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Syntectonic Construction of Geosynclinal Neptons

By

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Abstract

Neptons, volcans and plutons are somatic constituents of the earth's crust Definition and classification of neptons are given in the first and last chapters. The tectono-environments of geosynclinal neptons are discussed in the second chapter. The Neogenic nepton series of Shizuoka is described in detail as an example. Syntectonic construction of such series is analysed. Various features due to turbidity currents appear in the clinothems. Besides nepton, several new terms, such as quasi-cratonic basins and shelves, subundathem, clinothem front etc., are proposed.

Introduction

Field work has been carried on in an area of Neogene rocks in Shizuoka Prefecture since 1920 and much important paleontological and stratigraphic data have been obtained and published. However, several problems remain including the manner of sedimentary development of the rocks. The purpose of this paper is to lay a basis for study and description of certain types of sedimentary rock development, particularly for mobile orogenic belts such as Japan, and to illustrate them by application to the Neogene rocks of the Shizuoka area where they are well exemplified. Because the Neogene sedimentary rocks in the Shizuoka area are somewhat different in their development from the types of sedimentary development described by the pioneer geologists of western countries, the only applicable literature found among the older pulications was a small book "Deposition of the sedimentary rocks" by J. E. Marr. A recent paper by J. L. Rich entitled "Three critical environments of deposition, and criteria for recognition of rock deposited in each of them" in which such new terms as undathem, clinothem and fondothem were introduced, provided a basis for the development of other new terms which are necessary for the study and description of sedimentary bodies in mobile orogenis zones.

For the study of sedimentary rocks in mobile orogenic belts a "somatic" representation or consideration of sedimentary rocks as bodies is more applicable than the usual stratigraphical classification and facies analysis. For instance, the new term nepton which refers to a type of sedimentary body may not be needed by geologists who are studying continental sedimentary deposits, although there are some exceptions such as the Welsh Silurian. However, the need for the term would be easily understood by foreign geologists if they could see the Neogene stratigraphy of Japan. For in Japan, extremely thick sedimentary rocks comprise a number of overlapping bodies, that have developed during the staggering orogenic movements which have been in process during the long period of time since the late Paleozoic. Various special sedimentary phenomena which have resulted from turbidity currents were brought to my attention at a symposium on sedimentary phenomena in 1950. The consideration of the details of these sedimentary phenomena have been most helpful to me in observing the clinothems of Tertiary neptons in the field. The conjectured action of turbidity currents explains many minor features of clinothems which evidently take place only in sediments beneath turbidity currents. Although a few other intra-formational structures not previously described were observed, the object of this paper is to descibe the major structural elements of sedimentary bodies, that is, neptons, and not to present a premature comprehensive monograph on geosynclinal sedimentation.

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Definition

A nepton is body of sedimentary filling in any one basin. This definition is rather general, but from this general statement particular cases can be defined. Neptons built in geosynclines are called "geosynclinal prisms" by Daly (1938), because the typical shape is that of a long, plano-convex prism with its convexity at the floor. The masses of sedimentary rocks in geosynclinal basins are so variable in form that they can hardly be termed simply prisms. Therefore new term nepton may cover the variation in shape and in structure.

A partial nepton is a series of sediments which are visible on the land surface. The Tertiary sediments over the Japan islands occupy various independent local basins which may be mere apophyses of a larger geosyncline. Each sedimentary mass of these basins is presumed to connect with the larger main body of a prismatic nepton; but the entire body is not accessible on land. We can only deal with a smaller part of the larger nepton. Some such individual sedimentary masses may be shown as sister neptons.

Each nepton thus defined has its own individuality, not only in its shape and structure, but also in its development. Some geosynclines have long histories, for instance, the present East Asiatic geosyncline has existed since the Silurian period, although its axis has been fluctuated and resulted to shifted to the east.

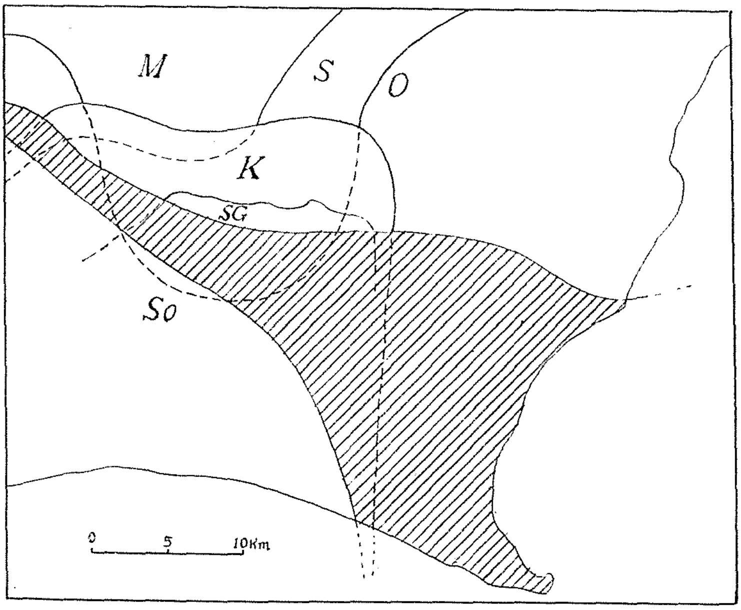

Fig. 1. The superposed neptons of the nepton series in Shizuoka prefecture. The lines show the inside limits of nepton areas, M: Mikura, S: Setogawa, O: Ooigawa, K: Kurami, SG: Saigo, shaded zone: Sagara-Kakegawa uncovered, So: Soga nepton. Compare fig. 3.

After the sagging movement of a basin has ceased, the process of nepton construction soon comes to an end. If the subsidence recrudesces, reconstruction of the nepton will start following the preceding nepton. However, if The stationary interval is finitely long, the new nepton is unconformable to the predecessor. A long-lived geosycline has a series of neptons. Two or more successive neptons in a nepton series may have grown in unbroken continuity; then they are conformable and the younger neptons are said to be regenerated. This phenomenon is somewhat like intercalicinal budding of coral.

The conformable relationship between any two successive neptons is not the same as the conformity in stratigraphy; for, in places, it may appear like an angular unconformity, because the rocks of the older nepton have been deformed and partly removed by erosion before regeneration. Such a diastem is usually well-marked compared with other diastems in the neptons. Tertiary stratigraphers of this country have encountered this kind of diastem which were called nonconformity or phenomenal unconformity (Ikebe, 1950).

A new nepton is unconformable to an older one when the interval was long enough to promote the operation of diagenesis upon the underlying rocks. The intervals have been termed stationary epochs, that is stationary in view of basin-making kinematics, but not quite tranquill, as the rocks were under stress.

The Paleogenic Setogawa, Early Miocene Ooigawa, Middle Miocene Kurami, Later Miocene Sagara, Pliocene Kakegawa and Soga groups in Shizuoka prefecture of Japan are a Tertiary nepton series. Of these, the Kakegawa and Sagara are a nepton, the former being the regenerated partial soma of a nepton, separated from the latter by a diagonal erosive diastem. Each of the other groups is an independent nepton of that series For instance, the Ooigawa nepton which is unconformable to the underlying Setogawa nepton is an independent member of the series. The diagenesis of the Kurami nepton has been advanced during the interval before the develoment of the following nepton, as seen by indurated pebbles provided from it. The details of these examples will be given in another chapter.

The following lines summarize the concepts stated above.

1. A nepton is a body of sedimentary filling in a basin.
2. A geosynclinal prism is a nepton in a broad sense.
3. A nepton in the narrow sense, that is a partial nepton, is an apophysis or a side part of a larger nepton (geosynclinal prism).
4. A real nepton is the visible part of a larger or smaller nepton.
5. Two apophyses of a larger nepton are twin or sister neptons.
6. Several assumed or deciphered sister neptons comprise a nepton group.
7. A nepton series consists of neptons which are made in successive basins in the same area.
8. A nepton is neither stratigraphic nor a mapping unit.
9. An interruption in a nepton series including a biostratigraphical hiatus and a diagenetic discontinuity is an unconformity, while a short stop of sedimentation or a slight removal of deposits are diastems.

Tectono-environments of geanticlines

The term nepton is apparently of no use on the continents. Japan being a geanticlinal mobile land, has many complex neptons and the individuals are very variable. Practically no basement massif is exposed on this land; but its back bone consists of the folded Paleozoic geosynclinal sediments and intruded granitic plutons. This complex is the secondary basement for the younger neptons. The geanticline is by no means like a craton, but the secondary basement complex behaves temporarily as if it is a part of real cratonic basement.

There are three distinctive tectono-environments for sedimentation in and around the geanticline: (1) quasi-cratonic basin, (2) quasi-cratonic shelf and (3) geosynclinal trough.

Quasi-cratonic basins are similar to intra-cratonic basins, except that the basins are usually in connection with the outer seas. Setouchi, the present day inland sea of Japan, is a typical example of quasi-cratonic basin. The inland sea basin is a composite basin composed of small elliptical elements. Past inland sea basins were the sites of the Miocene and Plio-Pleistocene nepton groups which are now exposed in the Kinki districts. The maritime humid climate of Japan does not permit an evaporite association to exist. Also there is no true black shale association. The quasi-cratonic neptons are like the unstable shelf neptons in their lithologic associations. The Plio-Pleistocene neptons of the Osaka, Kyoto and Nara basins have a common cyclical construction due to oscillatory movement or periodical disharmony in sedimentation.

Quasi-cratonic shelves are narrower and less stable than a true continental shelf. They have been made, in most cases, by wave erosion, but the outer parts are made of terrigenous sediment not essentially different from wave-built terraces. In lithologic association, the quasi-cratonic shelves are similar to unstable cratonic shelves and quasi-cratonic basins on one hand, and to geosynclinal troughs on the other, because one type is transitional to the others.

The neptons developed upon the shelves have constructions similar to the normal neptons of the continental borders, but their parts which are transitional to deep water deposits consist of alternating graded beds called clinothem* by Rich (1951).

A geosynclinal trough is the sedimentation environment of the fondothem and clinothem of Rich, if the geosyncline is not far from the source of sediment. The terrigenous sediment from the geanticline may rapidly fill up the deep. Certain larger submarine canyons may be similar to this environment. The scour and fill action of turbidity currents (F. P. Shepard, 1951) may appear in sections of sediment deposited in a small canyon. If a canyon is repeatedly a course for turbidity currents of high velocity, erosion is only operative as long as the environmental conditions remain stationary. Subsequent subsidence or other changes will bring about quick deposition of sediment. Therefore the side walls and bottoms of the submarine valleys will remain as diastems in the nepton thus under formation. Such a diastem may be called a "scour diastem". Scour diastems may take place in clinothems built outside the canyons, because of uneven configuration of the submarine slopes.

Niino (1950) reports that in some Japanese submarine valleys, Tertiary rocks are exposed on the steep walls. Shepard (1949) has also reported rock exposures in other canyons. This fact suggests the possibility of erosion by bottom currents, even if it is not assumed that the valleys were cut simply by turbidity currents. After the burial of a rocky canyon by sediment, the boundary of the filling and the basement is not a scour diastem, but is a distinct unconformity, for the fillings belong to an independent nepton.

According to Niino (1952), the distribution of sands around the canyons is

* Undathem is a sequence of strata deposited under the agitating shallow water; clinothem is that deposited upon a subaquatic slope; fondothem is muddy bottom deposit. Undaform, clinoform and fondoform are their environments.

transverse to the talwegs, and he noticed that the axis of distribution coincides with the direction of crossing of the canyon by strong shore currents. Since the current is not a density current, it may cross the canyon, instead of pouring down it: the sands are possibly transported to the top of the wall and then fall to the bottom, if the slope is steeper than the angle of repose under the water. Niino indicates in an equal percentage chart of sandy contents in deposits around a submarine canyon off Shikoku, that the lines cross the bottom configuration. This statement seems to suggest that the competency of clear currents is able to be ascertained by a theoretical analysis based upon the criteria given by Nevin (1946). The density interflows and surface flows (Menard & Ludwick, 1951) may spread over the canyons carrying available coarse sediment, while the clouds of bottom flows move down the slope following favorable channels.

Although turbidity currents are not known to erode, their capability of down-cutting cannot be denied as inferred by Menard and Ludwick (1951). Niino has observed no shift of water in submarine canyons strong enough to cut the bottom and Shepard (1951) states that the hypothesis of Daly (1936) will have to be abondoned. But this opinion does not neccesarily claim incompetency of turbidity currents in scouring action. The competency may be deduced from observed criteria of the past sediments, such as the scour diastems, the flutes (Rich, 1951) seen on the surfaces of muddy beds and the current beddings of sandy beds in the clinothems.

Shepard (1951) has suggested that subaqueous slumps or lands-slides are converted into turbidity currents and that these currents carry sandy sediment out along the talwegs of channels. Slumps may occur in the shallow shore waters at the edges of wave-built terraces or at the undathem edges (Rich, 1951). Outward growths of undathems will make the outer slopes so steep as to stand nearly at the angle of repose. These unstable edges are disposed to slide periodically. Shepard also suggests that the accumulation of decaying kelp and eel grass in canyon heads has an important effect in permitting the sand slides to occur. Seemingly the accumulation also takes place at the undathem edges. The fact that greywackes in past geosynclinal neptons contain abundant remains of seeweed, though by no means conclusive evidence, supports this suggestion.

Periodicity of slumps or slides reacts to the sedimentation of clinoforms. The characteristic rhythmic alternations of sediment in a clinothem may have originated from such a process carried on under the past sea. As has been stated by Marr (1929), the alternations may be due to more than one cause, for instance, shifting in the direction and change in the velocity of horizontal currents is no doubt operative at times. Rich thinks one storm makes one set of graded sediment. Rock falls of sea cliffs by undermining wave erosion may build unsorted breccia wedges intercalated between alternating finer sediment. The clinothem of the Kakegawa Pliocene is an example.

The words "embankment deposits" (Marr, 1929) mean deposits which were sloped and striped under the sea; therefore they are synonymous with clinothem. The term "Flysch type sediment" covers not only clinothems but also fondothems, inasmuch as the type Flysch is a nepton consisting of such elements.

Fondothems are an important part of the geosynclinal neptons. They are represented by blue grey massive mudstone or laminar shale with or without occasional thin discontinuous seams of silt or fine sand. Sapropelitic black shales may occar in fondothems where circumstances were favorable. Neither marl nor chalk is a component of a fondothem born in a tract contiguous to the land. Pumice and other ejecta are often found in the muddy rocks of fondothems.

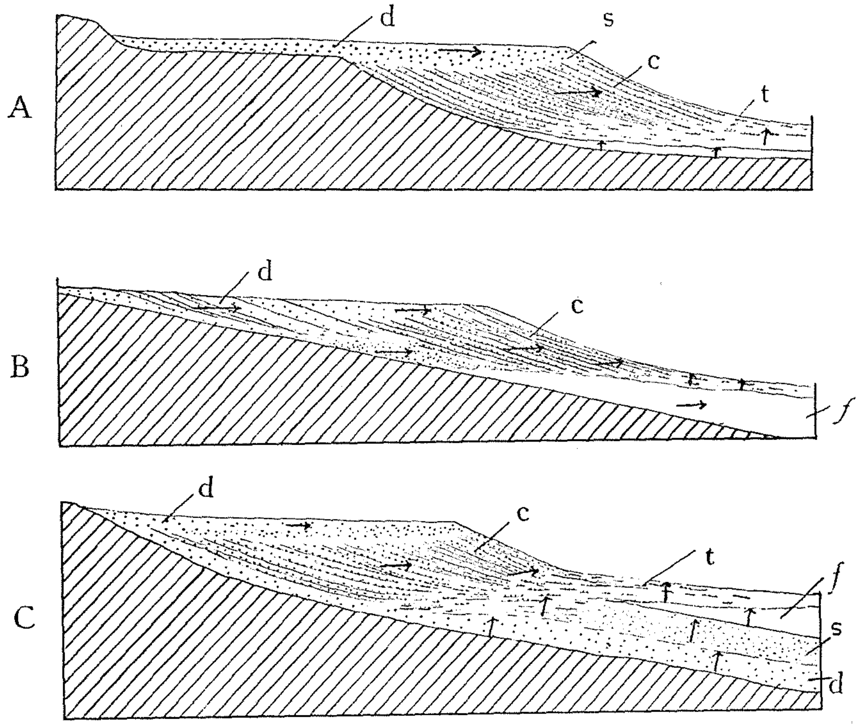

Fig. 2. Various nepton structures, schematic.
A. A nepton grown in a deep trough along a geanticline.
B. A nepton grown under a sea agressed almost instanceously.
C. A nepton born in a normally transgressive sea: the transgression accelerated during the final phase. The normal cyclic strata below are overlapped by the quickly developed clinothem and its front.
d: undathem, s: subundathem, c: cilnothem, t: cilnothem front, f: fondothem.
→: out-building growth, ↑: up-building growth.

Paleontological evidence tell the depths of the fondoforms, especially those of later Tertiary origin afford more efficient paleo-ecological criteria, as they contain faunas referrable to the present marine faunas.

A fondothem is not always simple in its structure. Many clinothems have initial dips up to 10°, but each front of the stripes passes into a blanket over the nearly horizontally layed pre-existent part of the fondothem in front. The sandy material spread over the fondothem seems to have been less substantial than over the clinoform, as observed in the Pliocene nepton of Kakegawa. The fine sand seams in the clinothem front which lie over the pre-existent fondothem are thin and discontinuous. The boundary between the clinothem front and the basal fondothem is a diastem, which is a wavy surface often marked by chain of small lentils containing glauconite grains, fossil fragments or fine conglomerate. A clinothem front is an element of a compound fondothem, transitional to the clinothem on the landward side and to the genuine fondothem on the off-shore side. A pre-existent part is another element; this part itself may change into a clinothem front which lies underneath the clinothem of later growth, or may be simply a mud belt deposit of early origin.

In syntectonic construction of neptons, complex combinations of fondothems, clinothems and undathems will be produced. A single nepton may cover both a quasi-cratonic shelf and a geosynclinal trough.

In conclusion, the above discussion may be summarized as follows;

1 A geosynclinal trough is a tectono-environment not far from a positive element which supplies clastic sediment.

2 Out-building of the undathem initiates quick growth of the clinothem.

3 Analytical studies of complex syntectonic constructions of various geosynclinal neptons are very important.

Sagara-Kakegawa Nepton

Stratigraphy of the Kakegawa Pliocene and the subjacent Sagara group has been described by the writer; since these formations comprise a complete nepton, they are an excellent example of syntectonic construction. The nepton relic now occupies the land area shown in the map. It was built in a basin after the middle Miocene. The foundation is made of older neptons belonging to the same nepton series: the Kurami (middle Miocene) of the north, the Ooigawa (Early Miocene) of the south-east and the Setogawa (Paleogene) at places are the chief members of the foundation.

As has been stated, the Sagara-Kakegawa nepton was deposited under two different environments, the quasi-cratonic shelf and the geosynclinal trough. The partial nepton built upon the shelf has been pronounced the normal facies of the Kakegawa group, while that of the trough to be the Flysch type facies.

Inference on the quasi-cratonic shelf part is to be made first. The basal

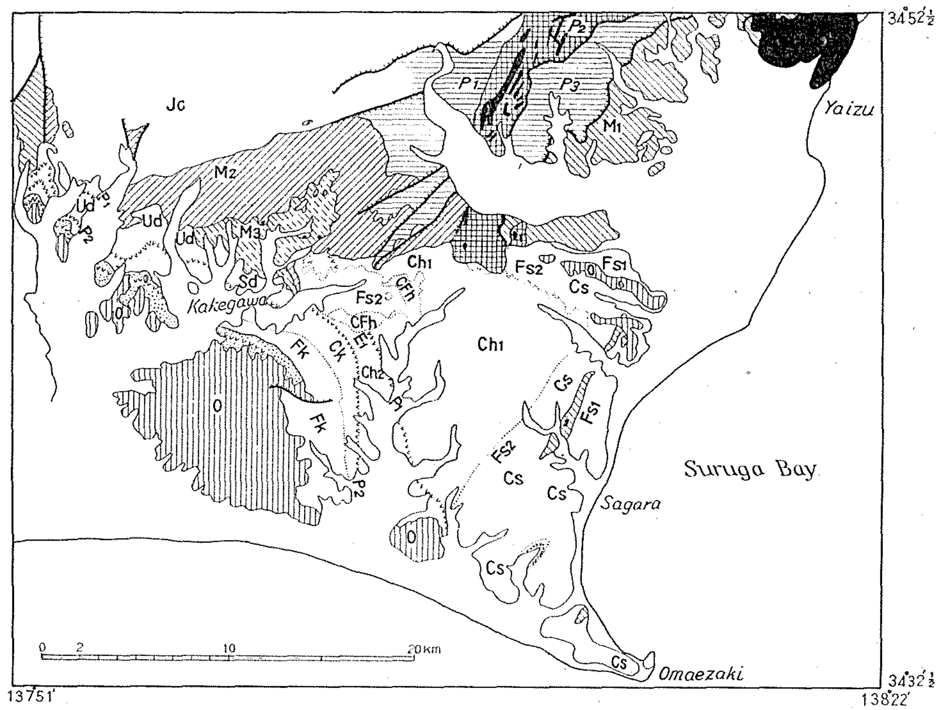

Fig. 3. Geological map of south-western part of Shizuoka prefecture to show the Tertiary nepton series, especially the Sagara-Kakegawa nepton.

Jc: Jurassic to Cretaceous neptons.

P_1, P_2, P_3: Paleogenic Setogawa neptons.

M_1, M_2, M_3: Miocene neptons, Ooigawa, Kurami and Towata groups.

O: The Ogasa formation, lower Pleistocene nepton.

Dotted: The Soga group, upper Pliocene nepton.

Black: Volcans and plutons.

Fs_1: Fondothem and clinothem front of the Lower Sagara.

Cs: Clinothem of the Sagara.

Fs_2: Fondothem of the Upper Sagara, Tamari formation.

Ch_1: Clinothem of the Lower Horinouchi.

CFh: Clinothem front over the Tamari (Fs_2) fondothem.

Ch_2: Clinothem of the Middle Horinouchi.

Ud: Undathem of Dainchi.

Sd: Subundathem of Tenno.

P_1, P_2: First and second pyrozones.

Ck: Clinothem and subundathem of the normal Kakegawa and clinothem of the Upper Horinouchi.

Fk: Fondothem, Kechienjian stage.

membr, the Dainichi sand bed, is a typical undathem that was built on the wave-cut terrace at the begining of the Kakegawa epoch.

The foundation sank, while the nepton grew. This process seems to be the usual one. The following standard section has been given in the writers papers:

(5) Hijikata (or Kechienji) mud: blue grey massive mud with occasional thin sands .... 224m.

(4) Nangô formation: alternations of sand and mud.................. 279m.

(3) Hosoya formation: massive silts and muds with ferruginous nodules, white fine tuff and pumiceous bed near the base............................. 32m.

(2) Tennô sand: blue fine-grained sands, passes to silt upwards, transitional top is alternating sands and silts .... 70m.

(1) Dainichi sand: brown medium-grained massive sand, conglomerate to the base, laminar sands to the top...27m.

Other cross sections show but slight changes. (1) and (2) are representing the Suchian stage, (3) to (5) are the type of the Kechienjian.

When nepton consists of superposed blankets of various sediments, columnar sections are similar at all points over the surface. But in case of a nepton built upon unstable quasi-cratonic shelf, we cannot expect a uniform sequence of strata at different places in that nepton, because the construction is compound according to the tectonic inequality of the basins. The zonal arrangement of the formations as shown on the geological map of the Kakegawa group, appears normal, but it is not known whether the upper members are wedges which extend north to overlie the lower members, or whether they are blankets as is the usual case. Unfortunately there is no deep well to attest the column. The only approach is observations on the outcrops. The complete figure of the nepton before erosion is restorable by accumulation of details observed on the land surface.

The shelf partial nepton of Kakegawa.

The Dainichi sand is a product of sedimentation over a submerging wave-cut terrace, so the bed is called an undathem. Heaps of shell fragments and lack of lamination prove that active undercurrents and agitation prevailed at the bottom. Marr suggested that owing to the winnowing process, the amount of sediment permanently deposited in the belt of variables will be much less than it would otherwise be; and a very long period of time may be represented by deposits of no great thickness, and having no important physical breaks occuring in them.

For instance, a deposit of sand only 70m. in thickness was produced while an enormous volume of sediment was laid down on the deep side. The biozones represented by the heaps in the undathem and the fossil-fragmental wedges in the clinothem prove this relationship. The tuffs as well are able to be pursued from the trough facies into the shelf facies, but missed amid the typical undathem, where the agitation may have well dispersed the accumulation of fine pyroclastic particles, and the current may have carried them away.

The main portion of the undathem is composed of medium-grained, homogeneous, quartz-rich subgreywacke, while it comprises also less sorted, current-bedded subgreywacke. The massive sand insensibly passes upwards into laminated sands with occasional intercalations of micaceous and carbonaceous shale. The lamination was retained to a certain degree, as the sands suffered only a minor winnowing process. Such well-stratified top parts almost always follow the bottom massive typical undathems of the Japanese Tertiary neptons, the writer has seen. The sand itself does not substantially differ from that of the massive undathem, hence the stratified top was made of superfluous sands carried in from the agitation belt by current.

There is no vestige which indicates the abrupt change from the massive bed to the stratified sand. Only a gradual sinking of the basement seems to have brought the condition favorable to deposit undisturbed stratified sands. Of course we can assume an existence of an agitation belt contemporaneous with the undisturbed belt overlapping the pre-existing undathem.

The medium sands of the Dainichi member are followed by the fine and super-fine sands of the Tennô member. The fossils in the latter indicate a sublittoral environment. The stratification of the Tennô sand is poor, as has been mentioned massive. At Tennôyama north of Kakegawa, there are several seams of coarser sand interbedded, exhibiting fairly good stratification, but other parts are massive and homogeneous showing an "onion weathering". The smaller light shells of mollusks are often piled up to form fossil balls or irregular masses. It may be seen that a slight agitating and winnowing process was operating down to that depth, but was accidentally interrupted by strong currents which brought coarse sediment from the littoral zone. A fine sand belt like the Tennô sand may originate in any submerging construction of a nepton on an unstable shelf. This lithotope taken into account as the transitional part between the undaform and the fondoform is given a new term "subundaform" and the deposit is called "subundathem".

The up-building sequence of strata mentioned above is now in contact with the out-building clinothem. The so-called transitional top part of the Tennô sand is really a clinothem over the Suchian subundathem. The alternating sands and muds are in no way interfingering offshoots of two neighbouring lithofacies.

The Hosoya formation consisting of muds and silts with pumice represents the lower part of the Kechienjian stage. It thins southeastward and is replaced by a part of the Upper Horinouchi formation of the trough facies. The two pyroclastic zones near Kakegawa are continuous into the Horinouchi facies. Going to the east, we see the basal tuff lies within the Dainichi facies, and the top within the Tennô subundathem. It is clarified that the pyrozones (new

Fig. 4. The Hosoya siltsone, a typical intermediate facies between subundathem and fondothem.

term for "pyroclastic zone") which represent time belts in a section, cut obliquely the superposed succession of various lithofacies.

The time belts are not well marked out by paleontological criteria, but the time-stratigraphical demarcation between the Suchian and Kechienjian is fairly evident.

The silts of the Hosoya formation at the city of Kakegawa contain sublittoral forms of mollusks and foraminifers, but the muddy beds of the upper part have in them *Limopsis tajimae* and *Planulina wüllerstorfi* indicating a somewhat deeper sea than the lower horizons in which *Glycymeris rotunda* and *Microfusus lischkei* prevail. This upper subdivision may be considered as to represent a transitional bed between a typical fondothem and the subundathem.

The Nangô formation is made of thin-bedded sands in the lower part and alternating sands and muds in the upper. These subdivisions resemble the alternating beds of the Horinouchi facies in their appearance; and indeed they are mere extensions of the corresponding parts of the latter. As in the Horinouchi, graded bedding, intra-formational contortion, crinkled lamination and stripped clays are very common in the Nangô formation. The lithology does not mean general emergence, but expresses the out-builded part of the quasi-cratonic shelf.

As has been mentioned above, there is a transitional bed inserted between the Tennô and the Hosoya. New cuts alnog a recently opened bypass road near Kakegawa exhibit the contact of the alternating sands and silts over the massive superfine sand.

The bed of alternations is by no means a passage between the two formations, but it is a fill in a submarine channel. The sand stripes are more or less graded, laminated, medium-grained greywacke. The laminae are often corrugated i. e. crinkled bedding (Kuenen and Natland, 1951) is fairly well-marked in the sands. The alternating stripes are abutting on the sloping surface of the underlying bed. The steep surface seems to have been the side wall of a channel which has been scoured by a converged under-current, presumably that of dense turbid waters.

The scour and fill operation of tubidity currents appeared repeatedly, as showh by doubled fills seen in the new cut at Kakegawa. These are the good examples of scour diastems. That the Iozumi tuff—about 7m pyrozone in the Hosoya—is missing between Taruki and Kakegawa, suggests removal of that part of the Hosoya by submarine erosion during the building process of the nepton. At Kakegawa, only a tuff scarcely attaining 10cm in thickness appears in the outcrop underneath the castle about 500m south-west of the road-cuttings. This thin tuff represents the upper subpyrozone of the Hosoya and the silty mother rock passes downwards into one of the fills of channels. Thus we can see the alternations (clinothem) are not the simple transitional top of the Tennô, but they

Fig. 5. Channel filling clinothem, at a cutting by the new bypass road, Kakegawa city. The channel scoured on the bottom made of the older channel fill.

Fig. 6. Scour and fill by turbidity currents; the subundathem Tenno sand below covered discordantly by the clinothem transitional member; new bypass road around Kakegawa city. The channel fill was scoured again as shown in fig. 5.

are the bases of the superjacent formations.

The topmost subdivision the Hijikata formation, (=Kechienji mud) is the product which resulted when subsidence was extreme. The massive mud contains fossils of pelagic forms side by sibe deep sea benthos, such as mentioned in the former papers; but the *Limopsis tajimae* and *Turcicula argenteonitens* association indicates an open sea bottom 200 to 2000m deep. This biotope as well as the lithotope comes up to a fondothem.

In the above lines, it was presented that each stratigraphical unit represents a specific component of the nepton. Stratigraphical classification, however, does not always agree with the internal structure of a nepton. In many cases, geologists have unavoidably put arbitrary demarcations between units. The analytical terminology of neptons seems to be more profitable in considering the geological developments than the conventional stratigraphical nomenclature.

The trough partial nepton of Kakegawa.

This Flysch type facies of the Kakegawa group has been named "Horinouchi facies". But, as it is conceived that the Pliocene sediment comprises a nepton together with the subjacent Sagara group (Upper Miocene—Yuian stage), the construction should be deciphered by an analysis of the entire partial nepton born in the same deep trough. For convenience the upper sectional nepton "Horinouchi facies" is analysed first.

The Horinouchi facies of the Kakegawa Pliocene is subdivided into three parts separated by two distinct pyrozones. The three interpyrozones have been named "Upper, Middle and Lower Horinouchi formations" respectively. The Upper Horinouchi and the overlying Hijikata corresponds to the Kechienjian stage, while the others belong to the Suchian * stage.

The aggregate thickness of the three formations has been estimated to be over 2000m. This enormous thickness measured in the usual manner is misleading, inasmuch as the section is a clinothem deposited on the slope of a submarine valley. Clinothems are sedimentary bodies like the foreset parts of deltaic deposits. The initial dip may be as high as the angle of repose of loose sand under the water. The rhythmic alternations of the lower and middle subdivisions around the town of Horinouchi dip westward with angles between 12° and 18°. Assuming the initial dip be 10° to 12°, it is possible to estimate the amount of tilting of the strata. The last value is equal to the dip of the lost undathem which most likely covered the clinothem.

There are many problems of turbidity currents unsolved as yet, but it is highly possible that the Flysch type rhythmic alternations are the product of such action under the sea as demonstrated by Rich. The writer has no quantitative criterion of turbidity currents, but he observed by a concrete embankment of a reservoir, that the muddy water artificially made by agitation flows down along the slope (30°) for some distance and then diffuses as an interflow. The bottom flow appears little accelerated, while the velocity of the interflow is quickly retarded and the muddy clouds fade away very soon after the diffusion. Although no interflow has been observed in the sea (Menard & Ludwick, 1951, p. 3.), many turbidity currents of comparatively low density which are probably of most frequent occurrence in the sea, cannot descend the bottom of the slopes. Even the underflows of turbid waters denser than any part of the sea waters may have very low velocities when they flow over the horizontal bottom.

The fading clouds of mud are most probably related to the origin of discontiunous sandy seams common in the fondothems. They appear as chains of fine sand lentils in the muddy matrix. Those lentils found in the Tamari formation a fondothem lying under the Horinouchi clinothem are flat, being much wider than thick; the boundaries are more or less irregular; the sands are fine to medium-grained, homogeneous and scarcely graded. They are rarely thicker than 3cm. In many cases the chains die away in one direction.

Thin discontinuous or continuous lentils of sand are the most characteristic

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* The stage name Infradainichian for the lowest formation inferior to the lower pyrozone seems to be not necessary.

feature of the clinothem front. Farther off the clinoform turbidity currents, but for a very few exceptions, do not fetch and drop the coarse sediment in the fondoforms.

Underneath the cliothem front, there may be the bottom-set fondothem which is the further end of a muddy blanket corresponding either to an early portion of the clinothem or to the other section of the nepton. The massive silty mud of the Tamari contains mollusks such as *Limopsis tajimae*, *Turcidula argenteonitens* and *Thatcheria mirabilis* showing a biofacies similar to that of the Hijikata formation.

The basal part of the Tamari is massive fine sand or silt that passes insensibly into the typical muddy rocks. The very base is a conglomerate with shell fragments unconformable to the Kurami Miocene. It is perceived that there is but a small subundathem below the main body of the fondothem indicating rather abrupt submergence at the beginning of the Tamari age. The pre-existing part of the fondothem is covered by the clinothem front. In many places around Horinouchi the diastem between these two parts of the Tamari is marked by a wavy contact with very thin glauconitic fine conglomerate or fossil-fragmental lentils. Often it was overlooked, at places.

The clinothem front has not been distinguished from the pre-existing fondothem in the mapping and it has been confused with the typical clinothem of the

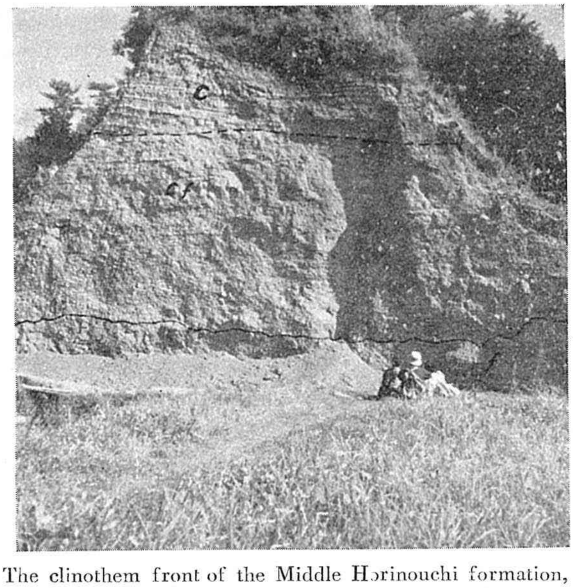

Fig. 7. The clinothem front of the Middle Horinouchi formation, observed at Ishigami north of Kakegawa. C: clinothem, Cf: clinothem front, f: fondothem, the Tamari formation.

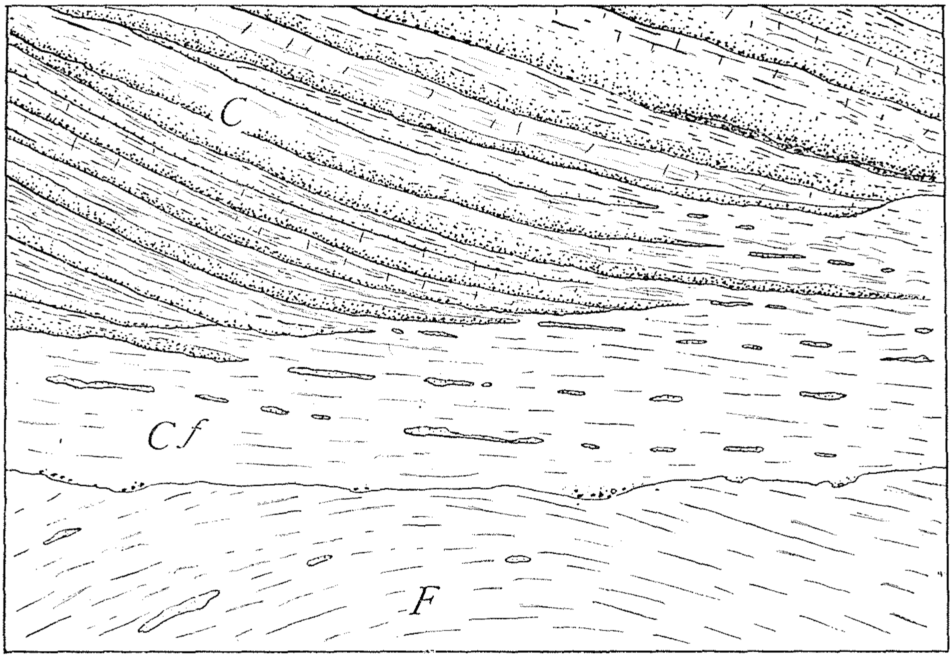

Fig. 8. Overlapping clinothem and clinothem front, diastem over the basal fondothem. C: clinothem, Cf: clinothem front, F: fondothem.

Horinouchi formations at exposures where the front has unbroken sandy seams. The clinothem front north of Horinouchi town frequently contains *Sagarites chitanii* which is not uncommon in the lower subdivision of the Horinouchi. The front parts exposed at loc. 901 a kilometer northeast of Kakegawa town yield cold deep sea shells such as *Euspira pallida*, *Propebela totomiensis* and *Limopsis tajimae.*

The surface area colored as the Tamari formation in the map shows a peculiar outline, and for this reason, the mapping work of the writer has been depreciated by some. The southern boundary of the area runs approximately at right angles to the general strike of the Horinouchi. Such a relationship between the two formations resembles an angular unconformity in which the superposition is reverse. But the Horinouchi beds always lie over the Tamari. As seen in many exposures, each bed of the alternations oversteps the subjacent bed along the boundary. Therefore, the bedding planes of the top beds are not perpendicular to the basal plane, but they make very low angles with the latter. The clinothem abuts on the pre-existing part of the fondothem along the south boundary, and there is few clinothem front. This side of the Tamari area probably represents a part of the wall of trough a large submerged valley.

The southwestern boundary is different. The general trend of the overlying Upper Horinouchi strata are parallel to the strike of the boundary plane which is an ill-defined diastem. It is evident that the upper strata of the clinothem overlapped the edges of those already formed subdivision. This is not a transgressive overlap, but an out-building overlap. Presumably, the trough, in which the lower and middle subdivisions of the Horinouchi were deposited, was filled up with sediment at the end of the Suchian age. However, the out-building construction of the clinothem did not come to an end with this event. The washed out material from the top of the shelf made a regular and even slope extending over both the Kakegawa and Horinouchi areas. The fore slope i. e. the clinoform surface was smooth. Supposedly turbidity currents glided over the slope as sheets almost continually, but certain voluminous streams strong enough to erode the bottom of loose sediment made minor channels of a dendritic pattern, and those remained as scour diastems after being filled with sediment.

The clinothem front is observed along the other sides of the Tamari area. It is difficult to distinguish the front from the pre-existing fondothem, which may be continuos to another older part of the clinothem. However, generally speaking, the front has more sandy beds and lentils, and its base is marked by the characteristic fossil-fragmental or glauconitic deposits. Some of the front sands are very thin and some strata of the clinothem have no frontal flat part, the inclined sandy stripes show wedge-like terminals, as observed in many exposures, on the surface of the underlying fondothem. Similar figures may appear in sections of the filled channels. Whether the diastem is representing an apparently horizontal initial surface of a fondothem or a steep side wall of a channel is difficult to infer. It is observed, however, that each sandy bed of the clinothem is made thicker toward the overlapping bottom, while each bed

a

b

c

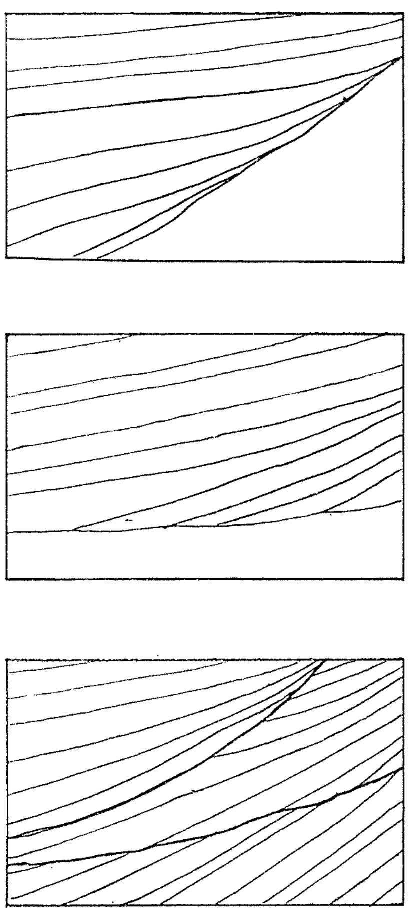

Fig. 9. a: converging bedding. b: diverging bebbing. c: cross-bedding of clinothem.

of the channel fill is made thinner close to the wall. Diverging bedding of graded strata over a massive muddy bed is a characteristic feature of the former case. It may be conceived that more sand grains accumulate upon lower parts of a slope. Diverging bedding is the structure of artificial embankments and natural talus. Contrarily converging bedding of alternating strata toward the boundary means the channel wall. The process of the convergency is related to the structure of the current, but such details are not the object of this paper. In the north hill area, there are many sections, in which several successive channels with the converging beds inside effectuate a type of cross bedding.

The sandy beds not terminate at the bottom are continuous over the apparently horizontal bottom forming the clinothem fronts. Therefore, there is a complex of a number of small discontinuous diastems, while the side-walls of channels are usually smooth and concave and will appear as a simple scour diastem.

The most characteristic feature of the clinothem is graded bedding. Every bed of the Horinouchi formations is 10cm on an average in thickness, of which basal 3 to 7cm is medium-grained greywacke and the remainder is mud. The greywacke sands are conspicuously laminated, often micaceous or carbonaceous, not well graded inside, but pass insensibly into the silt or mud above. Inasmuch as the gradation zones between the sandy and muddy beds are very narrow at several places, the sets often appear as if they are mere alternations. Winkler called such alternations of the Flysch "Bändermergel" and the normal graded beds "Flyschfazies".

Kuenen, Natland, Menard and Migliorini mentioned that the laminated sandy beds frequently show peculiar structures such as crinkled bedding, laminal contortion, stripped streaks of clay and clay pebbles. The surfaces of subjacent

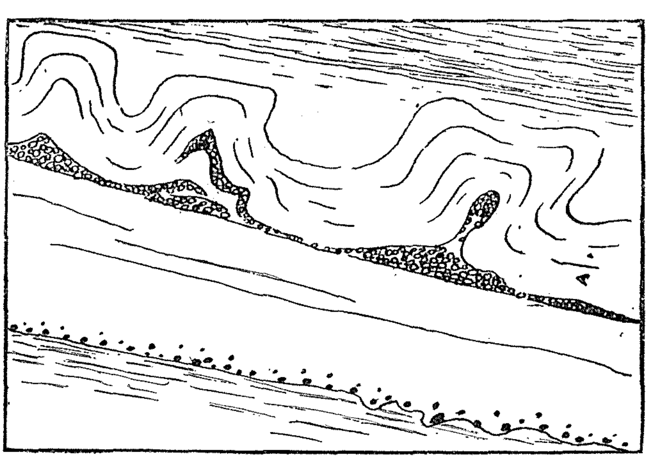

Fig. 10. Crinlked structure in a graded sand stripe with a pumice seam.

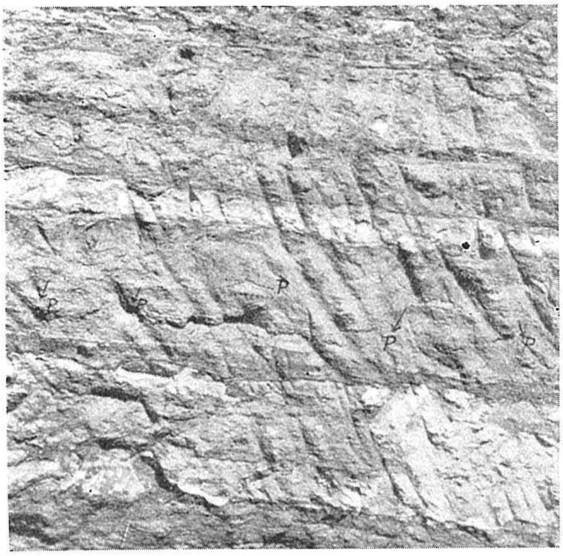

Fig. 11. Crinkled bedding in sandy bed between tuffaceous silty beds. Notice the pumiceous lentils P, Upper Horinouchi at Uchida south of Kakegawa.

mud beds are mostly uneven. The exposed bare surfaces show flutes (Rich, 1951), that were made by erosion of the under-currents. Parallelism of the long axes of flutes tell the direction of the currents. Current ripple marks as illustrated by Natland and Kuenen are very rare in the clinothem of Horinouchi.

The mechanism in formation of crinkled bedding suggested by Migliorini can be supported in part. Vertical cylindrical structures below the bulges are distinct with the crinkled laminae of the Horinouchi, but as shown in figs. 10, 11, 12, inside of such structures, more permeable laminae consisting of fine pumice intrude upwards. This is a favorable disposition for the hypothesis that extruding water by settling is the cause of crinkling. Although the complicate mechanism has not been clarified as yet, the curious deformation will be ascribed to work done by the under-flows.

The lower surface of a sand bed is occasionally extended downwards in irregular pockets. The present writer is given to understand that the pockets are rather rare when the subjacent bed is muddy. Natland and Kuenen mentions this very significant feature in the graded sandstones at Ventura River, California. They are considering that the pockets were developed by the coarse grains filling them, settling on a bottom of fine mobile sand and then sinking into the sand by differential loading. Even huge boulders in the clinothem of the Horinouchi were not efficient enough to make significant depressions underneath them.

Therefore, the bottom was not so slimy in this case.

As an indication of bottom slope, Natland and Kuenen noticed "pull-apart" structure in the Pliocene rocks of California. No similar structure is found in the rocks of the Sagara-Kakegawa nepton. Clay pebbles are only observed in certain thick sands such as the Daitoryu sand. The base of this bed was described as contemporaneous erosion in a note book of the writer many years ago. These medium-grained sand beds are massive, homogeneous and more quartzose alike. Most probably these exceptional sands are parts of wedges extended from the undathem above. At least two distinct beds of such undathem edge sand are found to the west of the town of Horinouchi abutting on the fondothem the Tamari formation; the lower bed 3m thick is the Daitoryu sand. These edge sands reappear in Higashi-Yamaguchi 5km north-west of Horinouchi. A few more edge sands are inserted in the Lower Horinouchi near the north border. Two separate fossil-fragmental limestones occur at Kumomyo north of Horinouchi. They contain shells of lived under shallow littoral waters such as *Suchium* and *Operculina*. This lithofacies is another aspect of the undathem edge sands.

Contortions in laminate sands are different from crinkled bedding, in that the contemporaneous deformation, being a type of similar folding, is much stronger and often overturned. The crinkled laminae frequently exhibit unparallel configurations, that show an internal cause as suggested by Natland and Kuenen, while the contortion is the formational deformation, in which the sheet of loose sand as a body was folded. Kuenen and Migliorini discovered a steep anticlinal

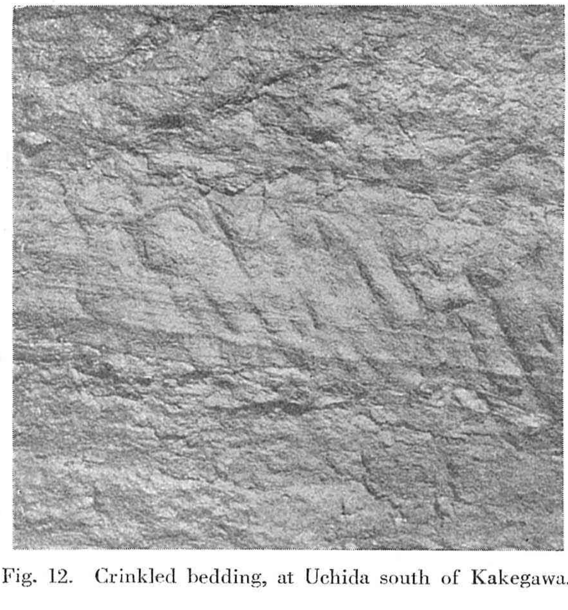

Fig. 12. Crinkled bedding, at Uchida south of Kakegawa.

Fig. 13. A peculiar intraformational structure in sand bed of the Nango formation; a more accentuated crinkled bedding? At Suginoya near Kakegawa.

fold in the distal silt and clay of the experimental deposits by turbidity currents. Kuenen and Menard (1952) consider that the deformation is due to sudden emplacement of overburden. Certain intra-formational distortions can be attributed to drag by the gliding superjacent strata of the clinothem. Forces exerted by dense currents or mud flows cannot be neglected. No more positive criterion is at hand to solve the problem.

However, contortions in tuffs are different from those in the sands. Presumably the mass of minute fragments of glass in water upon the slope was very mobile at the initial state. The complex folds of glacial ice are similar to the flow-folds of tuffs in appearance. A sheet of polycrystalline ice behaves as a plastic body by recrystallization, but a blanket of pyroclastic dough may act as liquid with a high viscosity. A slight devitrification in the diagenetic stage may exert cohesive forces in the mass of glassy particles. Accordingly tuffs of the pyrozones among the subconsolidated rocks of the clinothem make crags which are resistant to erosion. The folds of tuffs cannot be considered as effects of the drag by glide of the overlying sediments, since the boundary is blended and there is no slip plane around it. The fold axes are approximately parallel to the strike and normal to the initial dip; for instance, 2km SW of Horinouchi station, the axes run WNW, and the initial dip computed from the nearby flutes is SSW.

Kuenen and Menard observed in their experiment that the upper water film of clay and silt of one of the beds has been locally stripped off, and forms streaks passing up sharp angled wedges in the covering bed, There are a few natural examples of stripped streaks in the clinothem of Horinouchi. One observed at 1.5km west of Horinouchi, is shown in fig. 16. Besides a wedge of silt, there is a laccolith of sand covered by laminae of silt, apparently exhibiting the first step of the stripping process. It is known that the wedge is pointing in the direction of current, while the piece of silt layer stirred up reverse to the current has a torn rear surface. This peculiar structure seems to be in connection with the crinkled bedding, as it takes place by the side of large crinkles in the same bed.

Another structure is cracked mud. The mud bed is a meter thick massive mud in the Upper Horinouchi and is exposed 2.7km ENE of Kakegawa station. The cracks are open and filled with intruded sand which rose from the sandy layer beneath. The appearance is like an igneous intrusion on a small scale. The spaces occupied by sand were evidently widened after the rupture and most probably even a kind of stoping by sandy water was operative. The bed passes laterally into a sand bed which contains angular clay pebbles, reworked pumice and coarse sand grains. The cracked mud is presumably another result of the overburden, but the mechanism is not known.

Cross bedding is seldom seen in the clinothem, although there is a cross bedded micaceous greywacke bed in the Middle Horinouchi formation near Horinouchi.

Each bed of greywacke which composes the clinothem with the muddy matrix

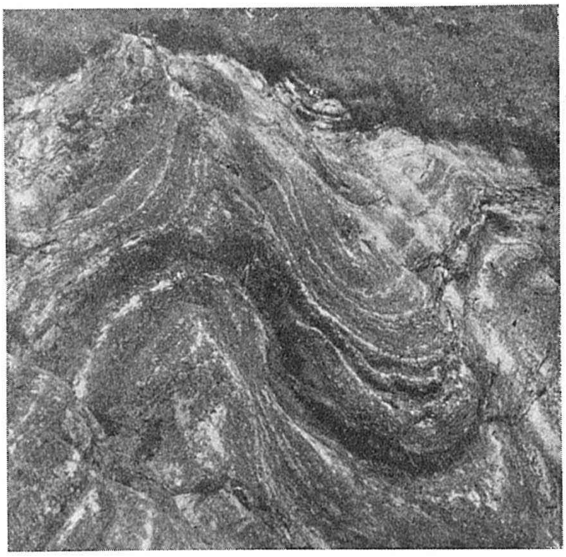

Fig. 14. Intense contortion in the pyrozone 1, near Horinouchi.

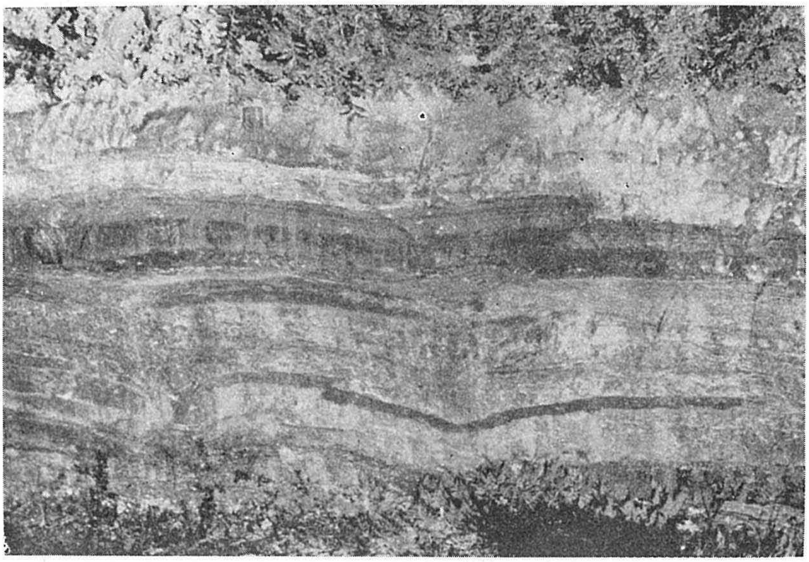

Fig. 15. The same horizon as fig. 14, but little contorted, slight folds and a fault suggest the origin of of contortion. About 4km south-east of the first locality (fig. 14).

is blanket like in form, being wide but thin. Extension of such a blanket cannot be measured, because the exposures are all small and discontinuous. Thousands of sand blankets are similar in grade, composition and in all appearances. The strata, however, are never infinitely spacious. There are many exposures in which certain beds are thinning away into the muddy matrix. Sometimes a tapered end is followed by a chain of sandy lentils which lie on the same level.

The sands are inferred to have been derived mainly from the north northeast by turbidity currents. The direction can be deciphered from the flutes and ripple marks on the surfaces in muddy beds.

In an early stage of the clinothem development, there was probably a sea cliff near the north boundary of the present Horinouchi formations. The cliff was made of rocks of the Kurami group (Middle Miocene); and there was but a very narrow wave-cut terrace in front. The Kurami rocks were more or less indurated, but not strong enough to hold a high cliff. Rock falls and land slides would have been very common. The fallen debris made tali and beaches along the foot of the cliff. The tali and beaches were embedded in the normal clinothem, making wedges of conglomerate.

The conglomerate contains heterogeneous boulders and pebbles; also shell fragments are a chief constituent at places. Large angular boulders of the

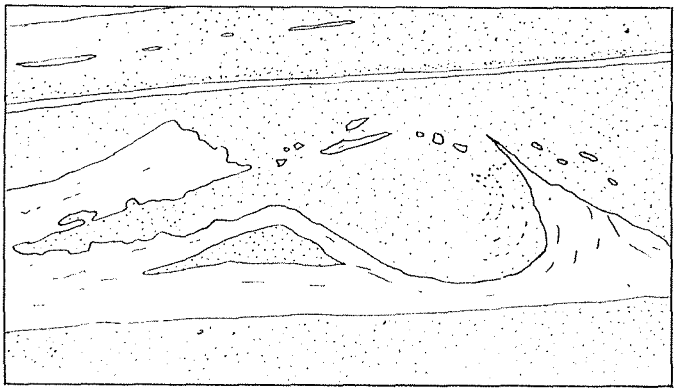

Fig. 16. Stripped off silty shale, side scale represents a meter. Observed near Horinouchi, in the Middle Horinouchi.

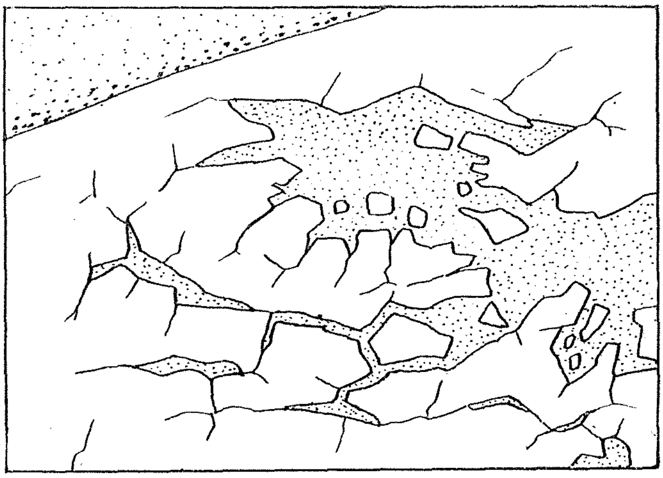

Fig. 17. Cracked mud with sand intrusion; in the Upper Horinouchi. Scale: side a meter.

Awagatake sandstones and hard greenish tuff mudstones of the Kurami take place at random in the conglomerate. Well rounded pebbles derived from the older rocks are not very common. The conglomerates are not sorted and not graded, but intercalate occasional seams of sand. They never pass into the greywacke bed. The matrices are variable, being conglomeratic, fossil-fragmental or silty. It is known by observation that the average diameter is large where the wedges are thick, but exceptional large boulders are frequently found in the thin sides.

Boulders larger than the thickness of conglomerate are not uncommon. The sandy or muddy beds over and below such boulders are bent as shown in fig. 19.

As has been mentioned, the conglomerates are intercalated in the clinothem, but they are thicker toward the north border and they replace all the normal clinothem members, making a peripheral zone of conglomerate. This zone ranges from the bottom to the top of the Suchian stage. All the wedges thin away within a zone few kilometers wide along the border. Density currents were probably operative to spread the finer material of the conglomerates, although the main parts of wedges seem to have been built by accumulation of fallen debris from the sea cliff.

A performance of submarine mud flows, the most viscous turbidity currents, unlike the the peripheral conglomerate, is a massive bed of muddy matrix with heterogeneous gravels, in so far as the writer has observed at Hisamine near Miyazaki, Kyushu. Such a thick muddy conglomerate does not occur in the nepton under consideration, but there are a few beds representing only small accidental slumps on the slope. Average density currents carried the boulders from the cliff seem to have been less bulky than those transporting medium sands from the north, as shown by thin layers of granules reworked from the wedges.

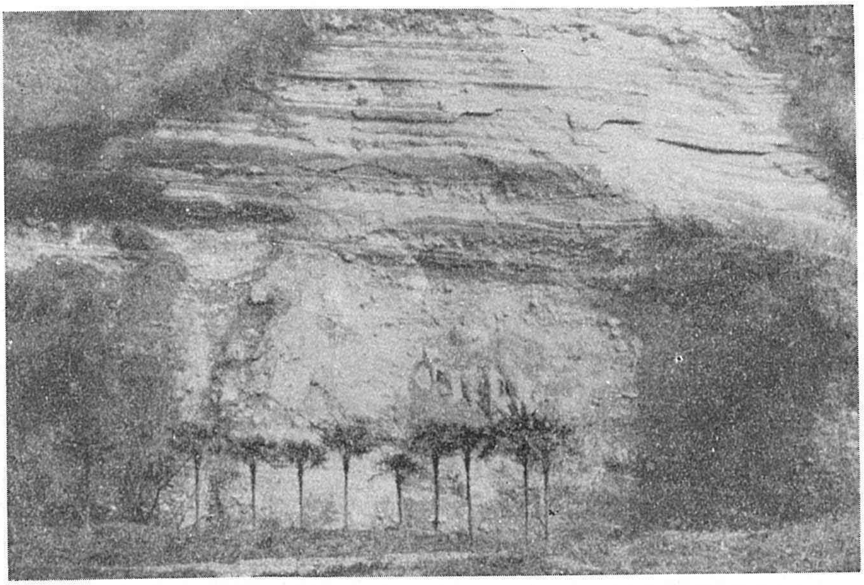

Fig. 18. The peripheral conglomerate of the Lower Horinouchi, Kamiyashiro east of Horinouchi.

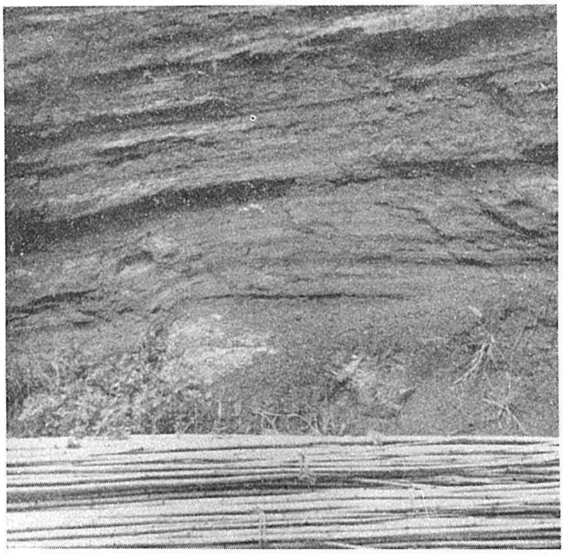

Fig. 19. Curved bedding over a huge boulder, not compaction, at Kawashiro north of Horinouchi.

Sagara sectional nepton

The lower section of the Sagara-Kakegawa nepton represents the Yuian stage. All of the strata which are included in the stratigraphical unit Sagara group make the sectional nepton. The stratigraphical relationship between the Kakegawa and the Sagara has been described as unconformable. This unconformity was shown by mapping, although it appears to be a disconformity in the outcrops. The diagenetic difference between the two units is very slight and the time gap is insignificant as shown by the paleonological criteria.

Generally speaking, the area in which the Horinouchi formations disposed are synclinal. The syncline plunges southwestwards and is very asymmetrical, the northeast limb being so wide and gentle that it may be referred to a general tilting, while the other limb is comparatively narrow and evidently effected by the upfold of Sagara. The intensity of the upfolding movement increased during the development of the Horinouchi clinothem and the movement did not cease after the completion of the construction of the nepton. The Horinouchi clinothem has developed filling the synclinal trough *pari passu* the depressing movement. The previous bottom material of the trough was the Sagara sediment.

There was no interval of sedimentation between the Sagara and Kakegawa, because the operation was carried on under the sea near shore; but before the out-building work proceeded, the the bottom material may have been uncovered elsewhere. Therefore, the seeming unconformity is by no means a true unconformity, but is a diastem.

The diastem between the Tamari fondothem and the Horinouchi clinothem has been stated in a preceding chapter. The pre-Suchian movement is proved by discordant deformation of the Sagara rocks as well as the Tamari. However, along the south-eastern boundary of the clinothem, the post Kechienjian movement caused an acute flexure of the strata of both the Horinouchi and the underlying Sagara.

The Sagara group is subdivided into several members. Inasmuch as the lithofacies is very changeable, the nomenclature seems to be redundant. The main part consists of a muddy fondothem, in which several clinothems are inserted. Some clinothems are conglomeratic being made of alternations of heterogeneous conglomerate, sand and mud. Two large lenses of beach gravels occur in a high level. The wedges of heterogeneous conglomerate originated from a precipitous shore to the north of the Sagara sea in the Yuian age. The sea cliff was made of the rocks belonging to the Lower Miocene in the main. The

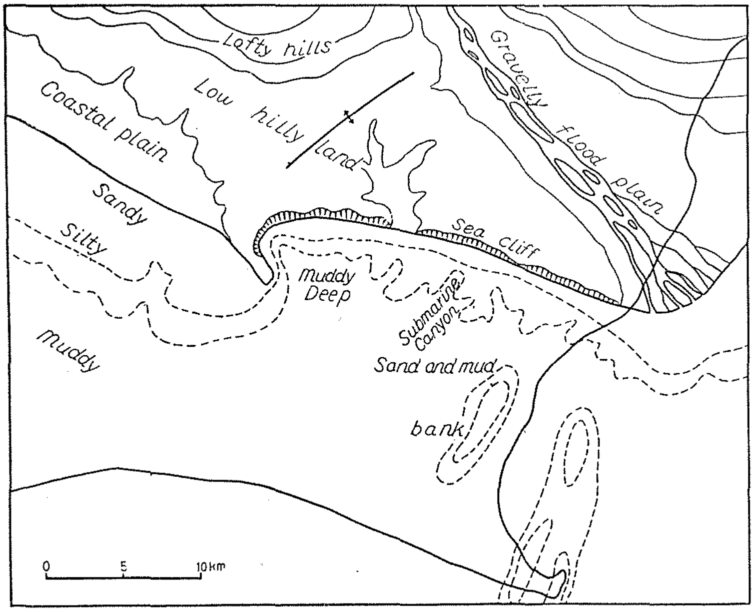

Fig. 20. Tentative paleogeographic map of the Suchian age (Early Pliocene) south-western Shizuoka prefecture. The area same as fig. 3.

beach gravels were derived from the mouth of a river, so that the well-rounded stones are similar to those found on the present beach near the mouth of the Ooigawa. More likely the conglomerates are components of the clinothem, or they be parts of a delta which was extremely asymmetrical, because of strong waves and currents. The pebbles rolled down the slope by gravity only, or possibly assisted by traction of turbidity currents which occurred frequently there at that time.

The conglomeratic clinothems are distinguished from the sandy clinothems as the former are pervading channels engraved on the latter. Both of the clinothems which have been considered belong to the same horizon, so that they represent different lithofacies. However, the out-building growth of the two clinothems was not synchronized. A more suitable stratigraphical term for this relationship is superpositin. There were at least two distinctive channels in the area now occupied by the Sagara sectional nepton. The north one was about 3km wide at Sakabe and the south one was presumably a little narrower at Hagima. Both the channels received the conglomerates of beach gravels, for they are extensions of an undathem, but there is no reason to suppose that the beds were deposits of a beach itself.

Anotner working hypothesis to explain the twofold fills is derived from a possibility of submarine head erosion by turbidity currents. When the scouring action was limited over the off shore muddy and rocky bottoms, the heterogeneous conglomerates were deposited downstream, but after the channel cut in nearshore deltaic, zone the reworked beach gravels became the chief material of the fill. This assumption is discrepant with the fact that the basement rocks were not exposed in the channels. Therefore, it is more reasonable to infer that the miscellaneous rock debris in the conglomerates were derived from the sea cliff as stated before. The lower conglomerate, however, contains a considerable amount of large and small blocks of the massive mud of the Sagara. Whether these blocks came from the wave cut terrace in front of the cliff or they were derived by slumps from the soft bed around the channels is not known.

Syntectonic Construction

As discussed in the preceding chapters, orogenic movements have disrupted with the construction of various neptons. It must be emphasized, however, that the movements were episodic and localized phenomena of long continuing creeping* movement of the foundation rocks. The mode of construction depends on tectonic intensity and supply of sediment. The paleogeographical circum-

* Creep is a plastic flow or a pseudo-viscous flow of rocks under the influence of continuously acting stress. A mechanical behavior of rocks in lithosphere, but not "creep" of surfacial weathered rocks.

stances of various Tertiary basins in Japan were similar to the present littoral environments around these islands, being well provided with a great amount of clastic sediment. This region of Asia has been a mobile orogenic belt ever since late Paleozoic times and it is emphasized that the movement was persistently most active during the Cenozoic Era.

Since the intensity is not a measurable quantity, its qualitative and comparative changes throughout the geological ages are only deduced from the criteria of field observations. Certain phenomenal revolutions have been overestimated by geologists. For instance, a nonconformity itself does not neccessarily prove an orogenic acceleration during that interval. In the process of stratal deformation, upfolds are apt to be localized, while other parts remain undisturbed. It is highly probable that localized disturbances have occurred in the geosynclinal development taking place under the sea for the most part. Therefore, a syntectonic nepton may comprise diastems resembling an angular unconformity. Immediately after the uplifted parts have been truncated by wave erosion and the purging work of currents, the undisturbed zones with the consecutive new sedimentary covering would have been disturbed, inasmuch as the distorting stress was still operative. The after disturbance and the truncatian may have occurred at the same time. The result is the overlying beds are apparently unconformable to the older sectional nepton. Even both the sections above and below in the initially undisturbed zones are intensely folded as the result of the consecutive orogenic force. The diastems over the primary upfolds may be a little larger than the corresponding diastems over the other parts, because there is but little sediment due to the erosion intervals. Such apparent nonconformities also take place in an older geosynclinal nepton which was grown under an intense tectonic environment. The writer is sceptical about the orogenic phase hypothosis thriving in this country, deduced simply and naively from "angular unconformity".

The Sagara-Kakegawa nepton at present is in an early stage of tectonic development. There are a few significant closed anticlines in the Sagara and Omaezaki districts. The wide area between the old land and the folded zone of the east was a depression forming a submarine trough in which the clinothem of Horinouchi has developed. The trough has been so prepared as ready to receive the sedimentation by turbidity currents before the beginning of the Suchian age, but the tectonic movement has not ceased at that time, as shown by the flexure of the clinothem along the east side. A similar configuration has existed during the preceding Yuian age over the same area. The hinterland was hilly, the sea-cliff was high, the wave-cut terraces were compound and the trough was very deep.

As has been already discussed, the west side of the Kakegawa area was the site of the quasi-cratonic shelf accompanied with a considerably wide coastal plain. This is a contrast to the tract of the high-relief in the east. The neptons upon quasi-cratonic shelves are different from those of the true cratonic shelves in their hastier construction under the violent tectonic environments and with the inexhaustible supplies of clastic sediment. The out-building works have been very quickly accomplished in subaquatic deperssions. Accordingly there are some considerable bulks of clinothem in the neptons. As demonstrated by Rich, it is highly possible that thick neptons chiefly consisting of several clinothems and fondothems have intervening wedges of undathem and subundathem. No conjecture on syntectonic developments of these compound neptons is made at present.

The construction of the east part of the Sagara-Kakegawa nepton took place in the basin of a high-relief. The fact conduce to that the stress seems to have been concentrated in the east. Inasmuch as clarified by the field survey, that the primary anticline of the east has been closed, and that farther eastward there are the secondary upfolds not yet closed, it is surmisable that a stronger stress zone have been transferred to the east, so that the clinothem in the Horinouchi basin was sheltered from a severe deformation. Such state of stress in the nepton was aroused by forces exerted from the moving basement.

The vertical components of the basement motion at various places in the area are hardly estimated with the geological criteria, but comparative vertical movements are able to be judged by the order of nepton elements. Assuming changes in supply of sediment are negligicle throughout the constructive work, a succession of elements as follows means accelerated subsidence: undathem-subundathem—clinothem—fondothem. Such a succession is the type represented by the shelf part of the Sagara-Kakegawa nepton. An abrupt submergence is presumably the chief cause of tachygenetic construction in which the bulk is fondothem when the supply of sediment does not match the movement. The Saigo formation (Miocene) in Kakegawa area is an example of the tachygenetic nepton, taking but small undathems and clinothems. However, a geosynclinal trough adjacent to an elevated geanticline, a chief source of inexhaustible clastic material, must be a site of thick clinothems with a cap of undathem. The undathem cap indicates the final aspect of the nepton construction in a trough. Therefore, during the accelerated phase of the sinking movement, several wedges of undathem would be inserted in the clinothem members.

Fluctuation of the movement is possible; yet, the relationship between the movement and the undathem insertion has not been made clear. In the course of later static stage of a tachygenetic construction, the fondothem may de successively covered by a subundathem and an undathem, but, since the bottom gradient is now very low, there happen very few turbidity currents to built a clinothem. If a nepton is uplifted in the final stage, the above process will be accelerated and after the intermediate element will be omitted, so that the undathem will directly cover the fondothem. In this case, the top element is well marked from the bottom elements with an erosion surface. This is not a disconformity, but a diastem.

Summary and Conclusion

A nepton is a somatic component of the earth's crust made of sedimentary rocks. Shapes and sizes of various neptons are variable, but a normal nepton on a continent has much greater width than thickness, and so makes a veneer over the basement. Geosynclinal neptons are depressed prisms in shape. Asymmetrical skew prisms are the generalized form of neptons born in a geomonocline. In the orogenic belts of the Alps and Himalayas, large parts of prismatic neptons are exposed, but in the geanticlinal archipelagos such as Japan islands, often only partial neptons that were formed in bays are visible on the land surface.

More than two such partial neptons of the same geological age make a nepton group. A nepton series consists of more than two superposed partial neptons of different ages. Each partial nepton belonging to a nepton series is a sectional nepton of the said series. A sectional nepton may be conformable or unconformable to a subjacent sectional nepton. An unconformity in a nepton series occurs, according to definition, when both tectonism and diagenesis of the older neptons have progressed considerably during the interval.

The area and forms of basins have changed from time to time. Also, the location of such a basins has shifted. Neptons compose the earth's lithic surface along with other geological components such as plutons and volcans. The term "volcans" marks the volcanoes, as well as the various hypabyssal igneous bodies. The basement complex, that is the older crustal material, is supposed to be made of complex groups of metamorphosed plutons, volcans and neptons. Plutons, volcans and basement complex are not the subjects at present; moreover, there is no need to give an account of them here for geologist.

It is a well-known fact, that the aggregate volume of the all neptons is very small compared with the other portion of the earth's crust, nevertheless the total area occupied by them on the land surface is quite large. The wide but thin veneering continental neptons are simple in structure and less objective in considering the syntectonic construction than those born in the mobile orogenic belts.

Various complete or partial visible neptons may be classified according to their geneses, to their environments or to their modes of construction. A tentative classification is as follows:

A, Cratonic neptons.

1, Intra-cratonic neptons, for instance, Jurassic and Createceous non-marine nepton groups of East China.

2, Marine transgressive neptons, for instance, the Mesozoic nepton of West Europe.

B, Geosynclnial neptons.

1, Geosynclinal neptons under low tectonic intensities.

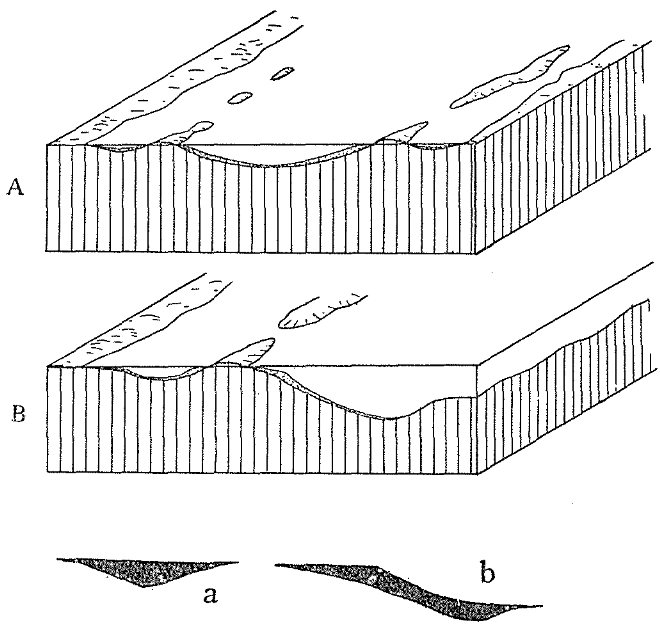

Fig. 21. Geosynclinal prisms: A, symmetrical prism at an initial stage, B, geomonoclinal prism at an initial stage; a, schematic profile of a symmetrical prism, b, geomonoclinal nepton.

2, Geosynclinal neptons under high tectonic intensities.

2a, Symmetrical prismatic neptons, like the Alpine nepton series. (Fig. 21, 24, A, a)

2b, Asymmetrical prismatic neptons, like the Circum-Pacific geosynclines. (Fig. 21, B, b)

The asymmetrical geosynclinal neptons (B 2 b) born in younger geological ages are only partially exhibited upon the land surfaces. These partial sectional neptons are classified into the following forms. The long term "partial sectional nepton" is now replaced by a single word "nepton" in short.

1′, Quasi-cratonic inland neptons.

2′, Quasi-cratonic shelf neptons.

α, normal neptons.

β, Tachygenetic neptons.

γ, Bradygenetic neptons.

3′, Geosynclinal trough neptons.

The last form (B 2 b 3′) covers several varieties, possibly be subdivided at least into tachygenetic and bradygenetic types; but, the differentiation seems to be very difficult. The trough neptons are made of elements, such as peripheral conglomerate, clinothem, clinothem front, fondothem, undathem edge sands (conglomerate), undathem and subundathem. Combination and relative volumes of these elements in a nepton should be analytically confirmed in consideration of its syntectonic construction.

Specialities in tectonic disturbance of various neptons after their developments are not the aim at this occasion, but, it is suggested that, generally speaking, cratonic neptons are broken in blocks, frequently accompanying surfacial low angle clean cut thrusts, whereas the thick geosynclinal neptons are intensely folded. Overfolding of a calcareous symmetrical prismatic nepton arouses superposed nappes, but a noncalcareous asymmetrical prismatic nepton series may make a bellows structure which is consisting of complicate isoclinal folds with high angle thrusts·

Behaviour of a quasi-cratonic nepton is not quite like that of a true cratonic nepton in deformation, inasmuch as it lies over a mobile geanticline. The secondary basement made of the older neptons and plutons is liable to flow under devoted certain state of stress. The effects of the foundation folding must be more evident in quasi-cratonic neptons than in the continental neptons.

Another suggestion is made herewith that the genetic classification of conglomerates will be emendable adding a few particulars;

1, Autochthonal basal breccias; irregular beds at the very base of tachygenetic neptons, often monogenetic.

2, Para-autochthonal peripheral conglomerates: wedges of subangular blocks and rounded gravels in marginal part of clinothems.

3, Allochthonal conglomerates, consisting of rounded pebbles derived from the nearby hilly land or remote places.

a, Normal basal conglomerates.

b, Bradygenetic conglomerates, fluviatile and deltaic origin.

c, Beach gravel edges in clinothems.

4, Gravelly mud flows: very thick turbidity flows, subaquatic.

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