Geologic interpretation of artificial strata in urbanized areas

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Abstract

It is most important that the geological significance of artificial strata and the stratigraphic relation between artificial and natural strata are clarified and the characteristics common to artificial strata are extracted and sorted out. These are the basic data for considering their effects on environment and natural disasters.

The northern part of the Boso Peninsula is selected as the study area in order to clarify the above problems. Stratigraphic analyses of artificial strata in the study area were carried out on the basis of geologic profiles prepared from drill logs. In addition, outcrops of artificial strata by trenching were observed and sketched in detail. Based on the results of these studies, sedimentary conditions of artificial strata were compared with those of natural strata.

The following are the main results of this study.

• The concept of unconformity should not to be applied to the discontinuity between artificial strata and natural strata. However superposing relations of the both strata have significant meaning in geo-environmental problems.

• The concepts in stratigraphy can be applied to hydraulic fills. The sedimentary conditions affect the occurrences of land subsidence and liquefaction and fluidization during earthquakes.

• The concepts in stratigraphy cannot be applied to filled strata, waste strata and surplus soil strata, because their formation processes are strongly affected by human activities.

• The artificial strata are products of human activities in the Quaternary Period, also called Anthropogene. The idea that the strata are similar to bioturbation (Kumai, 1991) is most reasonable.

Key-words: artificial strata, hydraulic fill, fills in valley plain, waste deposit, surplus soil deposit.

Introduction

The study area, the northern part of Boso Peninsula, is located in the southern Kanto plain. It is composed of coastal plains facing Tokyo Bay and the Pacific Ocean, of alluvial plains along the Tone River and other rivers, and of a tableland, 20 to 50 m in altitude. The valley plains dissect the tableland in dendritic pattern (Fig.1).

In the early 1950's, the Tokyo Bay area consisted of wide tidal flats along the seashore and extending into offshore zones, rice fields in the plains, and fields and copse woods on tablelands. Towns were distributed along railroads and main roads. But drastic changes of environment occurred since the high growth period of the Japanese economy in the 1960's. Land development and changes were made in both coastal and inland zones because by that time the area was an integral part of the Tokyo Metropolis, both geographically and socio-economically.

The rapid urbanization of the area resulted in the reclaimed lands on the nearshore zones of Tokyo Bay. The zones to the south of Chiba City have been developed as industrial complexes and the zones to the north have been developed mainly as residential areas and areas for public institutions.

The method of filling work is as follows. Sand and mud dredged from the seafloor are pumped up with sea water; they then flow through pipes and are
spewed from the vents into the projected area, which is surrounded by a barrier. The spewed materials with coarse grains or high specific gravities are deposited near the vent, while the fine-grained materials, like clay and sludge, are transported far away with the spewed water and deposited there. The vents are removed on occasion. Thus, the sedimentary facies formed by this method vary with the locations, and the facies differences are closely connected with the geologic hazards in hydraulic fill, such as a land-subsidence and liquefaction by earthquakes.

In inland areas, land improvement was mostly carried out in boundary zones between the plains and the tablelands. The valley plains were filled with materials leveled from hilly zones, which turned the zones into man-made lands with gentle slopes. These land developments reflect the various social needs such as meeting the increasing population of the urban areas and promoting industry in the rural area.

The uppermost zones of the valley plains are not only used as residential sites but also as landfill sites and depository sites for surplus soil. As the northern part of Boso Peninsula is near Tokyo, a large quantity of waste from houses and industries, e.g., raw refuse, sludge, plastic and scraps, and surplus soil from construction, are produced in and around the area and transported into the zone.

Man-made lands are generally characterized by such factors as topographic condition of lands, constituents of artificial strata and methods of filling. In addition, the geo-environmental problems in man-made lands are closely connected with these factors. Therefore, man-made lands in Tokyo Bay area and Boso Peninsula were classified by these factors, as shown in Table 1. In the study area, reclaimed lands in the bay area and along the Tone River belong to Ra and Rx types, respectively. Fills in valley plains are divided into Fs and Fw types.

In this study, the characteristics of the artificial strata were clarified stratigraphically and facies-wise. These results were compared with those of the natural strata. In addition, we examine whether or not the
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Geologic studies on artificial strata in the past

Most of the studies on man-made lands have been carried out from civil engineers' viewpoints, such as construction methods, land uses and disaster prevention (Japan Society of Civil Engineers, 1964). A large part of the geologic studies on these lands were carried out in connection with land subsidence. Geo-environmental studies began in earnest in the 1980's, when economic growth and development slowed down. In accordance with changes in social situations, it became
necessary to clarify geologically the characteristics of artificial strata. Moreover, the importance of such studies was increasingly recognized by various hazards, such as the 1987 earthquake of eastern offshore Chiba. It was noted that in spite of the relatively weak intensity of the earthquake at M 6.7, damages were concentrated in the man-made lands. In order to understand and cope with these occurrences, a symposium was convened in 1991 (Geological Society of Japan, 1991) with the specific purpose of discussing the relation between the natural and artificial strata. Namely, should we treat the weaker and more fragile artificial strata as "geologic beds"; and should we also treat the temporal, stratigraphic and physical contrast with the natural strata as "unconformities" or not. This was the first attempt to consider artificial strata from an integrated geologic viewpoint. Nirei et al., (1994) believed that the concepts of "law of superposition" and "stratigraphic units" should be applied to the artificial sediments. However, their stratigraphic interpretation has not been established yet, because of their very complicated structures and properties.

The following are the papers regarding the stratigraphic interpretation of artificial strata.

Characteristics of hydraulic fills in the Tokyo Port area were classified in comparison with those of natural sediments (Shimizu, 1983). Changes of sedimentary facies by liquefaction and fluidization during the 1987 earthquake of eastern offshore Chiba were investigated by trenching methods (Chiba Prefectural Government, 1989).

There are geologic disasters in fills which have been reported to be caused by the sequence of the artificial strata, which is reverse to that of the natural strata in the vicinity. The construction method is to fill valley plains with geologic materials cut from surrounding tablelands and hills. This structure was termed 'upside-down fills' (Cleaves, 1961; Institute of Geology and Paleontology, Tohoku University, 1979). One of the large ground failures due to the 1978 Miyagiken-oki Earthquake occurred in the upside-down fills forming terraced surfaces (Nakagawa, 1986). Hatori (1986) pointed out about the geologic conditions bringing forth such disasters. Thus, fills have been studied mainly regarding the relationship between the hazards and stratigraphy.

Waste deposits have seldom been treated as strata. In spite of such circumstances, Shimizu(1983) classified them stratigraphically. Nirei et al., (1996) investigated the stratigraphic units of these waste deposits, focusing on minerals newly remade in the wastes.

Purpose and method of this study

(1) Purpose

Lands created artificially are generally called "man-made lands". The strata forming them will be called "artificial strata" in this paper. In connection with this, the term "natural strata" is used for normal sediments.

Because of the process of deposition, the facies of artificial strata are inferred to change both laterally and vertically. Sandy parts are mixed with silty to clayey parts in the hydraulic fills of the Tokyo Bay area because of filling with sand and mud dredged from the bottom of sea. The facies of strata filling valley plains varies conspicuously and the order of layers are reversed in many places because sand and silt cut out of tableland around the valley are used for the fill. In other words, the artificial strata, consisting of Pleistocene sediments, often overlie Holocene alluvial sediments in the central zones of valley plains. Moreover, the origin of filled materials becomes older in ascending order. Waste deposits and surplus soil deposits are composed of various kinds of materials and they sometimes reflect the trend and the life style of the age.

The characteristics of artificial strata induce various geo-environmental problems in man-made lands, namely, subsidence by the compaction of deposits, liquefaction and fluidization phenomena at times of large earthquakes in the hydraulic fills and the fills overlying valleys, and the geo-pollution around waste and surplus soil deposits, and so on.

Thus, it is most important that the geological significance of artificial strata and the stratigraphical relation between artificial and natural strata are clarified and the characteristics common to artificial strata are extracted and sorted out. These are the basic data for considering their effects on environment and natural disasters. The above is the approach adopted for this study.

(2) Method

It is almost impossible to observe outcrops of artificial strata because the surface is flat. Observing drill cores is the best method to clarify the facies and the stratigraphy.

Many sites on reclaimed lands have been drilled in order to use lands appropriately and to prevent geologic disasters caused by soft sediments. Stratigraphic analyses of artificial strata were carried out on the basis of several geologic profiles prepared from drill
logs, in order to clarify the subsurface conditions of artificial strata. Same analyses were carried out in land-filled valley plains and depository sites for surplus soil with wastes, where drill data exist.

Liquefaction and fluidization phenomena occurred during the 1987 earthquake of eastern offshore Chiba in many localities of Boso Peninsula. Outcrops of artificial strata by trenching were observed and sketched in detail at several localities. Based on the results of these studies, sedimentary conditions of artificial strata were compared with those of natural strata. Accumulating processes and facies of artificial strata were also analyzed. Similar investigation and analyses were carried out in the depository sites for surplus soil, including wastes, and the landfill sites which generated polluting gas.

**Geologic setting of northern Boso Peninsula**

The subsurface geology of the northern Boso Peninsula is composed of the Shimosa Group, Holocene alluvial sediments, and artificial strata, in ascending order. The pre-Tertiary units are exposed in the eastern part of the Peninsula (Fig. 1). The lower member of the Pleistocene Shimosa Group consists of so-called “soft rock”, sandstone and siltstone, and the upper member is composed of gravel, sand, silt and their alternating beds. These underlie loam and they form tablelands and hills. Holocene alluvial sediments cover the Shimosa Group in the lowland areas. Holocene alluvial sediments are distributed not only in the Tokyo Bay area, the Kujukuri Plain and the Tone River areas, but also in many valley plains. They range in thickness from 10 m to 50 m, because surfaces of the Shimosa Group were eroded everywhere during the Würm glacial stage and then overlain by Holocene alluvial sediments. They are composed mainly of sand, silt and clay, with intercalations of peat.

In the Boso Peninsula, man-made lands are almost all distributed in the Tokyo Bay area and in the boundary areas between plains and tablelands. The lands in the Tokyo Bay areas are tidal flats filled with sand and mud dredged from offshore zones. The filled strata are mainly composed of fine sand to silt, 5 m to 10 m in thickness, and the lateral continuity is poor. Strata-filled channels are comparatively thick. Filled lands in inland areas are divided into two types. One type is the filling on rice fields with sand and silt which were transported from tablelands; the thickness of the fills is a few meters and their ground surface is almost flat. The other type is the filling of the uppermost portions of valley plains with soft sediments or soft rocks cut from the adjacent tablelands; the thickness exceeds 20 m in some locations.

In addition, wastes and surplus soils have been often used as filling materials in valley plains. Their thickness is also over 20 m, depending on locations. Some reclaimed lands are filled crescent lakes along the Tone River area.

**Observation of facies and stratigraphic analyses of artificial strata**

1. **Stratigraphy of hydraulic fills in bay areas**

Figure 2 shows some subsurface geologic profiles of hydraulic fills in the Tokyo Bay area. Two of these cross sections are parallel to an old shoreline and four intersect it. In the former sections, old seafloors are flat in the central parts of the reclaimed lands and high reliefs are recognized near the new shoreline. In the latter sections, the depth of the old seafloor increases offshore from the central parts of the reclaimed lands, which is located about 500 m inland from the new shoreline. Hydraulic fills overlie the old seafloors.

Hydraulic fills are examined in X-X’ and Y-Y’ sections parallel to the old shoreline. Lateral changes of the subsurface strata of the X-X’ section near the new shoreline are conspicuous and are largely composed of zones predominated by fine sand and of silt. Moreover, their facies are discontinuous laterally and relations between both zones are partly contemporaneous, heterotopic facies. The subsurface geology of the Y-Y’ section crossing the central part of reclaimed lands is composed mainly of fine sand, and contains intercalated silt beds in the lower and middle zones.

In the sections intersecting the old shoreline, A-A’, B-B’, C-C’ and D-D’, changes in the artificial strata of filled zones over seafloor deepening offshore are different from those of fills in the inner zones. In the former, silt of several meters thickness lies at the bottom of the fills and fine sand covers them. In detail, in the sections of western parts of the reclaimed land, A-A’ and B-B’, the upper planes of these silt layers deepen offshore in harmony with the relief of the old seafloor. In section C-C’, the main component is silt with an intercalation of about 4 m thick fine sand. The artificial strata on old flat seafloors on the inland side, in sections A-A’ and B-B’ can be divided into two types. One consists of fine sand from the bottom to the surface of fills, and the other consists of fine sand with intercalations of silt or of sand and silt.
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Section D-D' exists on the inner side of the above sections. Fine sand and clay, and fine and medium sand are accumulated in contemporaneous heterotopic facies. Their facies varies laterally in a very complex manner.

Thus, some parts of hydraulic filled strata are discontinuous laterally and they are characterized by contemporaneous heterotopic facies among sand, silt and clay layers.

(2) Facies of hydraulic fills

In order to elucidate the sedimentary facies of hydraulic fills, outcrops must be observed in detail. However, outcrops hardly exist on reclaimed lands. Therefore, trenched sections were examined in order to acquire knowledge of the sedimentary facies of fills. This trenching was carried out for the study of sand volcanoes during the 1987 earthquake of eastern offshore Chiba.

One of the trenches is at a reclaimed crescent lake and is filled with sand and mud dredged from bottom of the Tone River. The hydraulic filling method is similar to the one used in the tidal flats. The vicinity was used for rice fields at the time of this investigation. As groundwater tables existed in the shallow zones, the groundwater tables were lowered by pumping wells during the trenching. In order to clarify the structure in detail, not only sketching outcrops but also relief-peel, a method developed by archaeologists, was used.

The subsurface geologic profile of the sand volcanoes prepared from data acquired by trenching is shown in Figure 3. The Bottom of the old river lies at about 3 m depth. Therefore, every stratum in this section is composed of hydraulic fills. In this profile, funnel-shaped patterns correspond to the walls of sand volcanoes. Primary sedimentary facies at the time of filling remain on the outside of the funnel-shaped walls. They have parallel and cross laminations and are similar to facies of marine sediments.

(3) Stratigraphy of fills in valley plains
A subsurface geologic section of land filling the uppermost parts of an alluvial valley plain is shown in Figure 4. This valley was formed by dissection of hilly areas. The thickness of the filled strata is less than 5 m. The basements of the fills consist of Holocene peat and silt in the valley plains and of Pleistocene fine sand, silt and loam in the slopes of tablelands. Filled strata are composed of loam and medium sand, in ascending order. This medium sand underlies loam in hilly areas. Hence, the accumulated order of strata is reversed by cutting and filling works.

In addition, strata filled with Pleistocene sediments overlie Holocene alluvial sediments. These are upside down fills.

(4) Facies of fills

Observing outcrops are important for analyzing sedimentary facies of filled strata in detail. However, few outcrops occur in filled lands.

Sections of the artificial strata exposed by trenching are described here. The trench was cut in a filled area after the 1987 earthquake of eastern offshore Chiba (Fig. 5). Liquefaction and fluidization occur-

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![Fig. 3](image-url) Sedimentary facies of a sand volcano vent with liquefaction and fluidization, occurring in a hydraulic fill. Modified after Chiba Prefectural Government(1989).

![Fig. 4](image-url) Subsurface geologic section of artificial ground filled up in valley plain.
red in the filled strata of this site during the earthquake. They caused landslides in slopes (leftward in Figure 5 (b)) and the ground rose at the foot of the slopes. The amount is within 1 m height. A subsurface geologic section of the risen zone is shown in Figure 5 (a). Primary sedimentary facies at the time of filling partly disappeared by these phenomena in this figure. Accordingly, attention must be paid in observing the outcrops.

This artificial fill is about 3 m thick and the basements consist of silt, including peaty soil. Filled strata are composed of fine sand with silt blocks (thickness: 70 to 270 cm) and sandy silt with silt blocks in ascending order. The silt blocks are mostly 0.5 to 10 cm and rarely attain 50 cm in diameter. Five- to twenty centimeter-thick brownish soil covers these strata. The fine sand layer become thinner and the sandy silt layer become thicker with distance from the slope. Changing points in the thickness of the layer coincide with changes in the shapes of the ground surface.

Sedimentary facies were analyzed in detail as follows. The lower zone of the fine sand layer was liquefied and fluidized, and the silt blocks were dispersed. Muddy zones intercalated here were also torn off, but they had lain continuously before the earth-
quake. Moreover, it is inferred that such muddy layers were formed in pools formed by storms during stoppage of filling works. Laminae formed during the accumulation of strata occur only in the right side of the section. Others probably disappeared by the liquefaction and fluidization. The primary arrangements of silt blocks exist partially in the upper zone of the fine sand layer and the sandy silt layer, in which the above phenomena by the earthquake did not occur.

(5) Stratigraphy of waste deposits and surplus soil deposits

Little drilling and trenching has been carried out in landfill sites and depository sites for surplus soil. Examples of geologic columnar sections in a depository site for surplus soil, including waste, filling valley plains are shown in Figure 6. These deposits were contaminated by hexavalent chromium and these columnar sections were obtained by simple drillings for clarifying their contamination. Holocene alluvial sediments consist of sand with gravel and a muddy zone, such as peaty clay-like soil and peat, in ascending order and underlying the deposits. Many kinds of materials with various grain sizes, such as loam blocks, shell chips, slag, concrete blocks and plastics, are
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Fig. 7 Sedimentary facies of surplus soil deposits.

Fig. 8 Sedimentary facies of waste deposits. Modified after Nirei et al. (1996).
buried irregularly in surplus soil deposits. Their thickness ranges from 3 to 5 m and their lateral continuity is poor.

(6) Facies of waste deposits and surplus soil deposits

Figure 7 is a sketch of an outcrop produced by trenching. It is near the drill hole where the data for columnar section N in Figure 6 was acquired. The deposits can be divided on the basis of gravel, disposed materials and matrixes which bury the interstices. In this figure, sandy silt layers, including gravel, contain intercalated beds of silt and loam, both tens of centimeters thick. The processes of filling are inferred, as follows, from analyses of sedimentary facies. After the lower sandy silt zone was filled, filling works were stopped and the surfaces were leveled. Then materials consisting of loam and silt covered them, and sandy silt was filled again.

A sketch of an outcrop, prepared from data obtained from trenches of waste deposits, is shown in Figure 8. Crops in fields around the landfill site were affected by methane gas generated in these deposits. The deposits consist mainly of burned ashes from a garbage furnace near the site, raw refuse, and plastic fragments; and their thickness is about 12 m.

In detail, asphalt blocks and incombustible pieces lie in the bottom zone of the deposits. Ashes from stoker and fluidized-bed furnaces overlie them. The former ash contains many metal chips and the latter are composed of solidified ashes with a diameter from 2 to 3 cm. About 50-cm thick soil cover the wastes. Deposits of plastic fragments, with 3 to 4 m thickness, overlie them. Above these, about 2 m thick soils cover them. As a whole, the zones of plastic fragments overlie those of burned ashes.

However, stratigraphic units in waste deposits cannot be correlated with those in natural sediments, because their units are man-made, following the plans of reclamation.

**Discussions**

In environmental geology, various geologic phenomena are treated with connections to mankind and nature. Therefore man-made lands are the best materials to clarify whether man's approach is harmonious with nature or not. However, various problems, such as the adequacy of applying geologic rules and concepts to artificial strata and the stratigraphical positions of artificial strata, have not been solved regarding man-made geologic conditions. Furthermore, basic concepts regarding artificial geology have not been established yet.

On the other hand, geologic disasters and environmental damage characteristic of artificial geologic conditions have occurred. As already stated in this paper, these disasters and damages are affected by the formation processes of artificial strata, their properties, and the geologic conditions of their basements.

Therefore, the geologic characteristics of artificial strata are examined here on the basis of the results mentioned in the preceding sections.

(1) Discontinuity between artificial strata and natural strata

First, should the relation between natural strata and artificial strata be treated as an unconformity or not?

This term has been used regarding the discontinuity of structures and facies, and also the temporal contrast between strata overlying and underlying the "unconformity". Ijiri (1979) pointed out the importance of clarifying geologic events which caused the discontinuity. In addition, according to Ijiri (1972), the temporal contrast of an unconformity in Quaternary sediments corresponds to that of "bedding" of strata in Paleozoic and Mesozoic sediments, considering the rate of accumulation in these eras. On the other hand, eroded surfaces formed during the periods of low sea level are also correlated as an unconformities in sequence stratigraphy. Kumai (1991) has pointed out the importance of examining the relation of strata thoroughly from viewpoints of lithostratigraphy, biostratigraphy, physical properties and chronostratigraphy, in order to define an unconformity.

If relations between natural strata and artificial strata correspond to an unconformity from the above criteria, artificial strata become a stratigraphically important unit. This problem is discussed below through the results of stratigraphic analysis of artificial strata in Boso Penninsula.

Facies of hydraulic-filled strata in bay areas are similar to those of underlying Holocene alluvial sediments because they consist of alternation of sand, silt and clay dredged from offshore zones. They are, however, characterized by poor lateral continuity, compared with Holocene alluvial sediments.

The contrast in strength between filled strata and Holocene alluvial sediments depends on their facies and on the location. Where the filled strata, consisting of silt and clay, overlie Holocene alluvial sediments of sand, the contrast of strength is distinct and they are distinguishable as two velocity layers. However, where materials forming both strata are similar,
or where sand-filled strata overlie Holocene alluvial sediments of silt and clay, contrast in strength and velocity is poor. Contrast of dynamic properties is generally distinct between Holocene alluvial sediments and Pleistocene sediments rather than between filled strata and Holocene alluvial sediments. Therefore, microtremor characteristics are affected by the boundary of Holocene alluvial sediments and Pleistocene sediments (Kamura and Nirei, 1996). Relative density of strata is generally low in filled strata and comparatively medium to high in Holocene alluvial sediments. They are little affected by materials forming the strata.

Materials filling valley plains are mostly sand and silt cut from adjacent tablelands or hills. Contrast of facies between filled strata and natural strata depends on the locations, such as zones on slopes of tablelands and hills or on valley lines. On the slopes, the contrast of facies is poor because the materials of filled strata are similar to those of the underlying strata. Along valley lines, the contrast is remarkable because filled strata, mostly of sand and silt, overlie Holocene alluvial sediments, including peat. Continuity of filled strata is poor both laterally and vertically. Contrast of strength between filled strata and their underlying strata is distinct at slopes of tablelands and hills, and is indistinct along valley lines. In the latter zones, contrast between Holocene alluvial sediments and Pleistocene sediments is more distinct than that between filled strata and Holocene alluvial sediments.

Waste deposits in valley plains are quite different from natural strata and artificial strata. Contrast between waste deposits and natural sediments is striking. Moreover, the strength of waste deposits depends on the location and, therefore, it is difficult to clarify the contrast of strength between these deposits and the underlying strata. It is considered that waste deposits fall into the same category as the shell-mounds of Jomon age, namely, refuse grounds in human daily life.

On the other hand, a temporal contrast between natural strata and artificial strata is very short in geologic time scale. Mankind's activity cannot be correlated to geologic events such as diastrophism, because the areal scale is small and the universality poor.

From these facts, it is concluded that the discontinuity between natural strata and artificial strata does not correspond to the concept of an unconformity. However, it must be recognized clearly that the relation between them is a significant factor in examining geologic interpretation or artificial strata in urbanized areas.
vents and then deposited. Beds formed under such conditions lie with contemporaneous heterotopic facies. The number of beds is equal to the number of times of spewing and the facies of each bed generally resembles each other. Then the vents are moved to low filled zones, and the above process is repeated. Beds formed by materials spewed from the vent in the same locality correspond to a member in natural strata. Namely, these hydraulic filled strata are composed of accumulations of members. In the profiles of filled strata in the Tokyo Bay area (Fig. 2), member zones with similar facies are divided to stratigraphical units.

From these results, the concept of stratigraphy is applicable to the hydraulic filled strata.

(b) Artificial strata formed mainly by mankind's activity

Filled strata in valley plains are constructed by the following two methods. In one method, sediments forming tablelands or hills are excavated with large scale construction machines. They are transported to the project area by dump trucks and buried in valleys under gravity. The other method is that excavated sediments are pushed out to the adjacent valleys by the machines and are buried there. Waste and surplus soil deposits in valley plains are formed by similar methods. Ashes from incinerators of intermediate institutions for waste disposal and wastes from factories are transported to landfill sites by dump trucks and then buried there under gravity. Soil excavated from construction sites is transported to depository sites by dump trucks and then buried there.

These processes have the following common factors. Composition of buried materials is determined before transportation. They are transported to sites and deposited there with sorting by gravity. The sorting during transportation, which is the general processes of natural strata, does not occur in the above processes. Partial arrangements of silt blocks and of fine-grained materials occur during burial under gravity.

Stratigraphic units of the filled, waste and surplus soil strata are as follows.

Filled strata in Boso Peninsula are divided into several zones by their facies (Fig. 4). The stratigraphic division depends on the sediments of the tablelands cut as the materials for filling. The stratigraphic orders of layers in the fills are mostly reverse to those of the adjacent natural strata. Division of strata is possible because they are stratified.

Subsurface profiles obtained by trenching the land-filled valley plains is shown in Figure 5. They consist of fine sand, sandy silt and soil in ascending order. Sedimentary facies of each layer are mostly disturbed by liquefaction-fluidization and landslides. However, primary structures are preserved in some zones, and here laminae and arrangement of silt blocks are observed. It is impossible to recognize bedding planes.

Moreover, the sedimentary facies are clarified from observation of the subsurface profile by trenching in another filled area. This area, consisting originally of crescent rivers, was filled with sand and mud dredged from bottom of the Tone River. After that, this area was again excavated in order to mine iron sand within the dredged sand. Excavated zones were buried again by mountain sand transported by dump trucks. Therefore, this burying is similar to filling methods in inland areas. In this profile, a sand layer overlying the bottom planes formed by excavating the filled strata. This layer was accumulated at periods between the excavation and the filling work. It is inferred that these are aeolian sediments. Strata overlying the sand layer consist of a black sand layer, a sand layer with silt blocks partly intercalating black sand, a layer with sand, silt and refuse, a sand layer with clayey silt blocks, a clayey sand layer, and soil, in ascending order. Division of the filled strata is possible by classifying the filled materials. However, it is very difficult to distinguish bedding planes in artificial strata. In addition, shapes of the planes vary significantly because they are disturbed by large-scale construction machines such as bulldozers.

In waste deposits, the facies are affected by various kinds of wastes. For example, the profile of surplus soil deposits, including wastes, is shown in Figure 7. Division of the filled strata is possible by using materials forming the matrix, but lateral continuity of gravels and wastes is poor. Waste deposits shown in Figure 8 consist mainly of ashes and plastics. In these deposits, a rough division of strata is possible and their facies depend on conditions of location and of operation. The clarification of sedimentary facies is difficult because large-scale construction machines are often used at filling sites.

From these results, the reconstruction of sedimentary facies in the filled, waste and surplus soil strata is difficult because the processes are affected extensively by human activities. Accordingly, it is difficult to apply the concepts of natural strata stratigraphy to filled strata in inland areas. In the present state-of-the-art, for filled lands with a series of processes of sedimentation, the component artificial strata are rea-
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reasonably regarded as assembled bodies of geologic units, such as members. However, it is difficult to divide the strata into more detail. These also are similar for waste deposits.

(3) Geo-historical setting of artificial strata
The history of the earth is classified geologically into Paleozoic, Mesozoic and Cenozoic Eras, and the standards are based on evolution of animals and plants. The Cenozoic Era is distinguished from the Mesozoic by the appearance of mammals, and is divided into Tertiary and Quaternary Periods. Moreover, the Quaternary Period is characterized by man and is often called Anthropogene. In this period, the environment has been changed consciously by human activity, using hands and tools. These human activities, without trusting in natural providence, have the greatest impact on the earth. Archaeological beds in the late Pleistocene and Holocene (Chou and Nasu, 1991) and artificial strata constructed mainly in the 20th century, are human productions and different from natural strata in their formation. The differences between artificial strata and natural strata were clarified from the stratigraphical viewpoints. Kumai (1991) pointed out that artificial strata are similar to Bioturbation. The above results support his assertion.

Conclusions
Stratigraphy and facies of artificial strata in the northern Boso Peninsula were clarified and were compared with the natural strata.

The following is the main results of this study.

• The concept of unconformity should not to be applied to the discontinuity between artificial strata and natural strata. However, superposing relations of the both strata have significant meaning in geo-environmental problems.
• It is difficult to apply the concepts in stratigraphy to hydraulic-filled strata. The sedimentary conditions affect the occurrences of land subsidence and liquefaction and fluidization during earthquakes.
• The concepts in stratigraphy can not be applied to filled strata, waste strata and surplus soil strata, because their formation processes are strongly affected by human activities.
• The artificial strata are products of human activities in the Quaternary Period, also called Anthropogene. The idea that the strata are similar to Bioturbation (Kumai, 1991) is most reasonable.

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