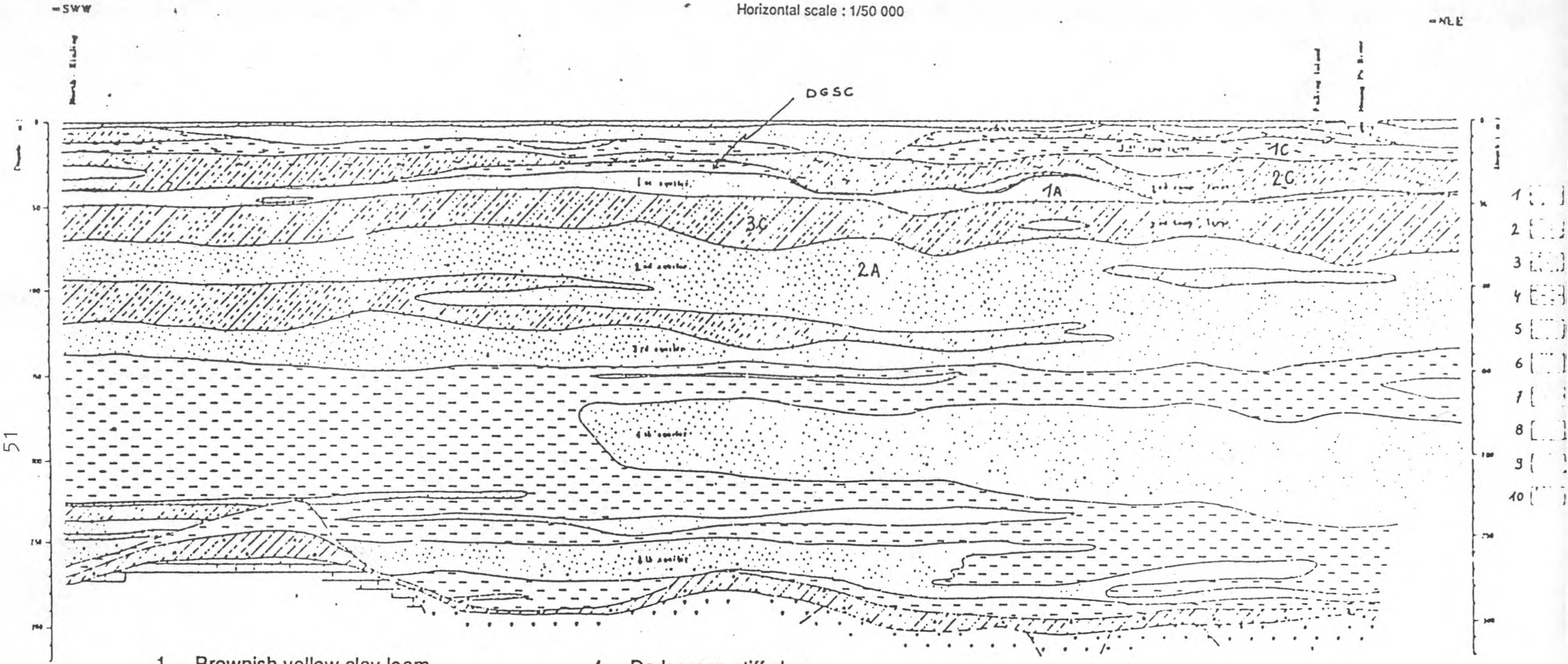
Holocene units

1. The uppermost part

The upper 1-3 m is always referred to as "artificial filling

Hydrogeological and Engineering Geological Profile between North: XinJing and FuXing Island of shanghai

Horizontal scale : 1/50 000



1. Brownish yellow clay loam
2. Muddy clay
3. Muddy clay loam
4. Dark green stiff clay
5. Clay loam with sand
6. Clay loam
7. Variegated clay
8. Silt and fine sand
9. Medium sand
10. Coarse sand and gravel

fig. 18

soil" in practically all the borings. In some cases additional data is mentioned as : "loam, containing rusty and dark spots, with oxidized iron spots, no bedding. The sediment is dense with low water content". In some borings the sediments are described as "grey yellow complex composition of fine silt, few sand with a lot of humic material" or as yellow brown sandy loam.

In the reference borings (CBG1-1 & CBG1-2) the top unit consists of brownish grey, becoming grey towards the base, silty clay to very silty clay characterized by rust mottling bearing some fragile gastropodes.

This uppermost unit of the Holocene sequence reflects the classical upper part of a reclaimed coastal plain generally called "the crust" in the literature. It reflects the final stage of silting up of the plain before it was reclaimed and controlled, by man by means of dikes, ditches and canals. Due to the reclamation of the land, the groundwater level is artificially controlled leading to the dewatering of the upper few meters of the deposits. This dewatering (by capillarity) resulted in the compaction of the sediments and the fluctuation of the groundwater table causes the Fe-mottling. The eventual original sedimentary structures faded away due to the human occupation, the present bioturbations, as well as to the dewatering and the fluctuation of the groundwater table.

In the K4 the situation is different as it shows a dark grey to black very silty clay with reduction spots, a lot of vegetation remnants and fragments of the bivalve *Corbicula*, amongst other shell fragments towards the lower part of the units. This situation however reflects clearly the occurrence of a small local gully or even a ditch in the uppermost part of the boring.

2. The First Compressible Layer (1C-unit)

In all the borings the first compressible layer (1C-unit), which in general extends until a depth of -10 m to -15 m, is

present in the entire area. It is mainly described as "gray muddy clay interlayered with thin silt lenses" or "gray muddy silty clayey loam* intercalated with layers of silt" or "bluish gray muddy and silty clay" or "gray muddy silty clay with silt". The kind of stratification sometimes mentioned, indicates mainly a horizontal stratification and "fish skin structure" or "flaky structure". In few borings shells or shell fragments are mentioned, as well as "stratified humus". It is very clear that this unit is far from homogeneous since in many borings sand is found, however irregularly distributed and at different depths. It is mentioned as: "gray sandy loam, with horizontal stratification", or "silty sand" or "silt alternating with sand" or "silt and sandy loam".
In some borings "gas-pore" or "needle texture" are mentioned, indicating in fact airholes, air bubbles or gas bubble cavities.

According to the reference borings this unit can generally be described as a grey clay with many thin siltlaminae and small siltlenses. These are irregular in frequency, size, thickness (mm to few cm), but with a dominant parallel, horizontal bedding. The silt is mainly occurring in small ripple bedding or micro-scale crossbedding, but distinct lenticular bedding with flat lenses, small-scale erosional features, small-scale load structures and some bioturbation structures, filled with silt, are often found as well. On this occasion it was found out that the Chinese circumscription "fish skin structure, like the skin of a fish" represents indeed nothing else than the lenticular bedding. Sandy sediments are restricted to the upper part of this unit.

The lower part of this unit (as from a depth of c.-7 m) obviously shows less siltlaminae and siltlenses although still having the same aspects. However this part is especially characterized by the presence of zones with thinly interlayered silt/clay bedding, like "the pages of a book" as the Chinese circumscription depicts it very well. This

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* In the Chinese nomenclature "loam" is used to indicate silty clay.

sedimentary structure can be interpreted as the typical tidal bedding and more particular as the pin-stripe tidal bedding (de Vries Klein, 1977). This type of bedding can also originate in moderately fast-flowing water, having a very high suspension content (Reineck, 1967). The entire unit is calcareous. The carbonate content is low in the clay and slightly higher in the silt. In general few shells are found, moreover most of them are broken and concentrated in thin laminae or sandnests, consisting mainly of juveniles. Some estuarine shells (mainly *Tellina*) do occur all over. Sporadically thin shell concentrations of marine shells (unidentified species) were found as well (e.g. K4 at 14.60 m).

The deposits of the 1C-unit obviously show a mud and silt dominated facies. They contain some typical sedimentary structures such as lenticular bedding, thinly interlayered silt/clay bedding and micro-cross-laminae, all indicative of the alternation of bedload and suspension deposition characteristic of tidal condition.

According to the explanation of Klein (1977), bedload deposition occurs during the higher velocity phases of a tidal cycle. Suspension deposition occurs in periods of lower velocity or non-existent flow, and tends to coincide with either the high-water slack period or the low-water slack period of a tidal cycle. The bedload processes are responsible for the relative coarse-grained sediments and the suspension deposition is responsible for depositing fine-grained sediments.

Different associations of structures will occur where these processes alternate, depending on the relative concentration of coarse-grained or fine-grained sediments and the relative duration of the bedload or suspension style of deposition. In the sedimentary process here, the relative volume of mud exceeds far the volume of silt and sand, hence the current ripples become isolated and are preserved as lenticular beds.

The deposits of the 1C-unit clearly exhibit evidence of tidal sedimentation. But it is critical to differentiate between sediments deposited on tidal flats (intertidal environment) and those deposited in the shallow subtidal environment. May be a tidally influenced shallow marine* facies (Johnson & Baldwin,1986) is to be considered as well, although very few sandy sediments are present. But it should be remembered that the area is adjacent to the Changjiang River and that during its Holocene geologic history it was very much influenced by the supply of sediment from the Huanghe River (Milliman,*et al.*,1985), both rivers transporting significant quantities of fine-grained suspended sediments on to the continental shelf. Nowadays the coastal waters are brown and muddy showing a sharp transition with the clearer offshore waters (Milliman, *et al.*, 1985).

Indeed the most favourable sites of mud accumulation are adjacent to major river mouths where mud blankets frequently extend even across the full width of the shelves (Johnson & Baldwin, 1986). If the high suspended sediment concentration is combined with a low wave effectiveness, the situation for mud to accumulate is even more favourable (Thompson, 1975).

The bubble cavities occurring in this unit can be explained in several ways. Air bubbles are commonly observed on intertidal flats which however show a more sandy facies. The bubbles are produced where the surf is flooded with water rapidly (Reineck & Singh, 1986). According to De Boer (1979) the entrapment of air in the sand of the intertidal zone is related mainly to the fact that the groundwater table follows the surface water level fluctuations with a phase lag, which depends upon the permeability and position within the sediment body. During long low water periods, the groundwater table sinks, while during rising tide the water level rises at a higher speed and covers the whole surface before the groundwater level reaches the sediment surface. Consequently, air is entrapped during flood phase within the upper part of

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* shallow seas (with a water depth of c. 10 - 200 m) in the sense of the area lying between those parts of sea dominated by nearshore processes and those dominated by oceanic processes.

the bed. Now the water starts to penetrate through the sediment surface downward into the sediment, the entrapped air is compressed, and the pressurized air extends into bubbles. During falling tide, the cavities are sustained by the friction of the grain fabric and surface tension of the sand-water-air contacts.

Bubble cavities have been found in mud sediments as well produced as a result of entrapment of air during rapid deposition of muddy sediments (Bull, 1964).

Gas bubble cavities occurring in muddy sediments also can have another origin. Decomposition of organic matter produces gas bubbles that are partly preserved as smaller cavities (Reineck & Singh, 1986). Such bubble structures are mainly found in muddy sediments rich in organic matter which however, is not the case for the 1C-unit deposits.

The lower part of the 1C-unit obviously shows less siltlaminae and -lenses. This can be explained by a more intense bioturbation reworking in that part or by a transition from mudflat (or higher mudflat, landward part) to mixed flat (lower mudflat) in the vertical sequence or a combination of both.

3. The Second Compressible Layer (2C-unit)

The second compressible layer is a clearly recognizable unit with some typical characteristics. It is found at a level between -10 m until -20 m and in some locations even until -35 m. In general it is described as: "clay", "clay loam", "loam" or "muddy silty loam", all labelled as homogeneous. The colour is grey, dark grey or sometimes brownish. The unit is especially characterized by reed rhizomes and plant fragments, which has been called: "decomposed roots, carbonized and non-carbonized reed rhizomes, rotten plant rootlets".

Another typical feature is the occurrence of what has been called "yellow and brown-yellow nodules". Additionally "gas-pore" or "needle texture" and "fish skin structure" (like the skin of a fish) or "flaky structure" are often mentioned in this unit. Only in few borings the lower part of this unit bears some siltlaminae and becomes even slightly sandy.

In the reference borings CBG this unit is described as a slightly silty clay with few parallel siltlaminae and siltnests, grey coloured with iron-oxide mottling at the top. There is very little to no physical stratification, but on the other hand it is very much characterized by a crumbly structure, showing evidence of physical ripening. Indeed very small and thin vegetation remnants (rootlets) are found.

Towards the lower part of the unit some small peat fragments as well as reworked organic material concentrated in thin laminae are present. At the very lower part however there are a lot of vertical root structures and pieces of wood (peaty wood).

The unit has a very low carbonate content (slightly higher in the silt). Small shellfragments do occur only very sporadically.

The K4 boring however shows a rather different aspect of the 2C-unit. The unit is found between -13 m until -37 m. The unit is much thicker than in general and moreover can be divided in different parts.

The very upper part (until -c.17.50 m) consists of a clay, low carbonate content, slightly crumbly, with numerous thick vertical root structures of reed, small peaty plant remnants as well as small thin vegetation remnants (rootlets) and containing sporadically fragile gastropodes. The abundance (or dominance) of plants and organic material in that part is very clearly shown in the presence of organic gyttja around -14 m and some peat detritus in very thin laminae are occurring likewise. That part is also characterized by these typical yellow and orange "nodules". On this occasion the origin of the "yellow and orange nodules" could be investigated. They consist of rather firm silty clay with no significant higher carbonate content and most of them were found still inside decaying roots or stems of reed.

From c.-17.50 m* on, another facies is shown: silty clay with a very thinly interlayered bedding, less vegetation remnants but somewhat more small shell fragments (rather fragile), amongst them gastropodes.

As from c.-19.20 m to c.-22 m the sediments are again characterized by the presence of reed, and small thin vegetation root traces, no distinct sedimentary structure but crumbly and, as in the uppermost part, these yellow and orange "nodules ".

As from c.-23 m the sediment becomes a dominantly strong silty clay, homogeneous, without physical stratification but still crumbly, however fine crumbly this time. Reed penetration decreases but the thin small vegetation remnants are still abundant. The yellow brownish nodules are not so frequent anymore. Carbonate content remains very low. Only at -30.70 m (till -30.80 m) a clayey peat** is occurring, and at the lowermost part (as from c.-35 m) some vivianite nodules are present.

It is worthwhile to mention that only in the CBG1-1 the boundary with the underlying unit could be observed, a boundary which showed to be rather gradual.

From the sedimentary facies, some ideas about the origin of the 2C-unit and its sedimentary depositional environment can be put forward. In the homogeneous silty clay sediments the most striking features are the deep vertical root structures, yellow and orange nodules, the lack of physical stratification (except a few discontinuous siltlaminae) and finally the crumbly structure.

All these features point to a salt marsh as an environment intimately related to adjacent bodies of tidal water, situated above mean high tide level and characterized by a dense vegetation. The crumbly structure is evidence of physical ripening as an effect of subaerial exposure or coastal emergence.

The yellow and orange nodules also display one of the

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* c. because of approximate depth indications by the geologist and lost and disturbed parts (2 m) in the core .

** sample has been taken for age determination by ^{14}C.

typical phenomena of salt marsh facies. According to Frey and Basan (1985) and Bouma (1963), iron is abundant in numerous saltmarshes and reacts with various organic and inorganic compounds. Ferric hydroxide, either in nodules or as linings of burrows or decaying roots is most obvious. The nodules remain soft but nevertheless are much firmer than the host sediments. In many instances these nodules are larger or more irregular than the original burrow systems.

The gas bubble structures found here might be explained as gas bubbles produced by the decomposition of organic matter and partly preserved as smaller cavities.

Considering the salt marsh as sedimentary environment for the 2C-unit, a remaining problem should be mentioned here, however. One of the principal characteristics of salt marsh deposits namely is their small thickness which rarely exceeds a few meters. But the deposits of the 2C-units, showing the typical features described above, reach a thickness ranging between 3 m and 20 m.

The 2Ca-subunit

In some parts of the studied area, the Pleistocene deposits are covered by sediments bearing a facies completely different than the typical one of the 2C-unit. These sediments (with a thickness of c.20 m) in particular occur in restricted areas where the Holocene deposits reach an important depth (up to c.-45 m). Therefore an additional subunit had to be introduced, provisionally called 2Ca. It consists of homogeneous grey silty clay with a horizontal stratification. Shells and shell fragments as well as reworked peat fragments are sometimes found.

This 2Ca-unit is most probably to be interpreted like the above described 1C-unit, as it shows many similarities with it.

4. The Dark Green Stiff Clay Layer (DGSC-unit)

In the geological setting of Shanghai a lot of attention and importance is paid to the occurrence of this unit, hence it is always considered as a keybed. Indeed this clay layer forms the top of the Pleistocene sediments.

Moreover from a geotechnical point of view it has the greatest bearing capacity of all the Late Quaternary sediments, hence it is not compacting any more, so the interest from the engineers for the clay is evident.

However from a geological and more particular from a sedimentological and genetic point of view very little is known about it.

In the borings it is described as: "dark green clay or dark green clayey loam." In general the clay layer becomes more silty towards its base. Its engineering geological characters are stiff, hard and dense, semi-solid state. In some cases additional data is mentioned, like:

- it contains humus
- locally interlayered with grey greenish thin silt
- a lot of rusty spots are found in the lower part
- at the top there are dark carbonized plants
- the soil mass is homogeneous, no bedding
- contains a small amount of yellowish brown iron cores.

The thickness of the claylayer ranges from 1 to 10m.

In the reference borings this unit is mentioned as: grey green slightly silty clay, compact, fine crumbly, becoming gradually more silty in the lower part. In the lower part numerous traces of thin vegetation rootlets are found, most of them having an iron-oxide rim. Small black vegetation remnants do occur as well. There is a very gradual transition with the underlying unit. The clay has no carbonate content and shows some iron mottling, although not at the very top.

The typical features of the DGSC-unit are the homogeneous mixture of clay and silt with plant remains, having an iron-oxide rim around the rootlets, and the lack of well-defined bedding. The combination of these characteristics are found in a flood plain environment and more particularly in the flood basin. Sediments of a flood basin contain the finest grains of all the alluvial sediments and generally they are fine silt and clay. The deposits seldom show horizontal bedding with textural differences. Organic debris and mottled structures are other important features.

According to the definition given by Reineck & Singh (1986), flood basins are the lowest-lying part of a river flood plain. They are poorly drained, flat, featureless areas of little or no relief located adjacent to active or abandoned stream channels. Flood basins act as settling basins, in which suspended fine-grained sediment settles down from overbank flows after the coarser sediments have been deposited on levees and crevasse splays. Thus, flood basin deposits represent the long-continued accumulation of fine-grained suspended sediment. The rate of sedimentation is generally very slow; usually a silt-clay layer, 1 or 2 cm thick is deposited during one flood period. In the lower reaches of a river, the area occupied by flood basins increases tremendously in relation to the area occupied by the river channels and levees. Such low-lying basins may occupy areas of few hundred square kilometers.

Thick flood basin deposits are produced if streams become more or less fixed in their position, so that longer periods are available for deposition in flood basins.

In a humid climate flood basins are low, wet, and thickly vegetated. In such areas they commonly develop as backswamps. Thick vegetation results in incorporation of much organic matter in flood basin deposits. But a differentiation is to be made between poorly drained and well-drained backswamps (Coleman, 1966). The latter bears a much lower content of organic matter, while in poorly drained swamps the organic matter even may accumulate in peat layers, which is not the case for the deposits of the DGSC-unit. In poorly drained

flood basins, which consequently are particularly swampy and waterlogged, large shallow lakes can sometimes develop.
In the working area of Shanghai the DGSC-unit is often interpreted as a river-lake deposit (internal reports and "Stratigraphical Columnar Sections"). The arguments for identifying it as lacustrine deposits are mainly its broad extension and the occurrence of siderite in the deposits. Indeed deposits with sedimentary siderite are often formed by biogenic processes in oxygen-deficient environments. But such environment does not necessary imply a lake; backswamps, peatbogs or even mudflats e.g., also are characterized by oxygen-deficient environments in which siderite is often found (Bariand, *et al.*,1978).

Considering the geometry and shape of the DGSC-unit however, it is most unlikely to assign a lacustrine facies to these deposits (see 5.1). Moreover, lacustrine sediments show a great variety of deposits with a specific pattern of sediment distribution and different sedimentary structures.

Freshwater lacustrine deposits in a deltaic environment (very shallow, but extensive lake) were studied by Coleman (1966). These deposits are made up of dark grey to black clays with silty lenses, the clay showing extremely fine laminations. Amongst other characteristics, these sediments are commonly bioturbated, sometimes lamellibranch shells in a living position are encountered, pyrite and vivianite are often found, but iron nodules are absent. The DGSC-unit does not reveal any of these typical characteristics. Therefore it should not be interpreted as a freshwater lacustrine deposit in a deltaic environment neither.

All the typical features of the DGSC-unit show evidence of deposits of a flood basin environment and a well-drained backswamp.

5. The First Aquifer (1A-unit)

In contrast with the other units, the First Aquifer (1A-unit) can geologically not be considered as one single unit bearing the same characteristics. What is usually called the 1A-unit will be divided here for the sedimentary facies in an upper part and a lower part.

Moreover in a number of borings, located in the southern part of Shanghai it is impossible to make any distinction between the First Aquifer and the lower-lying Second Aquifer as the Third Compressible Layer is lacking. This situation will be regarded later on as an additional unit. Thus only the sediments lying above the Third Compressible Layer and under the Dark Green Stiff Clay will be considered as the unit called 1A.

The Upper Part

From the borings the upper part of the 1A-unit can be characterized as: greyish yellow silty clayey loam, heavy silty sandy loam, yellow silt, brownish yellow loam mixed with a little silty sand or brownish yellow silt, partially intercalated with loam. Nearly everywhere rust mottling and unclear stratification is mentioned and in some cases vegetation remnants and humic material are present. The upper part of the 1A-unit may vary in thickness from 2 to 5 m.

In the reference borings the upper part (-25.60 m to -32.10 m) is very well developed in the CBG1-2 (although similar to the CBG1-1 boring). It looks as follows:

- the first half meter: there is no sharp or distinct change with the DGSC-unit, except for the colour. But he sediments are bearing a clear parallel ripple bedding in which curved non-parallel clay laminae are occurring.

- from -26.00 m to -27.50 m: brownish grey very silty clay with many regular thin parallel wavy silt laminae, a lot of vertical root structures, manganese concretions and many large rust mottling.

- from -27.50 m to -28.50 m: grey brown clayey silt with locally fine sandy zones, few thin clay laminae. The top again is characterized by very large rust mottles.
- from -28.50 m to -32.10 m: grey brown fine sandy silt regularly interlayered with thin even parallel clay laminae. The lower part is more clayey but with distinct sand laminae which become thicker and more frequent downwards. There is nearly no rust mottling any more but the entire sandbed itself shows an orange colour.

This upper part has no carbonate content in its entire sequence.

It can be summarized as an upward fining sequence, deposited by current ripples and grading upward into fine grained clay sediments. However the plant fragments, rootlets, iron mottling and manganese concretions indicate that this upper part was deposited above the groundwater level.

All the features point to the facies of natural levee deposits. Natural levees are wedge-shaped ridges of sediment bordering stream channels. These ridges are many times wider than the channels they border and rise as much as 5 m above the river bank into flood basins away from the channel.

Natural levees are formed by deposition of sediment when flood waters of a stream overtop its banks. The velocity is reduced, causing deposition of much of the suspended sediment near the channel. Coarsest sediment is deposited near the channel, and grain size decreases away from the channel. The rate of deposition also decreases rapidly away from the channel (Reineck & Singh, 1986).

Sedimentary structures of levee deposits include small-ripple cross-bedding, climbing ripple lamination, horizontal bedding, and parallel laminated mud layers. Sandy units are overlaid by muddy units. Generally a sandy layer, a few decimeters thick is overlaid by a muddy layer, a few centimeters thick. Sometimes sand and mud layers can be equally thick, or mud layer can be even thicker than the sand layer. Thus, in a vertical sequence sandy and muddy layers alternate each other. The levee deposits grade upward in fine-grained silt and clay sediments of the flood basin.

Soil-forming processes that lead to mottling of the uppermost part of a mud layer, are rather active. Larger levees support much plant growth. Thus, much plant debris and organic matter is incorporated into levee sediments (Collinson,1979; Reineck & Singh,1986).

The Lower Part

In the borings the lower part of the 1A-unit is indicated as follows:
- silty sand, silty fine sand or medium fine sand
- fine sand intercalated with clayey loam
- silty fine sand locally with clayey loam mixed with silty sand.

In some borings shells are present. The colour is almost brownish at the top changing into bluish grey or greenish grey downward. In few cases the sedimentary structure is mentioned, being a horizontal stratification.

In the reference boring CBG1-2, the lower part is found at a depth between 35.60 m - 47.60 m*. The description can be summarized as follows: silty fine sand with a gradually transition downward to a rather regular alternation of fine sand and silty clay to finally clayey silt with sand laminae. The colour is dominantly grey brown, plentiful orange coloured laminae; downward some greenish brown laminae are present but the very lower part is greenish grey.

The sediments have clearly horizontal parallel wavy laminations and cross-bedding changing into mainly thin parallel wavy lamination and flaser bedding in the lower part.

In the CBG1-1 boring the features of the lower part are identical; additionally a level of estuarine shells and shell fragments (mainly *Assiminea sp., Corbula fluminea, Hippentis sp.)* is occurring at a depth of -42.80 m.

The transition between the upper and the lower part of the 1A-unit is very gradual; the most striking change however, is the presence of $CaCO_3$ in the lower part which moreover is

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* lower limit is approximate as samples were missing in the core at that depth .

increasing towards the base of the unit.

In the K4 reference boring the 1A-unit shows a completely different picture. The upper part of it is missing completely and the lower part is not at all identical with the typical facies.

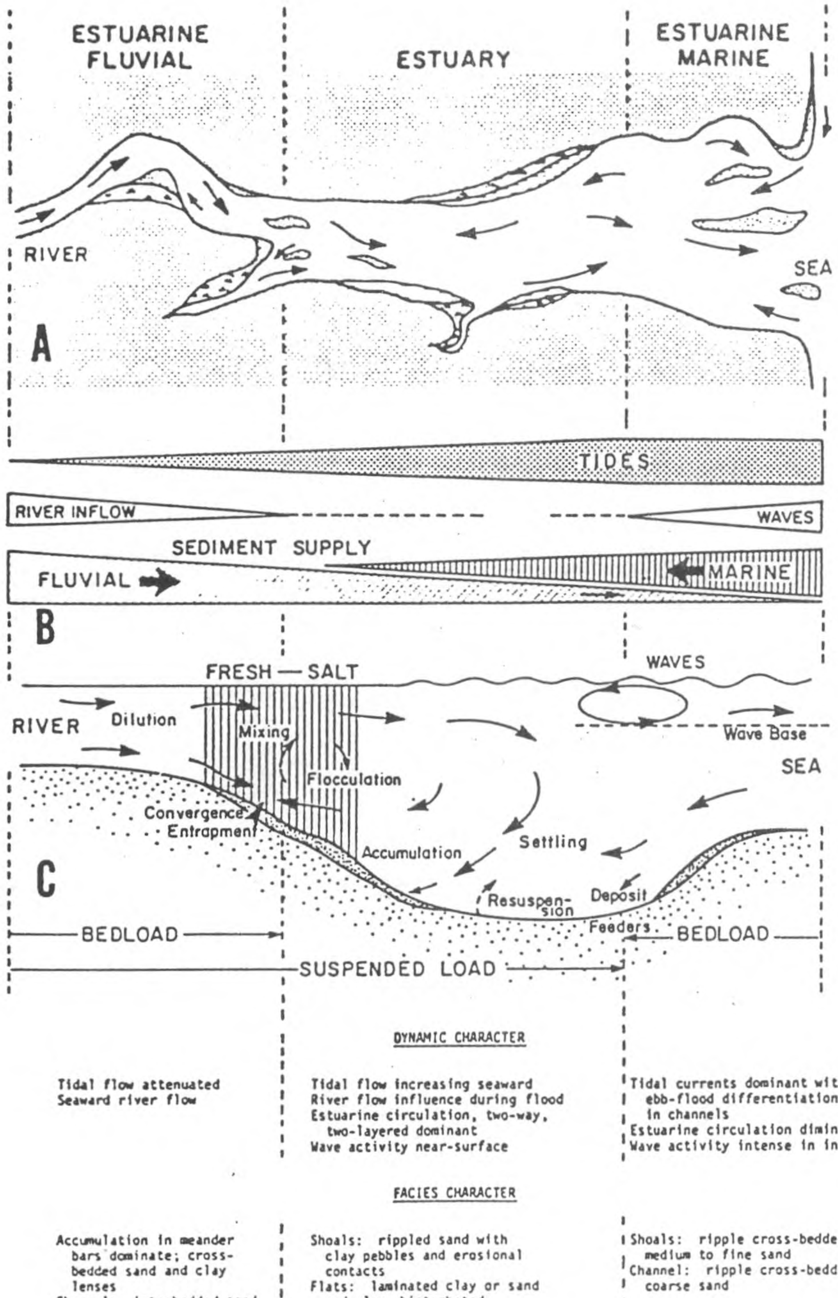
Indeed the lower part, only 1.70 m thick, (occurring at a depth of -43 m) consists of a green grey compact sandy clay becoming more silty and sandy downward. There is no carbonate content, except in the silt laminae where furthermore it is very low. That different facies was only found in two other borings, namely in G4 and in G16 at a depth of respectively -37 m and -40 m.

The 1A-unit is also different in the borings G63, G55 and F12 where only the upper part of the unit is developed.

The predominant sandy facies of the lower part of the 1A-unit obviously is related to channel fill activities. However the vertical sequence of this part is rather complex as all the characteristics of the deposits indicate a transition, from bottom to top, from marine to fluvial deposits. Such a transition is encountered in an estuarine environment.

An estuary is characterized by a complex dispersal system which is best approached by distinguishing areas dominated by fluvial, estuarine and marine activity (fig.19). The boundaries between areas are transition zones that shift according to river discharge, tides and meteorological forces and, over a longer time span, by sea-level changes (Nichols & Biggs, 1985). Dispersal in the fluvial area is controlled by river flow, the amount of sediment transported, and the dispersal pattern, depending on whether or not the river floods. Tidal flow is attenuated, especially during high river discharge, and net nontidal flow is seaward throughout the water column. Suspended sediment concentrations are diluted with distance downstream and partly sedimented in

DISPERSAL ZONES & ROUTES



	DYNAMIC CHARACTER	
Tidal flow attenuated Seaward river flow	Tidal flow increasing seaward River flow influence during flood Estuarine circulation, two-way, two-layered dominant Wave activity near-surface	Tidal currents dominant with ebb-flood differentiation in channels Estuarine circulation diminished Wave activity intense in inlet
	FACIES CHARACTER	
Accumulation in meander bars dominate; cross-bedded sand and clay lenses Channel: interbedded sand and clay; gravelly Marsh and swamps: organic rich clay and silt	Shoals: rippled sand with clay pebbles and erosional contacts Flats: laminated clay or sand and clay, bioturbated Marsh: massive clay with plant fragments Channel: clay and silt laminated and interbedded with sand lenses and shells, massive silt and clay, bioturbated, seaward	Shoals: ripple cross-bedded medium to fine sand Channel: ripple cross-bedded coarse sand

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Conceptual model of dispersal zones and routes in a hypothetical estuary; (a) plan view, submerged sand shoals and spits dotted, intertidal flats hachured, and marsh. Arrows show direction of water and sediment movement. (b) Relative intensity of dominant dispersal agents, tides, river inflow and waves along estuary length in relation to dominant sediment supply, either fluvial or marine. (c) Vertical-longitudinal section of main dispersal routes. Lower table summarizes dynamic factors and associated facies character.

(from Nichols and Biggs, 1985)

fig. 19

adjacent marshes, resulting in massive clay and silt that is rich in organic matter. Another part of the load is deposited in less energetic parts of the channel and on bars or is swept seaward into the main estuary. Bed load is directed seaward into the upper estuary. Some sand accumulates in meander bars but can be transposed from one bar to another during river floods (Allen, 1972). Sand can also accumulate on the channel floor following floods, whereas mud accumulates during low river discharge. The resulting deposit consists of interbedded sand and clay. Longitudinal bars are fed by sand bed load and consist of crossbedded sand with clay lenses or pebbles overlain by megaripples. Where fluvial supply is relatively high or tides are weak, the river builds a deltaic sediment mass in the estuary head or estuarine fluvial zone (Ryan and Goodell, 1972). Bed load of sand or flocculated fine sediment tends to accumulate where the river debouches into open estuary forming a delta front shoal. Dispersed fine sediment is spread unequally into adjacent swamps and marshes of the estuarine fluvial zone as swept through the main channel and spread seaward over a broad area of the main estuary (Nichols and Biggs, 1985).

As already mentioned, the characteristic feature of estuarine deposits is its transition between fluvial and marine deposits. In a transgressive sequence it is from fluvial to marine, in a regressive sequence from marine to fluvial. Terwindt *et al.* (1963) differentiated the fluvial and estuarine sediments in such a sequence model. The estuarine sediments are relatively fine-grained, containing rounded clay pebbles and shell beds in ripple areas. Moreover they contain different types of bedding, characteristically found in tidal environments, i.e. lenticular and flaser bedding, wavy bedding and thinly interlayered sand/clay bedding.

The lower part of this 1A-unit, consisting mainly of a clayey and sandy silt, can be attributed to an estuarine environment. According to Nichols and Biggs (1985), the sediments in the open water estuarine environment consist of monotonous sequences of silts and clays. Sand deposits 1 - 10 cm thick occur sporadically. These usually are present as lenticular layers, a product of concentration and reworking of the sands by currents. Ripple cross-stratification is rarely preserved. Occasionally scour-and-fill structures are present.

Shell and plant fragments are common, both scattered throughout estuarine sequences and concentrated in discrete beds. Extreme events, such as hurricanes or floods, may concentrate plant fragments in the deeper, lower energy portions of estuaries. Molluscs may colonize bottom areas, grow to adults, or be wiped out while still juveniles because of changing environmental conditions, leaving behind layers of shells in life positions with evidence of extensive burrowing or reworking in the underlying sediment.

Parallel laminations consisting of alternating of coarse and fine material are apparent in many low-energy estuarine deposits, particularly in deep oxygen depleted zones where benthic fauna and bioturbation are absent. These may be caused by seasonal fluctuations in suspended sediment load or character, or by variations of the amounts and kinds of organic matter supplied by the estuary. Sometimes these laminations are not apparent to the eye but are evident on radiographs of cores. Laminations can also occur in high energy estuarine deposits as a product of normal tidal periodic processes or aperiodic extreme events.

On the other hand sand occurs frequently in macrotidal estuaries which are characterized by a funnel-shaped form headed by a tidally influenced meandering channel (Elliott, 1979). In this case the predominant depositional features in the main part of the estuary (subtidal environment) are linear tidal sand ridges or tidal current ridges, deposited as bedload sediments. These ridges consist of low-angle cross-bedding fine sand with silt laminae.

The sedimentary structures of the lowermost part most probably indicate the influence of tidal currents. The interlayered sand/clay bedding, the wavy bedding, the evenly laminated sand and some flaser bedding are more particularly present in these areas where current velocities are low. For example on submerged shoal surfaces or on the upper part of the channel slopes where the deposits are predominantly horizontally bedded (Oomkens and Terwindt, 1960). Such bedding structures showing alternating sand/clay layering are related to the tidal phases showing alternation of current and slack-water activity.

Towards the upper part of the unit the sandy facies with horizontal bedding becomes predominant; a facies which is not the typical one of sediments in estuaries like described above.

The sandy facies may be explained as a result of the lateral migration of a channel producing extensive surface of channel-bottom sediments and additionally units of sandbars (Reineck & Singh, 1986). It should be mentioned that the typical channel-bottom or channel lag sediments never were encountered here. These in general consist of poorly sorted coarse-grained sand, intercalation of clay layers and many clay pebbles, showing megaripple bedding. Molluscan shells are quite common as well as peat pebbles or rolled wood-pieces (Terwindt, 1971). In this unit only layers of concentrated broken shells were found.

It would be most obvious to attribute the sand facies , which represents the transition from tidally influenced channel to fluvial-dominated river channel, to deposits accumulated in sandbars.

Based on only few borings, it is critical to differentiate whether the sand accumulated in meander bars (generally known as point bars) or as braid bars deposits. Moreover, there seems to be no well-defined differences in the sequence of point bar deposits and channel bar deposits for rivers with very fine-grained sediments. In fact, several rivers possess both point bars and channel bars at different time. Sometimes a point bar may even grow, becomes detached as a channel bar, and develop further (Reineck & Singh, 1986). These sand-dominant stream deposits are generally characterized by mainly horizontal bedding, low-angle planar cross-bedding and trough cross-bedding.

On the other hand lateral migration of channels can also produce a sheet of channel sand. These sheet sand deposits can reach a significant thickness as the channel is migrating continuously. Coleman (1969) describes that in 200 years the Brahmaputra River has carved a valley about 200 km long with an average width of 12 km. The average depth of sand laid down by the migrating river is on the order of 20 m, in localized areas up to 40 m.

6. The Third Compressible Layer. (3C-unit)

The Third Compressible Layer shows a well distinguished facies. In all the borings where it is present it has been described in a rather similar way as: "multi-layered bed": gray loam interbedded with thin silt and fine sand layers, horizontal stratification with layers with a thickness of cm and mm, some oblique lamination, fish skin structure, locally some shells and plants. The sand content increases downward and a thinly interlayered sand/clay bedding is dominating.

In the CBG reference borings a further differentiation could be made. The upper part of the unit consists of dark bluish grey clay with rhythmic alternation of very thin horizontal silt layers, like the tidal bedding and more in particular the pin-stripe tidal bedding. Lenticular bedding is abundant as well as bioturbation structures (from the horizontal type and escape traces) filled with silt or fine sand. The carbonate content is slightly higher in the silt than in the clay. The middle part (as from a depth of c.57 m) becomes gradually more sandy. Its facies shows an irregular alternation of clay and fine sand. Shell fragments are occurring in the sand. Sporadically heterogeneous beds consisting of clay mixed with coarse sandgrains, small pebbles and broken shells are present. In the lower part silt is increasing again while the sand gradually decreases downward. The sedimentary structures are identical to the upper part.

But toward the very base of this unit, the sand is increasing again in an irregular alternation with clay, showing wavy bedding and numerous small-scale crossbedding as well.

In the K4 reference boring the Third Compressible Layer shows a quite different aspect. The very upper part of the unit (the first 4 m) displays the classical facies and consists of a dark grey silty clay with many thin silt laminae, sometimes with pin-stripe bedding but also with small-scale cross-bedding and a lot of bioturbation structures. The very top of this part (c.10 m) is slightly humic and bears no calcium carbonate.

However as from -49.50 m a greenish grey silty fine sand is occurring with a thickness of about 10 m. The sand becomes gradually coarser toward the bottom. Some reworked peat remnants as well as wood fragments are present. In the lower part a lot of small gravels, most of them angular, are found. The base itself is formed by some gravel and a lot of shell fragments. The entire sandbed bears calcium carbonate.

This sandbed forms a sharp boundary with the underlying grey silty clay (1.50 m thick) bearing irregular thin silt laminations.

The next underlying unit (from -60.30 m to-62.90 m) again shows a quite different facies. It consists of a greenish grey very silty clay, rather compact, no carbonate content and no physical stratification. Toward its base it becomes silty.

This facies which is remarkable in the 3C-unit, and which was found in only one other boring (S8 at a depth of -60 m), reminds very much the DGSC.

The lowermost part of the 3C-unit in the K4 (-62.90 m to

-63.50 m) consists of at one hand an alternation of grey and greenish grey sandy silt with thin clay laminations and on the other hand a fine sand, bearing numerous parallel horizontal thin clay laminations. Downwards the whole becomes gradually a clay with rhythmic thinly interlayered bedding of silt. The carbonate content in the sand and silt is slighly higher than in the clay.

The sedimentary structures of the 3C-unit point to a tidal environment and more particular to intertidal and subtidal (cf.1C-unit). Indeed the typical characteristics are present, such as: the thinly interlayered silt/clay and sand/clay bedding (for respectively the upper and lower part), the lenticular bedding and the bioturbation structures.

The coarser and more heterogeneous parts are to be interpreted most probably as a facies related to smaller tidal channels and gullies of the intertidal zone.
According to Reineck & Singh (1986) these facies are mainly muddy in nature with a few sandy intercalations (coarsely interlayered sand/mud bedding) where shell layers and mud pebbles are always present. The heterogeneous badly sorted beds with coarse sand grains, small pebbles and broken shells can be interpreted as channel lag deposits, although clay pebbles have not been found. Such channel lag deposits may develop over wider distances than the width of the channel, as a result of channel migration.

Another explanation for the heterogeneous parts might be a temporary greater influence or even dominance of the river supply in its estuarine environment.

This certainly must have been the case in the K4 boring, where the 10 m thick sandbed with gravel and reworked plant fragments is occurring. In this boring it is not excluded that at the level of -60.30 m to -62.90 m the river dominance was total as a claybed with a flood basin facies was deposited indicating a temporary proper fluvial environment (cf.DGSC-unit).

7. *The Second Aquifer (2A-unit)*

As already mentioned before at the occasion of the description of the 1A-unit, only the sandbody underlying the Third Compressible Layer (3C-unit) will be considered as Second Aquifer.

This study only deals with the very upper part of the 2A-unit. It has been described as follows: "a medium fine sand, locally with fine gravel. It contains shells, echinoidea spines and thin layers of humic material as well as wood fragments. Locally oblique interlayers of loam are present." or "silty sandy loam or gray clayey fine sand, containing a little mica and quartz as well as humic matter". The colour is grey, or dark-green, or yellow grey or bluish grey.

According to the reference borings the 2A-unit can be considered as a heterogeneous sand body. This unit could be investigated more in particular in the K4 boring. The top shows a silty fine sand with more clayey silty zones in which a horizontal stratification is occurring. This changes very quickly to relatively coarser material and the 2A-unit becomes an (irregular) alternation of on the one hand medium sand mixed with gravel and on the other hand very silty zones in fine and medium sand, in which sometimes clay laminations are present. The gravel is always angular. The coarser parts are characterized by a very bad sorting. They consist of a heterogeneous mixture of sand, gravel (fine and coarse) with clay and mudflakes, indicating most probably a very quick deposition, no long transport, and with a huge supply of sediment.Such a deposition can be explained as a channel lag as well. The coarser parts have less carbonate content than the silty zones. Sporadically wood fragments were found.

The sediment characteristics of the 2A-unit which was considered here, point very much to an estuarine environment and more particular to the channel activity (cf. 1A-unit), but in the estuarine fluvial part, where the fluvial processes are still dominant and the estuary functions as a sink for fluvial and marine sediments.

The relatively coarse-grained and heterogeneous sediments were deposited most probably in channels while the finer sediments accumulated on sand bars or sand tongues located between the channels. Both are typical features of the subtidal zone of the estuarine environment.

8. The Sand Complex unit

In the southern part of the studied area the 3C-unit is lacking. Hence the Upper Pleistocene deposits, underlying the DGSC-unit (until a depth of 70 m), consist of only one single unit, which will be called the Sand Complex unit. Moreover, the DGSC-unit is often absent as well in some zones of that area.

The Sand Complex unit, which can reach a thickness up to at least 40m, shows a typical facies in almost all the borings of that southern area. It was described as follows: fine to medium sand, locally with loam interlayering. Some clayey silt zones do occur and sporadically concentrations of shell fragments and fine gravels are found. The sediments very often show horizontal bedding and cross-bedding. The top of the unit consists of a more silty and clayey facies over a few meters. The colour is almost yellowish brown at the top changing to bluish grey or dark grey downward.

It is most obvious that this Sand Complex unit was deposited in the same circumstances as the sand deposits from the 2A-unit and from the lower part of the 1A-unit.

In this particular area the channel and sand bar sediment accumulation from the subtidal environment (cf. 1A & 2A-unit) continued to develop so that the environment did not evolve to an intertidal flat, recorded in the silt and clay of the 3C-unit. Therefore this particular area clearly reflects (for the Upper Pleistocene) a continuous channel activity in the subtidal zone of an estuarine environment.

4.2. **Clay Mineralogy** (by Huang Huanzhong)

The clay minerals are a main component part in Quaternary sediments of Shanghai working area. To study the composition, vertical distribution and origin of the clay minerals are of significance in explaining the environments of deposition and the sources of sediments. 44 samples from Shanghai and 9 from CBG1-1 core have been provided for a detailed analysis of the clay composition by Liège Clay Laboratory with X-ray Diffraction (XRD). The XRD analysis has indicated that the major components of the clay minerals at different depth are almost the same while the minor ones have the slight variances due to the different palaeoclimatic environments and depositional conditions.

XRD analysis on the Clay Minerals

The particles of the clay minerals in the working area generally are very fine and components are much complex, comprising up to 13 different species or varieties through XRD analysis. The identification of the mixed clay components sometimes will bring the complicated data and mislead the analysis, so it is necessary for Liège Clay Laboratory to have a post-treatment before testing and analysing in order to get the expected results.

1. The treatment of the samples

a. "The routine XRD analysis was first carried out by referring to three classic tests, namely: the air dried stat (natural or normal, N), after solvation with ethylene glycol vapors (12 hours), and after heating to 500°C/4h. On the base of the preliminary characterization of the clay assemblages, other post-treatments have been performed as to reinforce the qualitative analysis. These post-treatments comprise: an acid attack (HCl, 4N, boiling), saturation with Li^+, followed by heating to 300°C and solvation with glycerol vapors."

b. "extraction of the adequate (2μm) grain-size by sedimentation and centrifugation in demineralized water, without any addition of flocculation or dispersion agent." "Organic matter as well as Fe or Mn sesquioxides were not removed."

c. "The clay fraction (2μm) was afterwards prepared as oriented aggregate before the preparation becoming X-rayed.

2. the components of the Clay Minerals

The report supplied by Liège Clay Laboratory "only focus on a brief description of the encountered clay minerals without entering the details of their XRD properties." The species of the clay minerals in CBG1-1 core mainly are Illite, Chlorite, Kaoline and Smectite. The dominant Illite is in the range of 52.95 %. The nature of them as follows:

Illite: "with acute peak (I_{ap}), referring to a stable structure, with all the interlayers filled with potassium cations; illite with enlarged peak (or foot) (I_{lp}), which corresponds to a illitic structure exhibiting some minor distended interlayers (these being expressed by the development of a slight assymmetry of the basal reflection at 10 Å); an open illite (I_o), with a global opening of the interlayers, a fact displayed by a well-development of the assymetrical peak at 10 Å in particular." "the increase 'weathering' of the illite structure is documented by a change of shape (or facies) of the basal (001) reflection centered (or with its apex) on 10 Å. The weathering sequence, with subsequent opening of the interlayers is : I_{ap}---I_{lp}---I_o. "The 10 Å peak is in reality a statistic globalization of an entire particles of illite (within the less than 2 μm) fraction. Consequently, when indicating the occurrence of, i.e. a illite with large peak (I_{lp}), that does not mean that neither a illite with acute peak (I_{ap}) and/or an open illite (I_o) is not present, but statistically the majority of the illitic population is comprising essentially the illite with large peak.

Chlorite : mainly can be identified from 14.2 Å and 4.7 Å by XRD and "may be entirely fresh (intact) or a part of the original chloritic stock may be already weathered before the sedimentation phase. In the latter case, the chloritic marterial may be entirely weathered into the mixed layer (14_C-14_V) or $C-(14_C-14_V)$."

Kaolinite: can be identified from 7 Å and 3.5 Å. "the occurrence of a chloritic complex $(C+(14_C-14_V)+V)$ with which the kaolinite does share common reflections." "the (001) and (002) reflection of the kaolinite, respectively located at 7 Å and 3.5 Å, can be easely confused or massed by the (002) reflection at 7 Å and the (004) reflection around 3.5 Å of the 'chloritic' complex." "In certain samples this doublet was not clearly exsiting and one has to refer to an acid attack; the latter does not affect the kaolinite, which preserves its (001) reflections whereas the chlorite is dissolved and consequently its characteristic reflections disappear in the X-ray pattern registred after attack."

Smectite: can be identified from its basal reflection (001) around 17 Å.

The quantitative calculation of the clay minerals here has "applied the usual method of the Liège's Clay Lab. This method consists in firstly correctly allocated the qualitation occurrence of all the clay components. Then, one selects in specific X-ray pattern the true intensity of the basal (001) reflection of the minerals. Following this composition and the measured intensity of the corresponding (001) basal reflection factor is introduced in the calculation (relative quantification)." "For instance, here are the values of these correction factors:

-Illite : 1

-Kaolinite : 0.7

-Chlořite, vermiculite, C-(14C-14V) : 0.35

-Smectite/ (10-14Sm)17 and Al_{17} : 0.25

The calculation (intensity of the (001) reflection by the corresponding coorection factor) provides a relative quantification of the specific clay component in the range of 10 % of the indicated value. Table 6 shows the percentage of the clay components mainly in CBG1-1.

Table 6 : The content of the major clay components in CBG1-1

Species	Maximum %	Minimum %	Average %
Illite(I)	62.6	43.3	52.95
Chlorite(C)	12.7	6.4	9.55
Kaolinite(K)	14.4	3.8	9.1
Smectite(Sm)	7.7	2.2	4.95

There are also some variations in vertical distribution of the clay components. Table 7 indicates the percentage of the clay components in the main engineering layers.

Table 7 : The content of the major clay components in the engineering layers in CBG1-1 in %

Species	Surface layer	1C	2C	DGSC	Brown-yellow	3C
Illite	49	51.8	49.6	47	56.2	62.6
Chlorite	9.8	10.3	7.4	12		10
Kaolinite	13	9.6	11.7	12	6.2	7
Smectite		5.5				

An extended analytical report on the composition and vertical distribution of the clay assemblages by Prof. Dr. J. Thorez (Liège Univerity) is enclosed in the appendix.

4.3 Grain Size Analysis of the boring CBG1-1

(by Huang Huanzhong)

Based on the lithological features, 35 samples above 70 m have been analysed in grain size by the central laboratory of Shanghai Geological Bureau, adopting "mm", "Mz", "Sd", "Sk", "Kg" as calculating unit. The sorting coëfficient of the sediment and the parameter of grain size have been calculated according to the formular proposed by Folk and Ward (Table 8 & 9, fig.20).

0-3.50 m: brown gray light brownish gray silty clay, cohesive and plastic and with a lot of iron spots and nodules. Below 1.50 m there are many silt laminae and vein-like bedding.

3.50-6.06 m: gray silty clay with silty fine sand thin layers in horizontal and occasionally lenticular and crossbedding. Below 5.95 m silt increases to 64 % and clay 32 %. Mean grain size (Mz) 5.72 Ø, standard deviation (Sd) 1.52 Ø and poor sorting.

6.06-9.94 m: gray silty clay interlayered with silt, good cohesion and soft plasticity with well-developed horizontal bedding and burrow structure, containing 65 % silt and 30 % clay. Mean grain size Mz 6.39 Ø, standard deviation Sd 1.69 Ø and sorting is poor.

9.94-20.08 m: brownish gray muddy clay. Soft plasticity and good cohesion with thick-layered horizontal bedding. Locally with fine sand laminae and well-developed bioturbation structures. More silt at 18-18.50 m and some brackish mollusc fossils and gray white shell fragments below 19 m. In this layer silt takes 44-55 % and clay 44-52 % and mean grain size is 6.28-6.53 Ø, standard deviation 1.42-1.57 Ø and worse sorting.

20.08-25.15 m: Gray brown silty clay, soft plasticity and cohesion and in crumbly structure, more pale yellow iron spots in irregular distribution, fish skin structure and needle-like gaspores can be found below 22.50 m. Some gray black humic

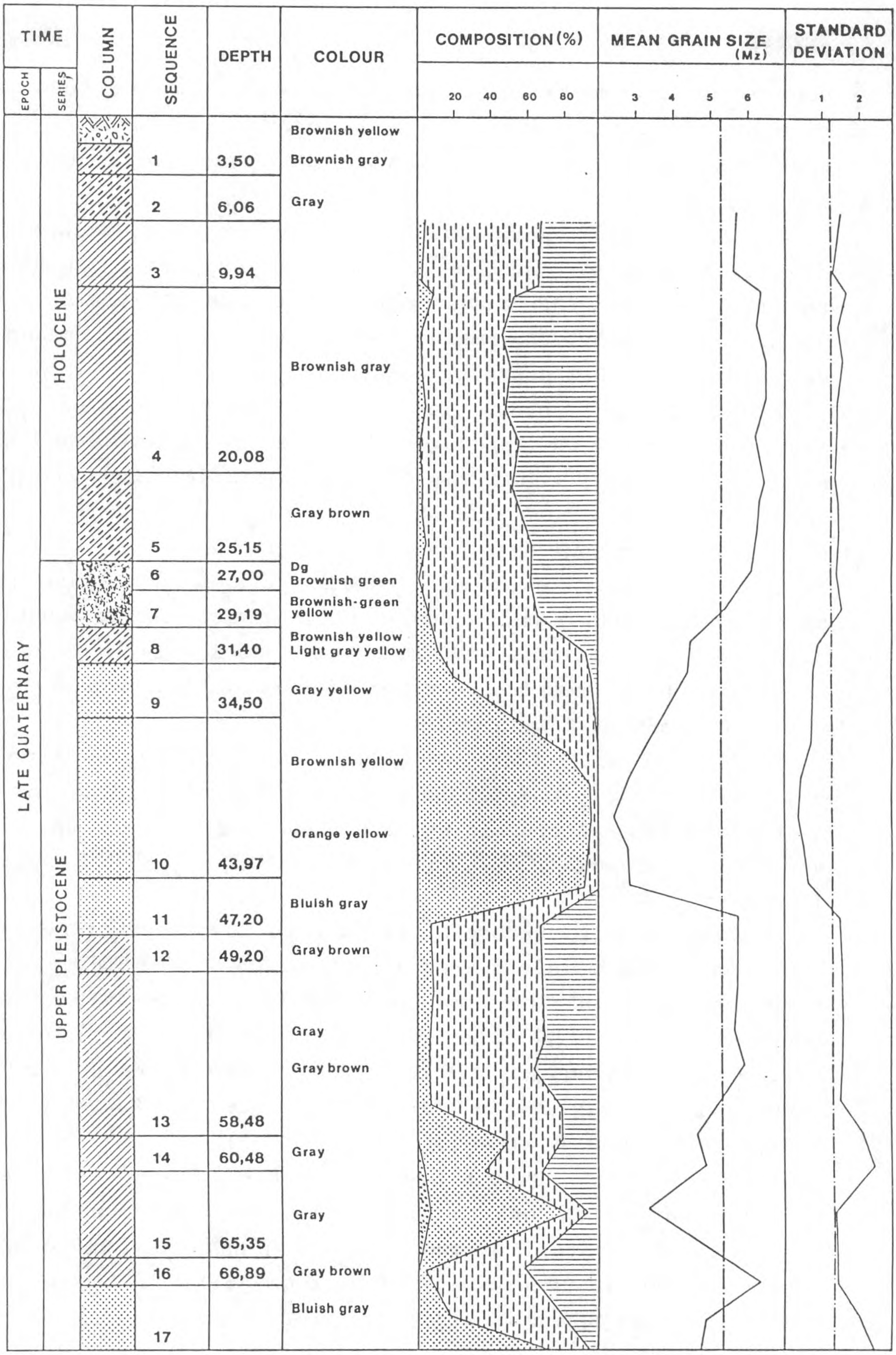

TIME
EPOCH
SERIES
COLUMN
SEQUENCE
DEPTH
COLOUR
COMPOSITION (%)
20 40 60 80
MEAN GRAIN SIZE (Mz)
3 4 5 6
STANDARD DEVIATION
1 2
LATE QUATERNARY
HOLOCENE
UPPER PLEISTOCENE
Brownish yellow
1 3,50 Brownish gray
2 6,06 Gray
3 9,94
Brownish gray
4 20,08
Gray brown
5 25,15
6 27,00 Dg Brownish green
7 29,19 Brownish-green yellow
8 31,40 Brownish yellow Light gray yellow
9 34,50 Gray yellow
Brownish yellow
Orange yellow
10 43,97
11 47,20 Bluish gray
12 49,20 Gray brown
Gray
Gray brown
13 58,48
14 60,48 Gray
Gray
15 65,35
16 66,89 Gray brown
Bluish gray
17

fig. 20

vegetation fragments i.e. roots and leaves of the reed, the content of silt is about 50-59 %, clay 36-47 %, mean grain size (Mz) is 6.29-6.45 Ø, standard deviation Sd 1.38-1.49 Ø and poor sorting.

25.15-27.0 m: Dark green silty clay, wet, dense and crumbly structure, pipe-like cracks and very small vegetation roots at the top. The percentage of silt and clay is 62 % and 37 % individually. The mean grain size is 6.12 Ø, standard deviation Sd 1.48 Ø and poor sorting.

27.0-29.19 m: Brown gray green, brown yellow green silty clay, dense and crumbly, downwards more iron nodules and silt with a little bit sand. The contents of silt, clay and fine sand are 59 %, 33 % and 8%. Mean grain size is 5.67 Ø, standard deviation 1.57 Ø and poor sorting.

29.29-31.40 m: pale gray, yellow clayey silt, cohesive and plastic with higher content of silt and little sand, at 31-31.40 m iron stripes well developed vertically in pipe-like structure. Silt occupies 80 % and fine sand 12 %, clay 8 %. Mz = 4.48 Ø, Sd=0.94 Ø with medium sorting.

31.40-34.50 m: Gray yellow silt, loose, mineral composition mainly quartz and mica, horizontal bedding, mostly silty sand laminae containing high clayey. Silt makes up 75 % and very fine sand 21 % . Mz = 4.38 Ø , Sd = 0.80 Ø , sorting is medium.

34.50-43.97 m: Redbrown, ironish yellow clayey fine sand, loose, minerals mainly quartz and mica. At 34.50-36.68m, redbrown clayey stripe-like thin bedding. At 40-43.97 m fine sand alternate with clayey silty fine sand laminations. Horizontal bedding is developed. This zone contains 81-95 % fine sand and only little silt. Mz is 2.32-3.21 Ø,Sd 0.38-0.82 Ø, sorting is medium to well.

43.97-47.20 m: Bluish gray fine sand, loose, in mineral composition mainly quartz and mica. The top contains more clayey constituents, horizontal bedding and gray white shell fragments (at 46.30 m more shell fragments). 91 % fine sand and 9 % silt occupy this zone. Mz = 2.79 Ø , Sd = 0.13 Ø medium sorted.

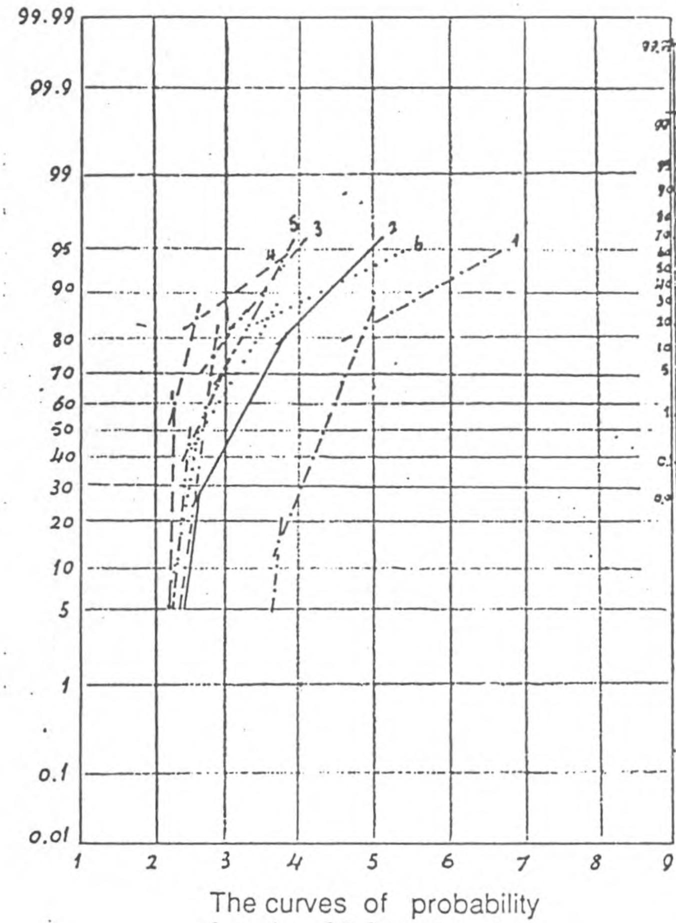
Table 8

GRAIN SIZE CLASSIFICATION

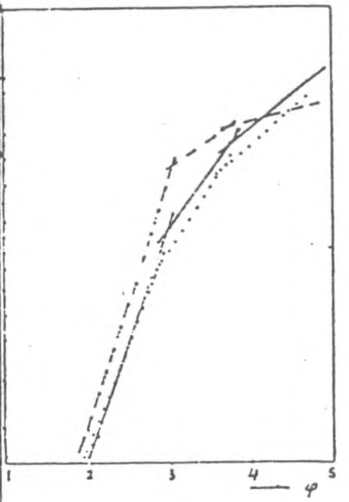
Standard Size Classes of Sediment	Ø	Diameter (mm)
medium sand	1-2	0.5-0.25
fine sand	2-3	0.25-0.125
very fine sand	3-4	0.125-0.063
silt	4-8	0.063-0.004
clay	> 8	< 0.004

Table 9

SORTING INDEX	DEGREE OF SORTING						
	Well Sorted <-------------------------> POORLY Sorted						
	1	2	3	4	5	6	7
	< 0.35	0.35 / 0.50	0.50 / 0.71	0.71 / 1.00	1.00 / 2.00	2.00 / 4.00	>4.00



The curves of probability
for the CBG1-1 borehole



sandbar of the
Changjiang River
(Jiuden sand)

1: 31.80 m
2: 35.80 m
3: 37.80 m

4: 39.80 m
5: 41.50 m
6: 43.50 m

fig. 21

Generally, the probability accumulation curves of this fine sand (fig.21) consist of three short straight lines, one indicating the suspended component, the other two indicating the leaped components (bedload) (the slope of the coarser is bigger than that of the finer one). The curves of probability accumulation reflect that the sand in the CBG1-1 is similar to the sand of modern Yangtze estuary sand bar.

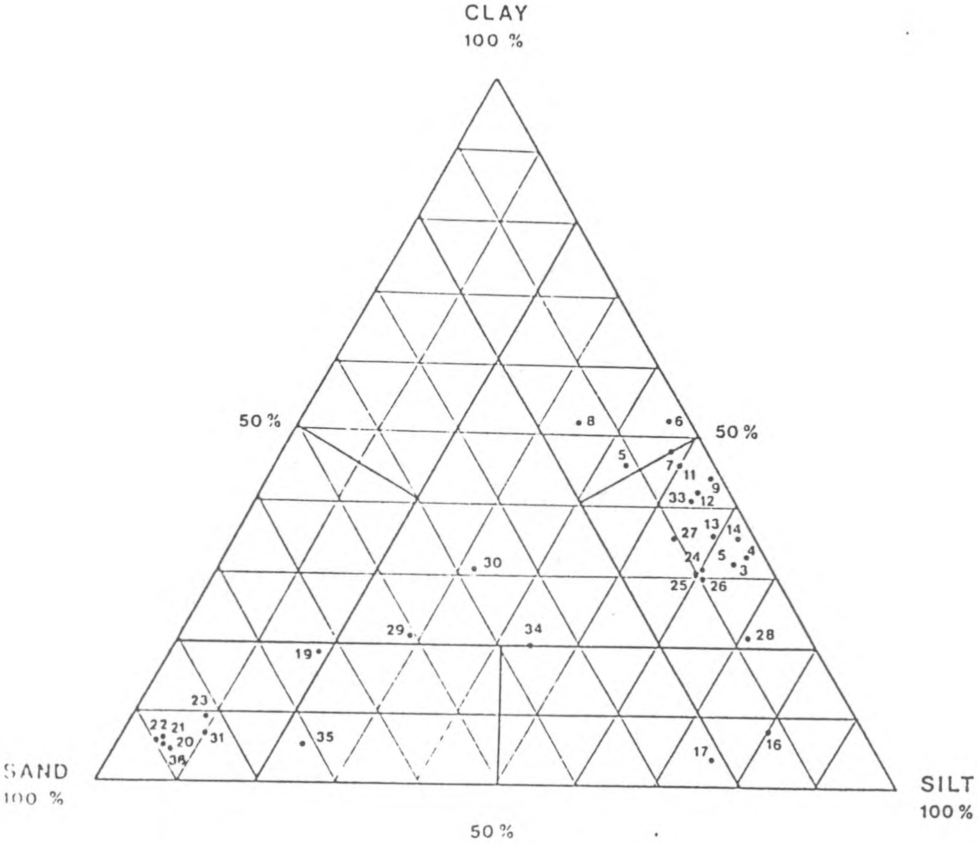
Moreover, the mollusc samples at 46.30 m (done by Prof. Chen, Saiying, Shanghai Nature Museum) have been identified as *Assiminea sp., Corbicula fluminae (Muller), Hippentis sp. etc.,* living in the estuary area with salt and fresh water together, corresponding with the environment which the curve indicates.

47.20-49.20 m: gray brown clay mixed with silt laminae, cohesive and occasionally crumbly silt. Below 48.30 m is clay with many silt laminae in horizontal bedding. In the lower part of this layer there are some humic vegetation fragments in black stripes. At 47.20-48.40 m, 49-49.20 m bioturbation and burrow structure are developed. Silt is 60 %, clay is 32 % and Mz 5.76 Ø, Sd = 1.50 Ø, poor sorted.

49.20-58.48 m: gray or gray black silty clay alternated with silty fine sand laminae in horizontal bedding. Below 49.20-51.30 m and 56.55 m, many fine sand laminae with bioturbation structure. Above 57.30 m, the content of silt 57-72 % and clay is 21-36 %. Below 57.30 m, the content of silt and clay is 29 % and 21 %, so the mean grain size in the top and middle is 5.28-5.94 Ø, Sd is 1.50-1.60 Ø, the lower part Mz 4.63 Ø, Sd 2.08 Ø, sorting is bad to very bad.

58.48-60.48 m: Gray silty clay with fine sand, the content of silt is 33 %, clay 31 %, fine sand 32%, medium sand 4 %. Mz = 4.88 Ø, Sd = 2.40 Ø, bad sorted.

60.48-65.35 m: Gray sandy clay with fine sand, cohesive and plastic. Above 63.89 m, gray fine sand in horizontal, lens and vein-like fine sand bedding. Below 63.89 m sandy clay alternated with fine sand laminae. Horizontal bedding is developed widely in this layer. The content of very fine sand is 63 %, fine sand 13 %, silt 10 %, clay 7 %, medium sand 7 %.



Sediments classification in triangle diagram of boring C.B.G. 1-1

fig. 22

Nº	Depth	M. Sand (%)	F. sand (%	V. F. sand(%	Silt (%)	Clay (%)
1	1.50-1.90					
2	3.50-3.90					
3	5.40-6.0			4	64	32
4	8.60-9.20			2	65	33
5	9.40-10.		4	5	44	47
6	11.40-12.			2	45	53
7	13.40-14.		2	1	48	49
8	15.40-16.0		2	2	44	52
9	17.40-18.0			1	55	44
10	19.40-20.					
11	20.0-20.60			3	50	47
12	21.40-22.0			3	54	43
13	23.40-24.0			5	59	36
14	25.40-26.0			1	62	37
15	27.40-28.0			8	59	33
16	29.60-30.			12	80	8
17	31.60-32.			21	75	4
18	33.60-34.0					
19	35.60-36.0		29	52	19	
20	37.60-38.0		71	24	5	
21	39.60-40.		86	9	5	
22	41.60-42.0		60	34	6	
23	43.60-44.		53	38	9	
24	47.60-48.			8	60	32
25	49.40-50.			9	60	31
26	51.60-52.		2	5	63	30
27	53.40-54.0			7	57	36
28	55.40-56.0			7	72	21
29	57.40-58.0		22	28	29	21
30	59.0-60.0	4	26	6	33	31
31	61.60-62.	7	13	63	10	7
32	63.60-64					
33	65.60-66			3	56	41
34	67.60-68		18	16	46	20
35	69.60-70	1	59	12	22	6
36	71.60-72		90	4	6	

Mz = 3.29 Ø, Sd = 1.40 Ø , and badly sorted.

65.35–66.89 m: Gray brown clay, cohesive and good plasticity. Pure clay, smooth cut-section in clay and crumbly structure. The content of silt and clay is 56 % and 41 %. Mz = 6.28 Ø, Sd = 1.45 Ø, sorting is bad.

66.89–71.36 m: Bluish fine sand with silty clay, the mineral composition mainly quartz, mica and other dark minerals. Horizontal bedding. 34-71 % fine sand, 23-46 % silt, 6-41 % clay, sandy content increase downwards. Mz = 4.68-4.84 Ø, Sd = 2.02-2.43 Ø, very badly sorted.

4.4. Palynology (by Huang Huanzhong)

The upper 70 m of the Shanghai CBG1-1 have been sampled and analysed systematically in order to study the paleoclimatic changes of the area concerned. The palynological research of 58 samples with an interval of 1 meter has been done in detail, finding sparse spore-pollen in the dark green stiff clay layer and the yellow sand layer below it (25.20-45 m). According to the distribution law of spore-pollen assemblage, it may be divided into two spore-pollen assemblage zones (Late Pleistocene and the Holocene) and eight subzones in ascending order.

1. The Late Pleistocene Zone

Pinus-Quercus-Artemisia-Gramineae

70-67 m:Gray fine sand mixed with silty clay, only finding *Pinus, Quercus, Artemisia, Ulmus, Cyclobalanopsis, Typha, Greatvanaeae* and *Selaginella*, etc.This suggests a cooler and somewhat dry climate.

Quercus-Carpinus-Castanea-Polypodium

67.-47.50 m: Gray brown silty clay mixed with fine sand. This zone contains rich spore-pollen, dominantly woody plants, accounting for 89.50 %. Of Gymnosperm, *Pinus* ranks about 10 % and *Picea, Keteleeria, Tsuga, Cedrus* etc 10 %; broad leaved *Quercus* 20-24 %, *Carpinus* 11.1 %, *Castanea* 11.1 %, *Cyclobalanopsis* 6-7 % and with *Juglans, Carya, Peterocarya, Myrica, Betula, Liquiaambar* and *Rhus* in addition. Moreover, in the grass vegetation *Artemisia, Cyperaceal, Typha* and *Polygonum*,etc have been discovered. Besides *Selaginella* etc *Polypodium* occupies 27.2 % in the spore vegetation, reflecting a vegetation consisting of a mixed evergreen broadleaf forest. This indicates that the climate was warm to temperate and humid.

Pinus-Quercus-Artemisia

47.50-25.15 m: Dark green clay and brownish yellow silty clay. The lower part of it is yellow silty fine sand. In this assemblage zone only *Pinus, Quercus, Artemesia, Gramineae* and *Polypodium,* etc. occur in small number. This demonstrates that the climate was of a cool and dry nature.

2. The Holocene Zone

Quercus-Pinus-Cyclobalanopsis-Polypodium

25.15-22.50 m: This zone mainly is gray silty clay, occupying about 68-85 % woody plants, 9-19 % grass vegetation and 12 % spore vegetation. Of them *Quercus* takes 24.6 %, *Castanea* 6.6 %, *Cyclobalanopsis* 64 %, *Pinus* 10-15 % and the next are *Picea* and *Keteleeria* etc. There also are *Betula, Carpinus, Juglans, Myrice, Ulmus, Liquiaambar* and *Rhus* etc.,belonging to the broad-leaved tree. The occurence of *Typha, Artemisia, Chenopodiaceae* and 7.5 % *Polipodium* reflects a vegetation consisting of a mixed coniferous/broadleaf forest. This shows that the climate was temperate to cool and somewhat dry.

Pinus-Quercus-Liquiaambar-Polypodium

18.20-22.50 m: Gray silty clay mixed with silt, containing abundant spore-pollen. The major constituents being *Pinus* (11.7 %),*Quercus* (17 %),*Liquiaambar* (10.1 %) and *Polipodium* (5.9 %); the secondary being *Cyclobalanopsis, Castanea, Rhus, Acer, Chenopodiaceae, Typha* and *Pteris.* They all suggest a coniferous/broadleaf forest and a temperate to humid paleoclimate environment.

Quercus-Castanea-Carpinus-Polypodium

18.20-13.50 m: Gray brown muddy clay dominates this zone. The woody plants make up 41-72 %, with 19.8 % *Quercus,* 6.2 % *Castanea,* 4.7 % *Carpinus, Cyclobalanopsis, Pinus* and *Liquiaambar,* etc. The aquatic plants i.e. *Polypodium* takes

23.9%, indicating the presence of a mixed coniferous/broadleaf forest and a warmer and humid climate.

Quercus-Carpinus-Castanea-Polypodium

13.50-7.50 m: Brownish gray muddy clay contains rich spore-pollen. Of them *Quercus, Carpinus, Castanea* occupy 15.60%, 6.6 % and 6.9 % and *Mognolia* etc. Besides, *Gramineae, Typha,* etc. have been discovered in the grass vegetation. In the spore vegetation, mainly *Polypodium* (17.7 %), *Selaginella* and *Zygnena* etc. can be found. All these reflect a vegetation mainly consisting of a mixed broadleaf/coniferous forest and a warmer, humid paleoclimatic environment.

Quercus-Pinus-Gramineae-Polypodium

7.50-0 m: Brownish yellow, brownish grey silty clay interlayers with thin silts. The assemblage of woody plants predominates this zone with the high content of 52-67 % (*Quercus* 22-24 %, *Juglans* 5 %, *Pinus* 14.7 %, *Myrice, Tsuga* and *Fagus,* etc.). The grass vegetation reaches 13-26 % (*Gramineae* 9.8 %, *Chenopodiaceae* and *Artemisia,* etc.). *Polypodium* 8-16 % and *Selaginella* etc. can be found in 20 % of the spore plants. All these represent a vegetation consisting of a mixed coniferous/broadleaf forest and a grassy marsh land type, indicating a temperate and humid climate.

4.5. **Micropalaeontology** (by Lin Jingxing)

In the Shanghai CBG1-1 boring 58 samples from the upper 70 m were analysed for microfossils by Lin Jingxing (Institute of Geology, Chinese Academy of Geological Sciences, Beijing), finding a lot of foraminiferal fossils. The results are as follows.

1. *The Holocene foraminiferal fauna and its palaeoenvironment.*

In the Holocene, there is no great variation in lithology and diversity curves of foraminifera, and no ^{14}C dating. So we only can have a detailed approach of the palaeoenvironmental evolution of the Holocene according to the variability of foraminiferal fauna.

The Holocene can be divided into 7 units from the base to the top (from the older to the newer) in the light of foraminifera assemblage.

Below 19.55 m to the boundary of the Holocene (25.90) a marshy facies is found. The assemblage of foraminifera is *Ammonia limnetes, Elphidiella kiangsuensis* and *Ammonia Tepida*. These are typical shallow water species. Amongst them, *Ammonia limnetes*, with high content of 60 % and living in the littoral marshy zone, is standard foraminifera for indicating marshy facies.

19.55 m to 14.55 m: littoral facies.

The assemblage of foraminifera is *Ammonia tipida, Quinqueloculina akneriana rotunda*, and ostracoda is *Neomonoceratina sp* and *Sinocytheridea* sp and diatom is *Coscinodiocus spp* and *Triceratium spp*. The shallow water species dominate this zone with the disappearing of *Ammonia limnetes* and the appearing of planktonic foraminifera *Globigerin spp*. The characteristics of whole foraminiferal assemblage have indicated that the environment at that time was changed into the open littoral facies zone from marshy facies. *Ostracoda Neomonoceratina spp* and *Sinocytheridea* are nearshore species and *Coscinodiocus spp* and *Triceretium spp* are the most abundant species in this littoral facies zone. This stratum is characterized by the whole biota assemblage.

14.55 m to 9.55 m : inner neritic facies.

The foraminiferal assemblage mainly is *Ammonia tepida, Globigerina spp* and *Bulimina marginate*. Among them planktonic *Globigerina* reaches over 20 %, showing the deepening of sea water and inner neritic environment. The other deep water species e.g. *Lagena* sometimes appears, but the assemblage of ostracoda and diatom has no great change and still is *Neomonoceratina* and *Sinocytheridea,* and *Coscinodiscus spp* and *Triceratium*.

9.55 m to 7.55 m: littoral facies.

In this zone, the diversity and abundance of foraminifera is decreased. The assemblage mainly is *Ammonia tepida* and *Nonion,* belonging to nearshore shallow water species. The abundance of planktonic *Globigerina* suddenly is reduced greatly. The ostracoda assemblage mainly is *Sinocytheridea longa* and *Neomonocertina spp,* belonging to littoral shallow water species. Therefore, this stratum should be littoral facies zone from the assemblage of microfossils and shallower water. The assemblage of diatom still is *Coscinodiscus* and *Triceratium*.

7.55 m to 3.40 m: inner neritic facies.

The planktonic foraminiferal *Globigerina spp* distinctly increases to 30 % and the deep water species e.g. *Lagena spp* reaches more or less 6 % as well. The great increasing in the diversity and abundance of foraminifera has indicated that this zone should belong to inner neritic depositional environment. The main foraminiferal assemblage is *Ammonia tepida, Globigerina spp* and *Lagena sp*. The ostracoda assemblage is *Sinocytheridea longa* and *Neomonocertina sp*. The diatom assemblage is mainly *Coscinodiscus sp* and *Triceratium*.

3.4 m to 2.2 m: littoral facies

Pseudononionella variabilis, Ammonia tepida and *Elphidium kiangsuensis* mainly have been found in this zone. *Pseudononionella variabilis,* with the content of 20 %, is

Curves of diversity and abundance of foraminifera

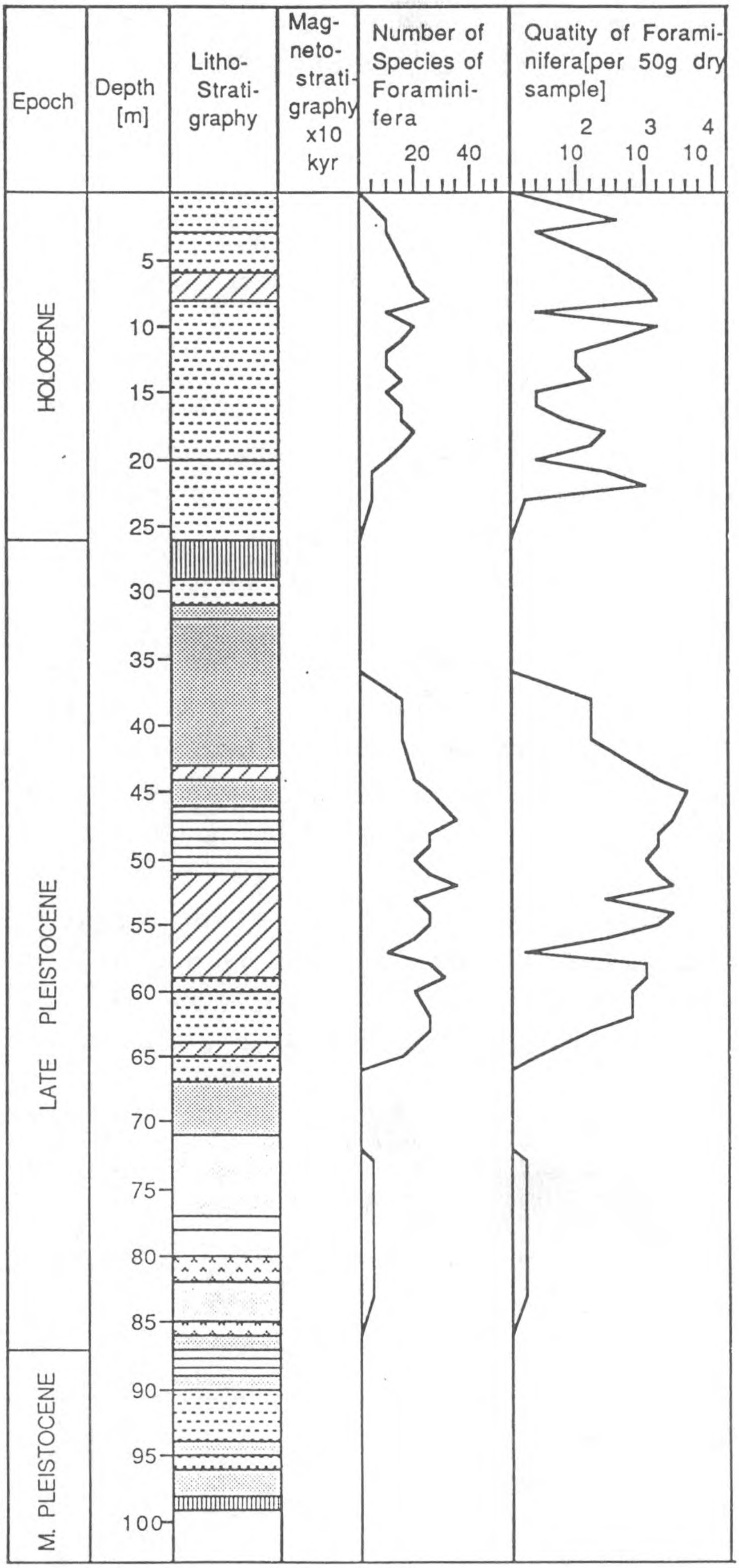


fig. 23

typical littoral shallow water species. As above mentioned, *Ammonia tepida* and *Elphidium kiangsuensis* are typical shallow water species as well. Thus it may be concluded that this zone belongs to the littoral facies depositional environment.

2. *Foraminiferal fauna of Late Pleistocene and its palaeoenvironment.*

As from the depth of 25.90 m to 34.50 m, no microfossils were found.

34.50 m to 49.20 m: the foraminiferal assemblage is *Globigerina, Florilus decorus* and *Ammonia tepida*. The curves of diversity and abundance of foraminifera are all in the high peak value period (fig.23). The inner neritic depositional environment is indicated by the occurrence of a lot of shallow water species, over 20 % of planktonic foraminifera and *Lagena*.

49.20 m to 58.48 m: the foraminiferal assemblage is *Florilus decorus, Ammonia tepida* and *Globigerina spp*. Though the inner neritic environment has been represented by the assemblage, the content of planktonic *Globigerina spp* decreases to 20 %, demonstrating a relative lower sea level period.

58.48 m to 66.89 m: the foraminiferal assemblage is *Florilus decorus, Ammonia tepida* and *Globigerina spp*. The content of planktonic *Globigerina* again increases to 20 %, indicating the deepening of sea water and transgressive period relatively. Sometimes *Lagena* reaches to 6 %, so it is inner neritic environment.

66.89 m to 71.36 m: sea water regresses from this area and no microfossils have been found. This stratum belongs to continental facies deposition and it is the period of the lowest sea level in Late Pleistocene.

4.6. Discussion

The results obtained from the different investigations are summarized in a comparative table (Table 10) and correlated with boring CBG1-1; the only one which was analysed for granulometry, palynology and micropalaeontology.

The several interpretations are conformable on some points but some important disagreements turn out.

The small differences in depths of the boundaries between the distinct units as established by the analysis are due to the fact that the depth of the sample range has been used as boundary, without taking into consideration the changes in lithology between the distinct units.

Pleistocene deposits

The deposits of the 2A-unit have been interpreted as being continental because of the absence of foraminifera. This is most remarkable for sediments bearing shells and showing clear tidal influence in their deposition. It is true that only one core (i.e. a single spot for the entire area) was analysed, which indeed is too limited to be conclusive.

One the other hand the sediment description indicates a probable quick deposition, no long transport and a huge supply of sediment. This points to a situation* of an estuary acting as a ***sink*** for the fluvial sediments, where the river processes are dominant (rather than the marine processes) as well as the supply of sediment in the river. Thus the sediments of the 2A-unit are dominantly fluvial but deposited in an estuarine environment and more particular in the fluvial part of it.

The comparison for the 3C-unit shows a rather good agreement. The terminology of *neritic* as put forward by the micropalaeontologic interpretation most probably needs some

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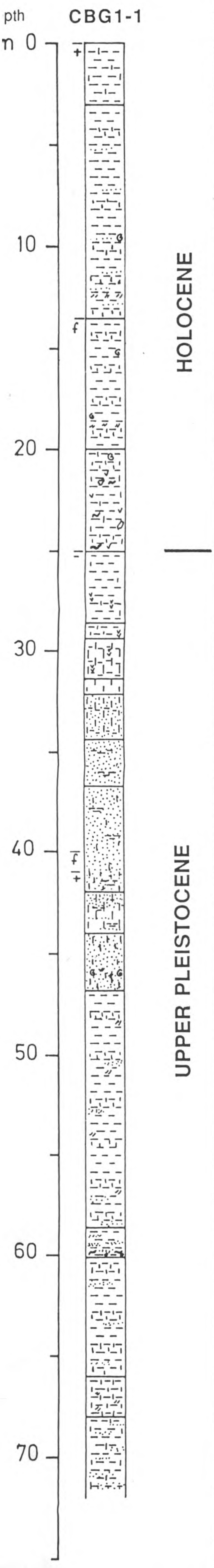
* at least for the upper part of the 2A-unit which is considered here.

Table 10 COMPARATIVE TABLE



	Lithologic units	Sedimentary environments	Interpretation granulometry	according to palynology		micropal.
HOLOCENE	1C unit	intertidal and subtidal		mixed coniferous/ broadleaf forest and grassy marshland	temperate and humid	
						shallow littoral
						inner neritic
				mixed broadleaf/ coniferous forest	warmer and humid	shallow littoral
						inner neritic
				mixed coniferous/ broadleaf forest	warmer and humid	
						open littoral
				coniferous/ broadleaf forest	temperate and humid	
						marsh
	2C unit	salt marsh (supra tidal)				
				mixed coniferous/ broadleaf forest	temperate to cool and somewhat dry	
UPPER PLEISTOCENE	DGSC unit	flood basin and backswamp			cool and dry	
						continental
	1A upper unit	natural levee and fluvial channel deposits (in lower part)				
	1A lower unit	estuarine channel deposits and sand bars				inner neritic (maximum of transgression)
			estuarine sand bar			
	3C unit	intertidal and subtidal				
				mixed evergreen broadleaf forest	warm to temperate and humid	
						inner neritic (with relative lower sea level)
						inner neritic (with increasing waterdepth)
					cooler and somewhat dry	continental
	2A unit	**estuarine channel deposits and sandbars**				

nuances (as already discussed in the literature review about the Holocene) and is therefore to be situated in the marginal - marine environment rather than in the proper marine. Moreover an onlap of neritic facies directly on continental facies without gradual transition in the vertical sequence is too abrupt and hard to realize even with an extreme rapid sea-level rize. All the data point to the fact that during the deposition of the 3C-unit the area is to be considered as an estuary*. Its lower part consists of a gradual transition from the channel and sandbar deposits (2A-unit) evolving gradually towards the more protected areas such as a tidal flat environment starting with mainly subtidal (deeper waterdepth from the micropalaeontological interpretation) to finally intertidal sedimentation.

Such a transition in the vertical stratigraphical sequence can be explained in different ways.

As tidal channels in estuaries shift back and forth with time, vertical sequences of estuarine sediments are generated. As the channels migrate, that part of the vertical section formed by the accretionary bank consists of interbedded sand and mud, flaser bedding, some cross-bedded sand, and some laminated mud. The part of the sequence deposited on intertidal flats may be either bioturbated sand or mud, which grades upward into supratidal mud facies (Boggs, 1987). Still according to Boggs (1987) migration of sandy channels produces a vertical sequence that begins at the base with a lag deposit composed of sand, shells, gravels, mud fragments and wood fragments. This lag deposit is typically overlain by cross-bedded or ripple-bedded sand, which in turn is overlain by intertidal-flat sediments and finally supratidal mud. Migration of muddy channels, which are more common in the upper reaches of estuaries, produces a vertical sequence that begins with a lag deposit overlain by laminated mud. The laminated mud in turn may either be overlain by cross-bedded mud or grade upward into intertidal-flat mud, which grades upward into supratidal facies.

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*estuary in terms of "a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage" (Pritchard, 1967).

Generalized Sequence of Sedimentary Lithofacies in a Transgressive Estuarine Environment. A. Axial and Vertical Trend. B. Lateral and Vertical Trend

A. Axial and Vertical Sequence of Sedimentary Lithofacies in the Estuarine Environment

	River ESTUARINE FLUVIAL	Seaward → ESTUARINE	Sea ESTUARINE MARINE
↑ VERTICAL			Coarse marine sands, massive or with abundant X-bedding, tidal current ridges with low angle X-bedding in fine sands with silt laminae
		Silt and clay with sandy lenses and laminae, massive silt and clay deposits	
	Massive silt and clay with abundant plant fragments and roots, sandy lenses, and laminations, grading downward into sand gravel and cobble		

B. Lateral and Vertical Sequence of Sedimentary Lithofacies in the Lower Estuary

	Shore SHORELINE DEPOSITS	→ SUB-TIDAL FLATS	Mid-Channel ESTUARINE MARINE
↑ VERTICAL			Coarse marine sands, massive or with abundant X-bedding (as above)
		Laminated and massive muddy sands and sandy muds	
	Sand, gravel, and shell with or without washover complex and muds with plant fragments and basal peat		

Table 11 (from Nichols and Biggs, 1985)

Another explanation for this kind of transition in the vertical stratigraphical sequence implies a change of a greater importance with a larger repercussion such as a change in sea level and/or change in sediment supply from the river.

During progress of submergence (by rising sea level) and sediment infilling, the locus of accumulation probably shifts from less energetic basins landwards to the current convergence zone (landward salt limit). In turn, this zone moves landward with rising sea level and up the river valley with rising base level. When finally the estuary channels are shoaled and convey much fluvial sediment directly to the sea, accumulation shifts laterally into remaining tidal flats, backswamps or marshes (Nichols & Biggs, 1985). With progressive infilling, the area shifts from estuarine fluvial over estuary towards estuarine marine and the function of the entire estuary changes from a sink for fluvial and marine sediments to a source of fluvial sediment for the ocean.

The vertical stratigraphic sequence in a transgressive environment, which is from the bottom up: estuarine fluvial, estuarine and estuarine marine, is illustrated in table 11.

The vertical succession of the 2A-unit, the 3C-unit and finally the 1A-unit (lower part) shows a great resemblance with such a transgressive sequence.

Most probably, both situations occurred during the deposition of the 2A-unit, 3C-unit and 1A-unit (lower part), i.e. the lateral as well as back and forth shifting of the tidal channels and a general transgression (submergence by a relatively rising sea level). The maximum of the transgression is expressed by the deposits of the 1A-unit (lower part).

Due to the shifting of the channels with time, the vertical sequence is not developed in an exact similar way over the entire estuarine reach. Indeed in some parts of the area the 3C-unit might be very well developed in the vertical sequence, while the 2A-unit will be restricted. On the other hand in other, adjacent areas, the accumulation of sand (2A-unit) in the channels and bars persisted leaving no suitable environment for the tidal flat sediments (represented by 3C-unit) to develop.

In fact such a situation occurred in the S - SE part of the Shanghai area where the 3C-unit is indeed very limited, to even completely absent due to the fact that in this particular zone the channels and sandbars prevailed during the entire transgressive phase.

However, in the comparative table (Table 10) the maximum of transgression ("high peak value period") as established by the micropalaeontology is not at all in agreement with the results of the palynological investigation indicating a cool and dry climate for the same period.

However, it is very remarkable that, according to the palynology, the same climatic conditions prevailed during the period that as well the 1A-unit (lower part) and the 1A-unit (upper part) as well as the DGSC-unit were deposited.

This result was not obtained by the interpretation of the sediment facies, neither by the micropalaeontology. Both investigations came to the conclusion that the upper part of the 1A-unit is completely different from the lower part. Indeed according to the sedimentological features the lower part of the 1A-unit is to be interpreted as channel deposits and sandbars from the estuary deposited during a maximum of marine influence. The upper part is to be interpreted as fluvial channel sand overlain by a natural levee and the micropalaeontological investigation revealed a continental facies. Thus the entire 1A-unit reflects from bottom to top a transition from an estuarine - marine environment to finally a proper fluvial environment.It is hard to realize that such a transition is occurring in a period characterized by the same climatic conditions and hence by the same sea-level stand.

Moreover a dry and cool period involves, in this studied area, a relative low sea-level stand. This certainly is not in accordance with a maximum of transgression. The climatic interpretation (from the palynological analysis) most probably is relevant for the upper part of the 1A-unit only, but the entire unit was interpreted as such because for the analysis only the depths of the sample range are considered without taking into account the lithological changes.

The transition from the lower to the upper part of the 1A-unit clearly reflects a lowering of the sea level and a deterioration of the climate. According to the micropalaeontology the marine influence decreases rather fast after the maximum of transgression. So the predominant marginal- marine environment was replaced by proper fluvial activity where sediments accumulate owing to channel flow and periodic overbank flooding.

In the studied area, the beginning of the fluvial activity is represented, in the vertical stratigraphical sequence, by fluvial sand (recognized at the base of the upper part) followed by a well developed natural levee deposit characterized by an intense plantgrowth indicating that the climate was not yet too dry and too cool. In the vertical sequence, the natural levee deposit is overlain by the sediments of the flood basin, or the DGSC-unit. Such a vertical sequence is explained by the fact that in a meandering system, sedimentation takes place essentially simultaneously in the channel, on point bars and in the various overbank environments (Boggs, 1987): in this case more particularly in the channel, on the natural levee and in the flood basin.

As lateral shifting of these different environments takes place owing to stream meandering, sediments from laterally contiguous environments will become superimposed or vertically stacked.

However, it is well known that natural levee deposits have low preservation potential in the depositional cycle because they are eroded by the channel when shifting. The preservation of the natural levee deposits here is due to the fact that the shifting, or natural migration of the channel in the entire area only happened one single time so that the natural levee was not eroded by the channel itself.

The dominance of the proper fluvial activity here coincides with a low sea-level stand which indeed occurred during the period characterized by cold climatic conditions. According to the literature, these conditions prevailed during the "Late Stage of the Late Pleistocene", and the occurrence of the lowest sea-level stand was situated about 15 000 years ago.

From the available data some ideas on the evolution of the Shanghai area during the Late Pleistocene can be put forward.

It was assumed that the deposits reaching a depth until 70 m still belong to the Upper Pleistocene, also called "Dali glaciation". The lower boundary of the latter could not be established from the available literature about the concerned area. The Upper Pleistocene as it is considered here, was characterized by two main events. The beginning of it shows a transgressive phase whereby the area becomes occupied by an estuarine environment. In that evolution the decrease of the fluvial activity and the gradual overwhelming of the marine environment is clearly reflected. During that period the area obviously was characterized by (relatively) warm climatic conditions. The climatic optimum most probably coincides with the maximum of transgression.

In the literature it is often mentioned that a transgression occurred during the Late Pleistocene. Zhou Mulin *et al.*, (1982) described a global transgression during an "*interglacial (or interstade) of the Dali Glaciation*" which he dated at 22 900 - 32 000 years ago, and in 1986 at 24 000 - 39 000 y.B.P.. Zhu 19..B situated the transgression and an extensive development of an estuarine environment around 35 000 years ago with a maximum of transgression at 32 000 y.B.P..

The transgressive phase resulted (in the Shanghai area) in the deposition of three distinct lithological units reflecting the vertical stratigraphical sequence of a transgressive estuarine environment: the 2C-unit (at least the top of it), the 3C-unit and finally the 1A-unit, lower part. The absence of one of the units in the vertical sequence of a particular area is to be explained as a prevalence of a subenvironment in that particular area during the evolution (or part of it) leading to a much better development of another lithologic unit. This is the case for the absence of the 3C-unit in the S - SE part of the Shanghai area where the channel activity from the estuary persisted during the entire period of the transgressive phase, resulting in an important accumulation of sand deposits, called the Sand Complex-unit.

The second main event during the Late Pleistocene consists of a regression. In the estuary the main influence decreased gradually while the fluvial activity became predominant. Finally the entire area was occupied by an alluvial valley, in which the river little by little arises the alluvial relief. Successive floods, each depositing a gradually outward -tapering layer of sediment seem to be capable over the years of slowly elevating the active channel by building up its more immediate surroundings. The process of elevating the channel cannot proceed indefinitely, however, for the more the channel and its borders are raised, the easier it is for the river to abandon its elevated position in order to construct a new course at a lower level in another location (Allen,1985). In 1986, Nanson gave a rather different explanation about the process of abandoning a course in favor of a new one. He stated that overbank deposition gradually builds a flood plain of fine-textured alluvium over a period of hundreds or thousands of years,following which catastrophic erosion by a single large flood, or a series of more moderate floods, strips the flood plain to a basal lag deposit from which it slowly reforms. This periodic destruction appears due to the progressive development of large levee banks and flood-plain surfaces of highly variable relief. As the levees and flood plain grow, overbank flow is gradually displaced from the broad flood plain into the main channel and flood-plain backchannels, with a resulting concentration of erosional energy. Vertical-accretion flood plains at different stages of development result in a wide range of bankfull recurrence intervals, even along the same river.

Anyhow the process of abandoning an alluvial ridge in favour of constructing a new one is known as river avulsion and belongs to the most important of all fluvial processes.

The fluvial environment was very extensive (seaward of Shanghai) as the flood basin clay (DGSC-unit) has been found in several locations of the (present) inner shelf (Milliman & Jing Qingming, 1985).

That period of regressive phase and fluvial predominance coincides with cold climatic conditions leading to a low sea-level stand, and according to the literature, most probably the lowest sea-level stand of the Late Pleistocene.

However the climatic conditions could not be too dry as the natural levee deposits are characterized by a soil formation and also on the flood basin plant growth was present. Anyhow very dry climatic conditions would not allow the fluvial system to develop so distinctly. On the other hand there is no evidence of peatgrowth on the flood basin, indicating most probably that the conditions were not suitable, i.e. not wet enough, for it. This is another reason why the development of a lake, in which the DGSC-unit would be deposited as it is often mentioned in literature, is hardly conceivable.

All these evidences point to the fact that during this regressive phase the area was characterized by calm, low activity conditions, where vertical accumulation dominates in the depositional environment, without any erosional features.

Nevertheless, in the literature it is very often mentioned that the period during which the DGSC-unit was deposited, was characterized by intensified erosion of rivers. But it is known that the effect of a change in sea level on the stream channel, called thalassostatic effect, is really limited to the very mouth of the river and shelf areas (Fairbridge, 1968; Begin *et al.*, 1981). Only in these limited areas intensive erosion will occur as result of sea-level lowering.

Furthermore it should be mentioned that with large rivers, the channel regime is often controlled by the climate of the source area rather than that prevailing in the flood plain (Collinson, 1979).

Holocene deposits

In the Holocene deposits only two distinct lithologic units could be recognized. For the lower one, the 2C-unit, the different approaches and analysis all came to the same conclusion, i.e. a deposition with a marshy facies, more particular a coastal salt marsh typified by a dense reed vegetation. On the other hand banks of dense reeds can occur on intertidal flats as well which are then situated along an estuary but characterized by low salinity (Reineck & Singh, 1986).

However, the facies of the sediments clearly reflects a.o. a subaerial exposure although in a marginal-marine environment, thus indicating a deposition at least above high water level. According to the palynological investigation, the climate during the period of deposition of the 2C-unit changed from cool to temperate and from dry to humid.

In the 1C-unit no significant differentiations could be observed in the sedimentary facies. According to the palynology it was deposited during warm and humid climatic conditions, changing finally to a temperate climate towards the end of the period. The vegetational analysis does not give enough detailed information in order to differentiate any change in the sedimentary subenvironments.

Only on the base of the micropalaeontological investigation some ideas about a slightly changing environment can be deduced. These changes most probably are only related to a different waterdepth of the environment in which the deposition occurred. Also here the terminology of *neritic* needs some nuances, as was previously discussed.

It can be concluded that the 1C-unit was deposited in a tidal influenced estuarine environment, more particularly in an estuarine and estuarine - marine subenvironment where silt and mud accumulate in the more protected tidal flats and the sand is concentrated in the channels, sand bars and shoals located near the estuary inlet. The changes in waterdepth can be explained as a lateral migration of the subtidal and intertidal areas owing to shifting of the channel with time. Different dynamic processes (short-term like waves and tides as well as long-term processes like the rate of sea-level rise) and a change in the nature and quantity of available sediment might be as well at the origin of the changes in waterdepth. However the observed features are too limited here to be conclusive.

The information about the Holocene deposits of the Shanghai area revealed some ideas about its evolution.

The flood basin clay from the Upper Pleistocene is directly overlain by fringing salt marsh deposits,(2C-unit) representing the very first deposits owing to the postglacial sea-level rise as there are no evidences of basal peat (only in some exceptional cases). The basal peat reflecting the initial rising of the sea level and the amelioration of the climatic conditions after the glacial period, most probably could not come into being in the studied area due to the clayey substratum (see above,4.1.2). Basal peat development may be expected on the sandy zones of the Upper Pleistocene fluvial deposits.

The salt marsh deposits already reflect the incoming marine influence and indicate that the area was changed into an estuarine environment again. However the area was not directly invaded by the sea as such as from the beginning of the

Holocene, like it is often described in the literature.

The general amelioration of the climatic conditions resulted in an all over renewed activity of all sedimentary depositional and erosional processes and not at least from the river itself.

This is indeed the reason why the deposits of the 2C-unit could reach such an important thickness. Normally with a fast sea-level rise, salt marsh deposits very seldom reach an important thickness as the environment quickly submerges and changes to an intertidal and subtidal one, resulting in an onlap of tidal flat deposits on salt marsh deposits in the vertical sequence. Only when sea-level rise does not exceed the net rate of sedimentation, the salt marsh development can persist.

But in the studied area the sea-level rise was very fast in the beginning of the Holocene, so it must be deduced that a huge supply of sediment was involved to keep up the salt marsh and prevent it from submergence during a rather long period.The huge supply of sediment was provided by the river. The gamma ray investigations (see Second Part of the study) did reveal indeed that the origin of the sediments are predominantly fluvial.

However, the salt marsh environment did not persist indefinitely and the sea-level rise finally became predominant over all other features. The salt marsh was pushed landward and in the studied area the marine influence was more and more pronounced, leading to the development of tidal flats in an estuarine environment, reflected in the deposits of the 1C-unit.

In the tidal flats first an intertidal subenvironment generated (the open littoral facies from the micropalaeontology), later evolving into a subtidal subenvironment (the inner neritic facies from the micropalaeontology). However, a marine environment with waterdepths up to 20 m, as was put forward in the literature, is far too exaggerated, because it brings the area into a shelf environment. How could such an area, with a very large extension, then silt up until the level of the present coastal plain, characterized by a very flat morphology ? In general, the entire Holocene sequence hardly exceeds a thickness of 30 m and the 1C-unit itself reaches a thickness ranging from 12 m to max. 25 m. On the other hand, if in that shelf area mud accretion did not reach a thickness of about 20 m, a significant sea-level drop of several meters in the second half of the Holocene is to be involved, which indeed is hard to realize.

The silts and clays comprising the flats from the deposits of the 1C-unit, were supplied by the rivers Huanghe and Changjiang, and were dispersed to the flats largerly by most probably tidal current and littoral drift.

These subtidal deposits from the 1C-unit might coincide with the maximum of the postglacial transgression often found in the literature and situated in the early Atlantic period (see tables 3 & 4).

On many occasions in the literature it is concluded that after the maximum of transgression (with a sea level higher than the present one) the sea level lowered gradually to reach its present position. The sediments of the studied area exhibit no such evidence, however. On the other hand, a seaward growth of the flats by mud flat accretion, also called a depositional regression, did occur most probably and was possible at this open coast because of high rates of mud supply and low wave energy (Thompson, 1968). Such a depositional regression does not necessary imply a lowering of the sea level.

The depositional sequence as reflected by the 1C-unit represents a development of the mud flats accomplished during a period of relatively uniform conditions of high mud supply, very limited reworking (involving low wave energy) and continuous depositional regression or coastal progradation.

The process of coastal progradation is supported by the occurrence of sand ridges which, judging from 14-C dates of mollusc shells, accreted in a seaward direction (Chen Jiyu *et al.*,1985). The formation of sandridges on the coastal plain excludes really the proper marine or shelf environment.

4.7. Stratigraphy of the Upper Quaternary deposits

The results from the sedimentary and lithological analysis have been assembled in a stratigraphical table (Table 12). The stratigraphical units were established according to the International Stratigraphic Guide (Hedberg, 1976).

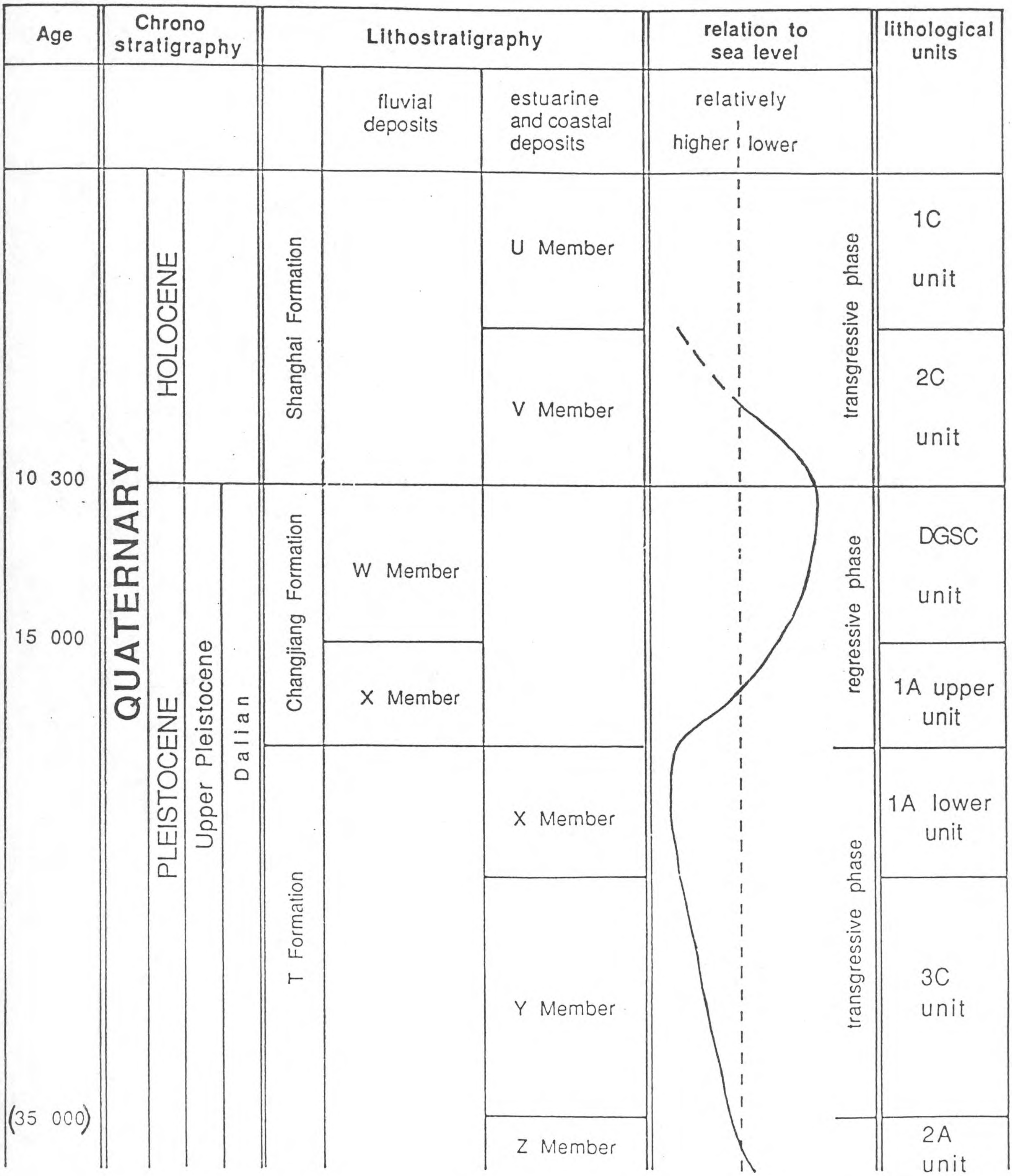
It should be mentioned immediately that the table is only a proposal. A formal stratigraphical table is to be worked out by the Chinese counterpart because of the regional and local implications (literature, geographical names, additional data, etc.).

Concerning the chronostratigraphy, the Quaternary System is divided into two series: a younger Holocene Series and an older Pleistocene Series. From the latter only the Upper Pleistocene Subserie is considered in this study (without knowing its lower boundary) and more particularly the dalian Stage which represents in the chronostratigraphy a unit of relatively minor rank in the conventional hierarchy. The name "Dalian" has been chosen after the (informal) use of the Dali glaciation.

Concerning the lithostratigraphy, the typical lithologic features from the lithologic units served as a basis for the lithostratigrphic units. The formation has been used as the primary formal unit of lithostratigraphic classification. Three formations have been introduced, viz. T Formation, Changjiang Formation and Shanghai Formation. However, it is imperative to introduce a geographical name for the T Formation and to elaborate a comprehensive definition of the proposed stratigraphic units. For that purpose this study is far too limited so that the essential regional and local evidence are not enough known.

The formations have been divided into members. A distinction was made between deposits related to the fluvial system on the

Stratigraphy of the Upper Pleistocene and Holocene



Age	Chrono stratigraphy				Lithostratigraphy			relation to sea level		lithological units
						fluvial deposits	estuarine and coastal deposits	relatively higher ¦ lower		
	QUATERNARY	HOLOCENE			Shanghai Formation		U Member		transgressive phase	1C unit
							V Member			2C unit
10 300		PLEISTOCENE	Upper Pleistocene	Dalian	Changjiang Formation	W Member			regressive phase	DGSC unit
15 000						X Member				1A upper unit
					T Formation		X Member		transgressive phase	1A lower unit
							Y Member			3C unit
(35 000)							Z Member			2A unit

Table 12

one hand and deposits related to the estuarine and coastal plain system on the other hand. Again, the members must be labelled with a geographical name derived from the type localities which are to be fully described (thickness, lithologic character, biostratigraphic character, structural attitude, geomorphic expression, unconformaties or hiatuses, conditions of deposition, nature of boundaries of unit (sharp, transitional, unconformabel,etc.), and distinguishing and identifying features characterizing unit at type locality).

In proposing a name for a subsurface unit, like it is the case here, the borehole in which the type section is present, becomes the typelocality.

The X Member is extending from the T Formation to the Changjiang Formation and consequently has to bear the same geographical name. The extention of the X Member from one formation to another was necessary because it is impossible to define properly the boundary between the fluvial related deposits and the estuarine and coastal plain related deposits, respectively as it is characterized by a gradual transition.

The relation to sea-level stands has been indicated as well in the stratigraphical table. The relation is very relative and the dotted line does not indicate at all the present day sea-level stand.

5. Geological setting of the Shanghai area

5.1. Lateral and vertical distribution of the lithological units.

The borings (and the interpretations of the cone penetration tests (CPT) and well-loggings to a certain extent) have been correlated in several cross-sections covering the entire studied area (fig.5). The correlations between the borings were established on basis of the sedimentary characteristics themselves and not on basis of the premised engineering and hydrogeological units. Therefore the borings had to be drawn on a exaggerated vertical scale, otherwise all details would have dissapeared. However, for the sake of representation and clearness, the cross-sections had to be reduced and labelled with the distinguished units, resulting from the correlations. The detailed logs of all the borings are enclosed in the appendix.

The west-east cross-sections will be discussed successively from north to south and later compared with the south-north cross-sections. Two panel diagrams (fig.24 & 25) were established in order to visualize the interrelationship between all the cross-sections and to give a general overview of the spatial extension of the lithological units.

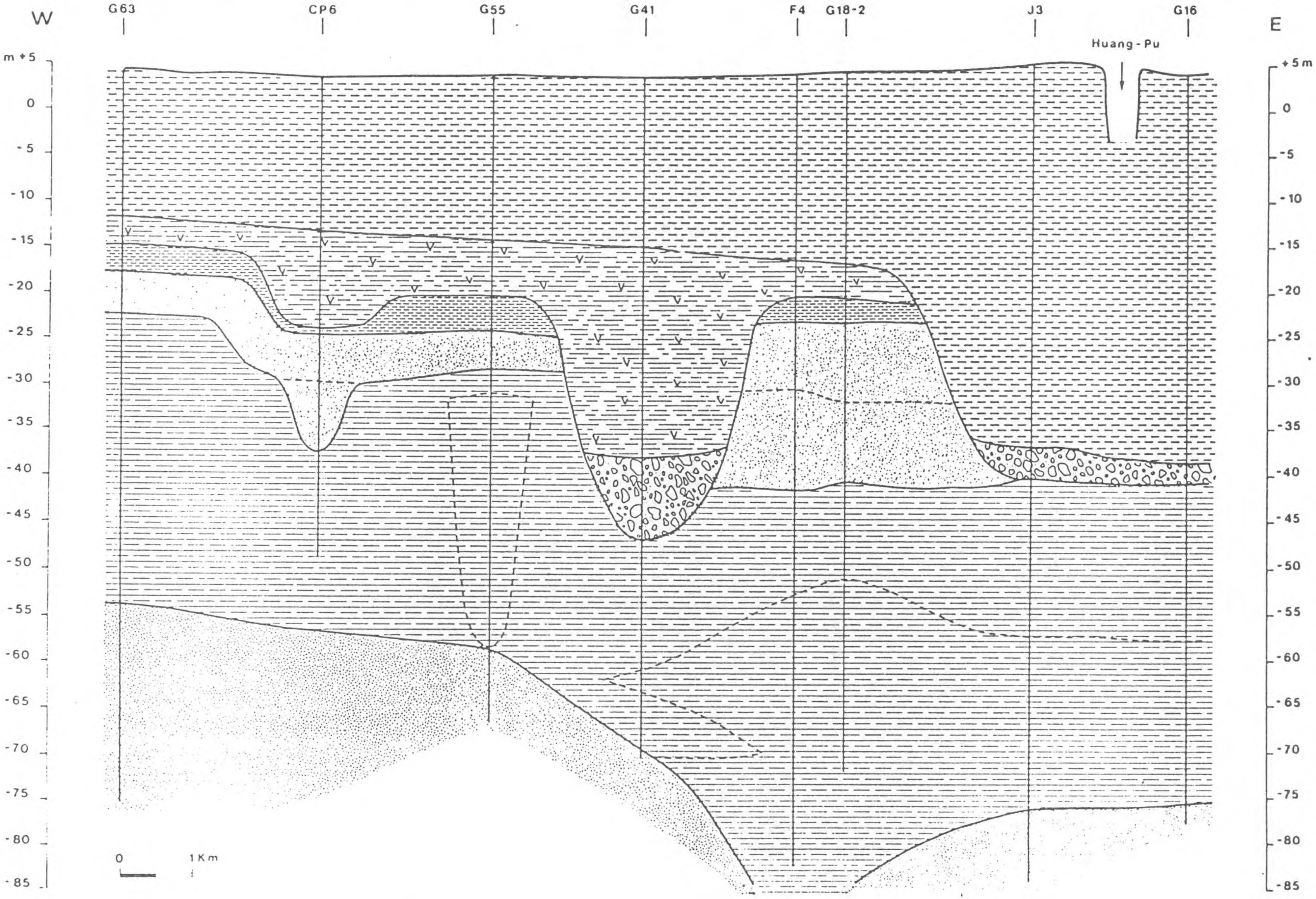
Cross-section n°2

Cross-section n°2 is the most northern one in the Shanghai area. The lowermost unit, the 2A-unit, from which only the top is considered here, is occurring at a relatively high position (-54 m) in the western part, and dips in an eastern direction where it is found as from -70 m and even deeper at F4. The upper boundary of the unit generally shows a rather gradual

LEGEND FOR THE CROSS SECTIONS

▤	1C-unit
▤	2C-unit
▤	2Ca-subunit
▨	Reworked Pleistocene deposits
▤	DGSC-unit
░	1A-unit
▤	3C-unit
▒	2A-unit
░	Sand complex unit
-----	Limit between respectively: -upper and lower 1A-unit -sand/clay and silt/clay from the 3C-unit
G63	Number of boring
CP3	Number of cone penetration test
124-2	Number of well-logging

CROSS SECTION N° 2



transition with the overlying 3C-unit. In the western part, the 3C-unit is situated at a significant higher level where it is found between -23 m and -54 m. In the eastern part itgenerally occurs between -41 m and -75 m. In this cross-section, in particular in the eastern part, it is clear that the lower part of the 3C-unit consists of a sand/clay, and the upper part of a silt/clay interlayering. In the G55 boring, however, a sand/clay interlayering is predominant in nearly the entire 3C-unit, with an increase of sand towards the base of it. It most probably is to be interpreted as deposits of a local channel in the tidal flat.

The difference between the western and eastern part of cross-section n°2 is also expressed by the 1A-unit. In the west, only the upper part of the 1A-unit is present, while in the east also the lower part of it is very well developed, although in the centre and very east, lower and upper part are both lacking due to erosion. It is clear that the channel activity itself, reflected in the lower part of the 1A-unit, never occurred in that particular western part and only a natural levee was developed (except for the CPT 6). This explains at the same time the higher position of the top of the 3C-unit which was not, or very little, affected by erosional activity of the channel in the western part, in contrast with the eastern part.

The DGSC-unit is overlying the upper 1A-unit. It is also lacking in the centre and in the very east of the cross-section. The DGSC-unit reaches a thickness of about 3 m (except in CPT 6), and is occurring at a slightly higher elevation in the very west. The top of it shows a fair flat topography, interrupted by erosional zones.

Indeed, the DGSC-unit, representing the final Upper Pleistocene deposits, has been significantly affected, as well as parts of the 1A-unit, as illustrated in G41, J3 and G16. In G41, the 3C-unit is directly overlain at a level of -48 m by a rather heterogeneous deposit of about 4 m thick, consisting of greenish grey clay, silt and sand with cross-bedding. The sand increases towards the bottom which itself consists of a shell lag. In turn, that rather heterogeneous deposit is overlain by another 4 m thick layer, consisting of an interbedded clay/silt with oblique stratification in which some shell fragments and plant remains are present. None of these layers shows the typical features of the 2C-unit. A rather similar situation is found in J3 and G16, where the 3C-unit is directly covered by a more or less 3 m thick layer consisting of greenish grey sand. In boring J3 the description indicated silt, although the granulometric composition yielded 100 % sand. Again, this layer does not show any similarity with the very typical 2C-unit.

The 2C-unit covers the DGSC-unit with a thickness of about 5 m, however, it reaches an exceptional thickness of 23 m in that kind of depression situated at G41. The top of it shows a very flat surface, gently dipping in an eastern direction. But in the very east (J3 and G16), no sediment characteristics of the 2C-unit are found any more. Finally, the sandy silt and clays from the 1C-unit covers the whole. This unit here reaches a thickness of about 18 m, but with an exception in the very east where nearly the entire depression is filled for about 43 m with sediments bearing the same characteristics as the 1C-unit. Only boring G16 is slightly different, showing from -39 m to -19 m mainly sand interlayered with clay bearing a lot of shell fragments and some plant remains, and from -19 m to -12 m a silty clay with at its very base a sandbed with a concentration of shell fragments. It should be mentioned that the actual Huang Pu River is located in that area.

In the 1C-unit, nearly every boring shows differences in lithological characteristics. For the 1C-unit no boring is alike, i.e. the succession of layers with different lithologies (ranging from sand, silt to clay) is changing from one boring to another, implying small lateral and vertical facies changes, which indeed is very typical for tidal flat deposits. But the data are not dense enough to make any significant correlation. Hence the nearly 20 m thick deposit had to be considered as one single and entire unit. A denser boring grid and a detailed sedimentological study of the cores, certainly would reveal a better insight in the processes of sedimentation and in the evolution of the subenvironments during the last silting up phase of the plain.

Cross-section n°1

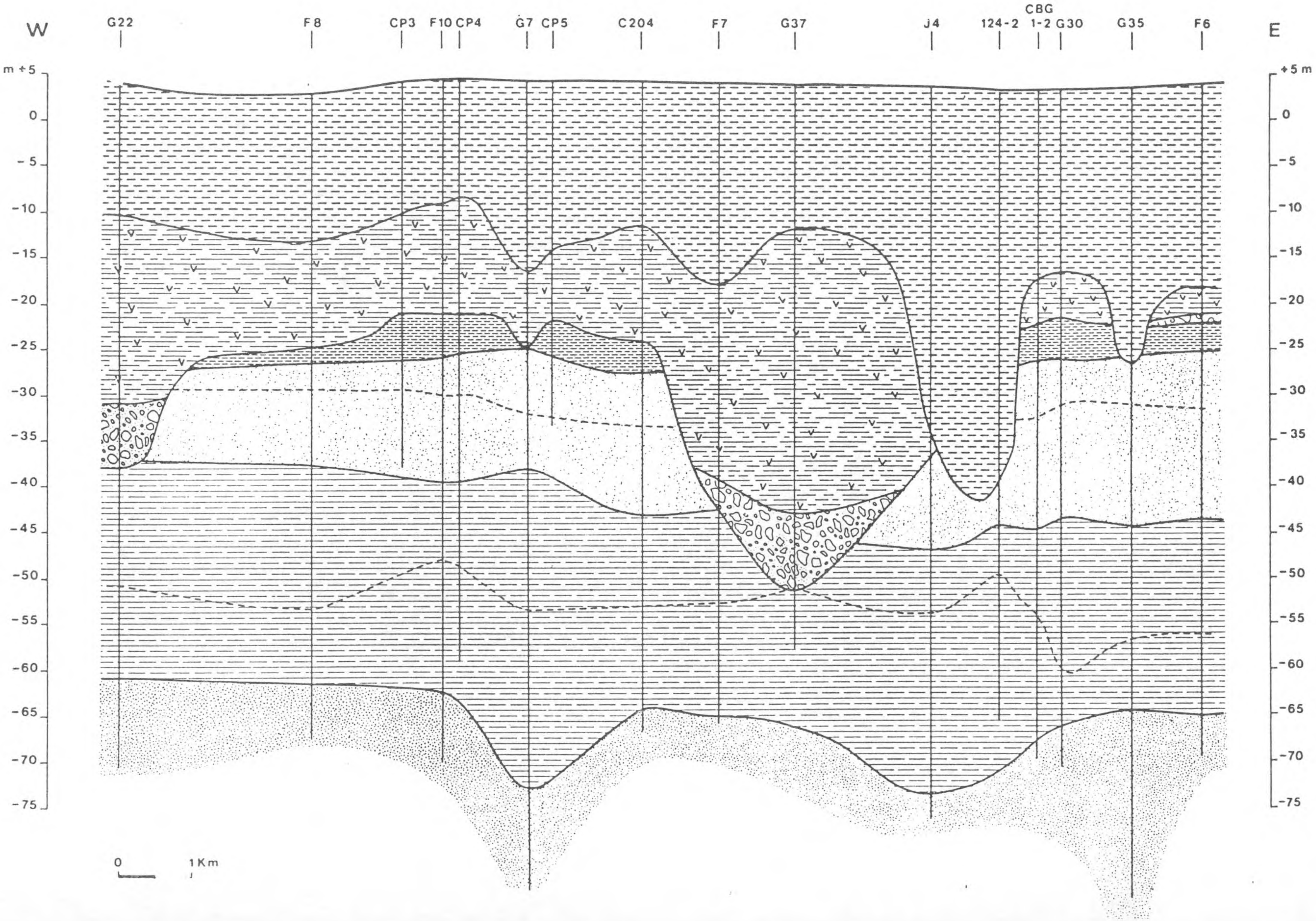
The top of the 2A-unit shows a rather regular surface situated between -60 m and -65 m with some slightly deeper parts (G7 and J4). The 2A-unit again shows a very gradual transition with the overlying 3C-unit, also depicting a regular distribution. The top of it is slightly higher in the west (-37 m) than in the east (-43 m). Also here a distinct differentiation is shown between the lower sand/clay interlayering evolving gradual into a silt/clay interlayering. In boring G22 the lower part is even predominantly sandy, so it is critical to conclude whether or not it belongs to the 2A- or the 3C-unit. Only in boring G37, the 3C-unit is affected by erosion.

In contrast with cross-section n°2, the lower and upper part of the 1A-unit are both very well developed here, although in the eastern zone of the cross-section, the lower part of the 1A-unit reaches a somewhat greater thickness. However, almost in the central zone of the cross-section, at the location of borings F7, G37, J4 and well-logging 124-2, and in the very west, the 1A-unit is affected by erosion and is even completely absent in some zones, as a result of it.

Except for that central zone and the very west, the 1A-unit is overlain by the DGSC-unit. The latter here reaches a thickness of about 3 to 4 meters and its top does not show a very regular flat surface any more, although its lower boundary is rather horizontal and more or less at the same level (-26 m). This indicates that, in the zones where it is not completely eroded, it may have been affected by erosion.

The centre of the cross-section and the very west are here

CROSS SECTION N°1



also characterized by rather important depressions. The central one is reaching until a depth of about -50 m and is initially filled with green grey sand bearing plant remains at the very base. This is covered by a grey silty clay layer which in turn is overlain by a brownish green silty sand and clay with horizontal and oblique stratification. In boring F7, the depression is initially filled with a 3 m thick, rather heterogeneous layer consisting of green silty sand, medium sand and some gravels. It is overlying the 3C-unit with a sharp boundary. In the west, in boring G22, the depression which reaches only a depth of -38 m is filled with a greenish grey and dark brown silty clay with a lot of plant and peat remnants. At the bottom a thin peaty clay, showing clear horizontal bedding, is found. This greenish grey clay reaches a thickness of about 7 m and its upper boundary is sharp. These initial fillings of the depressions do not exhibit at all the characteristics of the 2C-unit.

The 2C-unit is overlying the DGSC-unit and the initial fillings. It attains a thickness of about 12 m in the western part of the cross-section, and only about 5 m in the eastern part. In the depressions an exceptional thickness of about 20 m is reached. In this cross-section, the top of the 2C-unit does not show a regular flat surface. Moreover, in the central depression, at the location of boring J4, the 2C-unit is very limited and occurring rather deep, and at the location of well-logging 124-2 it is lacking completely. In these zones the 2C-unit is replaced by predominantly sandy sediments of the 1C-unit, which by that reaches an exceptional thickness of 45 m. The sediments which are filling up the depression at J4 and G35 (as well as J3 and G16 from cross-section n°2) have been interpreted as belonging to the 1C-unit because of the similarity in facies with it. However these sediments could as well represent a tidal channel facies from the 2C-unit.

But in cross-section n°1 and n°2 the geometry of the 2C-unit points to the fact that it has been eroded in turn during the Holocene. The process responsable for the erosional activity this time was not the river activity like at the very beginning of the Holocene, but the incision was caused by a tidal channel. Erosion caused by tidal channels is inherent in the hydrodynamical system of tidal channels and does certainly not necessary imply any lowering or raising of sea level. It is well know that during storm surges tidal channels can shift from one position to another or a new one can come into being, leading to significant erosion of the tidal flat.

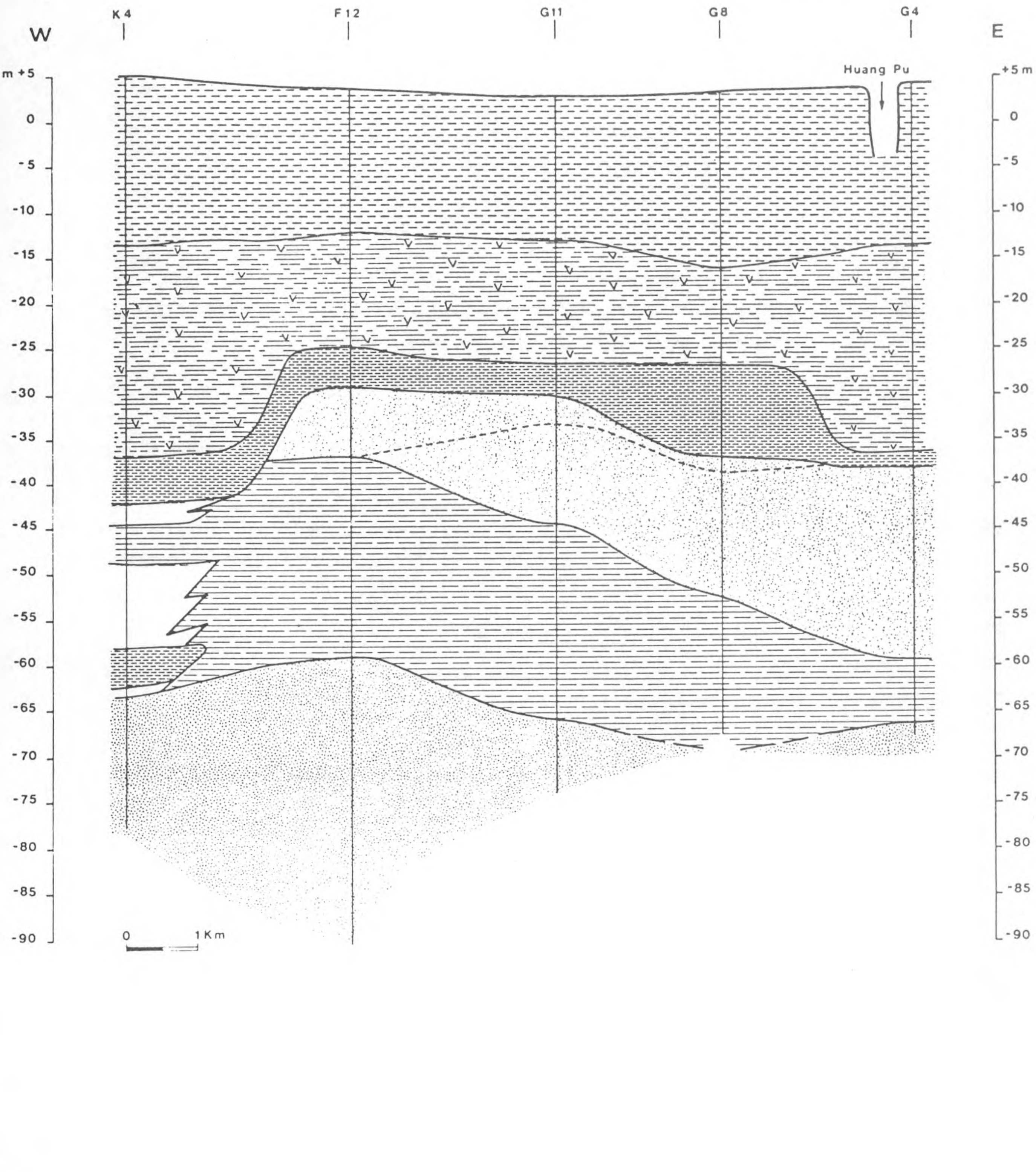
However, it should be mentioned that this erosional phenomenon is located in the surrounding of the present Huang Pu river and it is not inconceivable that the erosion is in close relation with the coming into being of the Huang Pu itself. In that case a change in the general sedimentary conditions and a.o. a change in the sea-level stand might as well be involved.

In general the thickness of the 1C-unit ranges about 15 m in the western part of the cross-section. Quite a lot of lateral and vertical facies changes obviously occur in the 1C-unit, but the lack of a detailed description of the sedimentary characteristics does not allow to interprete these changes more in particular. In the borings F8 and G7 e.g., the dominantly sandy sediments with a shell lag at the base and a sharp lower boundary, most probably can be interpreted as the facies of a small and local tidal channel.

Cross-section n°3

In cross-section n°3 the top of the 2A-unit is slightly lower in the eastern than in the western part. It is overlain by the 3C-unit which is wedging out in an eastern direction. Moreover, the sediments also become much more sandy in the eastern part. In this cross-section the distinction between the lower sand/clay and the upper silt/clay interlayering is

CROSS SECTION N° 3



not so well pronounced anymore.

In the very west of the cross-section, the K4 boring (between -63 m and -49 m) exhibits features completely different from the typical characteristics of the 3C-unit. The 2A-unit is directly overlain by a sandy silt which in turn is overlain by a homogeneous compact silty clay finally covered with sand in which a fining up was observed. The colour of the sediments is predominantly greenish grey.

As was already discussed (see 4.1.2.) these particular deposits clearly reflect a dominance of fluvial activity and most probably were not deposited in the marine-estuarine but in the fluvial-estuarine environment. It is very critical to correlate these predominantly fluvial deposits in the sequence as no data are available in the western surrounding of it.

In the K4 boring, the 1A-unit does not show the classical features neither. Above the 3 m thick silty clay, which may be correlated with the 3C-unit, again a predominantly fluvial deposit is found reaching a thickness of only 2 m. These deposits do not show any similarity with neither the sandbars nor the natural levee deposits of the 1A-unit. The sequence of it consists, from bottom to top, of a slightly humic silty clay, fine silty sand, compact sandy clay grading upwards into a homogeneous compact clay (to be correlated with the DGSC-unit). The colour is green grey and all the sediments are non-calcareous.

Until now, only one possible explanation can be put forward about these different deposits of the Upper Pleistocene in the K4 boring. All the features point to the fact that this particular area of Shanghai must have been located in the very neighbourhood of a fluvial channel. The lower part of the Upper Pleistocene sequence consists of channel and channel lag deposits, correlated with the 2A-unit (cf. 4.1.2.). It is overlain by a flood basin deposit which in turn is covered by again channel lag and channel deposits. Such a succession most probably indicates the lateral migration of fluvial subenvironments. The occurrence of only a limited layer of deposits from the marine-estuarine environment (3C-unit) on top of the fluvial sand, can be explained by a short dominance, and hence a larger lateral extension of the marine-estuarine environment pushing back temporarily the fluvial, or fluvial-estuarine environment in that particular area. It can be presumed that the 3C-unit most probably is wedging out in an even more western direction. The marine-estuarine environment could not prevail for a long time and was again replaced by fluvial activity resulting finally in the development of a flood basin clay, obviously to be correlated with the DGSC-unit.

In cross-section n°3, the 1A-unit shows some interesting features. The lower part of the 1A-unit is very well developed in the eastern part (boring G4). However it does not evolve to the typical natural levee deposits of the upper 1A-unit, but in stead of it, a greenish fine sand was found overlain by a compact sandy clay bearing some plant remains. The latter can be compared and correlated with the sandy clay underlying directly the classical DGSC-unit in the K4 boring. The absence of the proper DGSC-unit in the G4 boring may be due to the fact that it never developed in that particular area because of the presence of an active stream channel, or it simply has been eroded in a later period.

As from boring G8 towards the west in the cross-section, the lower part of the 1A-unit becomes thinner, while on the other hand, the upper 1A-unit is even more developed and finally, at the location of F12, forms the totality of the 1A-unit.

The 1A-unit is overlain everywhere by the DGSC-unit showing a rather flat surface situated at the level of about -26 m, except in the very east and west where it is occurring at -36 m. By that the deposits of the 2C-unit reach an important thickness (22 m) in these areas whereas in general they are about 12 m thick in that cross-section. The 1C-unit here is very regularly distributed and consists of silty and clayey sediments with only one important facies change occurring in the very east (G4) where predominantly silty sand is found. It is worthwile to mention that the Huang Pu river is occurring in the vicinity of boring G4.

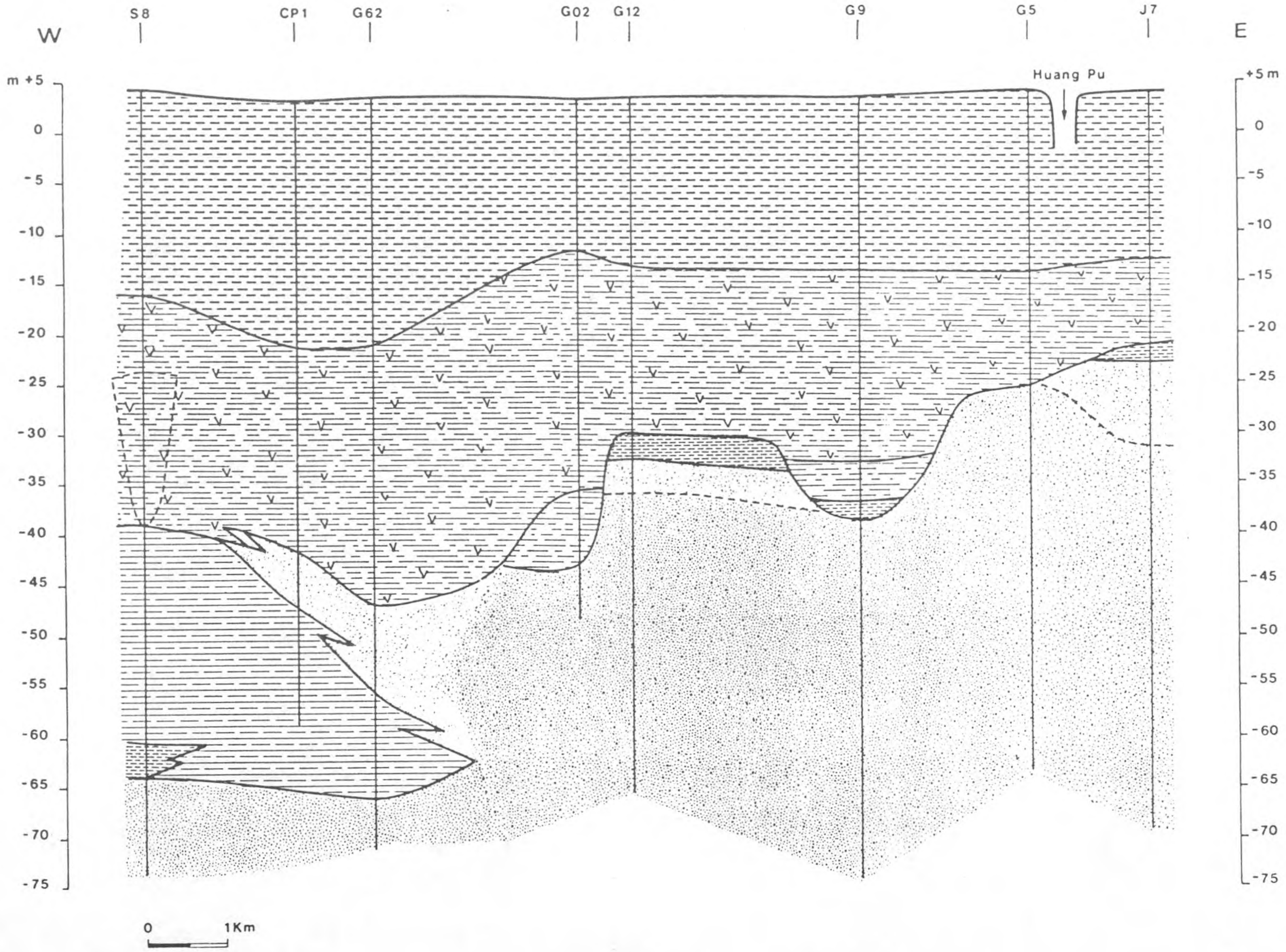
Cross-section n°4

Cross-section n°4, located in the southern part of the Shanghai area, shows a quite different picture. The 2A-unit as such only occurs in the western part, where it is overlain by the deposits of the 3C-unit which moreover are wedging out very quickly in an eastern direction.

In boring S8 a rather similar situation as was discussed for the K4 boring in cross-section n°3, is occurring here. On top of the sandy deposits of the 2A-unit, a compact clay was found at exactly the same depth (-60 m) as in K4. Although the description of the S8 boring does not reveal many data, the clay most probably can be compared and correlated with the lowermost flood basin clay of the K4 boring.

East of G62, the 1A- and 2A-unit can not be distinguished any more. Predominantly sandy deposits, with local clay and silt beds, are found, forming the Sand Complex unit. The top of the Sand Complex unit reaches as high as the level of -31 m. In the uppermost part of the unit the sediments do not exhibit evidence of natural levee deposits and the sand is directly covered by the DGSC-unit, except in the very east at location J7. However, in boring G5 the DGSC-unit is completely lacking, most probably due to the fact that in that particular area the flood basin never came into being because of the occurrence of the active stream channel (cf. boring G4, cross-section 3). That also might explain the high position of the top of the Sand Complex unit. The relationship between the high lying channel sand of boring G5, and the lower lying flood basin clay in boring G9 is to be interpreted as a phenomenon of river avulsion (see 4.6.). The absence of the natural levee is most probably due to the erosion of the

CROSS SECTION N° 4



migrating channel. It should be mentioned that the lowermost position of the DGSC-unit (-37 m at G9) is exactly the same as the lowermost one in cross-section n°3 (boring K4 and G9).

The geometry* of the DGSC- and Sand Complex unit as it can be deduced in cross-section n°4, clearly shows that the DGSC-unit could not be deposited in a lake, as it is assumed in the literature.

The Holocene sequence as depicted in cross-section n°4, shows a rather complex situation, at least the lower part of it. The lower part is not formed by the classical 2C-unit, but by its lower subunit (2Ca) consisting of silty clay. In boring G9, a peaty sandy clay is occurring at the top of it, while in G02 a 10 cm thick peat layer with wood fragments is found. The wood has been dated by 14-C at 10076 ± 126 y.B.P. (ref. GL86073). From the very brief boring-descriptions it is difficult to conclude whether the peats are in situ or are to be considered as reworked. From the stratigraphical position in the sequence, it is more likely to consider them as reworked.

At both locations the 2Ca-subunit is occurring in a depression. The origin of both depressions is different, however. At G9 the depression is formed as result of the latest river avulsion, thus just before the flood basin clay was deposited in that particular area. The depression in the western part of the cross-section shows an important incision into the 3C- and Sand Complex unit from which the upper parts are distinctly eroded. This depression shows similar features to the depression described in the cross-sections n°1 and n°2.

As was previously discussed (see 4.6.) the beginning of the post-glacial period is characterized by a general amelioration of the climatic conditions. This resulted in an all over renewed activity of all sedimentary depositional and erosional processes. Especially the river itself became very active again, because it is known that with large rivers, the channel

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* shape as a function of palaeotopography or geomorphology of the depositional environment.

regime is often controlled by the climatic conditions of the source area rather than those prevailing in the flood plain. That renewed activity of the river led to a.o. important erosion resulting in rather deep incisions in its own former flood plain. Although the sea-level rise was forthcoming, and the marine influence was extending more and more on the emerged offshore, the river eroded important parts of the Upper Pleistocene deposits from its former flood plain. Some of these eroded deposits were found most often as channel lag at the base of the depression (cf. borings F7, G37, G41).

It is clear that the incision occurred due to the amelioration of the climatic conditions, thus after the last glacial period, and more particularly at the beginning of the post-glacial period. The post-glacial period coincides with the Holocene Series. Since the lower boundary of the Holocene Series has been determined arbitrary at 10300 years B.P., it is, from a pure stratigraphical point of view, rather critical here to say that the incision took place at the beginning of the Holocene as such. Absolute ages only can give a decisive answer.

But for the sake of comprehensibility of the succession of events, the term Holocene will be used here (informally), indicating the period occurring after the last glacial period and characterized by the general amelioration of the climate.

In cross-section n°4 the 2C-unit shows its typical characteristics only in the eastern part. Exceptionally here a peat is occurring at the base of it at location G12. The 2C-unit reaches a thickness ranging between 8 m and 18 m. But in the west, as from G02, the presence of reed and yellow nodules is not so abundant in the lowermost deposits of the 2C-unit as usual. Moreover in boring S8 the sediments are predominantly sandy with interlayered bedding of silt and clay. The cross-section also depicts that the part of the 2Ca-subunit has been eroded. Those features indicate that the lower deposits are to be attributed to the sub- and intertidal environment rather than the supratidal in that particular area. The sandy sediments of boring S8 most probably reflect a gully facies from a local tidal channel.

The deposits of the 1C-unit are mainly silt and clay. From the boring descriptions no distinct facies changes could be observed.

Cross-section n°5

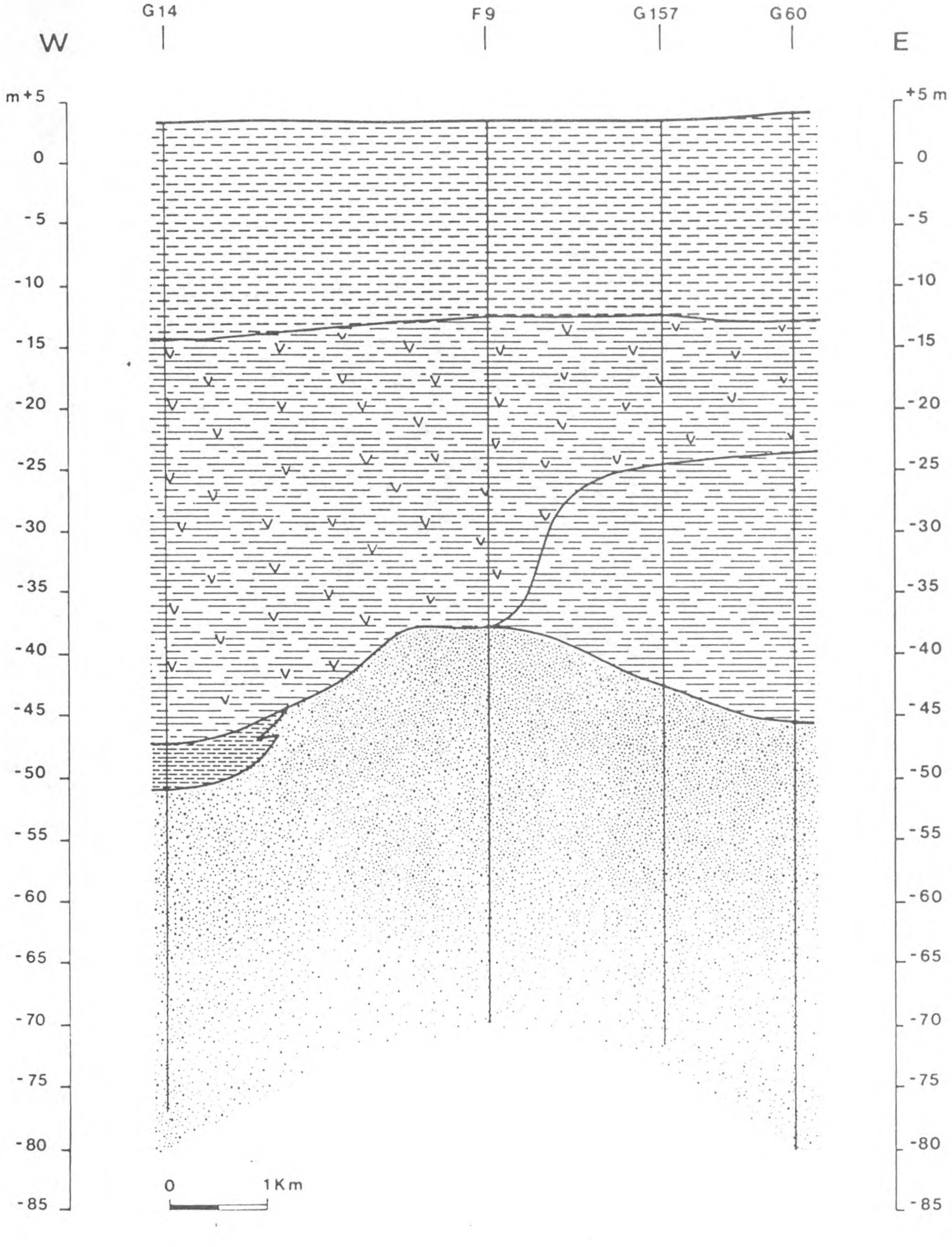
Cross-section n°5 is situated in the lowermost part of the Shanghai area. It depicts a completely different situation. The Pleistocene deposits here are only represented by the Sand Complex unit reaching as high as the level of -37 m and only in the west, the DGSC-unit is present. It is situated at the lowermost level ever observed in the Shanghai area (-47 m).

The Holocene deposits show a rather complex situation. In the east homogeneous silt and clay deposits were found reaching a thickness of about 20 m. They are overlain, with an obvious erosional contact, by a sandy facies (in the east) of the (lower) 2C-unit and finally by the deposits of the classical 2C-unit.

The homogeneous silt and clay deposit has been interpreted as the 2Ca-subunit and the sandy sediments as the subtidal and intertidal facies of the 2C-unit (cf. cross-section n°4). The situation here most probably only reflects the frequent lateral and vertical facies changes occurring in an evolving tidal flat environment, but the low density of borings and the insufficiency of the sediment description do not allow to make any further conclusive interpretation about this situation.

The several borings have been correlated in a north-south direction as well in order to demonstrate the interrelationship of the different sedimentary units and to complete the information on the geometry of the units (cross-section n°7, 8, 9 and 11).

CROSS SECTION N° 5



One of the most important features demonstrated by these cross-sections is the wedging out* of the 3C-unit in a southern direction. Another feature about the 3C-unit found expression here, namely its very high position in the north western part of the Shanghai area (cross-section n°7, 8 and 9) and the evidence of erosion by the channel activities, leading to the deposition of the 1A-unit (cross-section n°9 and 11). The comparison of cross-section n°11 and 9 reveals that the latter deposits have been eroded in turn (in a limited area) during the beginning of the Holocene.

The different levels of occurrence of the DGSC-unit, indicating the different steps of river avulsion, are depicted very clearly also.

Finally it is shown that in general the upper part of the 1A-unit is much better developed in the northern parts (cross-section n°7, 8 and 9).

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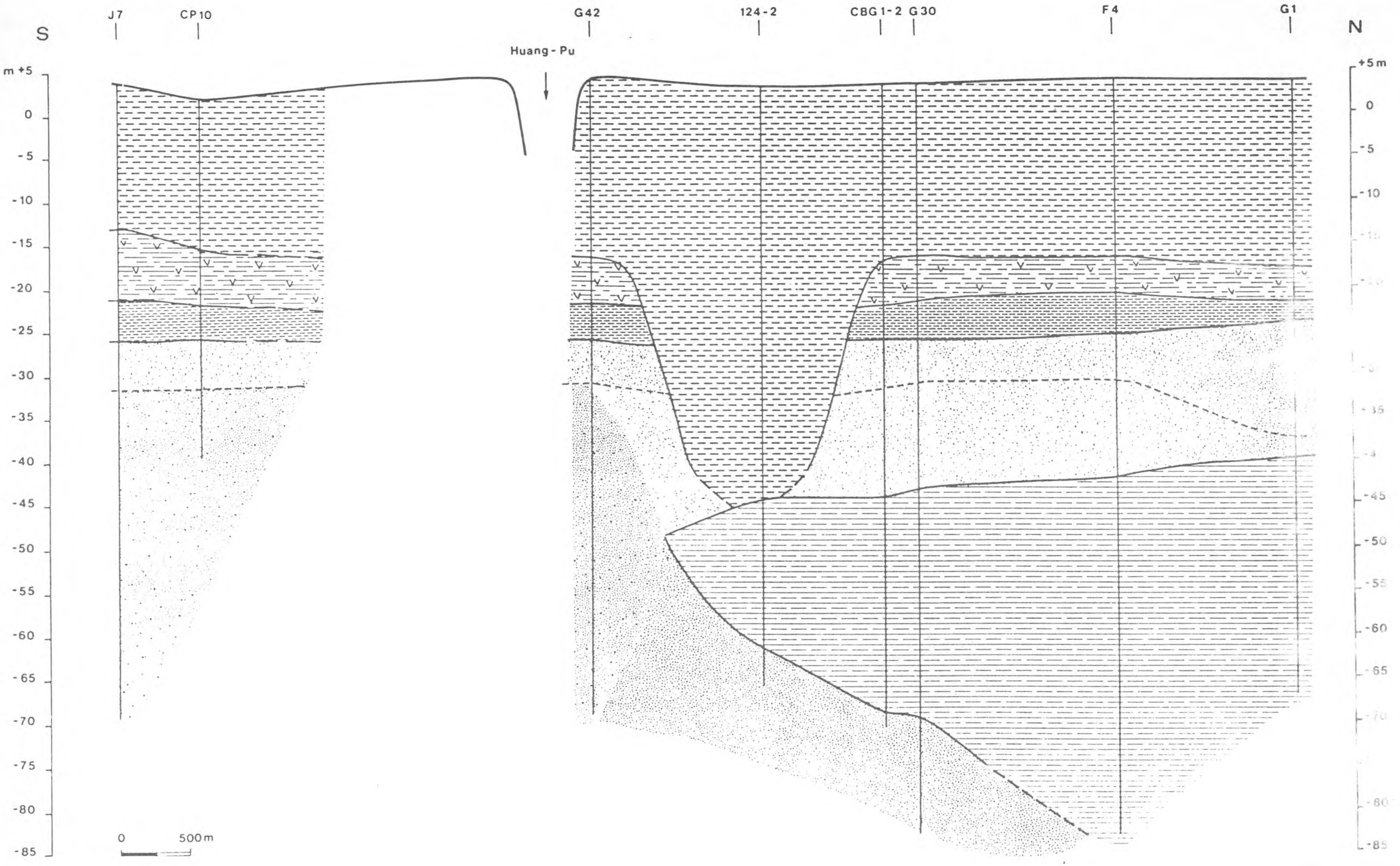
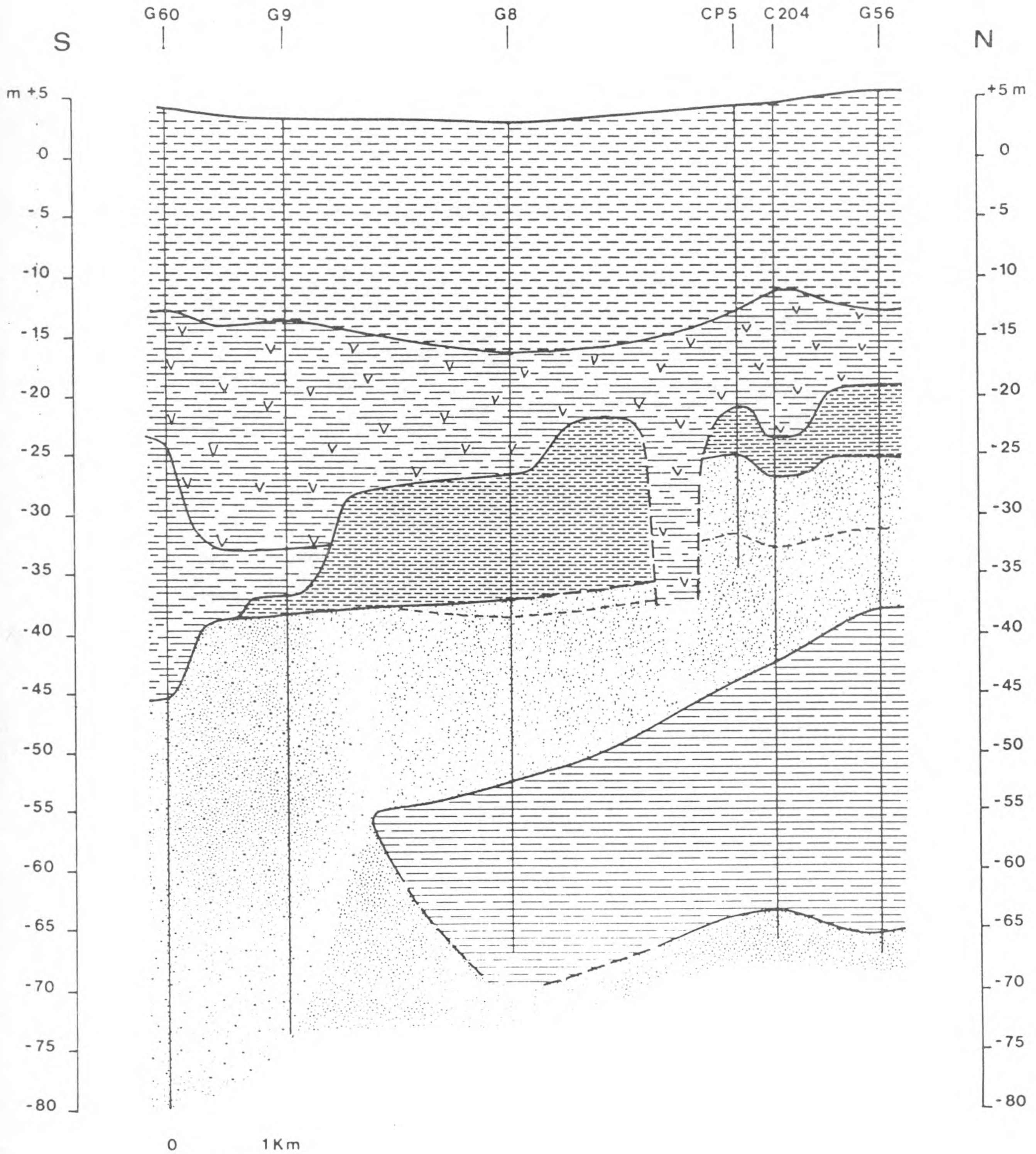
* it is true the representation is too exaggerated,due to the exaggerated vertical scale.

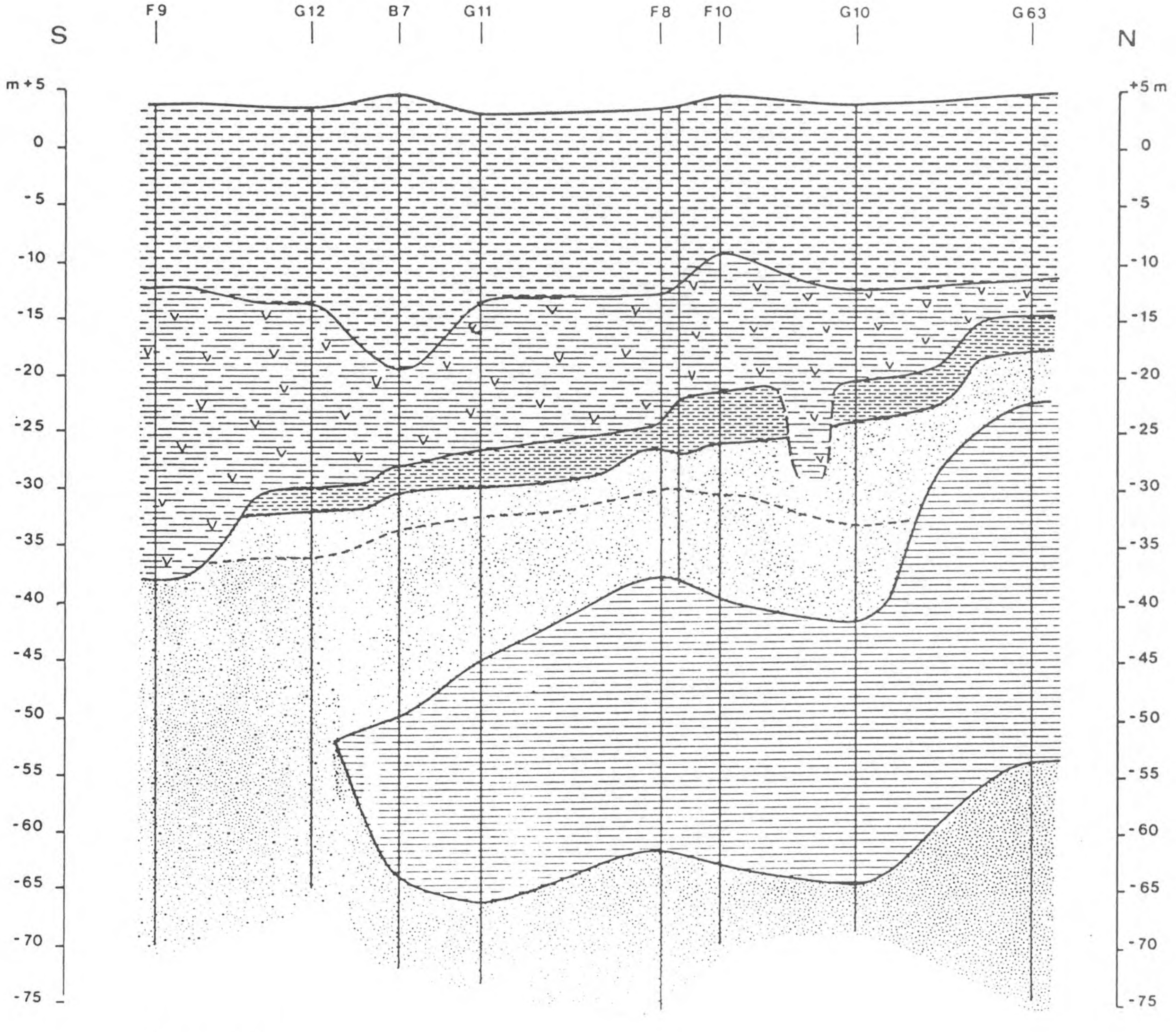
CROSS SECTION N° 7



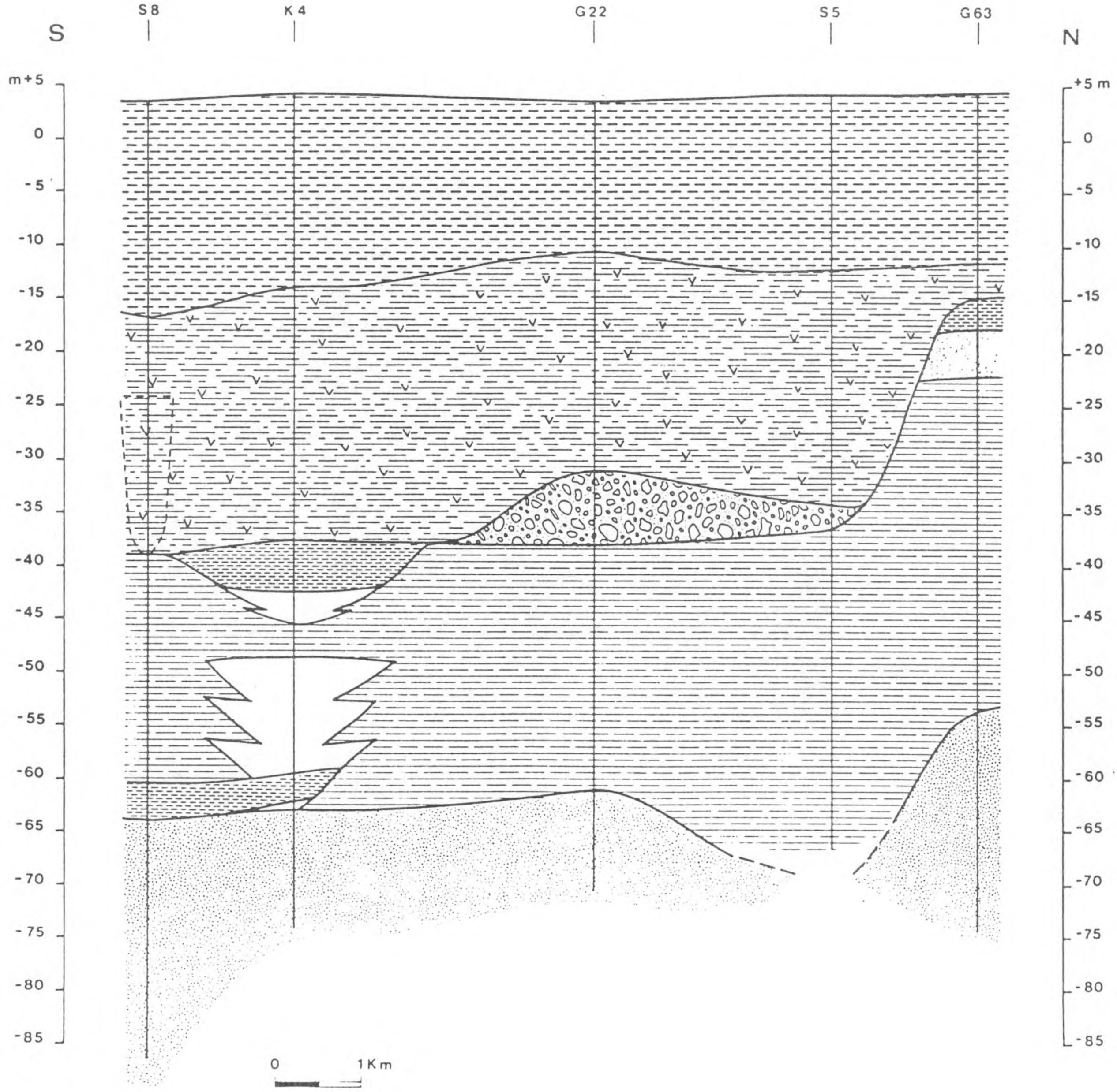
CROSS SECTION N° 8

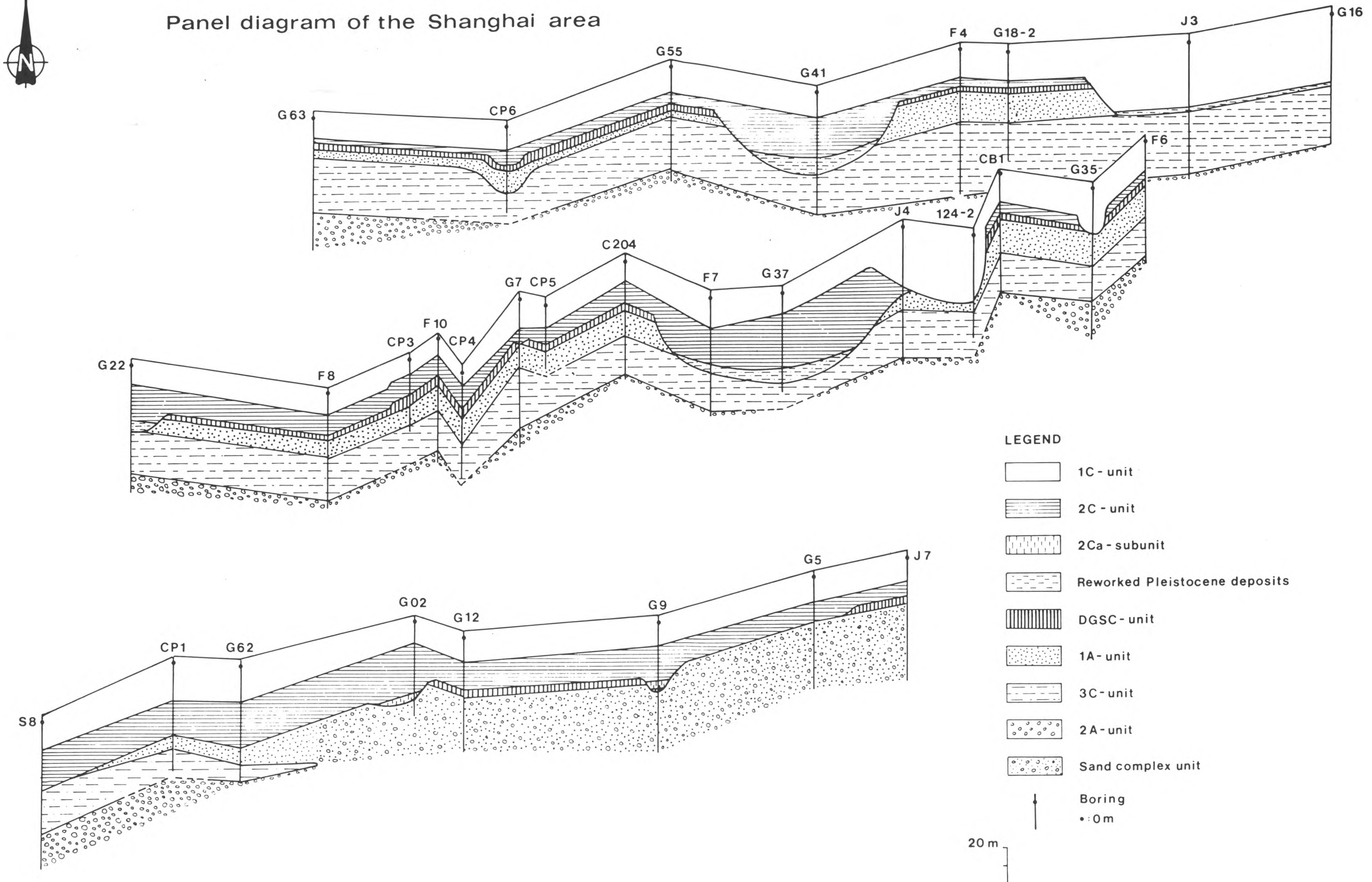


CROSS SECTION N° 9



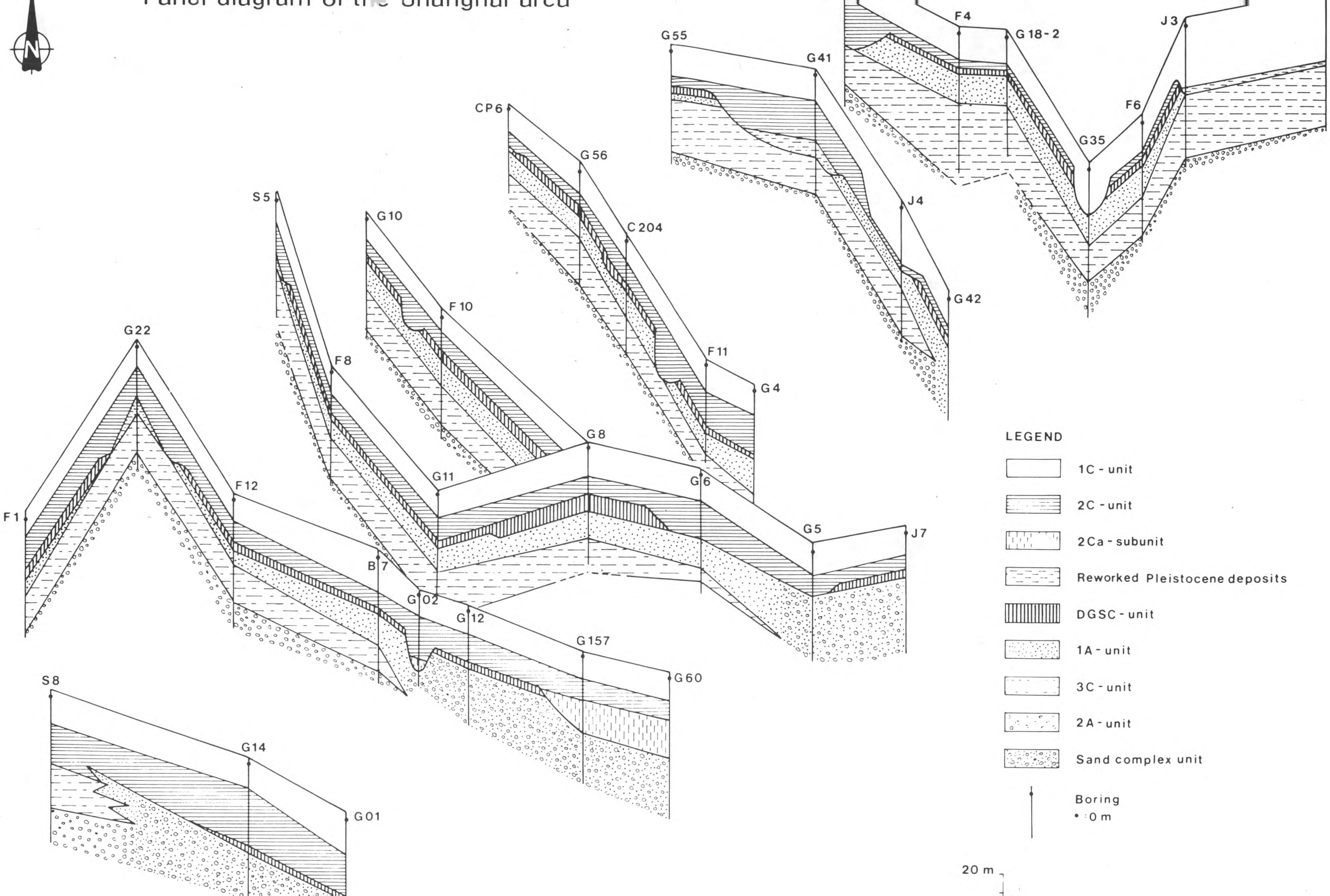
CROSS SECTION N° 11





Panel diagram of the Shanghai area

Panel diagram of the Shanghai area



5.2 Profile type map for the Upper Pleistocene and Holocene deposits.

For the representation of the different lithological units on a map, the method of ***profile types*** was adopted (De Jong & Hageman, 1960, Hageman, 1963, Baeteman, 1981 & 1987, Huybrechts, 1985). A profile type map or sequence map consists of a series of profile types. Each profile type represents a well-defined succession and combination of distinct units. The profile type map thus offers the possibility of representing the spatial extension of complete sedimentary sequences, giving the map a three-dimensional character. Thus a colour on a profile type map does **not** represent one single layer or unit, but a typical succession and combination of different units. This is in contrast with the conventional geological maps, or so called surface maps, only representing the geographical distribution of individual layers within few meters of the surface.

As coastal plain and flood plain sequences are characterized by frequent lateral and vertical (facies) changes, it is imperative to depict the deeper parts of the sedimentary sequence as well, otherwise the geological map is of very limited use. Only a three-dimensional representation can reflect these changes in the entire sequence of deposits. The conventional geological maps provide little to no information about the nature and spatial extent of lithological units as from a certain depth. For coastal and alluvial plains they only depict the nature of deposits from its latest silting up. So the advantage of a profile type map is quite obvious.

The profile type map of the Shanghai area shows in a general overview three distinct zones depicting main differences. The first zone is formed by what could be called the complete or classical sequence, consisting of, for the Upper Pleistocene deposits, the 2A-, 3C- and 1A-unit covered by the DGSC-unit and for the Holocene deposits the 2C- overlain by the 1C-unit. This zone is represented by the profile types 2, 3 and 4, covering the greatest part of the map.

A second important zone is differentiated by the absence of the DGSC-unit. It is represented by the profile types 5, 6, 7, 8, 9 and 12 which are found in two west-east zones and in a north-south zone.

A third zone is distincted by the presence of the Sand Complex-unit, where the 3C-unit is lacking. This zone is represented by the profile types 9, 10, 11 and 12 occurring in the southern and south-eastern part of the map.

In the first zone some minor differences, all related to differences in the 1A-unit, turned out to be significant. In profile type (pr.t.) 2, occurring in two limited areas, only the upper part of the 1A-unit is present. This indicates that in these areas the natural levee deposits are well developed, but the channel deposits never came into being. On the other hand in pr.t. 4 only the lower part of the 1A-unit is present representing the channel deposits. It is quite possible that in this particular area the natural levee deposits have been eroded by the channel itself due to its lateral shifting during its depositional cycle characterized by frequent river avulsions. Furthermore the flood basin facies (DGSC-unit) is occurring at one of its deepest positions in that area, indicating the latest fase of aggradation.

A rather exceptional situation in the classical sequence, at least for this concerned map, is occurring in the very WSW part of the map where the pr.t. 1 was selected to distinct the proper fluvial facies intercalated in the 3C-unit. In fact, the S8 boring, now represented by pr.t. 5, should be closely related to pr.t. 1 because in the lower part of the 3C-unit a compact clay, which could be interpreted as a flood basin deposit, was also found. However the boring description of the S8 gives to little information to be conclusive on that point, so that the S8 boring has been grouped into pr.t. 5 instead of selecting a new profile type for again just one single boring, which should be avoided for the sake of clearness.

A second important zone, intersecting the map in a west-east and north-south direction, is mainly characterized by the absence of the DGSC-unit. But the sedimentary sequence in this zone shows significant differences, except for the two lower units, viz. 2A- and 3C-unit. Pr.t. 5 and 6 reflect an important development of the 2C- and 1C-unit, respectively, in consequence of the presence of a depression caused by erosion at the very beginning of the Holocene. Both profile types show that the vertical filling of the depression is formed by a channel lag deposit consisting of reworked Pleistocene material. In the borings grouped into pr.t. 5 however, the channel lag deposit was not always found. Pr.t. 6 obviously reflects a much complexer situation showing a renewed incision during the Holocene which eroded the deposits of the 2C-unit. In the areas depicted by pr.t. 7 and 8, the incision did not reach that important depth because the 1A-unit is still present in the sedimentary sequence. In some borings the upper and lower part of the 1A-unit are present, while in other borings only the lower part is found. For the sake of clearness of the map, no new profile type has been selected to demonstrate that differentiation. Both possibilities has been grouped and indicated in the legend as "1A upper may be absent". It is quite probable that such a sequence as represented by pr.t. 8 can be found all along the depressions instead of only in the restricted areas like it is drawn on this map, but the density of borings is too low to be conclusive about that. The difference between pr.t. 7 and 8 concerns the Holocene deposits and is identical with the difference between pr.t. 6 and 5.

The southern part of the map shows important differentiations due to on the one hand the presence of the Sand Complex-unit (to be found in pr.t. 9, 10, 11 and 12), and on the other hand due to more in particular the second west-east depression, represented by pr.t. 9 and 12. Furthermore a part of the depression and a narrow zone just north of it exhibit a sedimentary sequence where the initial Holocene filling consists of the 2Ca-subunit overlain by the typical 2C- and finally by the 1C-unit. The occurrence of the 2Ca-subunit is reflected in pr.t. 9 and 10.

In that southern part of the map, the depression is bordered by an area showing a very simple sequence (represented by pr.t. 11) where the DGSC-unit covers the Sand Complex-unit and is in turn overlain by the 2C- and 1C-unit.

In the very SW, the profile type 3 is again occurring, because in the lower part of the sequence the 3C-unit is found, wedging out towards the east.

Taking into account the very low density of borings, the profile type map of the Upper Pleistocene and Holocene deposits of the Shanghai area reveals a rather good general overview of the lateral and vertical distribution of the distinct lithological units until a depth of about 70 m.

It is clear that the geological setting is determined by the presence of the erosional depressions from which the sedimentary sequences show differentiations according to the intensity of erosion and the evolution the area experienced during the Holocene. As already mentioned above (5.1.) it is not inconceivable that the filling up of the depressions, especially in the eastern part of the area, is in close relation with the development of the Huang Pu River.

On the other hand, it is striking that no significant indications could be observed in the borings about the development and evolution of the Suzhou Creek, crossing the studied area in an east-west direction (fig.1). The Suzhou Creek most probably used to be one of the tidal gullies transecting the tidal flat that occurred over the entire area towards the end of its Holocene history, before it silted up completely and became the actual coastal plain. For a particular reason the Suzhou Creek did not silted up and remained an open, active gully. But it is quite probable that in the studied area several other gullies were occurring (at different times) which did silt up and which could eventually be detected in the sedimentary sequence of the Holocene deposits. A denser boring grid and a detailed sedimentary study of the cores certainly would reveal much more information about these features.

Inherent in the system of profile type maps, depth indications are lacking. Therefore two isohypse maps were established in order to display the depth contours of the two main features of the area, viz. the top of the DGSC-unit and the base of the Holocene deposits.

5.3. Additional isoline maps

Morphology of the top of the DGSC-unit.

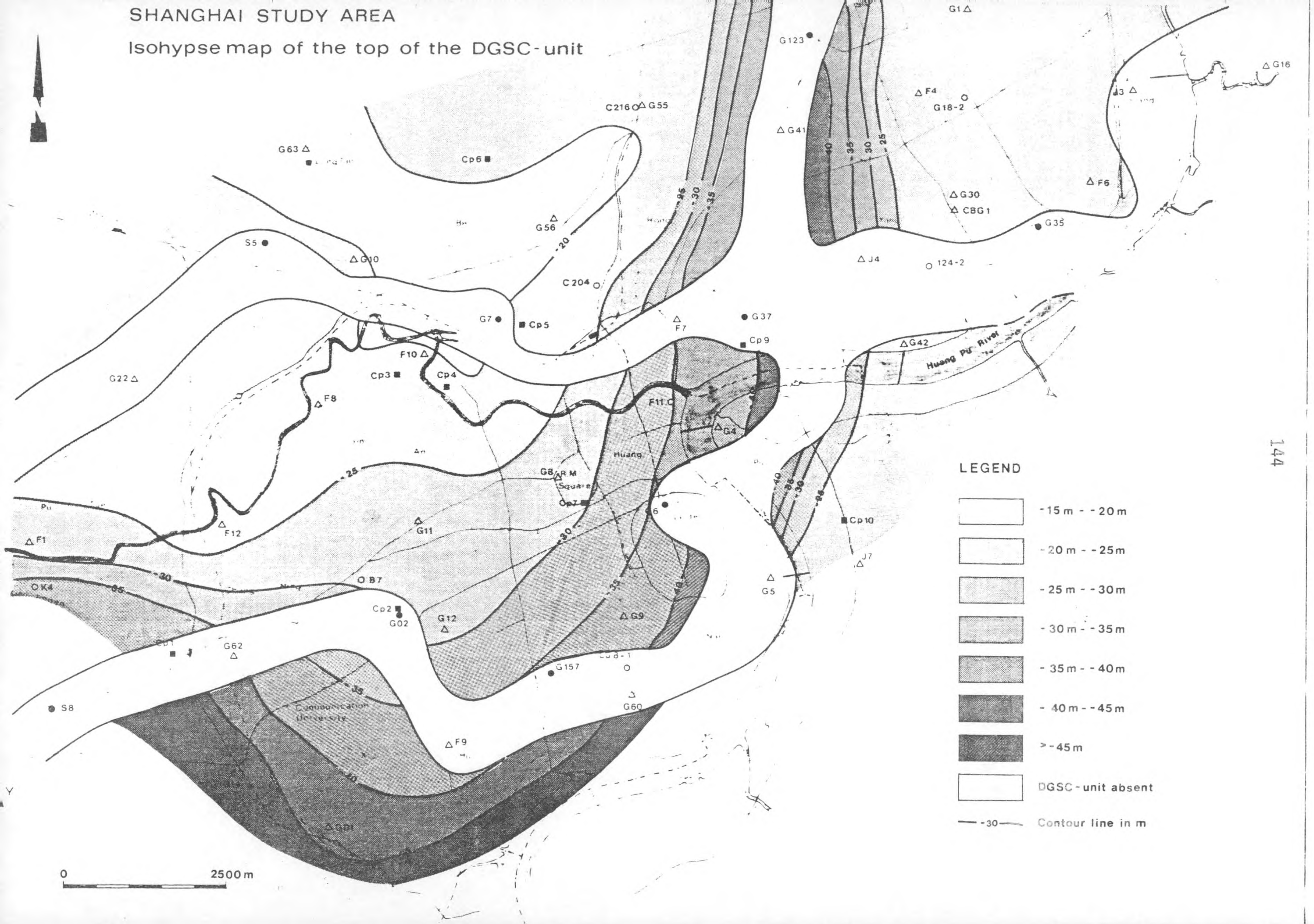
The top of the DGSC-unit, consisting of a flood basin clay, shows a rather regular configuration (see isohypse map of the top of the DGSC-unit). Its highest position, between -15 m and -20 m, is situated in the NW part of the area. The top then gradually dips in a S, SE and E direction to a level between -20 m and -25 m where it remains over a quite large extension. As from -30 m the top dips rather quickly towards the S and SE and the lower most observed point reaches -47 m at boring G14. In the eastern part of the map the top is again occurring for its greatest extension on a level between -20 m and -25 m.

Such a morphology, as very well depicted in the central part of the map, reflects the different cycles of river avulsion, occurring each time in a more south-eastern direction, and each time on a lower position.

It is very critical to interpret the dipping of the top of

SHANGHAI STUDY AREA

Isohypse map of the top of the DGSC-unit



the DGSC-unit, which is located in the very northern part of the area, in a similar way, because the spreading of the borings is far too restricted. It is quite probable that the configuration of the depression is only due to the erosional activity which happened at the very beginning of the Holocene.

From a morphological point of view it is clear that the DGSC-unit can not be interpreted as a lake facies, as it is believed in general.

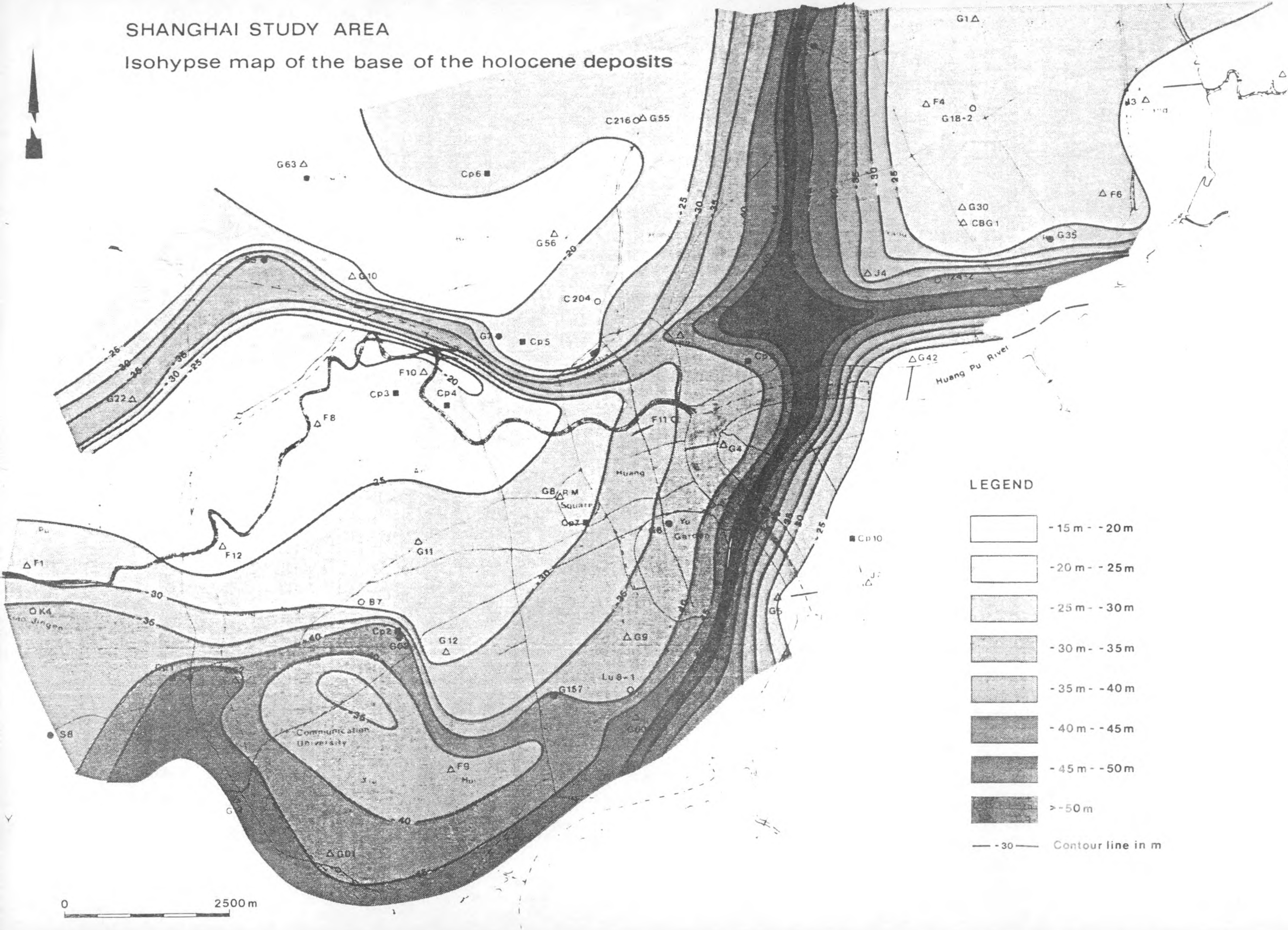
The absence of the DGSC-unit most probably also has different origins. In the N-S depression located in the central part of the map, it is not inconceivable that the flood basin clay never could develop because of the prevailing channel activity in that particular zone. But in the areas bordering this depression in the west (e.g. G9 and G4) the flood basin clay has been eroded by the events which happened at the very beginning of the Holocene.

It is worthwhile mentioning that the configuration of the areas where the DGSC-unit is lacking has been drawn on base of few data points which moreover are located far from each other. Therefore the configuration of these zones can only be looked upon as giving a general trend and it is self-evident that a denser boring grid would reveal a much more exact configuration of the zones.

Isohypse map of the base of the Holocene deposits.

It is obvious that the greatest part of this map is similar to the isohypse map of the top of the DGSC-unit, as the top of the latter indeed forms the boundary between the Pleistocene and Holocene deposits. Only the zones where the flood basin clay is lacking, will depict important differences.

The base of the Holocene deposits reaches its maximum depth of -52 m at G37 located in the N-S depression. The northern most W-E depression shows depths between -30 m and - 35 m, while in the southern W-E depression the base is situated much lower as it is ranging between a depth of -40 m and -45 m even with few deeper points.



SHANGHAI STUDY AREA

Isohypse map of the base of the holocene **deposits**

6. Final Considerations

The Changjiang coastal plain is pre-eminently an area where at one time coastal processes dominate the situation and at another time fluvial processes are overwhelming all activity. The Changjiang river, however, presents the primary factor in the entire Late Quaternary history. The river forms an estuary which has been shifting back and forwards in time, leaving a complexity of deposits in the stratigraphical sequence.

It is very well known that all over the world estuarine deposits rarely consist of a single fill sequence formed at only one high sea stand as, at least during the Pleistocene and Holocene, it seems that the estuarine environment reoccupies the same places during various transgressions.

In such deposits it is not evident at all to interpret subsurface data. Because of the similarity of the deposited lithofacies, the stratigraphy of any one drillhole is extremely complex. This also explains why the use of general and broad cross-sections only leads to misinterpretation and therefore should be avoided at any time.

The Quaternary research in the Changjiang coastal plain and more particularly in the Shanghai area revealed several new interesting features. Although the available data are rather restricted, some generalities on its geological history during the Late Quaternary, based on the analysis of sedimentary facies and facies succession, can be pointed out.

The Upper Pleistocene deposits considered here (until a depth of about 70m) consist of a sequence showing the transition from an estuarine environment to a proper fluvial one. The estuarine environment is represented by a sandy deposit, called the "Z" Member in the proposed stratigraphy and forms, what is usually named, the Second Aquifer. In the sequence it is followed by a dominantly clay deposit,the "Y" Member which is known to be sensitive to compaction. The latest unit of the estuarine environment is again formed by sand deposits, the "X" Member, which gradually is replaced by fluvial sand and silt heralding the (last) fluvial phase of the Upper Pleistocene sequence. Both sand deposits form the First Aquifer. In the southern part of the area, the First and Second Aquifer are joined.

Finally the silting up of the fluvial sequence is completed by the formation of a flood-basin clay. This clay deposit, known as dark green stiff clay and called the "W" Member, represents one of the most interesting deposits in the area of Shanghai, since it is the only unit characterized by a high bearing capacity (for the upper 70m). All the evidence of the sedimentological and stratigraphical investigation yielded clearly that the clay has been deposited in a flood basin during a period of low sea-level stand, and it is not to be interpreted as a lake deposit like it is generally believed. Indeed the fact that the clay deposit is (relatively) compact, is exactly the reason why it never could be deposited in a lake. When and under which circumstances would then the sediments have time to dewater and compact ?

The absence of the "W" Member in certain zones of the Shanghai area has a twofold origin. The geometry of the clay deposit obviously shows several steps in the process of river avulsion. With the last (and lowermost) step, the river did not yet has the occasion to build up a new flood basin adjacent to its new position, so in this particular zone only dominantly sandy deposits from the channel itself are found.

The second origin is an erosional one rather than a depositional one. Indeed, at the beginning of the post-glacial period, or Holocene, the area is characterized by an overall renewed activity due to the general climatic amelioration. Especially the river itself became very active again, leading to significant erosion in its own former flood plain.

In the Holocene period the area again changed to an estuarine environment, represented by dominantly silty clayey sediments. Only two significant units could be recognized, *viz.* the "V" Member, consisting of mainly supratidal deposits and the "U" Member, representing the silts and clays deposited in the tidal flats of the estuary. Both deposits are very sensitive to compaction, hence called the "Second Compressible Layer" and the "First Compressible Layer", respectively. The tidal flats were characterized by relatively uniform conditions of very high mud supply (from the Huanghe and Changjiang rivers) and very limited reworking by marine processes, resulting in a nearly homogeneous thick sequence of silt and clay in which no significant changes in depositional conditions are recorded. These uniform depositional sedimentary conditions led to a continuous depositional regression or coastal progradation of the area.

The investigation of the Upper Quaternary deposits revealed that the geological setting of the Shanghai area is not to be looked upon as a simple succession of regular parallel running units. Its depositional and erosional history resulted in a regional variability and diversity and in a stratigraphical complexity of the coastal sequence.

These features are to be considered critically when evaluating the hydrological and geotechnical properties of the area.

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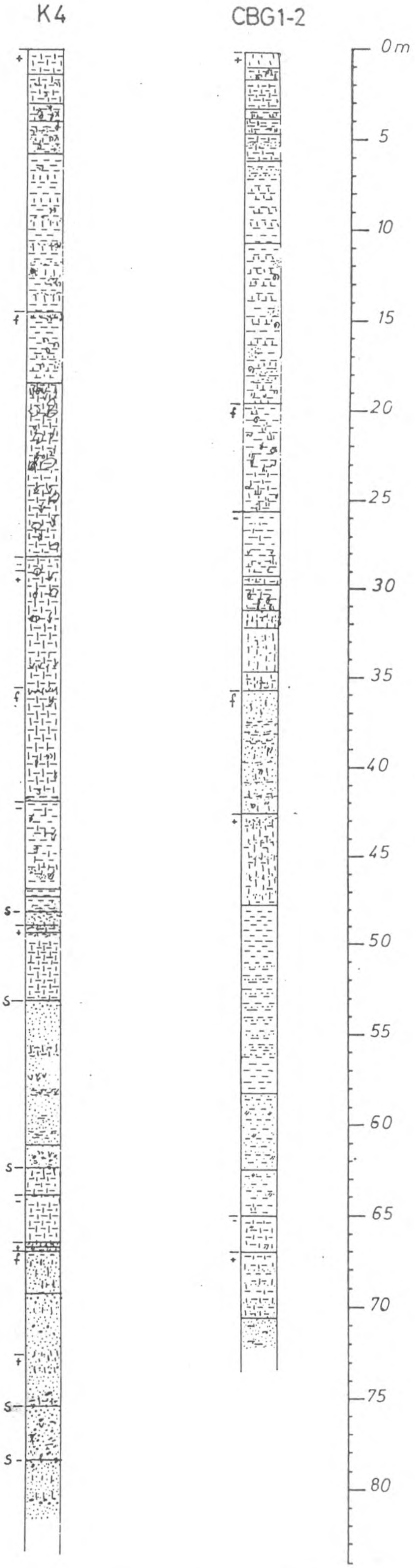
LEGEND FOR THE BORELOGS

▤	clay	▨	root penetrations
▥	silt	○	yellow nodules
░	sand	◩	shells/ -fragments
▦	silty clay	⊤ +	$CaCO_3$
▒	sandy clay	⊤ f	few $CaCO_3$
⠿	gravel	⊤ –	no $CaCO_3$
■	peat	s –	sharp boundary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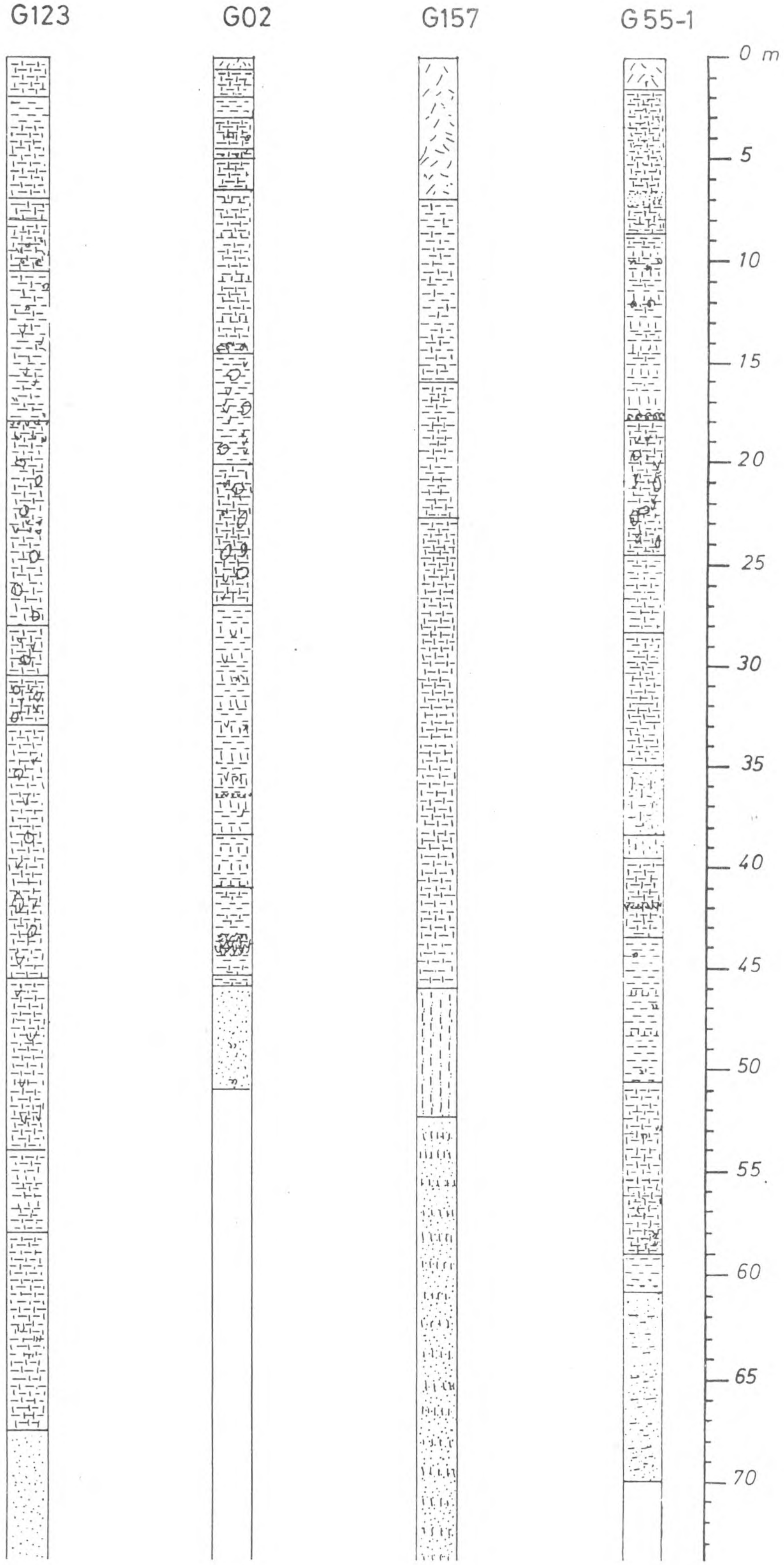
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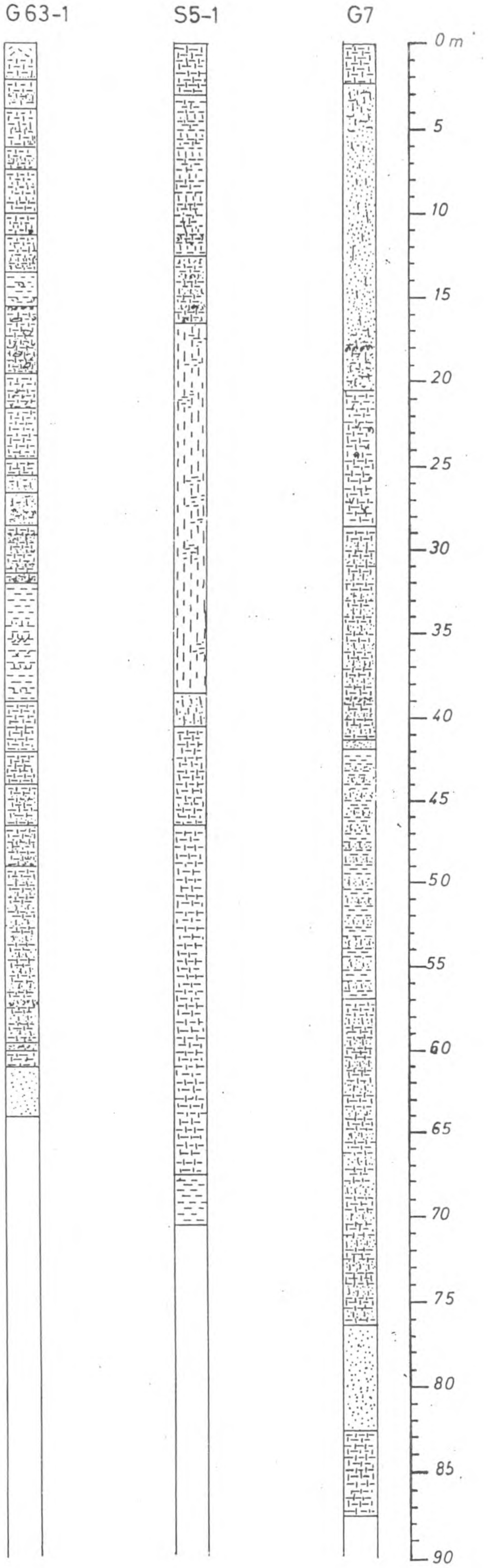
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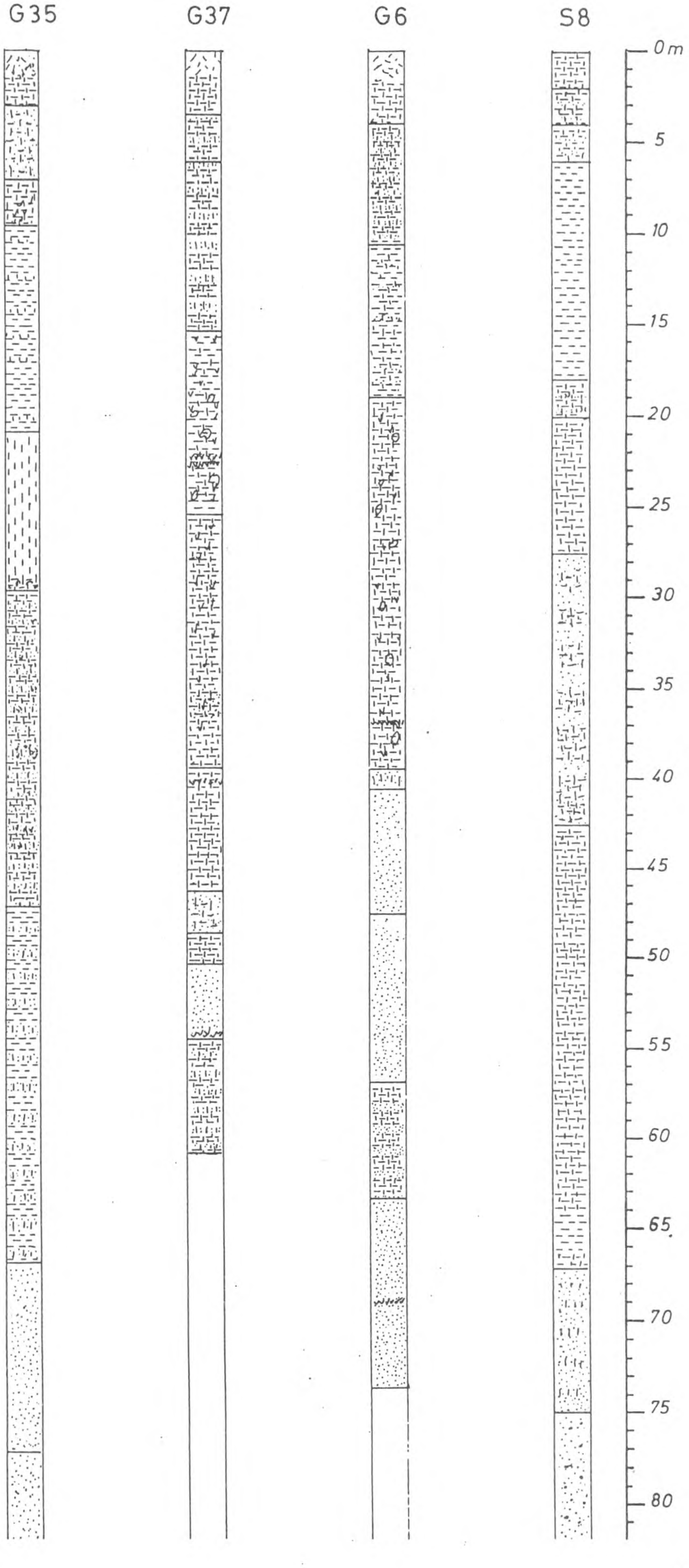
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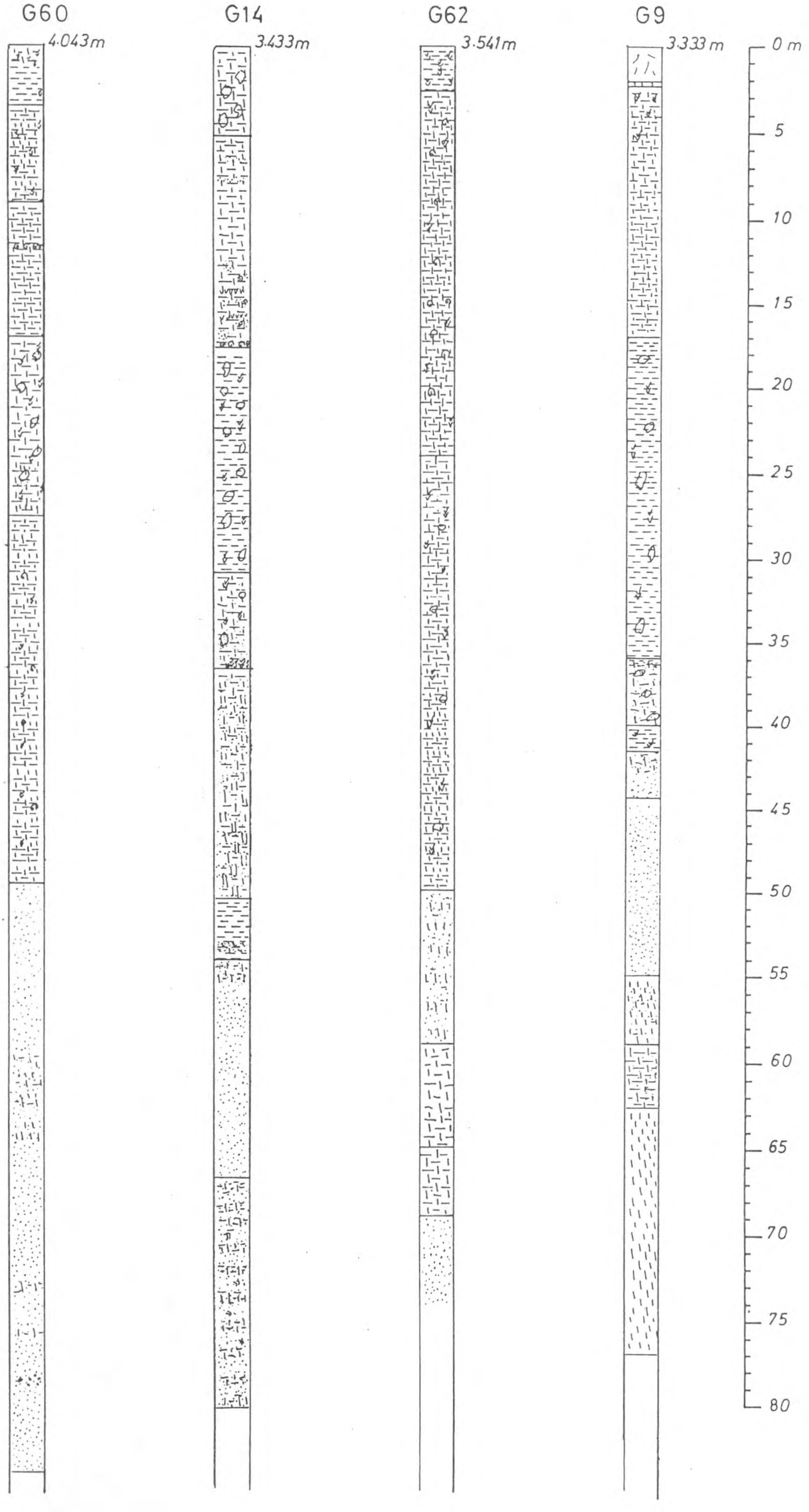
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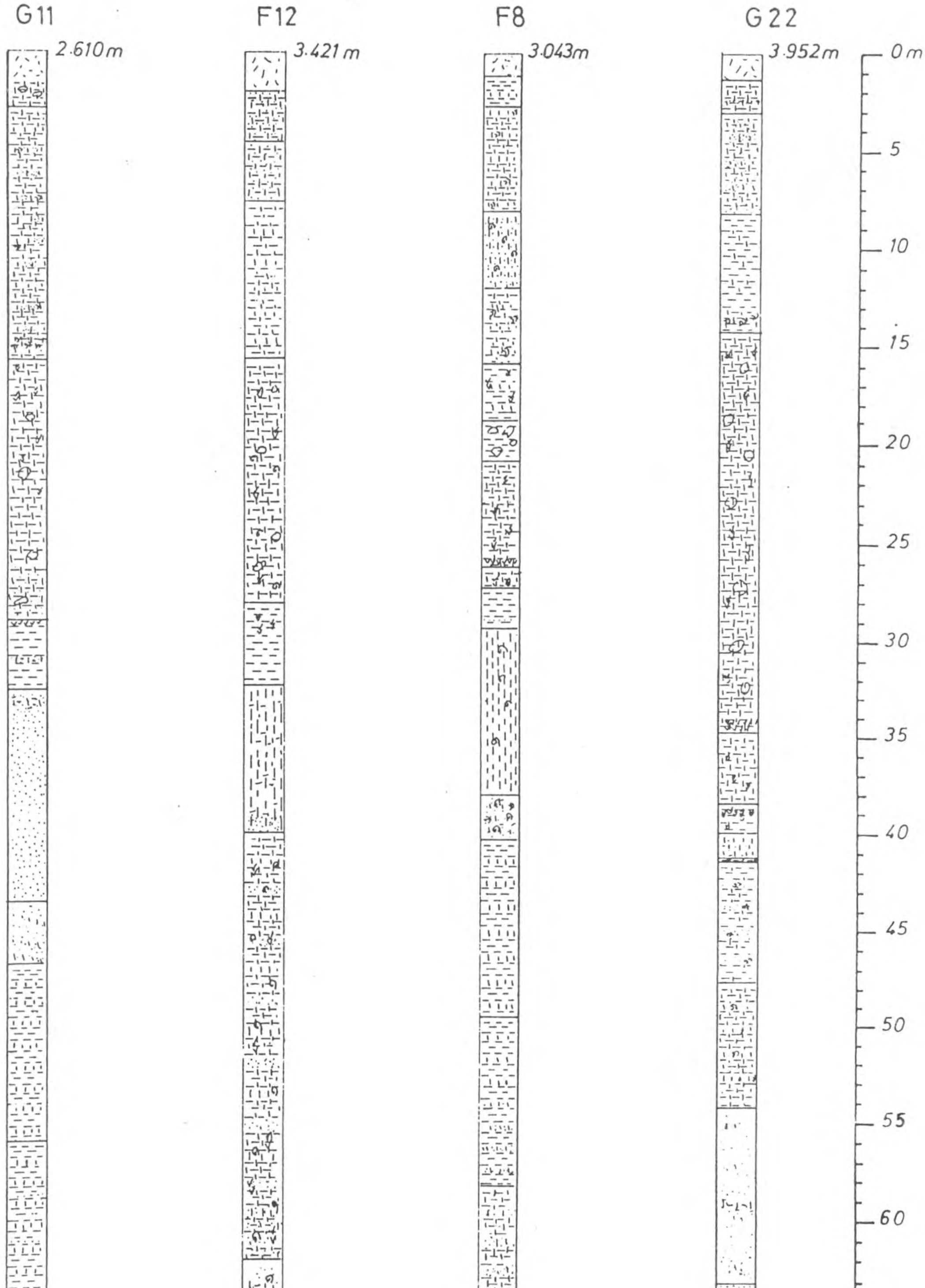
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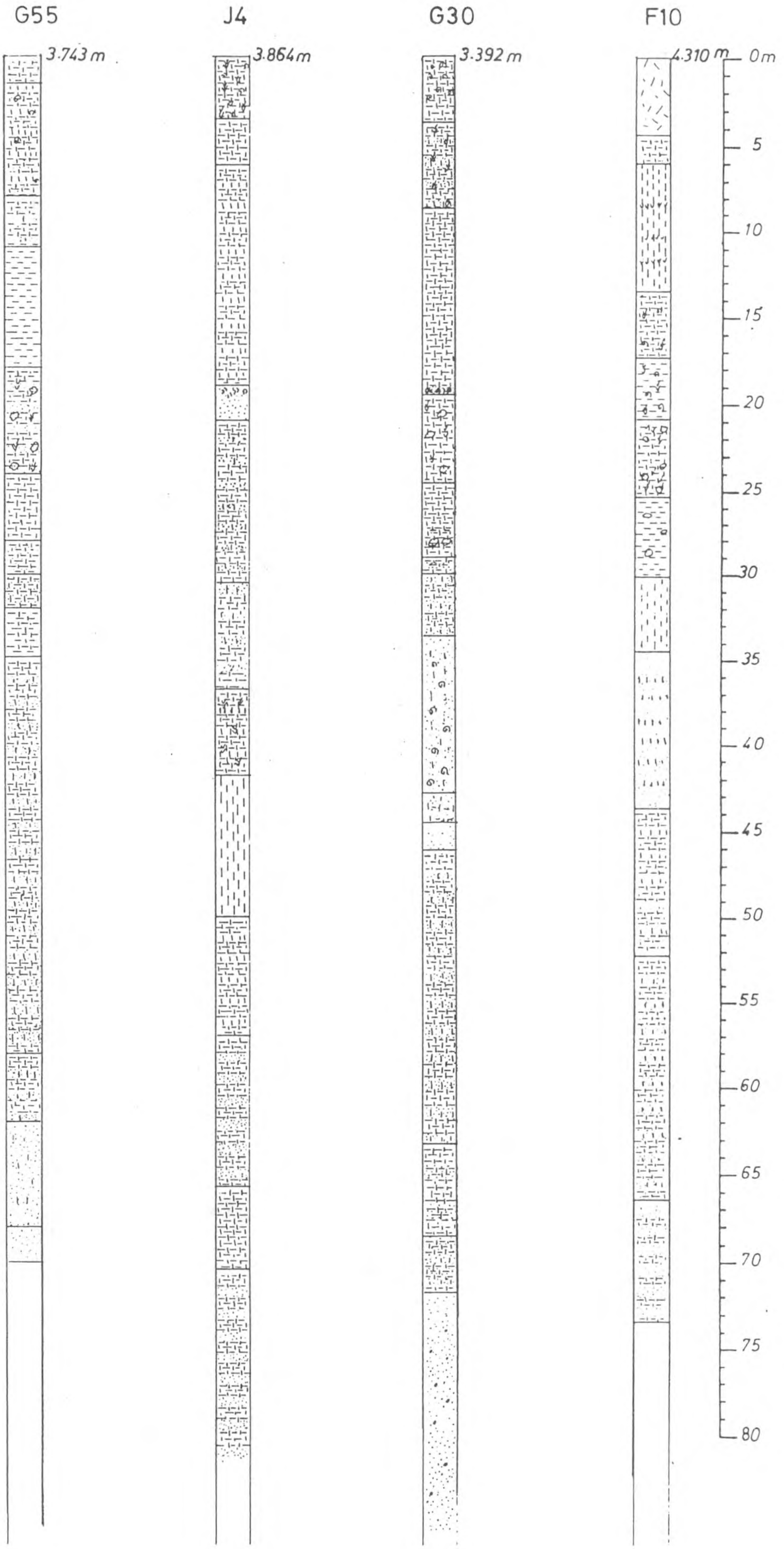
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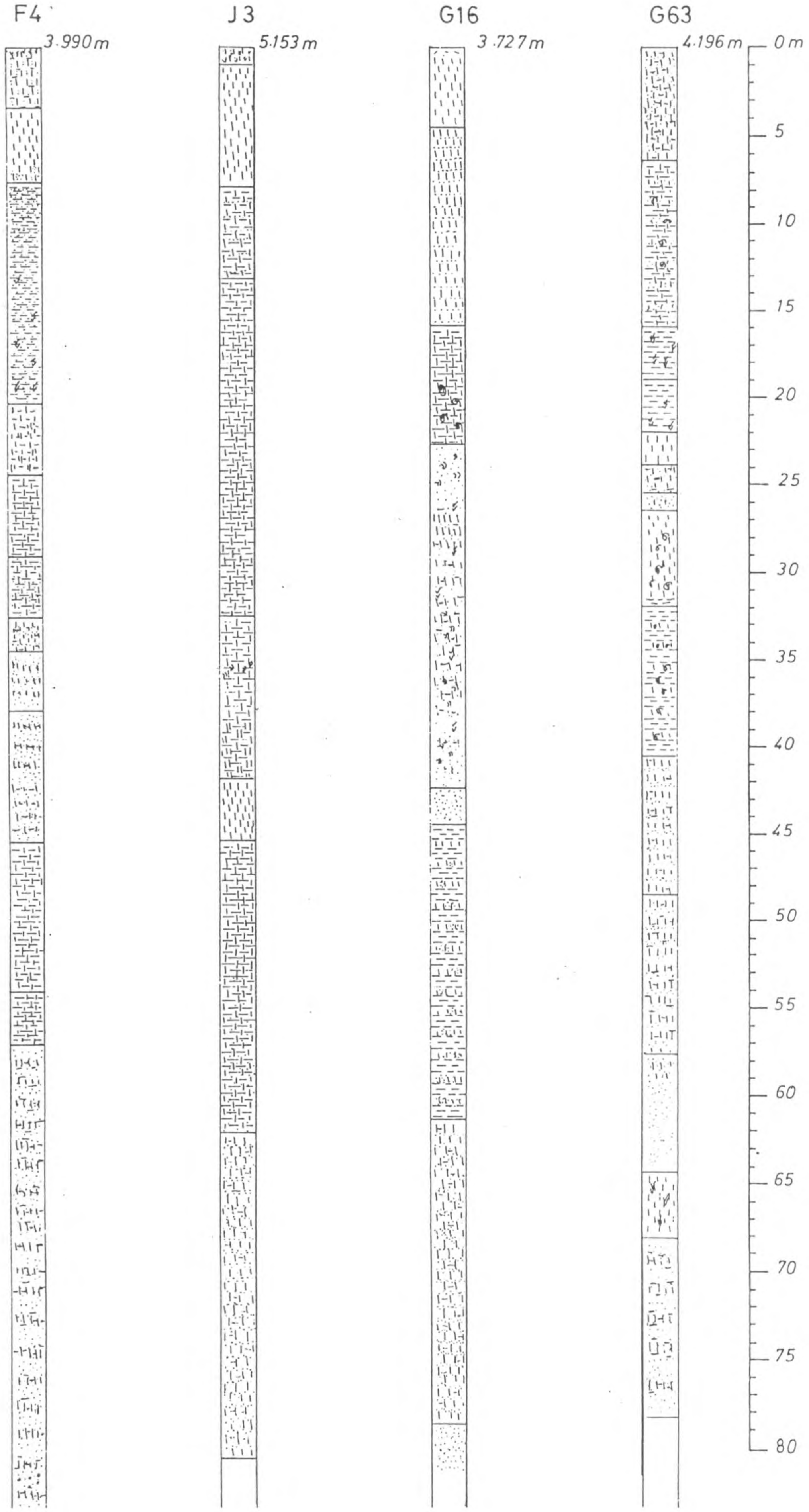
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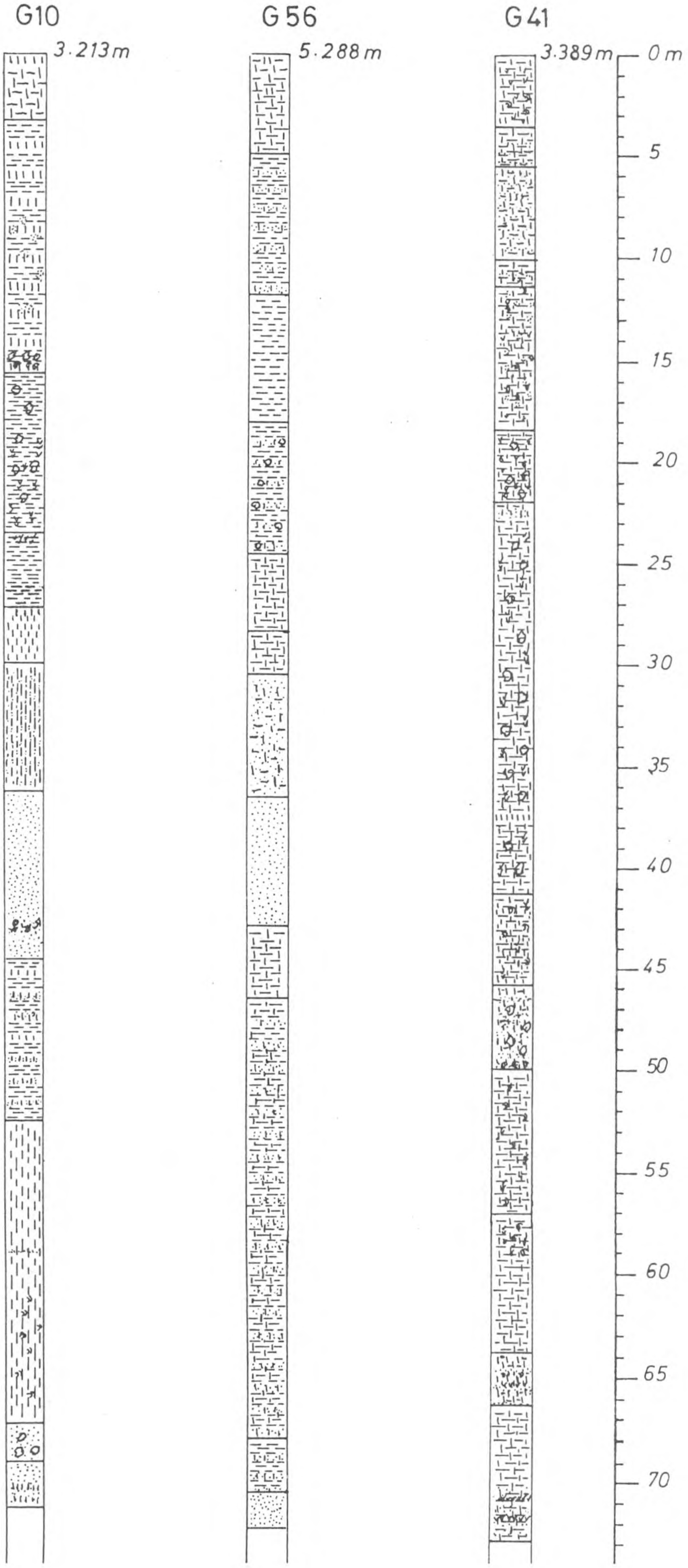
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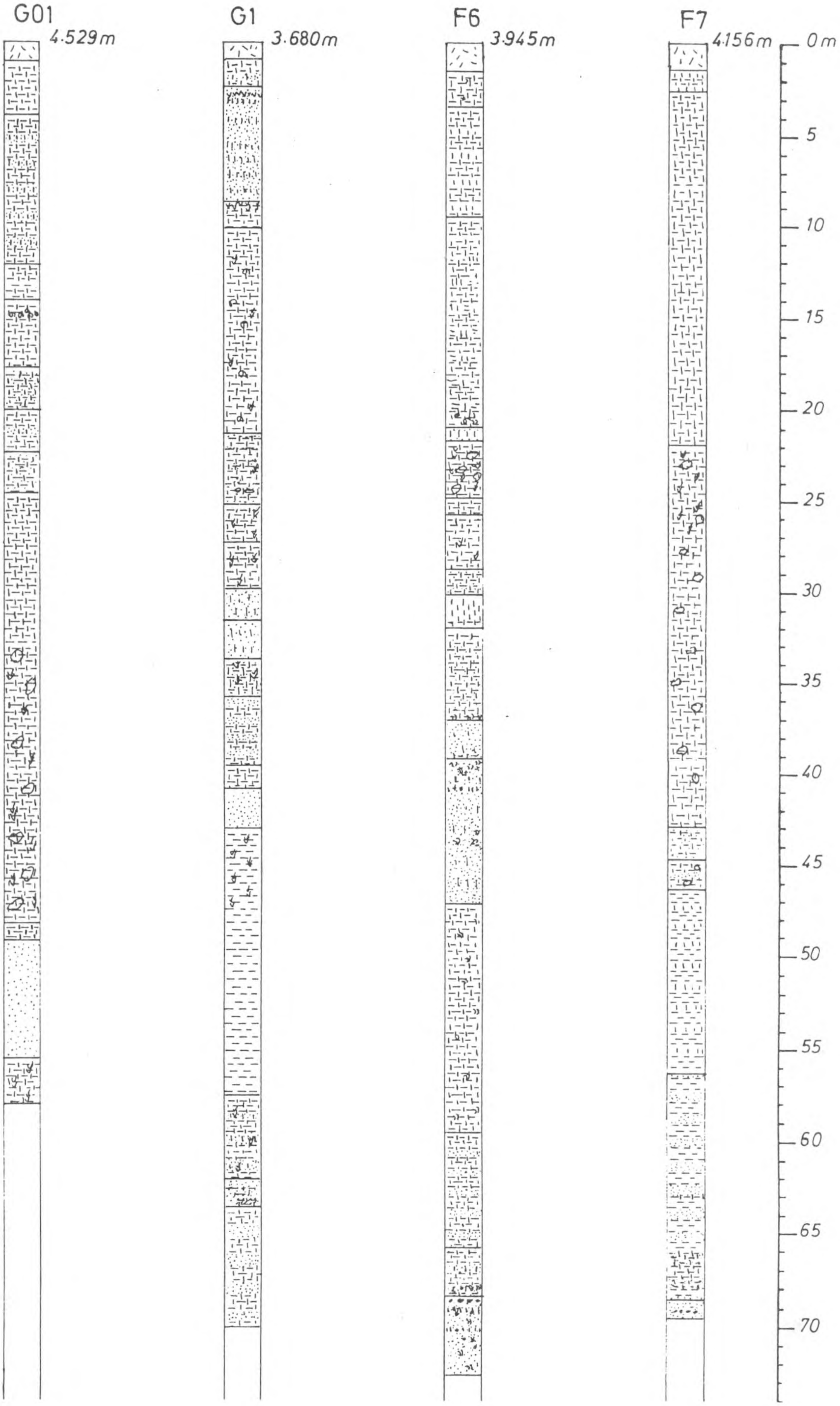
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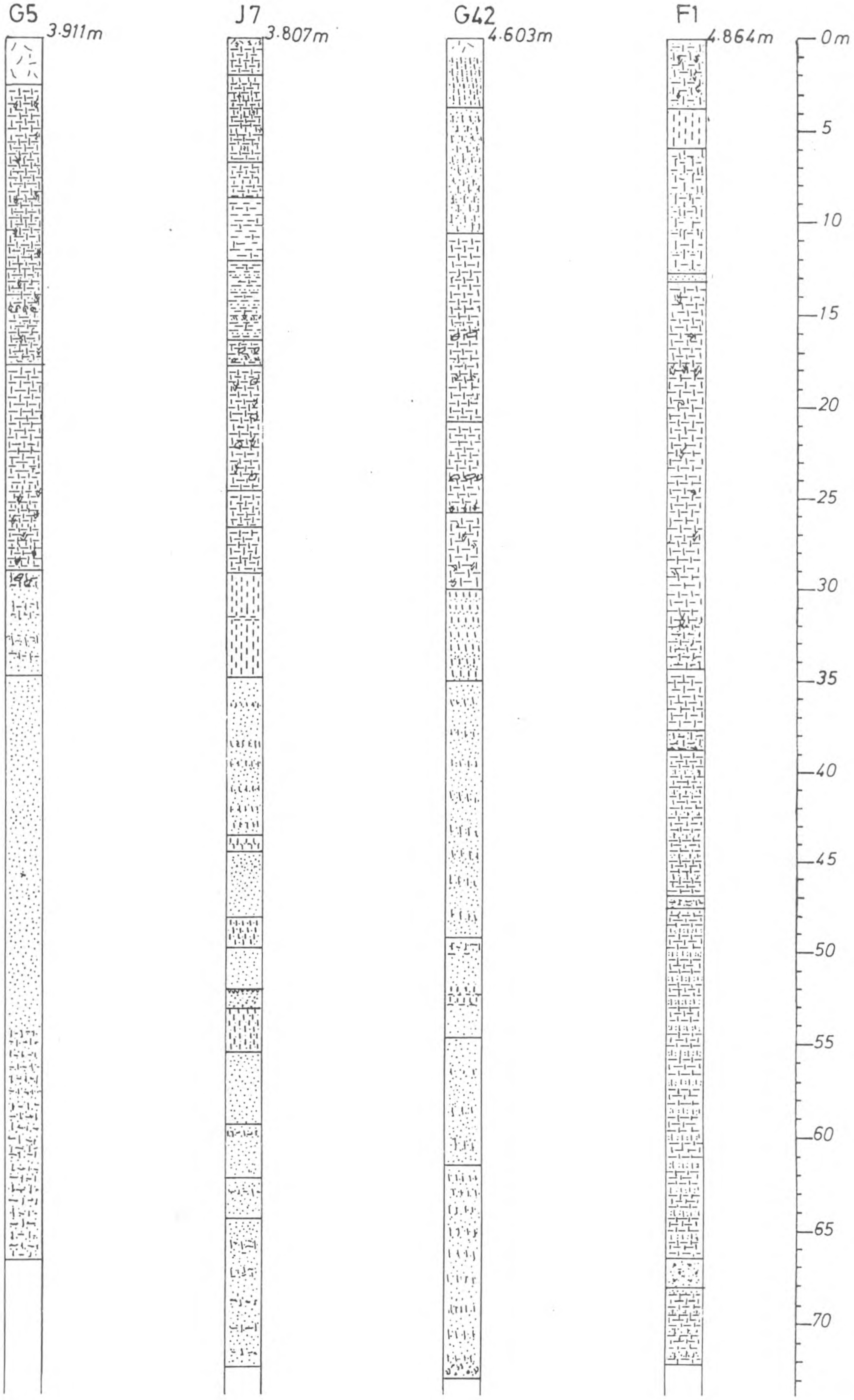
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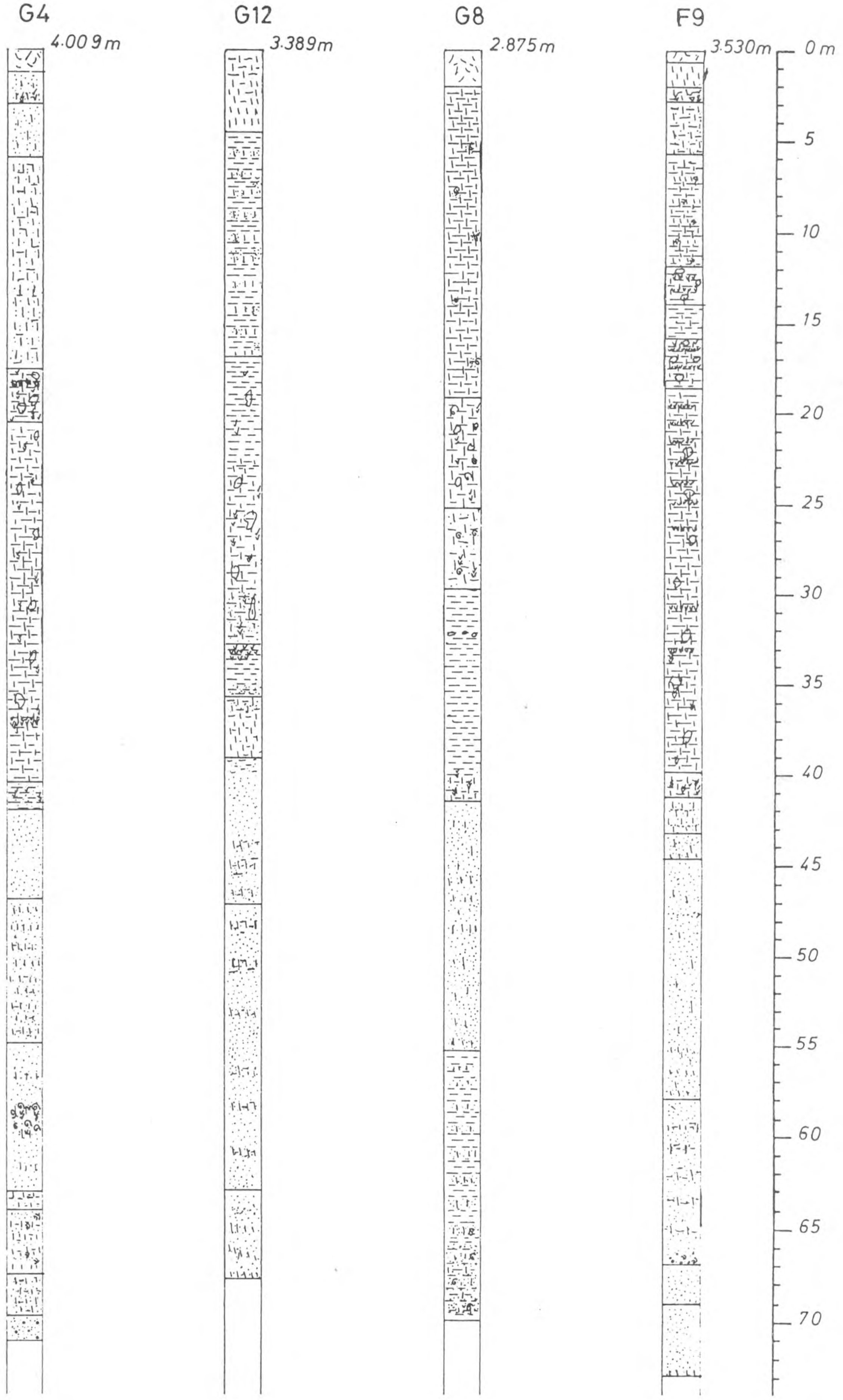
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subject: ANALYTICAL REPORT ON THE COMPOSITION AND VERTICAL DISTRIBUTION OF THE CLAY ASSEMBLAGES IN FIVE CORES(SHANGAI, CHANGZOU,K4, CBG1-1 AND 1-2)

MATERIAL

53 samples from Shangai, Changzou, cores K4, CBG 1-1 and CBG 1-2 have been provided for a detailed qualitative and quantitative analysis of the clay composition (both in the less than 2 and 16μm) by X-Ray Diffraction (XRD). The complete list of these samples is provided in annex.

METHOD OF STUDY

For the purpose of a detailed investigation of the clay composition of the samples, the latter have been prepared according to the usual procedure of the Liège's Clay Laboratory: extraction of the adequate grain-size by sedimentation and centrifugation in demineralized water, without any addition of floculation or dispersion agent. This condition allows to carry on a proper analysis of the material, at a state the more possible in situ as possible. Organic matter as well as Fe or Mn sesquioxides were not removed. The clay fraction was afterwards prepared as oriented aggregate before the preparation becoming X-rayed.

The routine XRD analysis was first carried out by referring to three classic tests: namely:the air dried state (natural or normal, N), after solvation with ethylene glycol vapors (12 hours), and after heating to 500°C/4h. On the base of the preliminary caracterization of the clay assemblages, other post-treatments have been performed as to reinforce the qualitative analysis. These post-treatments comprise: an acid attack (HCl, 4N, boiling), saturation with Li^+, followed by heating to 300°C and solvation with glecerol vapors. The acid attack is usually introduced for a proper differentiation between kaolinite and chlorite when a specific doublet (cf. the (002) reflection of kaolinite, and the (004) reflection for chlorite) is not clearly shown in the X-ray pattern. The Li^+- saturation is indicated for a further distinction between smectite sensu stricto , and swelling structure(s) which upon glycolation might exhibit particularly the typic (001) relfection expanded to 16.6è17Å.

The different clay components, including the simple clay minerals (as illite-mica), chlorite, vermiculite, kaolinite) and the mixed layers (interstratified structures)(the latter being composed of several species) have been thoroughly identified by referring to their specific behaviour upon the different identification tests (N, EG, 500, acid attack, Li^+ saturation).

Beside the purely qualitative analysis, a semi-quantification of the different clay components has been completed. In the absence of any standardization of clay minerals associated within a clay assemblage, and following the normal procedure of Liège's Clay Lab, the relative percentage of each of the identified mineral has been calculated. This was performed by referring to the intensity of the basal spacing d-(001)Å of the clay component , which was direcly measured in the diffractogrammes (or X-ray patterns) ; the intensity for each mineral was further corrected by an appropriate factor, and the different products (cf. intensity X correction factor) were adjusted to 100%. In any case the values do not represent a true, absolute %, but better a relative % within a range of 10% around the calculated values. For instance, if within a clay fraction, the contribution of illite is of 56%, the indicated value is in the range of 50 to 61%. Better % cannot become provided as many factors, among them the crystallinity of the mineral; may influence the calculation.Nevertheless as all calculations have been completed according to the same "internal" rules, what is important is the general vertical trend in the distribution of the clay composition within the five cores, and any lateral comparison of qualitative and quantitative data between the analysed cores.

For some particular clay mineral, as for illites and smectites, a "crystallinity has been estimated (see further).

The clay mineral composition of the analysed samples is perticularly complex with an assemblage comprising up to 13 different species or varieties; consequently, as to extractsome specifi trends, a internal grouping of some of the minerals has been illustrated by building up what can be called " intensity ratios" curve. The meaning and use of these curves will be commented later in connection with the qualitative and quantitative data.

Taking into account the nature of the geomechanical problem,complementary calculations wre introduced. Indeed, it has appeared of some interest to contrast stable clay minerals, clay minerals with swelling (expansion) properties, and clay minerals which do not normally swell when in contact with water, but which towards water do play a role that can be simply labelled or named " water acceptors".

Finally, a Hydrolysis Index has been calculated and its curve put in correlation with both the vertical mineralogical trend, and with the intensity ratio curves.

Tables 1 and 2 display the analytical data as quoted above, for the qualitative and quantitative contents, the values of the intensity ratios (values multiplied by a factor 100), the swelling (Sw) content (at the level of the sum of swelling clay minerals), and the "water acceptors" (H_2O acc.), and finally, the Hydrolysis Index or weathering index (WI).

NATURE OF THE CLAY MINERALS

One will here only focus on a bried description of the encountered clay minerals, without entering the details of their XRD properties.

As already mentioned above, a distinction has to be made between the simple clay minerals on the one hand , and the random mixed layers, on the other hand. Each of these "species" will be reviewed and commented, as to clear up their importance in the framework of the clay mineral analysis connected with the subsidence problem

1. Illites.

A "crystallinity" differentiation has been made between three sub-species: illite with acute peak (I_{ap}), referring to a stable structure, with all the interlayers filled with the potassium cations; illite with enlarged peak (or foot) (I_{lp}), which corresponds to a illitic structure exhibiting some minor distended interlayers (these being expressed by the development of a slight assymmetry of the basal reflection at 10Å); an open illite (I_o), with a global opening of the interlayers, a fact displayed by a well-development of the assymmetrical peak at 10Å in particular.

Thus the increase "weathering" of the illite structure is documented by a change of shape (or facies) of the basal (001) reflection centered (or with its apex) on 10Å. The weathering sequence, with subsequent opening of the interlayers is : I_{ap}--- I_{lp} --- I_o.

The 10Å peak is in reality a statistic globalization of an entire particles of illite (within the less tha 2 µm) fraction. Consequently, when indicating the occurrence of , i.e. a illite with large peak (I_{lp}), that does not mean that neither a illite with acute peak (I_{ap}) and/or an open illite (I_o) is not present, but statistically the majority of the illitic population is comprising essentially the illite with large peak.

2. (10-14_{Sm})I

This connotation refers to a small fraction of the illite population which interlayers are further distended (opened, degraded) ,and consequently are sensitive to a swelling (expansion) with the polyalcools (as Ethylene glycol) and thus with water molecules. This swelling fraction is normally mixed with the more stable illitic particles, and can only become identified when treated with ethylene glycol. It also corresponds to a certain kind of preliminary mixed layer, built up by predominant illitic layers , with minor distended interlayers behaving upon the tests (glycolation and heating) as any smectite minerals. Hence the connotation (10) for illite, 14_{Sm} , for smectite, put between parentheses, and with I outside the latter as to indicate the origin of the mixed layer (the slight degradation of the illite parent mineral).

3. (10-14_V)

This connotation refers (THOREZ, 1975, 1976), to a random mixed layer built up by illitic layers (10) and distended (opened) interlayers which behave like vermiculite (14_V) upon identification tests. Because the natural opening of the interlayers, with a partial removal of the original potassium cation, the unfilled interlayers are accepting some water molecules. (10-14_V) is thus a water acceptor as quoted above.

4. (10-14_C)

This mixed layer is built up also by illitic layers buth its interlayers (distended by weathering and later filled by Al-hydroxyl pillars) behave like a chlorite. The structure is stable upon heating , contrarily to the (10-14_V) and cannont consequently be compacted in the nature.

5. $(10\text{-}14_{Sm})14$

This connotation refers to a mixed layer formed by illitic layers and comparatively equant opened interlayers which react,upon glycolation, as a normal swelling (smectite) mineral. 10, stands for illite layers; 14_{Sm}, stands for swelling interlayers, and the 14(Å) figure outside the parenthese is indicating that the mixed layer is able to swell at half way between a stable illite (10Å) and a sensu stricto smectite (17Å).

6. Chlorite (C)

This mineral is readily identified through the different tests and may be entirely fresh (intact) or a part of the original chloritic stock may be already weathered before the sedimentation phase. In the latter case, the chloritic material may be entirely weathered into the mixed layer ($14_C\text{-}14_V$) or even vermiculite (V), or may comprise an association of C plus ($14_C\text{-}14_V$) and/or V. A slightly weathered chlorite can also be connated : C-($14_C\text{-}14_V$), as to contrast this structure with an entirely fresh (inact) chlorite (cf.C).

As for the case of illite (I),one has to considered that the "chloritic" stock is not strictly composed by intact chloritic particles, but that , on the contrary, the statistically predominant stock of particles (either of intact or moderately to strongly weathered population) will influence the final identification and mineralogical differentiation of the chloritic stock.

7. ($14_C\text{-}14_V$)

This connotation describes a former choritic structure (C) in which the interlayers (which originally were entirely filled with a hydroxide, Mg-,layer) have become distended with the partial removal of the hydroxide layer. Consequently some of these interlayers are opended and thus accessible to water molecules (cf. H_2O acceptor) and behave like vermiculite upon the identification tests.

As indicated above, between the intact chlorite (C) anb this mixed layer comososed by chloritic layers and vermiculite-behaving interlayers, there exists an intermediate form or stage represented by the structure with the connotation: C-($14_C\text{-}14_V$), in which the chlorite layer (14_C, C) are largely predominant comparatively to the distended interlayers with a vermiculite beheviour (14_V).

8. Vermiculite (V)

Usually vermiculite finds its origin and formation through the degradation (weathering) of a host, original or parent chlorite. It is also a typic water acceptor, but an unswelling clay mineral. However, as ($10\text{-}14_V$) has also been identified in the clay fraction of all the analysed samples, it is not excluded that a part of the identified vermiculite might be also made by a degradation product of the illitic stock.

9. Smectite (Sm) and Al_{17}

These two clay components have to be considered combined at the standpoint of identification. Indeed, smectite is , by definition, a clay structure able to expand (swell) when in contact with water or with polyalcohols (cf. ethylene glycol or glycerol).

Typically any smectite when treated with i.e. ethylene glycol displays its basal reflection (001) around 17Å (this very reflection being located between 12 and 14,5Å in the natural or air dried state). However this 17Å expansion does not necessarily point to the occurrence of a true smectite (montmorillonite, beidellite, etc.). On the contrary caution must be forwarded as to differentiate accurately those clay minerals corresponding to the simple clay mineral variety (such as montmorillonite or beidellite) ,from mixed layers illite -smectite (connotation: ($10\text{-}14_{Sm}$) in which the relative proportion of the expanding (interlayers) is higher than that of the stable and unswelling illitic layers. Such ($10\text{-}14_{Sm}$) mixed layers eventually show after glycolation a broad 17Å peak (or reflection) which may lead indeed with a confusion with true smectites.

When these mixed layers ($10\text{-}14_{Sm}$)17 are predominantly represented within the clay mineral assemblage, some further investigations can be carried on, for instance the real % of swelling (inter)layers. This can be achieved by referring to specific diagrammes or curves, as these mixed layers may bear a % of swelling (interlayers) not exceeding 60% even if there exists a 17Å peak after glycolation. However such calculation cannot be completed in case of a minor participation of the mixed layer in the clay assemblage, and if the latter is bearing a complex association of clay components as for the here investigated samples (up to 13 different clay components).

Beside this swelling (or expandability) calculation, there exists also an indirect way as to fix up the "crystallinity" of the swelling components. This can be obtained by combining a v/p (BISCAYe's 1964) ratio, and by fixing a shape classification of the basal 17Å peak. The v/p ratio consists in measuring the height of the "valley" aside the 17Å and to subdivide this value by the height (intensity) of the 17Å peak itself. When the swelling material is abundant but also homogeneous, the v/p ratio has positive values. When the material is badly crystallized, the value is equal to zero; and when the swelling component is badly "crystallized" , the v/p ratio has negative values. In the case under consideration, the v/p ratio is either near zero or simply negative, and this points eventually to badly crystallized mineral. On the other hand THOREZ (1976) has proposed in combination with the v/p ratio, a qualitative appraisal of the "crystallinity" by considering five classes, from A to E, with possible transitional varieties (such has i.e. CD, DE). The best " crystallized" variety is allocated the A connotation, the worst "crystallized one, the E connotation. Further, when the investigated swelling component ranges in the A to B classes,there is a chance that the material corresponds to a real simple clay (smectite) mineral, even if not necessarily swelling up to 100% (cf. occurrence of 100% swelling layers). On the contrary, if the investigated swelling material ranges from C to E, this better corresponds to mixed layers ($10\text{-}14_{Sm}$) for which , because the randomly interstratification of illitic (minor) layer and smectitic(major layers or interlayers), only a single "mimetic" 17Å develops after glycolation.

In the case under consideration, all "smectite" ranges between C -class and E-class, a fact that readily points to the occurrence of random mixed layers ($10\text{-}14_{Sm}$)17 rather than true (simple) smectite. The worst "crystallized" class, E, is largely predominant in al; the investigated samples, and there never occurs neither the A-nor the B-class: in other words, there does not exist any smectite in the samples, with characteristic of a "well-crystallized" specification. As to contrast the classification, two series has been considered,one which consists of taking into account the CD class, and one the remaining D,DE and E classes.

Beside swelling material (cf. the (10-14_{Sm})17 C to E classes), it has been also taking into account the occurrence of a complementary clay component . This component is here labelled: Al_{17}, and corresponds to a fraction of the original swelling material which, in the course of the genesis before sedimentation, has had its openend interlayers filled with Al-hydroxyl pillars or islands. This has resulted to have the material naturally swollen up to 17Å in the air dried state already, with no possibility to swell with water or ethylene glycol. This Al_{17} component thus corresponds to a fraction of the swelling material at the genetic point of view, but at the one of soil mechanic has also to be grouped with the other swelling components as being able to become a water acceptor (however with no further swelling property has the interlayers are already naturally and fully "swollen").

10.Kaolinite (K)

The mineral has been readily identified in the preparation despite the occurrence of a chloritic complex (C + (14_C-14_V) + V) with which the kaolinite does share common reflections. Indeed, the (001) and (002) reflection of the kaolinite, respectively located at 7Å and 3,5Å, can be easily confused or masked by the (002) refelction at 7Å and the (004) reflection around 3,5Å of the "chloritic" complex. However in practically all the investigated samples there exists, in the diffractogramme (or X-ray pattern), a clear double peak (or doublet) at 3,5Å (cf. 3,56Å for kaolinite and 3,53Å for chlorite). In certain samples this doublet was not clearly existing and one has to refer to an acid attack; the latter does not affect the kaolinite, which preserves its (001) reflections) whereas the chlorite is dissolved and consequently its characteristic reflections disappear in the X-ray pattern registred after the attack.

QUALITATIVE ASSEMBLAGES OF THE CLAY MINERALS

Tables 1 and 2, and Figures 1 to 5, display the qualitative distribution of the clay components identified accurately in all the samples. These illustrations refer to the less than 2 µm fractions only, as the clay composition of the less than 16 µm fraction is practically the same.

QUANTIFICATION OF THE CLAY MINERAL ASSEMBLAGES

For a proper quantification of so complex clay assemblages, with contrasting occurring minerals, both simple clay minerals and randomly interstratified ones, one has to recall tha t there does not exist any true method of quantification. This latter lacks for many reasons, among them the relative intervention of some minor minerals , the "crystallinity" states of others, etc. It is not the place here to discuss the matter.

However one needs anyway a kind of quantification as to extract any trend in the vertical distribution of the clay assemblages from core to core. One has here applied the usual method of the Liège's Clay Lab. This method consists in firstly correctly allocated the qualitative occurrence of all the clay components. Then, one selects in specific X-ray pattern the true intensity of the basal (001) reflection of the minerals. Following this composition and the measured intensity of the corresponding (001) basal reflections, an appropriate correction factor is introduced in the calculation (relative quantification). For each clay component, consequently a product is obtained by multiplying the intensity of the basal reflection by the corresponding correction factor.

For instance, here are the values of these correction factors:
- Illite : 1 / kaolinite: 0,7 / chlorite, vermiculite, c-(14_C-14_V): 0,35 / smectite / (10-14_{Sm})17 and Al_{17}: 0,25 : (10-14_V) and (10-14_C) : 0,4/ (10-14_{Sm})14 : 0,30 / (10-14_{Sm})I : 0,8.

The calculation (intensity of the (001) reflection by the corresponding correction factor) provides a relative quantification of the specific clay component in the range of 10% of the indicated value (see page 2).

OTHER PARAMETERS

The clay composition of the investigated samples appears to be relatively complex as shown by the contents of the Tables 1 and 2, or in the Figures 1 to 5. (see also Table 3 which provides the internal organization and relation of the identified components).

Because this complexity in the mineral composition as well as at the standpoint of the relative proportion of the combined minerals, it is worth to try to compare some of these outside the whole set of minerals. To achieve this restricted comparison, it has been introduced now for some years a graphic presentation of the intensity ratios. These are calculated by measuring the intensity of the basal reflections of the different minerals and by applying intensity ratios. Those which have been here selected are presented in Table 4 (upper part). They interest particularly: "smectite" + Al_{17}, illite and kaolinite. Other ratios have been also calculated but their trends do not offer high variations in the present study.

Consequently three specific intensity ratios have been choosen: 17/10, 17/7 and 10/7, and their values (multiplied by 100) are both collected in Tables 1 and 2 and the trends (vertically displayed) ,illustrated in Figures 1 to 5. The first intensity ratio : 17/10 contrasts the swelling clay components relatively to the illite mineral. The second ratio: 17/7 contrasts the same set of swelling minerals relatively to the stable (unswelling, too) kaolinite; the third and last ratio: 10/7 contrasts illite and kaolinite. The "fall-out" of introducing these ratios in any clay mineral analysis is to better allocate the fraction(s) which could bear an immediate interest in the framework of the soilmechanic properties. Further on, by grouping both the swelling fraction and the water-acceptors separately from the other clay minerals, it is worth to globalize and differentiate the stable (illite, chlorite,kaolinite) fraction from the one bearing swelling components ((10-14_{Sm}, Sm, and Al_{17}) and the one comprising all the components which are water acceptors (V, (14_C-14_V), (10-14_V). The calculation for the two latter groups is reported at the right side of Tables 1 and 2.

A last parameter has been also calculated, which refers to the Hydrolysis or

Weathering Index (WI). This parameter ,represented as a curve in Figures 1 to 5, and compared with the trends of the Intensity ratios, is indicative of the final stage of weathering reached by the clay stock before sedimentation or after this phase if some further weathering has developed (i.e. by pedogenesis).

The calculation of this WI is reported, with an example, in Table 4.If the clay composition bears only fresh,intact clay minerals, the value of the WI is of 1. With increasing weathered components, the WI increases as well and may reach values as high as 100. In other words the WI takes into account ,within a single value and representative curve, both the clay composition and the trends shown by certain grouping of clay minerals as containes,in particular, in the intensity ratios (here 17/10, 17/7, and 10/7). Indeed, as shown by the combined trends of these ratios and of the WI inFigures 1 to 5, one can directly see that the evolution of the representative curves is practically parallel.

JACKSON'S WEATHERING SEQUENCES

One can ask ownself why the investigated clay composition of the material does show so a complex association wherein both intact and slightly to highly weathered components are actually associated. In fact, the investigated material is a sediment and the latter bears in its clay composition the signature of the material weathered or not uphill on the continent, before the erosion , transport and sedimentation in the sedmentary basin where presently the sediment has become accumulated. The transport process has contributed to mix up the clay material within the sediment, the latter , as quoted above, being made by material generated from different potential sources, with different impacts of the atmospheric and/or pedogenetic weathering. As a consequence the final deposit naturally became composed of various clay minerals in particular. Generally speaking, one can trace back the genesis or better the source conditions of the accumulated and sedimented material by referring to Jackson's sequence (as presented in Table 5. The different clay components, simple clay minerals and mixed layers, can so find back their very place within the kind, stages and trends of the parent minerals which have undergone specific weathering processes. For further details, refer to THOREZ,1986.

For instance, Illite will degrade (weather) by producing open illite, then different mixed layers ($10\text{-}14_V$), $(10\text{-}14_C)$ and/or $(10\text{-}14_{Sm})$ before the end product(s) of the weathering reach(es) either vermiculite or smectite, and finally give(s) rise to the neoformation of kaolinite. In a parallel way, but with some dephasing (chlorite being more sensible to weathering than illite), chlorite weathers step by step by producing first the mixed layer $(14_C\text{-}14_V)$ and then vermiculite. Smectite can further weather and through neoformation, can develop kaolinite sensu stricto or a transitional stage represented by a mixed layer kaolinite-smectite (K-Sm). Jackson's sequence focuses on the weathering of parent clay minerals such as illite and chlorite. This weathering proceeds step by step, and in the in situ conditions, the parent minerals produces associations of still fresh,unweathered and differently weathered components. So, when the weathering is not complete and completely achieved,one can find in situ a mixture of illite (intact) with already some slightly weathered by-products such as (10-14) mixed layers and possibly the end products ,either vermiculite or smectite. When the weathering is not intense, the predominance of the clay minerals will be restricted to the still fresh states. If, at the source, the weathering has been fully developed, the by- and end-products of the weathering will be predominantly represented, whereas the intact fraction of the parent minerals will be either at the minimum of contribution or will be absent from the clay composition.

In and after sedimentation, and particularly when the accumulated material is essentially detrital, one cannot take into account any neoformation of clay minerals (i.e. kaolinite, smectite) as far as field investigation does not produce any definitive clue (i.e. the occurrence in the core(s) of paleosoils).

On the other hand as one has to face in the case under consideration with practically a whole stock of sediment, the very source of the latter can be various at the standpoint also of the weathering stage so far achived by the parent material. The erosion uphill may have reworked fresh substratum as well as pedogenetised one. Downhill,in the sedimentary basin, both products, intact and fresh material, become mixed without direct indication of the contribution of the two stocks. Therefore the neeed to try to differentiate accurately the qualitative and quantitative contribution of the two states: fresh and weathered minerals, within the process described synthetically by Jackson 's sequence. Therefore, also, the occurrence in the analysed materials, of "antagonistic" clay minerals such as fresh chlorite and illite,on the one hand, and of smectite, mixed layers and kaolinite, on the other hand. Therefore, the occurrence of a statistic population of illite for instance, which can at the same moment group fresh and slightly destructurated illite; accordingly to the relative abundance of either the fresh or of the degraded stock of illite, the latter mineral will be indentified as intact ' acute peak) illite or as slightly degraded (large peak or open variety) illite.

Further considerations can be forwarded here, but they are not taking place in the analytical framework which essentially focuses on the relationship between the clay mineral occurrence and properties on the one hand, with their geomechanical properties, on the other hand.

COMMENTS ON THE CLAY MINERALOGICAL ANALYSES

Figures 1 to 5 display the qualitative analyses of the investigated samples, grouped core by core, with indications about the vertical trends in the distribution of the associated major and minor clay components (left-hand column), contrasting trend shown by the swelling fraction and "water-acceptor" fraction (middle column), and the trends indicated by the intensity ratios 17/10, 17/7 and 10/7 and by the weathering index I.

The qualitative and quantitative trends supported by the different clay components are presented according to the depth of the sampling and not following the stratigraphy and the lithological log. Consequently these data should be "reworked" as to take into account the layering of the sediments and the thickness of the layers from which the samples have been taken of..

Illite and kaolinite are the dominant clay components in practically all the cores. Illite is, on its side, largely predominant comparatively to even kaolinite, and this is independant from the kind of variety (illite with acute or with large peak, open illite). The other clay components, in particular the mixed layers, are occurring in less amounts or are simply lacking in some samples.

At first sight,it appears rather difficult to extract a real trend within the complex clay association displayed by all the samples and consequently within the vertical distribution. Indeed, beside illite and kaolinite, the complex clay association is such that no clear cut or evolution can be traced.In the details, some mixed layer(s) may missing locally in the vertical distribution but re-appear down and up the layer. Chlorite is practically always present apart in some samples (Changzou 2,8-4,5-5m, and 38,9m; GBG 1-1 30,2m). This mineral is generally accompanied by its by-products of weathering, namely the mixed layer (14_C-14_V) and/or vermiculite (V). But these two minerals may not necessarily become associated and one of them can only occur.

Smectite, as either the corresponding simple clay mineral or better the mixed layer (10-14_{Sm})17 with the CD to E classification, does not appear as a predominant component. On the contrary, even when combined with the Al_{17} component, the swelling mineral is not very important as thought normally. In brief, with a detailed clay mineral analysis as here produced and displaying an association comprising up to 13 different species with practically the same relative proportion, it appears difficult to trace any vertical trend, as mentioned above, or to easy the comparison between the cores themselves.

However if one groups separately the swelling components (Sm + (10-14_{Sm})I + (10-14_{Sm})14 + (10-14_{Sm})17 + Al_{17}) on the one hand, and the water acceptors on the other hand (namely the vermiculite + (10-14_V) + (14_C-14_V), even by not knowing or unabling to fix what relative amounts of water precisely these components may accept), and by placing together the relative amounts of these two combinations, it appears some trends as indicated in the middle column of the Figures 1 to 5. There occurs indeed some minima and maxima in the total amount of these swelling and water acceptor layers. These trends or occurrence should be confronted with both the structure of aggregates (as to be obtained by the SEM - scanning electron microscopy) and the other mechanical properties of the sediment. Such a confrontation of data provided by the two different methods of study: the XRD analysis and the geomechanics , could further be checked by referring to the illustrated trends presented in the right side column of the figures 1 to 5, where the curves relative to the intensity ratios (17/10, 17/7 and 10/7) and to the WI are also presenting some vertical evolutions with minima and maxima. It is beyond the task of the XRD analysis to provide an explanation to these vertical trends. Now these trends may be somewhat faulse in their representation as the analytical data have been only allocated according to a depth of sampling and not in relationship with the beds or layers of sediment. As the lithological log had not been provided here, the analytical data should be re-allocate correctly on these logs by referring to all the values presented in Tables 1 and 2.

Liège, July 8, 1989

Prof. J.Thorez

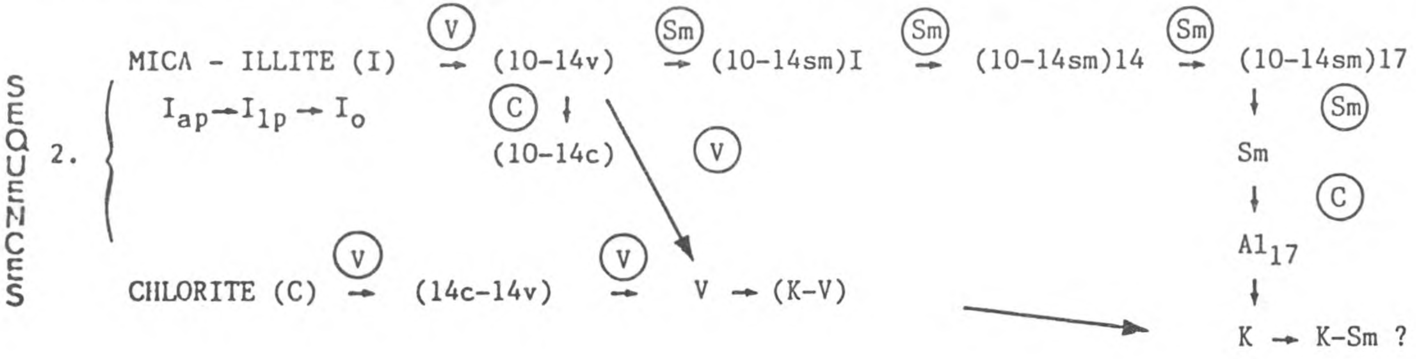
JACKSON'S WEATHERING SEQUENCE, ADAPTED TO THE CHINA'S MATERIAL (RECONSTRUCTED SEQUENCE)→

1. PARENT (CLAY) MATERIAL : (In situ weathering) mica + chlorite

(V): vermiculitization

(Sm) : smectitization

(C): chloritization



3. ⇨ EROSION, TRANSPORT, SEDIMENTATION

Sedimented stock : (still) fresh clay material : I, C

: slightly weathered clays : (10-14v) , (10-14c) (10-14sm)I , (14c-14v)

: moderately weathered clays : (10-14sm)14 , (10-14sm)17 Sm , (K-Sm) , (K-V) , V

: highly weathered clays : K , Al_{17}

4. XRD ANALYSIS

Complex clay assemblages
- if predominant clay (fresh) unweathered : rapid erosion & transport or cold climate
- if predominant weathered clay minerals : erosion & transport of pedogenetized substratum

INTENSITY RATIOS

$$I\ 17Å\ /\ I\ 10Å = 17/10 = \frac{Sm\ /\ (10\text{-}14sm)17 + Al_{17}}{I}$$

$$I\ 17Å\ /\ I\ 7Å = 17/7 = \frac{Sm\ /\ (10\text{-}14sm)17 + Al_{17}}{K}$$

$$I\ 10Å\ /\ I\ 7Å = 10/7 = I/K$$

OTHER INTENSITY RATIOS HAVE NOT BEEN ILLUSTRATED IN THIS INVESTIGATION

HYDROLYSIS (WEATHERING) INDEX

1. Detailed XRD Analysis - qualitative
   - (semi) quantitative (with correction of %)
2. Hydrolysis state for each identified clay phase
3. Multiplication of each % of a specific mineral by corresponding hydrolysis state
4. Sum up products (cf. % XRD hydrolysis states)
5. Multiplication (cf. 3) of sole parent mineral(s) : I, C
6. Dividing 3. by 5. MI

Example

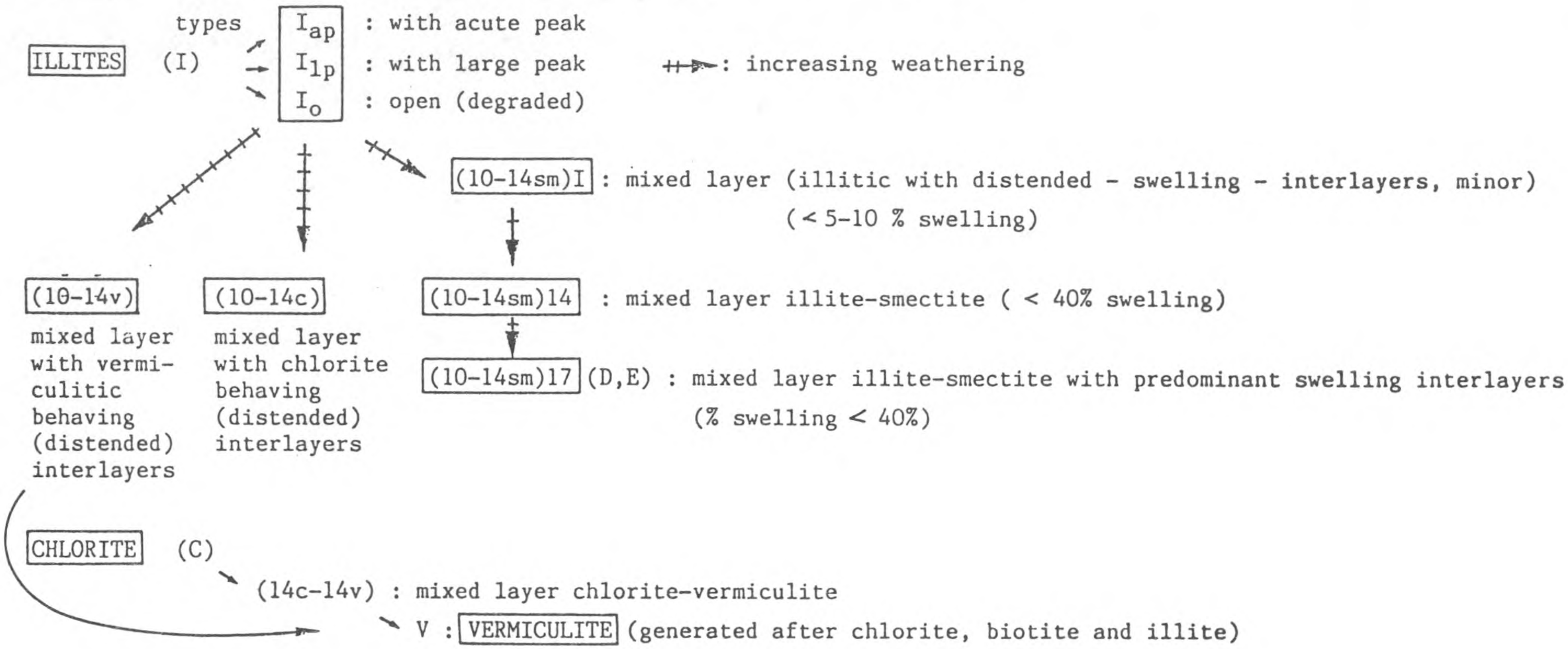
1.	I : 47,9%	(10-14sm)I : 5,3%	(10-14v) : 7,9%	C : 8,7%	(14c-14v) : 9%	(10-14sm)17 : 9,2%	K : 12,1
2. correction factor	1	1,25	2	1	2	5	7
3.	(47,9)x1 = 47,9	5,3x1,25 = 6,6	7,9x2 = 15,8	8,7x1 = 8,7	9x2 = 18	9,2x5 = 46	12,1x7 = 84,7

4. = $\boxed{227,7}$

5. 47,9 + 8,7 = $\boxed{56,6}$ If only intact (fresh) clay minerals : MI = 1

6. 227,7 / 56,6 = $\boxed{4}$ with increasing contribution of weathered minerals : MI increases

CLAY MINERALS (< 2 μm) FROM CHINA (Changzhou, Shangai, K4, CBG 1-1, CBG 1-2)



ILLITES (I) types
I_{ap} : with acute peak
I_{lp} : with large peak
I_o : open (degraded)

⟶ : increasing weathering

(10-14sm)I : mixed layer (illitic with distended - swelling - interlayers, minor) (< 5-10 % swelling)

(10-14sm)14 : mixed layer illite-smectite (< 40% swelling)

(10-14sm)17 (D,E) : mixed layer illite-smectite with predominant swelling interlayers (% swelling < 40%)

(10-14v) mixed layer with vermiculitic behaving (distended) interlayers

(10-14c) mixed layer with chlorite behaving (distended) interlayers

CHLORITE (C)
(14c-14v) : mixed layer chlorite-vermiculite
V : VERMICULITE (generated after chlorite, biotite and illite)

KAOLINITE (K) Classification
SMECTITE (Sm) (A → CD)
Al_{17} : naturally "swollen" fraction of smectite, with Al-hydroxyl interlayers

ACCESSORY MIXED LAYERS
K - V (kaolinite - vermiculite)
K - Sm (kaolinite - smectite)

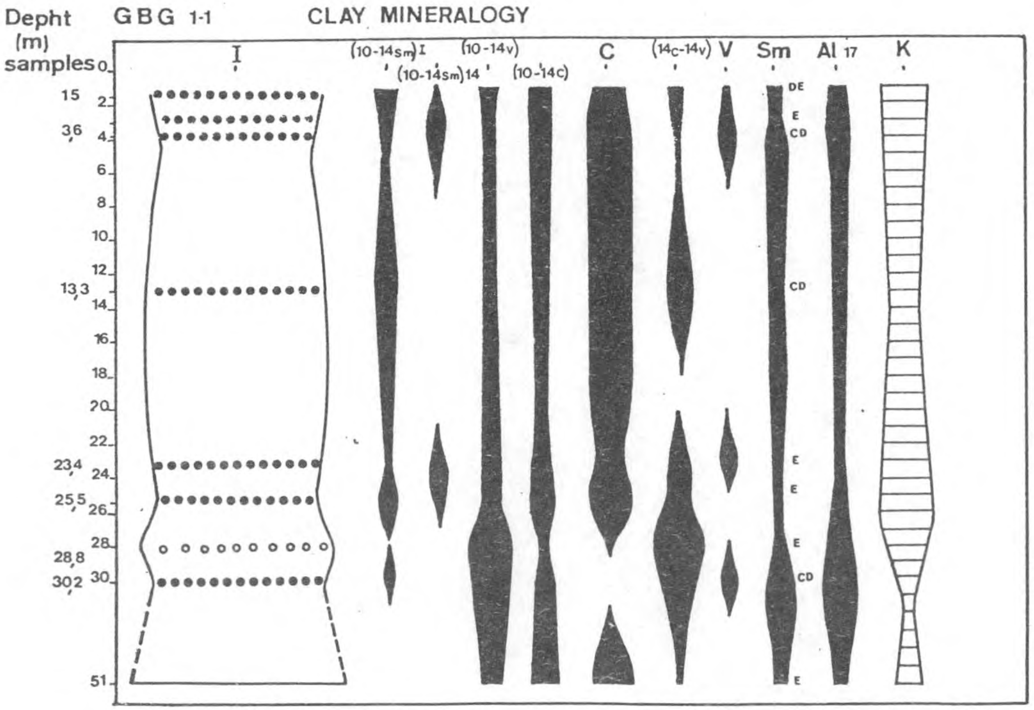
CHINE

IDENT.	N° LABO	Ipa	Ipl	Io	(10-14sm)I	(10-14v)	(10-14c)	(10-14sm)14	K-V	K-Sm	C	(14c-14v)	V	Al_{17}	Sm	K	2 ACCEPT. H_2O	3 SW	(2+3)	17/10	17/7	10/7	WI
CHANGZHOU																							
4,5 m	6642	-	-	55	11,2	-	12	-	-	-	-	-	11,6	6,4	3,8	-	11,6	15	26,6	74	287	384	3,36
32,30 m	6643	-	-	46	11,5	1,9	7	-	11,1	-	-	3,8	-	3	4,2	11,5	16,8	15,7	32,5	62	178	285	5,7
25,47 m	6644	-	49,5	-	7,4	-	7	1,9	-	-	7	7,9	-	1,7	2,8	14,8	7,9	12,1	20	34	80	232	4
38,90 m	6645	-	-	35,5	17	-	8	-	-	18,5	-	-	-	-	4	17	-	39,5	39,5	93	135	144	9,67
5,0 m	6646	-	51,3	-	7,7	-	8,3	-	11,5	-	-	3,2	-	4,5	5,8	7,7	11,5	16,7	28,2	37	205	470	4,9
2,8 m	6647	-	-	53,6	8,3	-	9,9	-	6,8	-	-	-	7,8	2	4,3	7,3	14,6	12,6	27,2	41	215	515	4,2
SHANGAI																							
1,8 m	6648	53	-	-	5,7	-	8	2,3	-	-	6,9	1,1	-	-	5	18	1,1	13	14,1	38	75	199	4
3 m	6649	46	-	-	5,4	-	4,4	4	-	-	5,1	11	-	1,7	0,9	21,5	11	10,3	21,3	31	47	150	5,3
4 m	6650	59,2	-	-	2,4	-	2,7	-	-	-	4,4	-	1,6	1,4	1,4	26,4	2,1	3,8	5,9	17	27	157	4,35
6 m	6651	61,1	-	-	-	3,3	-	-	-	-	4,4	3	-	-	3,2	25	6,3	3,2	9,5	15	26	170	4
7 m	6652	60	-	-	4,7	2,8	2,8	-	-	-	7	2,3	-	1,9	3,5	15	5,1	8,2	13,3	31	89	284	3,3
8 m	6653	-	45,8	-	10,2	-	6,6	6,2	-	-	7	-	-	2,2	2,2	19,8	-	18,6	18,6	40	69	174	5,1
12 m	6654	-	54,9	-	6,3	6,5	2,5	4,7	-	-	6,8	2,7	-	2,3	2,3	11	9,2	13,3	22,5	34	57	168	3,5
24 m	6655	-	58	-	-	-	8	2,2	-	-	7,3	-	4,4	2,2	3,7	14,2	4,4	5,9	10,3	41	67	162	3,6
32 m	6656	72,4	-	-	-	-	-	5,4	-	-	6,3	4	-	1,8	2	8,1	4	7,4	11,4	19	120	640	2,4
37 m	6657	62,8	-	-	2,8	1,4	4,9	4,2	-	-	7	1,2	-	2,6	0,9	12,2	2,6	7,9	10,5	22	37	166	3
46 m	6658	63	-	-	2	4,8	-	-	-	-	5,2	4	-	2	5	14	8,8	7	15,8	19	31	163	3,2
58 m	6659	-	57,5	-	6,2	-	6	3,7	-	-	5,9	-	1,5	1,9	3,1	14	7,6	13	20,6	21	33	154	3,6
68 m	6660	61	-	-	5,6	-	4,9	2	-	-	5,9	0,7	-	0,9	5,5	13,5	0,7	13,1	13,8	18	27	145	3,28
150 m	6661	-	45,4	-	19,5	1,7	6	6,3	-	-	3,2	1,5	-	1,9	4,2	10,3	3,2	30	33,2	51	157	307	4,6

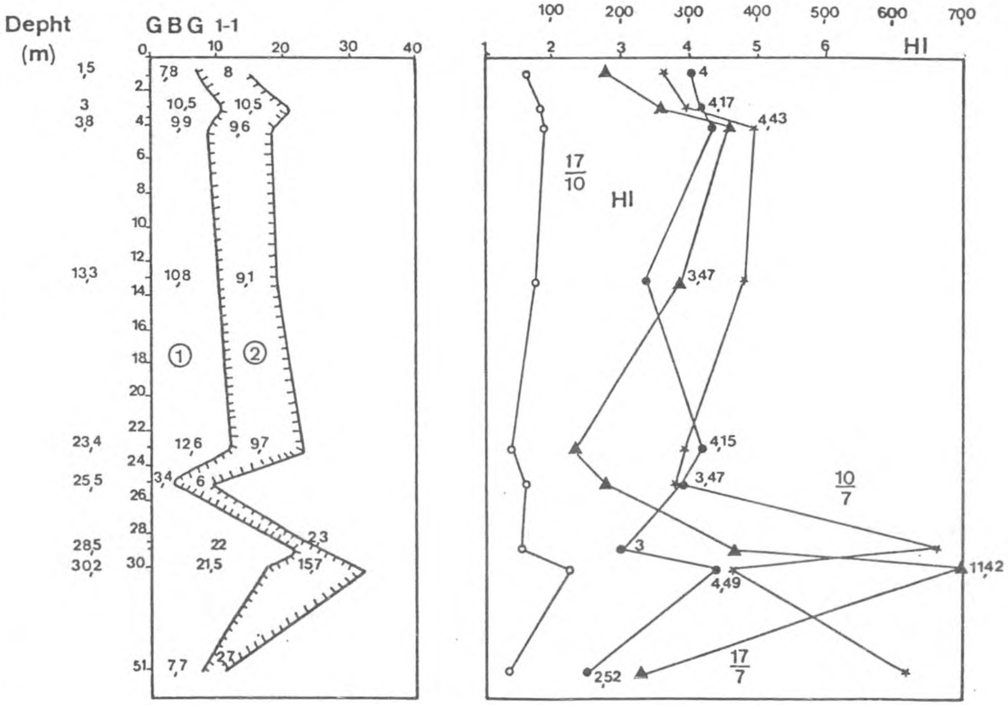
1) I + (10-14c) + C + Al_{17} + K
2) (10-14v) + V + (14c-14v) + (K-V) = ACCEPTEURS D'EAU (ADSORDEURS)
3) (10-14sm)I + (10-14sm)14 + (10-14sm)17 / Sm + (K-Sm) = ACCEPTEURS D'EAU ET GONFLANTS (ADSORDEURS)
17/10 = Al_{17} + Sm/I
17/7 = Al_{17} + Sm/K
10/7 = I/K

CHINE (SHANGAI) 2e SERIE

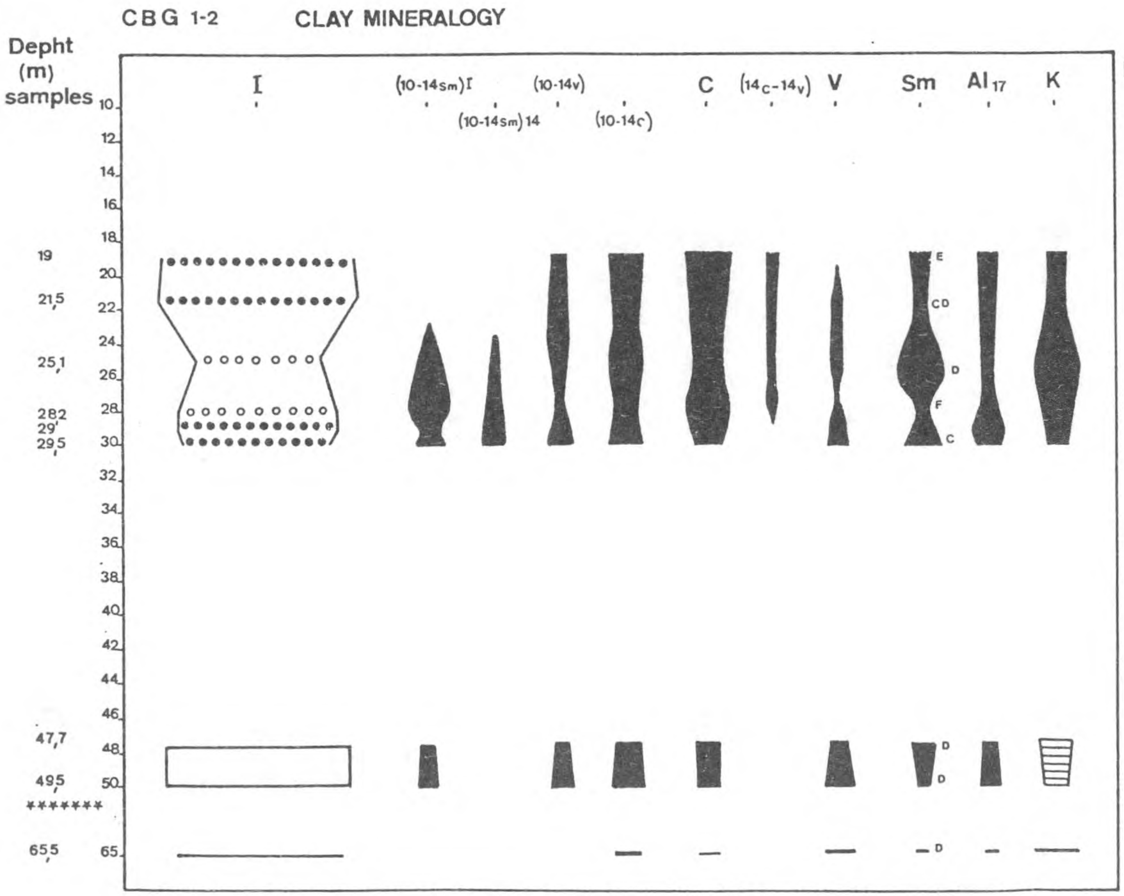
IDENT.	N° LABO	Ipa	Ipl	Io	(10-14sm)I	(10-14v)	(10-14c)	(10-14sm)14	C	C-(14c-14v)	(14c-14v)	V	Al_{17}	Sm	(10-14sm)17	K	17/10	17/7	10/7	Sw	H_{20}AC	WI
- K4 3,5 m	7672	-	-	48,4	3,1	9,4	-	-	7,8	-	7,8	2	5,8	-	E 7,1	8,6	105	406	387	10,2	19,2	3,96
14,5 m	7673	-	47,9	-	5,3	7,9	-	-	8,7	-	9	-	-	-	E 9,2	12,1	77	212	276	14,5	16,9	4
18,5 m	7674	-	51	-	3,9	9,7	-	-	8,2	-	6,8	-	2,9	-	E 4,4	13,1	57	158	276	8,3	16,5	3,85
30,5 m	7676	-	50	-	-	3,8	6,1	5,7	7,7	-	6,1	-	3,2	-	E 5,4	12	65	182	282	11,1	9,9	4,20
39,5 m	7678	-	49	-	6,8	4	6,1	3,4	7,5	-	1,5	4,8	4	-	E 3,4	9,5	60	215	360	13,6	10,3	3,95
42 m	7679	-	54,2	-	3,9	1,3	7,8	1,3	10,4	-	-	-	2,6	-	E 4,1	14,4	48	125	260	9,3	1,3	3,55
47 m	7680	-	40,2	-	8,5	3,4	7,7	3,4	10,2	-	4,3	-	8,5	-	DE 3,6	10,2	121	335	276	15,5	7,7	4,87
47,2 m	7681	-	50,3	-	7,3	2,6	10,6	3,3	-	6,6	3,3	3,3	4	-	E 3,3	5,3	59	375	633	13,9	9,2	3,35
48,9 m	7682	-	49	-	4,7	1,9	8,5	-	-	7,5	0,9	6,6	4,7	-	E 4,7	11,3	77	235	305	9,4	9,4	4,16
49,7 m	7683	-	47,7	-	3	2	6,7	5,1	9,2	-	1,5	3	4,1	-	E 3,4	14,3	59	137	232	11,5	6,5	4,43
62,3 m	7684	54,8	-	-	5,5	6,8	-	-	6,8	-	4,8	2	3,4	-	D 4,3	11,6	53	179	333	9,8	13,6	3,58
66 m	7685	50	-	-	-	7	4,4	-	8,8	-	4,4	-	6,1	-	DE 5,3	14	91	230	252	5,3	11,4	4,27
- CBG 1-1																						
1,5 m	7687	-	49	-	5,2	3,9	6,5	-	9,8	-	2,6	1,3	5,9	-	DE 2,8	13	67	178	268	8	7,8	4,0
3 m	7688	-	47,5	-	2,8	2,8	7	4,2	10,5	-	3,5	Tr	7	-	E 3,5	11,2	88	260	296	10,5	10,5	4,17
3,8 m	7689	-	46,8	-	1,1	3,4	5,7	3,4	10,3	-	1,1	5,1	5,7	CD 5,4	-	12	91	357	390	9,9	9,6	4,43
13,3 M	7690	-	51,8	-	4,2	4,8	3,6	-	10,3	-	6	-	4,2	CD 5,5	-	9,6	75	282	374	9,7	10,8	3,47
23,4 m	7691	-	49,6	-	1,5	6	7,4	5,2	7,4	-	-	5,2	3	-	E 3	11,7	44	130	291	9,7	12,6	4,15
25,15 m	7692	-	47	-	3,4	3,4	8,5	-	12	6	-	-	5,1	-	E 2,6	12	63	175	275	6	3,4	3,84
28,9 m	7693	-	-	56,2	-	11	-	-	-	7,8	11	-	5,5	-	E 2,3	6,2	55	363	654	2,3	22	3,0
30,2 m	7694	-	50	-	3	9,2	6,1	-	-	-	7,7	4,6	7,7	CD 7,7	-	3,8	123	1142	357	10,7	21,5	4,49
51,3 m	7695	62,6	-	-	-	6	7	-	10	-	1,7	-	3	-	E 2,7	7	36	225	615	2,7	7,7	2,52
- CBG 1-2																						
19 m	7696	-	56	-	-	4,5	9,7	-	12,7	-	3	-	5,2	-	E 5,2	5,2	67	500	750	5,2	7,5	2,85
21,5 m	7697	-	57,3	-	-	4,6	8	-	10,9	-	2	2,9	4,3	CD 4,3	-	5,7	60	400	667	4,3	9,5	2,83
25,1 m	7698	-	-	35,9	6,3	4,5	9,1	1,4	8	-	1,1	5,1	2,8	D 14,4	-	11,4	111	250	225	22,1	10,7	6,16
28,2 m	7699	-	-	47,4	10,8	-	8,8	4	11,5	-	2	-	4	-	E 2	9,5	43	150	350	16,8	2	3,57
29-29,5 m	7700	-	-	48,3	-	5	9,3	5,6	8,7	-	-	3	7,7	-	E 4,1	8,7	96	375	390	9,7	8	4,13
29,2-29,5 m	7701	-	-	43,3	3,4	6,3	9,5	-	-	-	10,5	4,7	6,6	C 9,4	-	6,3	146	705	482	12,8	21,5	5,65
47,7 m	7702	55,2	-	-	2,9	3,6	6,7	-	6,4	-	-	5,8	3,3	D 6,7	-	9,4	48	200	413	9,6	9,4	3,59
49,3 m	7703	55,5	-	-	3,4	3,4	8,5	-	7,3	-	-	7,3	4,3	D 2,2	-	8,1	46	220	480	5,6	10,7	3,28
65,5 m	7704	51,4	-	-	-	3,6	8,2	-	6,8	-	-	9	4	D 4,3	-	12,7	62	175	280	4,3	12,6	4,17

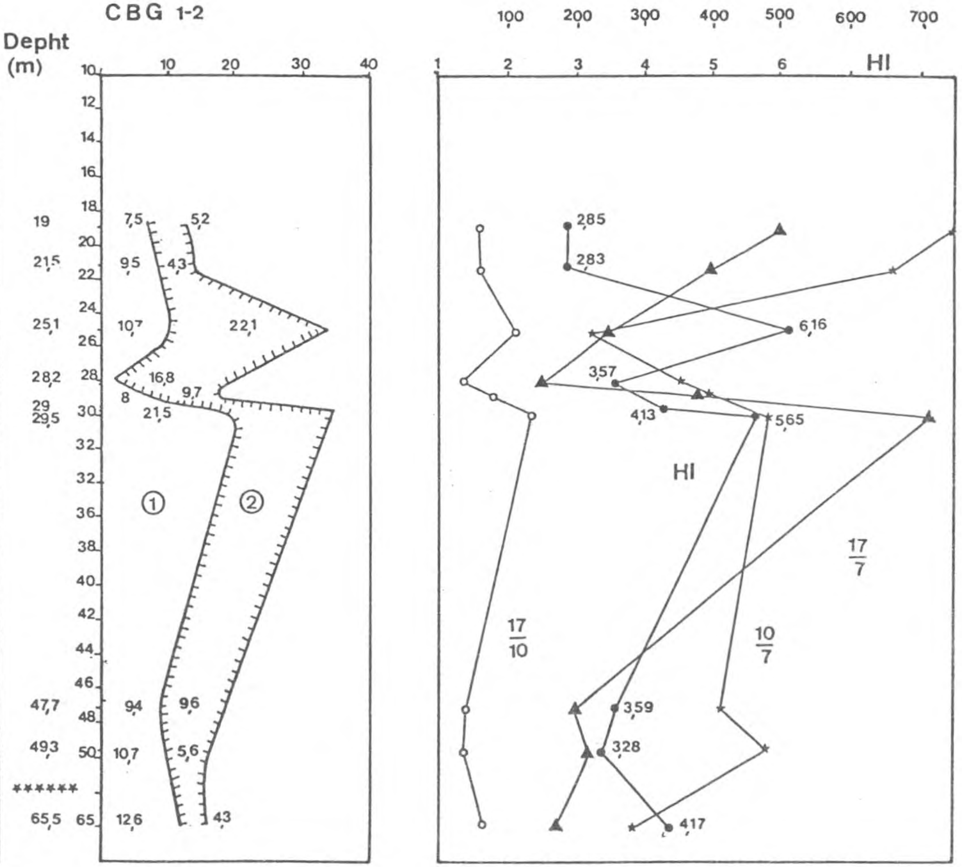


Depht (m) samples
GBG 1-1
CLAY MINERALOGY
I
(10-14Sm) I
(10-14Sm) 14
(10-14v)
(10-14c)
C
(14c-14v)
V
Sm
Al 17
K
DE
E
CD
CD
E
E
E
CD
E
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
51
15
3,6
13,3
23,4
25,5
28,8
30,2

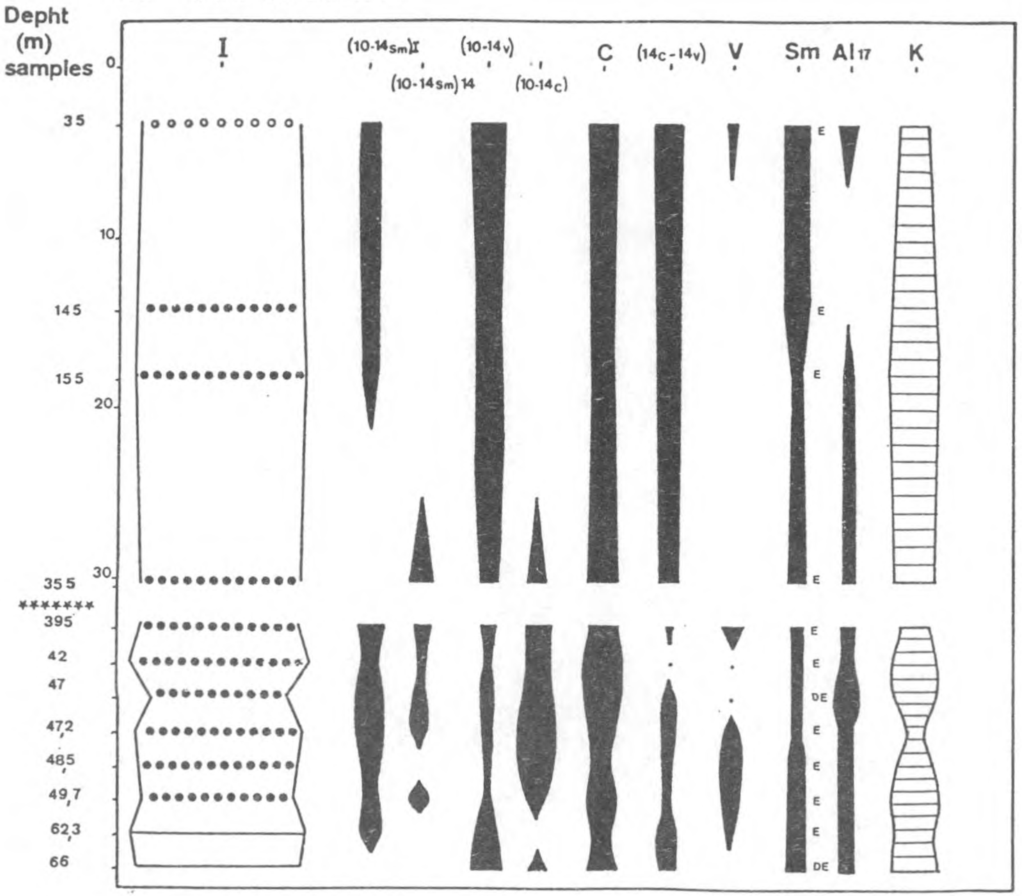


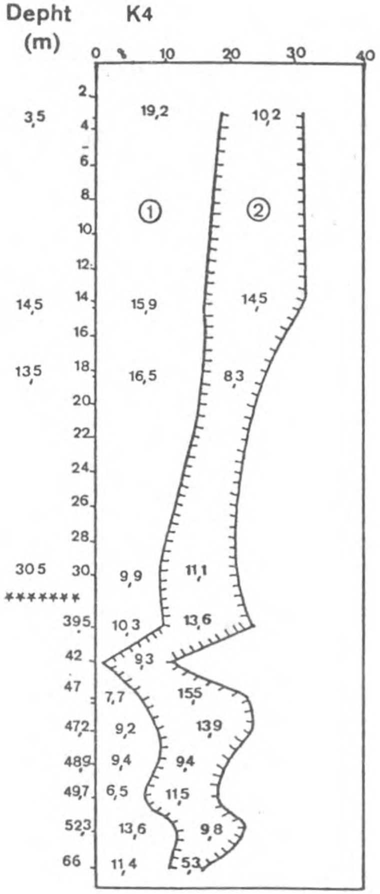
Depht (m)
GBG 1-1
0
10
20
30
40
1,5
3
3,8
13,3
23,4
25,5
28,5
30,2
7,8
8
10,5
10,5
9,9
9,6
10,8
9,1
①
②
12,6
9,7
3,4
6
22
2,3
21,5
15,7
2,7
7,7
100
200
300
400
500
600
700
1
2
3
4
5
6
HI
17/10
HI
4
4,17
4,43
3,47
4,15
3,47
10/7
3
1142
4,49
2,52
17/7

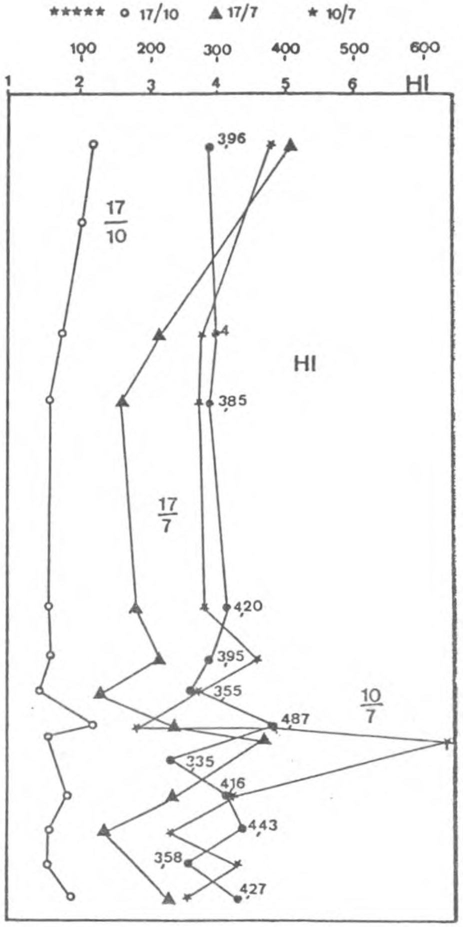

CBG 1-2
CLAY MINERALOGY
Depht (m) samples
I
(10-14sm)I
(10-14sm)14
(10-14v)
(10-14c)
C
(14c-14v)
V
Sm
Al17
K
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
65
19
21,5
25,1
28,2
29
29,5
47,7
49,5
65,5
E
CD
D
F
C
D
D
D
****

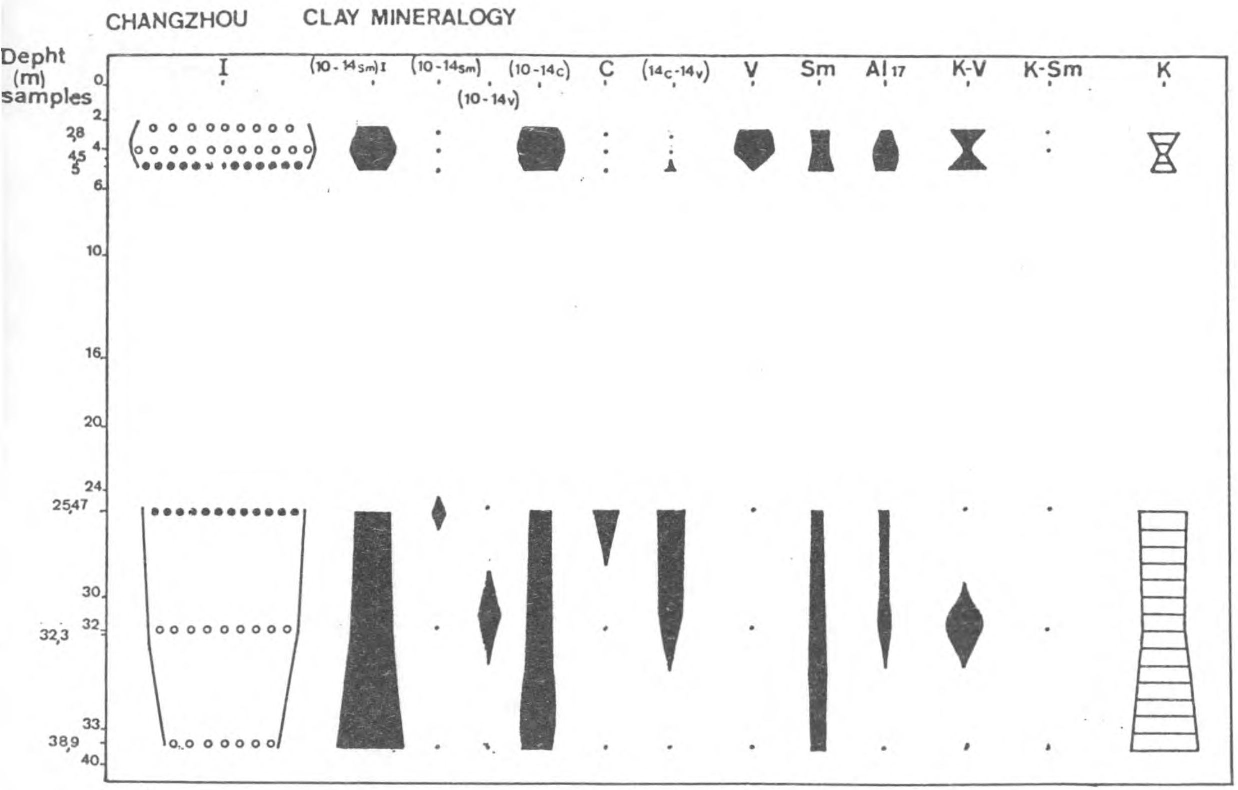

CBG 1-2
Depht (m)
10
20
30
40
100
200
300
400
500
600
700
1
2
3
4
5
6
HI
19
21,5
25,1
28,2
29
29,5
47,7
49,3
65,5
7,5
5,2
9,5
4,3
10,7
22,1
16,8
9,7
8
21,5
9,4
9,6
10,7
5,6
12,6
4,3
①
②
285
283
6,16
3,57
4,13
5,65
3,59
328
417
HI
17/10
10/7
17/7
******

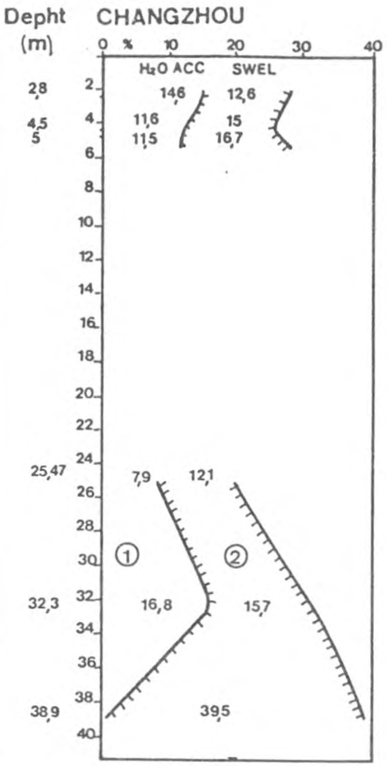
K4 CLAY MINERALOGY

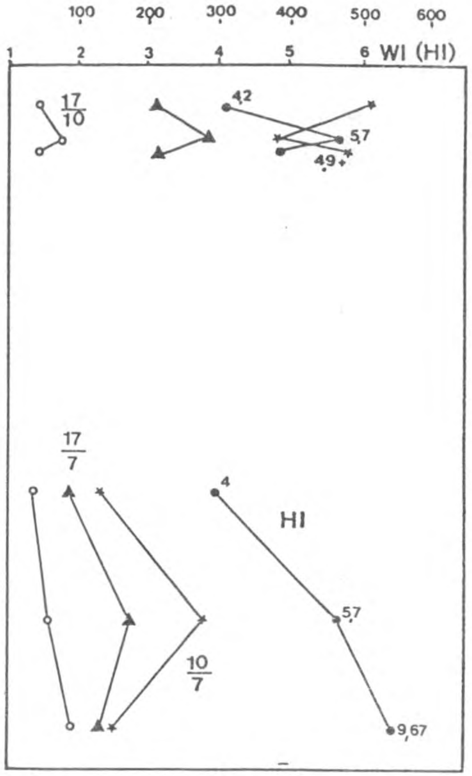


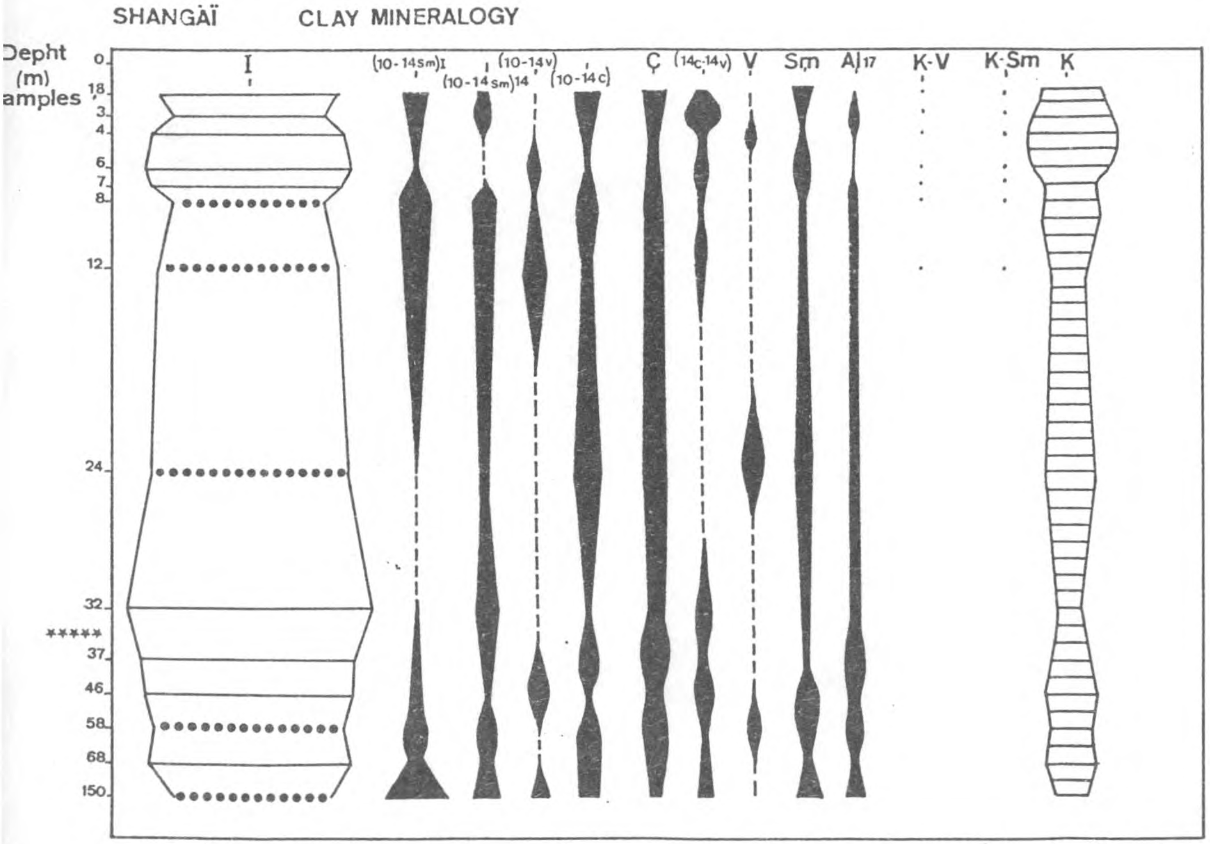




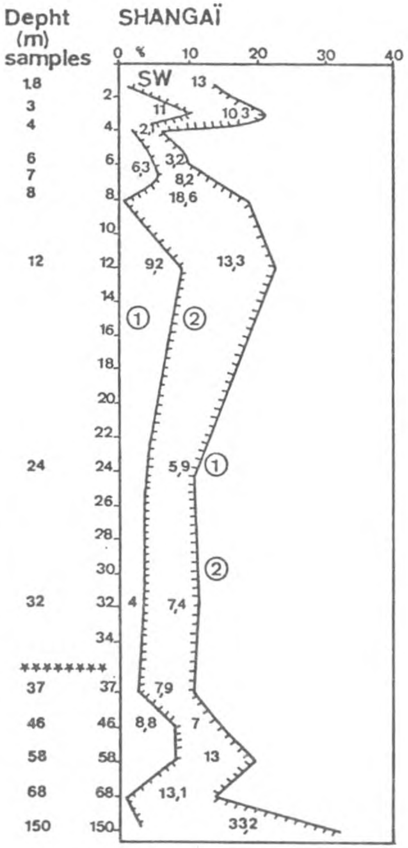

CHANGZHOU
CLAY MINERALOGY
Depht (m) samples
0
2
2,8
4
4,5
5
6
10
16
20
24
25,47
30
32
32,3
33
38,9
40
I
(10-14Sm)I
(10-14Sm)
(10-14v)
(10-14c)
C
(14c-14v)
V
Sm
Al17
K-V
K-Sm
K


Depht (m)
CHANGZHOU
0 % 10 20 30 40
H₂O ACC
SWEL
2,8
4,5
5
25,47
32,3
38,9
14,6
12,6
11,6
15
11,5
16,7
7,9
12,1
16,8
15,7
39,5
①
②

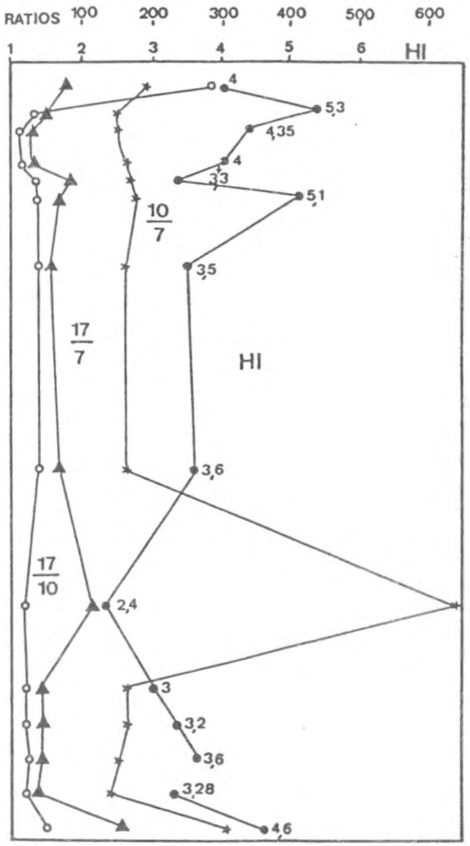

100 200 300 400 500 600
1 2 3 4 5 6 WI (HI)
17/10
4,2
5,7
4,9
17/7
4
HI
5,7
10/7
9,67



SHANGAÏ
CLAY MINERALOGY
Depht
(m)
amples
I
(10-14Sm)I
(10-14Sm)14
(10-14v)
(10-14c)
Ç
(14c-14v)
V
Sm
Al17
K-V
K-Sm
K
0
18
3
4
6
7
8
12
24
32
*****
37
46
58
68
150



Depht
(m)
samples
SHANGAÏ
0 %
10
20
30
40
SW
1.8
3
4
6
7
8
12
24
32
****
37
46
58
68
150
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
37
46
58
68
150
13
11
10,3
2,1
3,2
6,3
8,2
18,6
9,2
13,3
①
②
5,9
①
②
4
7,4
7,9
8,8
7
13
13,1
33,2



RATIOS
100
200
300
400
500
600
1
2
3
4
5
6
HI
4
5,3
4,35
4
3,3
5,1
10/7
3,5
17/7
HI
3,6
17/10
2,4
3
3,2
3,6
3,28
4,6