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STUDIES OF THE SUB-MARINE DEPOSITS OF THE COASTS
OF THE UNITED STATES AND THEIR BEARING UPON
PRESENT-DAY SEDIMENTATION.

F. T. Thwaites.

The references are in possession of W. H. Twenhofel

__Introduction__ The following preliminary studies were started in 1908 under the direction of Professor Blackwelder and the report mainly written at that time. Unfortunately the limitations of American libraries in the way of works on the subject of present-day sedimentation are very great. Most of the work on the subject has been done in Europe as geologists here are interested more in field and economic geology, while abroad they have passed beyond and are now merely elaborating their former knowledge. omit The writer has not endeavored to find all the incidental references to sedimentation in geological works. Much of this material is of too speculative a nature or based on too slight observations to be of much value. A slight critical inspection will reveal to any one the extent to which pure speculation and inductive reasoning have shaped the judgement of most students of this subject. Most of us, the writer included, are too ignorant of the sea, its methods, its moods, and characteristics, to have the real background of intimate acquaintance upon which safely to found any theoretical conclusions. Moreover, the fact that the bottom deposits can be only studied in plan and not in section hinders us from readily interpreting their significance. Then too, the difference if any, in physical conditions, temperatures, currents, tides, winds, and so on between now and the ancient geological periods, is virtually unknown, and too many have in the past allowed their imaginations to run away with them.

For the reasons set forth above, the subject of marine sedi-

I think a boiled-down version of this paper, esp. the last part, is well worth publishing. I'd advise cutting out most of the <u>Pessimisms</u> on the first page and a half, bringing it up to date as to Vaughan's work in Gulf of Mexico, and then sending it to Vaughan to see if he'll criticize it and advise about its publication.

L.M.

mentation, the foundation of all stratigraphical studies, has never been thoroughly worked out. [Apparently most geologists seem to think that they know all there is to be known about it and do not pursue the subject beyond its most elementary phases. Most American text books are very poor in their treatment of this important subject.] A close study of the methods of sedimentation is especially important today now that we have gotten away from the idea that conditions under which the older rocks were deposited were necessarily different from those of the present time. It is also of great importance to know more about marine sediments now when we must discriminate them more carefully from those of continental origen, as well as in the reconstruction of geography of ancient times. i/

omit all up to here?

Possible Fields for Study. Almost all of the sedimentary strata with which we have to deal were deposited in comparatively shallow water. The interiors of the present continents like the Mississippi valley, not the borders of the oceans possess the fullest sedimentary series. Almost the only exception is our southeastern Coastal Plain. Both from the evidence of the strata and for dynamical reasons it is improbable that any portion of the present land has ever been depressed more than a few hundred feet below sea level, at most not more than a few hundred fathoms. As a measure of the possible depth to which the continents may at times have been submerged, we can cite the known thickness of over 2500 feet of undisturbed Paleozoic marine sediments in the Mississippi valley. (From the occurrence of such a thickness it may readily be seen that at times water might have been at least

shallow water?

Chalk?

Much more

[*(Chamberlin & Salisbury, vol. III.) — Insert above.]

this deep over the continental interiors although the frequent marks of shall ow water origin in the Paleozoic sediments shows that very deep water was the exception rather than the rule. There is, however, no reason to deny the possibility if not the probibility of quite deep epicontinental seas for it is well known that the continents are not always in strict accordance with the theory of isostacy

Possibility yes, No probability.

Why?

Unfortunately we have few seas today comparable with those of Paleozoic times. The continents are now out of water after the great earth movements of Tertiary times, and have scarcely begun to settle back again to the position which they seem to have occupied most of the time during recorded geologic history. The White, Black, Baltic, North, and Irish seas and Hudson Bay are among the best examples of epicontinental waters that exist today but glaciation has affected them so as to lessen somewhat their value for the present work. The same fault is also to be found with the northern lakes. The Caspean, Aral, and Dead seas are excellent examples of sedimentation under desert conditions but this lies outside the field of the present work. Behring Sea and several extensions of the continental shelf are all that remain. Of the last, parts of the Atlantic coast of North and South America, some of the banks of the Antillean region, and a few shallow seas north of Australia are the best. Most of the shores of the Pacific, Indian, and Southern Oceans descend abruptly to depths of 2000 to 5000 fathoms.

Sure?

Yellow, etc
Hudson B

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__Previous Investigations__. Aside from a few English investigators whose brief works will be cited later, the sole

Many geologists to appreciate importance

geologist to appreciate the importance of the study of modern sedimentation was Delesse. In 1871 he published his work entitled "Lithologie du fond des Mers." This work was compiled from all existing hydrographical surveys as well as from personal investigations on the beaches and off the coasts of France. The subjects treated include the nature of the bottom deposits, their relation to the shores, probable age if not recent, relation to currents, etc. Although the author belonged to the old school of cataclysmic geologists (see reviews by Lebour, and Firket) this book stood as the sole work in the field to the time this paper was first written. This work was not then available. In revision it has been read but the descriptions of the American coasts are very meager. In more modern days, M. J. Thoulet and the engineers of the French Hydrographic Office have compiled lithologic maps of the sea bottom off the French coasts designed for the use of mariners. Other European nations seem to have done the same but none of the charts are available. Grabau cites some German and French authors on this subject but their works are not available at Madison.

Attention was diverted about the time of Delesse to the exploration of the unknown region of the deep sea, the blue water "off soundings". The famous expeditions of the "Challenger," "Blake", Albatross" and other vessels were made with this view entirely and on their maps of bottom deposits all those of terrugenous origin are grouped under the same color. Aside from some study of the green and blue muds, coral reefs, greensand, and a few other rather deep water sediments, little of value for the present study can be obtained from their results, otherwise of such great importance. However, they demonstrated that no part of the continents has ever been under the deep sea.

<u>Sources of Information</u>. Although the United States Coast Survey has collected thousands of samples of the sea bottom and they have been at times examined by experts whose reports are published, but one satisfactory map of the distribution has been published (Pourtales, 6) and that is far from accurate in detail. Three maps of the English Channel are available but otherwise there is nothing of any great value in our libraries. The investigation has therefore been confined to the coasts of the United States with adjacent portions of Canada and Mexico and maps constructed on the Coast Survey sailing charts from the more detailed coast and harbor surveys.

On these charts, in accordance with ancient custom, the configuration of the bottom is indicated by figures showing the soundings in fathoms but contour lines are now being introduced. The nature of the bottom is indicated by abbreviations, the characteristics indicated being those best adapted to determination by seamen who chiefly use a tallowed lead. They are as follows:

wh	white	sft	soft	P	pebbles or pieces
gy	gray	hrd	hard	S	sand
gn	green	stk	sticky	M	mud
bu	blue	rky	rocky	R	rocks
rd	red	crs	coarse	G	gravel
yl	yellow	fne	fine	Co	coral
bk	black	brk	broken	C,Cl	clay
				O,Oz	ooze
				Sh	shells

Kelp, mica and a few other substances are sometimes denoted.

As may readily be seen these characteristics, however valuable to the navigator in determining his location in thick weather, are of little value to the geologist. The terms "hard" and "soft" are especially used in inland waters to denote the character of the anchorage and are of course virtually meaningless. "Rocky" also may mean either bare rock or boulders. On the charts made by many different surveyors and at different times, these terms have not been used with uniformity while occasional errors of proof reading are apparent.

Formations Mapped. In view of these limitations the only divisions which could profitably be made are as follows:

(1) Silicious sands and gravels. These sands always contain more or less comminuted shell which ocasionally predominates, but the separation of shell banks could not be made with any pretence to accuracy. Are you sure?

(2) Muds or clays, chiefly kaolin and extremely fine sand. Muds are of all colors but gray, black, brown, blue, and green are most common; the last owe their color to glauconite. Shells and silicious organisms are found but generally life is less abundant on soft bottom.

(3) Muddy gravel; this is found chiefly in places like the Gulf of Maine. It is said to be most favorable to life as it is in quiet water and furnishes support to fixed forms as well. Its origin is by no means always clear.

(4) Greensand or glauconite is much more abundant than is usually supposed. Where present in a green mud it has not been separated. As it occurs as a filling of foraminiferal or other small shells it is often rusty rather than green (Pourtales, Murray & Renard) but occasionally, as on the Pacific coast, the

color is so deep that the bottom is designated as black sand. In general this recent formation may be distinguished by the greater number of unaltered shells, from accumulations of older greensands, such as most of the areas marked as "greensand " on the chart probably are. The origin of greensand is not fully understood but the best treatment of the subject will be found in the Challenger Report of Deep Sea Deposits (Murray & Renard); it is there stated that glauconitic deposits both arenacious and argillacious form an interrupted band around the edges of the continental shelves just below violent wave action, ~~and~~ where there are no mouths of large rivers.

awk

Needs revision

(5) Rock bottom; under this head it has been sought to show only areas of consolidated bed rock.

(6) Calcareous bottom. The subject of modern limestones is essentially a chemical and biological one and has been investigated by others. For that reason it will be only briefly touched upon here and all the various kinds of calcareous deposits have been grouped under one color. These comprise both chemical, organic (shell and coral remains) and detrital sands and muds mainly derived from the destruction by waves of coral reefs.

(7) Mixed bottom has been shown where silicious sands grade into calcareous or the exact character of the bottom is not known; the hydrographers do not distinguish between these different sands unless the calcareous is distinctly coraline.

Topography of the Sea Bottom.

As we are practically confined to the study of deposition along the continental shelf a few words are needed in order to describe it. It is commonly said to be a gently sloping platform bounded at its seaward edge by a steeper slope beginning at about a depth of 100 fathoms (Murray & Renard, Fenneman). This is only approximately true, however and it should be explained that the 100 fathom line is shown as the outer border both because it approximates to the edge of the shelf and is the limit of depth at which soundings can be made by a hand-line with any pretance to accuracy. In general it lies well beyond the top of the slope which begins very gradually. The depth of this top, or rather break in the slope, varies from a few fathoms on the Bahama Banks to an average of 50 or 60 on open coasts, while there are many places where the true continental border does not begin until a depth of several hundred fathoms is reached. [It therefore appears that the border of the shelf is not always the edge of a cut and built terrace as some have supposed (Blake, Fenneman, Harrison, Delesse) but is primarily a structural feature as shown by Chamberlin and Salisbury]. Proof? Why not both?

The surface of this submarine extension of the continent is usually nearly a perfect plain, regular and monotonous as may be seen in its upraised portions on the Coastal Plain where not yet eroded. Near shore, however, especially within the 20 fathom line there is considerable irregularity. Mariners are continually warned by the Coast Pilot not to approach the land any closer than that line in thick weather on account of the misleading deep holes which occur near shore.

It is the so-called submarine valleys of submerged fiords which intrench the continental shelves in all latitudes and generally off the mouths of rivers, that offer one of the most interesting questions of submarine geology. Studied chiefly by Spencer in this country and abroad by Buchannan, Hull, Huddlestone, Nansen, and others (no ref. except to Spencer), a sharp controversy has been waged over their interpretation. Therefore the subject will not be here taken up. Some good examples are found on the map of the Gulf of Mexico (McGee, maps) but unless soundings are much more numerous, little can be made of them; with the idea that these areas of broken bottom are submerged valleys, the contours naturally will shape themselves into such; [with the idea that they are fault blocks, they become such to the mind of the investigator]. Much more sounding and current meter observations are needed in these localities but the expense of such work is so great that there is little prospect that it will be done. For this reason the studies of the bottom or even the attempt to contour it, have not been carried into the Carrebean Sea, the seat of comparatively recent mountain-making movements.

If not to be considered, why waste so many words on the subject.

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DESCRIPTIONS OF THE REGIONS STUDIED.

<u>Atlantic Ocean</u> -- (shown on U.S.C. & G.S. sailing chart 1000, Cape Sable to Cape Hatteras.)

<u>Gulf of Maine and Georges Bank</u>. The Gulf of Maine in its broad outline, is a bowl-shaped basin nearly enclosed on its seaward side by the broad, low, curving, broken ridge comprising Nantucket Shoals, Georges Bank, Brown Bank, and Seal Island or German Bank (Mitchell). This ridge averages 80 or 90 miles in width and 500 to 1000 feet in height , very gentle sloped if seen on land but sufficent to profuundly influence the tidal

currents and bottom deposits. It is believed to be a wasted chain of islands (Shaler,2 , Upham) of morainic origin. The average depth of water is 20 fathoms or more but the summit of Georges Shoal comes within a few feet of the surface at low tide; tide rips occur there and on Seal Island Bank. The dangerous channels through Nantucket Shoals have been well studied by the Coast Survey (Mitchell,1,2,4,7) and the rapid changes noted. Two types of shoals are distinquished: dumping grounds of sediment falling from a fairly constant current into quiet water and dunes which travel before the current as do those on shore before the winds. (Mitchell, 2)

Why call dunes? Is that not a new meaning of the term

The material of the banks is mainly coarse yellow or gray silicious sands with black specks of basic minerals and many pebbles and boulders of glacial origin. (There are relatively few shells but, as is well known, these shoals are much frequented by fish.) In sheltered bays only, as behind Nantucket, muds are accumulating. (see also Murray,2).

Connection?

Within the basin of the Gulf of Maine, the depth is generally about 100 fathoms and the bottom is very irregular. Some of the features like the course of the 100 fathom line in lat. 43 strikingly suggest moraines. Most of the bottom is covered with mud of brown, gray, green and blue colors with large areas of pebbly mud. The sands are generally confined to the shallower portions but patches of sand and even gravel also occur in great depths. Neither these nor the patches of muddy gravel seem to bear any relation to the configuration of the bottom. Near shore the occurance of mud or muddy gravel is in part explained by the presence of marine plants (Davis,C.A.) A remarkable fact also, is the slight development of sand along the irregular and rocky coast of Maine; the charts of the region are, however, very unsatisfactory. Cape Cod extends north beneath the water level in Stellwagen Bank and Jeffrey Ledge, sandy ridges enclosing mud holes just as the larger banks to the east enclose the main basin. Bare rock bottom occurs in such shoals as Cashe Ledge, and off the coast of Maine but not over such large areas as might be expected in view of the strength of the tidal currents, expecially in the bay of Fundy with its enormous tides (Krümmell). This bay contains much muddy bottom (Delesse).

The tidal currents on the wier at the entrance to the Gulf are very powerful and dangerous to navigators during the frequent fogs; they have therefore been well studied by the coast survey (Mitchell, 6). By the principle of the composition of forces and on the assumption that the sands move like dunes the following results were arrived at.

Sta.	Depth	Locality	Dist. traveled by a particle	Resultant Dist.	Resultant Azimoth
1	60f.	S. channel	18.93 miles	5.25m.	211
2	35	W.side Geor. Bank	24.70	6.42	263
3					
4	29	Mean on Geor. B.	33.00	2.28	2
5					
6b	125	E. Channel	18.77	11.03	129
7	52	N. Chan. near Br'n B.	21.00	5.21	310
8	65	E. " " S.I. "	20.40	5.00	58

Mitchell states that this shows that Georges Bank is in a state of unstable equilibrium, apparently because there is a point between stations 3 and 4 where the effects of the flood are equal and opposite. It will be seen that to the west of this point transportation is towards the northeast while to the east it is towards the northwest, southwest and south. The shoals of Nantucket are traveling west and south. The stations are not the same in all cases as those shown on the chart; further details of the currents will be found in the Coast Pilot.

Block Island Soundings. The roughly triangular area of mud with its apex located some 25 miles southeast of Block Island is known to mariners as the "Block Island Soundings", and has always been a great aid in making the land during thick weather when the sun is obscured; now with submarine bells and wireless telegraphy the case is somewhat different. The outlines of the area differ greatly on different maps (Pourtales, 6, Lindenkohl); the detailed charts of the Coast Survey have been followed but even on these it is rather poorly defined. It is probably changing all the time. The clay is blue or green in color and very sticky. There are also more or less sand, gravel, and shells on it. The surface is stated by Lindenkohl to be more or less reddened by oxidation. The seaward limit of the muddy area is at about the depth of 1000 fathoms and it extends along the edge of the continental shelf from Cape Sable to Cape Charles or even beyond (see analyses). It is in this clay that the famous "submarine canyon of the Hudson" is cut to a depth of 3800 feet (Spencer).

The shallower portion of this depression is floored with a clay similar to that of the Block Island area and with a crust of sand and gravel. It is this which forms the so called "mud holes", off New York harbor. (See chart).

Several patches of a green sand occur in this vicinity.

Pourtales mentions one off the entrance to New York harbor which he thought was a submarine outcrop of the Cretacious of e New Jersey; the others shown on the charts are of unknown origin and composition. It is also said that two small areas of rock occur, but they are not indicated on the charts.

Sandy Bottom. South of Long Island, a nearly uninterrupted sandy bottom covers the continental shelf, which varies from over 100 to less than a score of miles in width. The form of its surface is shown by 10-fathom contours near New York, and is often very complicated. The vague suggestions of valleys should be considered with caution, for this sand is all in motion, as is shown by the discolored water "on soundings" and by the fact that the "mud holes" have been buried out to a depth of 18 fathoms or so. As has been mentioned before, the bottom is more irregular inside the 20-fathom line than to seaward of it. The depth at the bottom of the steeper slope up to the beach rampart, varies from 3 to 12 fathoms, the higher figure prevailing on open stretches away from rivers (Fenneman). The extreme of complexity is reached south of Cape May, where such shoals as Five Fathom Bank, Winterquarter Shoal, and the dreaded Diamond Shoals off Cape Hatteras. With these shoals are associated holes with a bottom of blue, black, and sometimes pebbly mud. A few spots far out from shore are muddy. Along the edge of the platform are several embayments, called submerged valleys by some.

The inner limit of the sand is the beach rampart and dunes (McGee, Shaler, 5, Norfolk Folio, and other works on the shore geology, harbor works, etc.) The steeper slope is built up to form the profile of equilibrium as demonstrated by Fenneman. Inside this rampart are the sounds, with their associated salt marshes. These have been well studied by Shaler, C. A. Davis, and the engineers of the Coast Survey. It is impossible to map the bottom deposits, as the charts use only the terms "hard" and "soft"; as far as can be seen they consist of a mixture of sand and mud, for the sorting action of the waves is feeble and they are kept stirred up by the tidal currents. They are more closely controlled to fluviatile than marine conditions.

Long Island sound is predominantly blue mud, while Chesapeake Bay shows a cordon of sandy beaches. For further information of these inland waters, their currents, deposits, etc., reference must be made to the reports of the Coast Survey (catalogue) and of the Fish Commission on the oyster beds of those regions; the subject was not fully investigated. Much additional information may be found in the various comparisons of old and new surveys which will be found under the head of "Shore line changes", in the catalogue of Coast Survey publications as well as the reports of the Army Engineers.

The sands of the Atlantic coast are fairly well rounded silicious material, with a slight amount of hornblende and feldspar and some pebbles. (Pourtales, 5, Murray, 2). Some of the last are from rocks not exposed on the coast. Shells are often very abundant, and an analysis in lat. 28-4, long. 80-13, shows equal parts of sand and broken shells. Delasse distinguished several shell banks in less than 50 fathoms off Florida, Georgia, and the Carolinas. Off New York, Pourtales says that at 100 fathoms the shells of Glogigerina are equal in number to the grains of sand. He found a fairly definite zonal arrangement of the Foramnifera according to the depth of water, with practically none out to 10 fathoms, and only a few on the mud of the Block Island clays.

The transition to mud, usually of green or blue color, takes place on the average within the 100-fathom line, and is very sharp, as such changes go; but in places the sand extends down to much greater depths, as off Cape Hatteras. The following analyses by Murray (2) show the character of the muds to the south of that promontory, beyond which no map has been made:

	Lat.	Long.	Depth	$CaCO_3$	Organ	Minerals SiO_2	Fine washings
Gray mud	39-50	70-11	466f	3.5%	6%	80%	10.5%
Greenish gy.do	32-24	78-44	142	47.6	8	40	4.4
Green mud	33-19	76-12	457	59.4	5	20	15.6
Gy.m,fne.s.	28-21	79-52	100	Infusoria and sponges			

South of the peculiar cuspate capes, of which Hatteras is the most northern, the beach rampart becomes broken and the rivers flow directly into the sea. For descriptions of the features of this coast, and for that matter, of the other coasts we have to deal with reference may be made to the works of Abbe, Gulliver, McGee, and Shaler; the second named contains an extensive bibliography of the subject.

The chief feature of this southern coast which concerns us at present, is the occurence of patches of greensand on the edge of the shelf, at depths of 50 to 100 fathoms (Pourtales, 5). These are not noted on the chart, and are hard to locate upon it from the small scale map upon which they were displayed.

Rock bottom is also reported 14 miles NNE of Bald Head, N.C., in 9 fathoms, and close to Cape Fear River in 7 fathoms. That reported on the lower portion of the continental platform in lat. 30-10, long. 78-45, was not confirmed by the Coast Survey. These spots are apparently limestone, and are covered with a rich growth of corals and gorgonians, for which reason they attract the fish and are known as "fishing banks". Others may exist near Cape Fear, as corals are thrown up on the beach by storms.

Florida Coast. After passing St. Johns River Inlet, the sandy barrier is backed by low dunes (Dall & Harris, Matson, Sandford, Shaler, 6) and stretches with extreme regularity to Cape Florida. At the same time the submerged platform narrows, and its outer edge rises until only 30 fathoms below sea level. Its surface is covered with silicious sand, with a few mud holes off river mouths and in the lee of such slight promontories as Cape Canaveral. This silicious sand ends near Cape Florida and Soldier Key. Gibbs states that at the cape there is 20% of lime. For many miles to the north it has overlapped and buried the coral reef of the keys (Sanford).

Blake Plateau. At the edge of the shelf there is a moderately steep slope down to 400 fathoms or more, which is covered with calcareous mud (see analyses above); below this is an extension of the continent in the shape of a plateau, named by Agassiz after the Coast Survey steamer "Blake", which was used in exploring it. The surface of the triangular plateau which stretches from Cape Hatteras to the Bahamas, is often rocky, and is stated by Agassiz to be swept clean of mud and ooze, and to be nearly barren of animal life. The charts, however, show plenty of coral sand and mud, while the 300-fathom bank in lat. 31-37, long. 78-33, is covered with globigerina ooze with some silicious sand (Craven and Maffitt).

Florida Reef. Leaving the question of the Blake Plateau for the present, we have next to consider that once famous menace to navigators and old time resort of pirates and wreckers, the Florida Reef. It has been so often, [although sometimes incompletely], investigated by both Agassiz, Hunt, Pourtales, and other officers of the Coast Survey, that little need be said of it; the region is just now very much in the public eye by reason of the opening of the Key West railway along the keys. The latest observations by Sanford are naturally the best and correct many old errors.

Briefly described, the Reef consists of two lines- the outer chiefly submerged, having coral reefs, the inner 4 to 7 miles inside, and separated by a shallow channel of low mangrove-covered keys. To the east the inner reef consists of dead coral but westward this changes to oolitic limestone. Behind, these islets and lagoons grade into the mangrove and other swamps of the Everglades, described by Agassiz, Griswold, Heilprin, and Shaler. In the inner or ship channel there is a westward current, while outside the line of rocks, the bottom, covered with calcareous ooze and poor in life, falls off to a depth of several hundred fathoms into the Straits of Florida, or Bemini, which are traversed by the swift and warm eastward current of the Gulf Stream. At a depth of 90 fathoms, however, there is an interruption of this slope in the shape of the Poutales Plateau, which is largely rock bottom and has a mixximum a/

Grammar

width of 18 nautical miles and a depth at the outer edge of 300 fathoms. Most of its length, it is narrower, and covered with coral sand and shells. Specimens of the rock (Agassiz) show that it is composed of shells of animals such as are now living on its surface, where there is an extremely rich fauna; there is no evidence, however, that this is anything but a surficial deposit. Below, in the greater depths of the straits, the bottom composed of glogigerina and pteropod ooze; (by an error, this was not mapped by Agassiz 2, p. 166). Agassiz ascribed the abundance of life on the rock bottom to the food supply brought by the Gulf Stream. why mention ?

The recent studies of the Florida Geological Survey (Matson, Sanford) in connection with the building of the Key West railway have much changed all former notions of this region. The results of drilling at Key West (Hovey) and at many other points (Hunt, Sanford), show that only from 50 to 100 feet of recent or even Pliocene limestones occur. Below, Tertiary marl, and quartz sands occur, Below this at from 700 to 900 feet, corresponding closely with the Pourtales Plateau, occurs the firmer Tertiary limestones. The quartz sands thin markedly to the west so that at Key West they are believed to be absent, the modern oolitic limestone and associated marks rest upon slightly consolidated Pliocene deposits of similar character. This disposes pretty well of the idea that there is any very extensive "modern limestone bank" as thought by Agassiz. Nevertheless, it is clear that some deposition of calcareous deposits is now going on. These are formed in three ways: 1- the skeletons of corals and their detritus, 2- calcareous remains of shell fish, etc. (and 3- possibly by chemical precipitation off the mouths of

now established

rivers (Sanford). Willis' ideas as to limestone deposition in the Everglades are now discredited. The most important place where ! calcareous material is being laid down is in the chanells behind n/S/ the main line of keys. The debris worn from them is carried by tidal currents into these quieter waters and forms the basis of the mangrove-covered islands. Shell ridges, and banks also occur in these waters and there may be some chemical precipitation of calcium carbonate derived from the solution of the older limestones of the Everglades. Sanford is inclined to think that the oolitic Key West limestone was formed by the induration of debris from the older reef, which collected into oolitic around small grains ? of sand.

<u>The Gulf Stream</u> The greatest velocity of the Gulf Stream at the surface is somewhat above five miles an hour, and its temperature something like 80 degrees Fahrenheit. The speed varies with the tides and winds; the true tidal currents set north and south between the keys, carrying much limy mud into the lagoons behind them. The least depth of the straits is 327 fathoms at the northernmost current section. Some of the bottom, there, is rocky, for the "Blake" lost several anchors while measuring the currents; at other times, however, mud and ooze were brought up. The best summary of the work done on the currents, is that by Pillsbury, (who pointed out the errors of former surveys, such as those described by Agassiz and Pourtales.) why mention While there appears to be some current clear to the bottom, it is very slight, 325 fathoms being the average depth of no current; below, some flow in the contrary direction has been found. Reference One half of the volume of water passes above the depth of 100 fathoms.

<u>The Bahamas</u> On the south and east sides of the straits are

the broad platforms called the Bahama Banks. The average depth of water upon these is 4 fathoms or less, while in the passages between, called valleys by Spencer, several hundred fathoms are found. The slopes are sometimes very steep; Agassiz, 1 mentions one of 38 degrees on the north side, towards the ocean. It should be remarked that most of the keys and rocks are on that side which is the windward one. The geology of these islands has been described by Agassiz, Nelson, and others. The keys are oolitic limestone while the bottom deposits are calcareous sands and muds.

West Coast of Florida. Turning now to the west coast of Florida, we find what should be a most interesting field for study; a shallow sea, not much affected by tides or currents, and bordered by a low land. Unfortunately, very little information is available. The coast is low, and with few good harbors (Shaler). Pourtales maps the Florida Bank, as it is called, as mixed calcareo-arenacious bottom; while, on the other hand, Agassiz regarded it as a "modern limestone bank". Silicious sand, pure white in color and strongly mixed with lime, appears at Pine Keys (where it accounts for the different vegetation) and at Cape Sable, stretching north from there (Pourtales, Gibbs, Heilprin). It should be noted that this wide spread of silicious sand is also found in the older rocks of the peninsula, and that it now covers the whole surface (Dall, Shaler, 6, Heilprin, 1). We have here a transition from clean silicious sand at the north, where the land is covered by the sandy Lafayette formation, to calcareous sands and muds at the south, just as is the case on the east coast. The transition off shore, in the muddy belt, is probably more gradual.

West of Cape Apallachacolia is an area of coral sand of doubtful interpretation; it is probable that much of the coral noted by the hydrographers in deep water is really the fragments of bryozoans. The edge of the continental shelf is not well marked here; it is apparently submerged about 500 fathoms, while the transition from sand to mud is at about 30 to 50 fathoms, about the level of the edge of the Florida Bank. At the 88th meridian there is a remarkably sharp change from sand to mud, along a line perpendicular to the coast. Prof?

The great delta of the Mississippi is the next feature to attract our attention, but it has been so fully described by geologists and engineers that little description needs to be given. Borings have disclosed that it consists of a mixture of marine, brackish, and fresh water deposits to a depth of nearly 2000 feet (Harris and Veatche). However, only a portion of these are of recent age (Shaw). On the surface, abandoned beach ramparts of sand and shells are found, they are often discordant in direction with those of the present coast. Much information about the delta may be found in the reports of the Army Engineers who have worked on the improvement of the passes (Humphreys and others). The recent work of Shaw on the "mud lumps" is especially important.

t?

The submarine extension of the delta is manifested to a depth of nearly 2000 fathoms. The reentrants in it have been interpreted as valleys by Spencer and others, but this seems to require a considerable stretch of the imagination. The bottom deposits are chiefly blue and gray muds; only the shallows are sandy in places most exposed to the waves. An analysis of a gray mud by Murray, 2 in lat. 27-55, long. 88-53 shows:

$CaCO_3$ - - - - - - - - - - -	10.3%
Coarser minerals- - - - -	10.0
Silicious organisms - - -	3.0
Fine Clay - - - - - - - - -	76.7

The isolated sand bars off the delta, are continued to the west as far as Galveston. The coast is low and often swampy, and little information is available about it. Most of these sandy spots seem to be shoals, but some are not; while in general the mud becomes more sandy off shore, and "corals" are sometimes reported in the deeper water. The confusion is such, however, that it is impossible to separate these deposits. The beach is apparently sandy, but the charts do not generally denote the material, while the coastal formation is a blue clay (Dumble, Adams).

At Galveston, a test hole off Fort Point on the bar shows (Adams):

Water	14
Fine sand with shells and some clay	32
Clay with sand and shells	9
	55

The 3000 foot well at Galveston shows:

Buff Gray sand	46
Reddish brown clay	17
Mottled red and blue clay, with shells and lignite, (probably Tertiary)	37

As we go west, the sandy barrier becomes wider, as do the lagoons; the latter are shallower than those of the Atlantic coast, by reason of the lower tides. They are mud-bottomed, with oyster beds, while Gilbert reported white limestone in one place.

The edge of the continental shelf is poorly defined along this coast, at a depth of 50 to 100 fathoms; there appears to be a secondary shelf at 950 to 1000 fathoms. To the south, along the Mexican coast, it is better marked, but the more regular slope down to Sigsbee Deep is probably more apparent than real, since the soundings are much less numerous than on the broken bottom off Texas.

Mexican Coast. Off the Mexican coast, also, the sandy be~~s~~lt is narrow, the depth of transition varying from five to fifteen fathoms. Coral is occasionally met [with], and two large reefs are found at Vera Cruz (Heilprin,2). As these long remained unknown to scientists, it is possible that there are others. As far south as the Gulf of Campeche, we may be sure that the sand marked on the chart is dominantly silicious, but beyond there is great doubt as to its character. Delesse regarded it as such, but Yucatan is almost wholly limestone, of which the portion along the north coast is of Guaternary age (Heilprin, 3, Sapper, Schott). Analyses of muds are available from two localities.

Why?

Named after Guatemala? And is this older or younger than the Missourian glac'n?

Brown river mud, NE mouth of Rio Grande in 489 fathoms.

Lat. 26-40, Long. 96-01	
$CaCO_3$	2.8%
Minerals	25.0
Silicious organisms	1.0
Fine Clay	71.2

Clayey volcanic mud, SE. Cape Roxo in 511 fathoms.

Lat. 20.59, long. 96-39		
$CaCO_3$	15.1%	
Min. (av. size 1mm)	50.0	(includes pumice and glauconite)
Silicious organisms	3.0	
Fine clay	31.9	

Campeche, or Yucatan, Bank would offer another excellent field for study, were more information available. Agassiz,1 regarded it as another "modern limestone bank", but Heilprin doubted the correctness of such a conclusion. The shore line of Quaternary(?) limestone, however, supports that view, while there are numerous coral reefs upon it. An analysis of coral mud from the edge of the bank shows:

Greenish gray calcareous mud from lat. 22-06, long. 92-13.

$CaCO_3$	67.8%
Minerals inclu. glauconite, av. size .05 mm.	3.0

Silicious organisms	10.0	
Fine clay (?)	19.2	(Murray, 2)

The coast as described by Schott, is remarkable for the barrier of sand and shells 170 miles in length, with scarcely any openings, a circumstance due to the underground drainage of the country, which prevents the formation of rivers.

Currents of the Gulf of Mexico. If one looks upon any ordinary map of the oceanic currents of the world he will find the Gulf Stream depicted as entering the Gulf of Mexico through the Straits of Yucatan, 1100 fathoms deep, turning west across Campeche Bank, with its 30 to 50 fathoms of water, and then following the coast around nearly a complete circle to make its exit throught the Straits of Florida. Such a course would be in defiance of all known laws of hydraulics, and its falsity must be known to every navigator of the Gulf. Nevertheless, many ingenious theories have been built upon it, such as those of Louis Agassiz and Le Conte respecting the origin of the Florida peninsula. As a matter of fact, current meter observations (Haskell) and the experience of engineers (Adams, Humphreys) show that no such current exists. The fact that ships in going north to Gulf ports generally make their landfall west of the course on the chart, would indicate a circulation in the opposite direction. Tidal and atmospheric influences mask any such effect.

Needs evidence to support statements.

Pacific Coast.

S/ San Fransisco to Bering Sea-- show on sailing chart S.

On the Pacific Coast of North America, the conditions for the study of sedimentation are still poorer than they are on the Atlantic and Gulf shores. The continental shelf is very narrow, the 100-fathom line being within a very few miles of land, and often times enters inland waters.

Near San Francisco the terrace is broader than usual, and floored chiefly with micaous sand to a depth of several hundred fathoms. To the south, however, patches of blue mud approach close shore, with areas of green sand outside of them. Rock bottom occurs on Cordell Bank and in the Golden Gate. Although the tides are quite moderate, there are a bar and well developed mud flats within the bay.

To the north, the coast is nearly all bold and mountainous (Davidson), with few important rivers or harbors (Shaler, 5). The Klamath is the largest river south of the Columbia. In spite of the fact that this is a very exposed coast, the border of the blue, brown, and green muds is often found in as little as 18 fathoms of water; although, on the other hand, sand is sometimes found to reach far down the continental escarpment. The black sands, which chiefly occur in deep water, are stated by Murray and Renard to be glauconitic, as is the green mud. On Heceta Bank, in lat. 44, there is a considerable area of so-called coral bottom associated with the rocky ledge. The borders of the sandy area are very irregular there, as off the mouth of the Columbia.

The Columbia, the greatest river of the coast, brings down much sand; there is little mud on its bed, except just inside the entrance off Astoria. The sand contains much magnetite garnet and heavy minerals, and even gold and platinum. These precious metals are found in much of the Pácific coast sands which are sometimes worked for them (Coos Bay Folio, and other works on geology of the region) on the raised beaches. More sand is found to the north of the mouth of the Columbia than to the south, but there is an extensive rocky area in lat. 40-45.

From lat. 46 to 47 no detailed charts are available, but it is unlikely that any remarkable features exist.

In the land-locked waters of the Strait of San Juan de Fuca, Puget Sound, and the Gulf of Georgia behind Vancouver Island, peculiar conditions are met with. These channels, though often very narrow, are deep, 100 odd fathoms and no bottom being frequently noted on the charts, while depths of over 200 fathoms are sometimes recorded. In other words they are typical fjords believed by many to have been deepened by glacial action. The shores of Puget Sound are cliffs of glacial sands and till, but to the north the bed rocks form the coast and many islands. Tidal mud flats occur off some river mouths, as at Tacoma and Seattle. As a result of this irregularity of bottom, and the glaciation, the bottom deposits are so varied in character that it is impossible to map their distribution with any degree of satisfaction. The same remark applies to all the northern waters in the fjords and straits. A great lack of data also prevails, for in these regions the great depths close shore render the lead unnecessary. ~~of little or no use~~ to navigators (Coast Pilot, Alaska); while on the anchorages the charts distinguish for the most part only "hard", "soft", and "rocky" or "foul" ground. So far as known, muds predominate here as in most northern waters. Considerable information respecting the inland waters can be obtained from the reports of the Fish Commission of the salmon fisheries.

Much of the bottom on these bold shores is bare rock, but some of the extensive areas shown on the charts may only be covered with boulders. A vast number of rocky ledges do exist, however, of which many are marked on the chart as "P.D." (position doubtful) or "E. D." (existence doubtful). As rocks are yearly discovered off the best charted coasts, both by accident and with the drag, one can readily imagine how many await discovery in these less frequented waters.*

Outside the fringing islands, conditions like those described to the south are found, but a much less number of soundings has been made. The drainage of many glaciers is discharged into these waters, increasing the amount of mud; while floating ice carries coarse material off shore.

Along the Aleutian Islands, the continental shelf is somewhat wider, but with many rocks and ledges. Gravel, sand, and mud are mixed with very irregular boundaries, although the last is generally found in the deeper places. "Coral" is distinguished in several localities, notably at Cape Clear, in lat. 59-50, long. 148. Mud flats of chocolate-colored mud occur off river mouths, as in Cook Inlet.

BERING'S SEA AND ARCTIC OCEAN.

Shown on Chart T.

The eastern portion of Bering Sea is one of the most extensive areas of shallow water off the Pacific coast. It has been fairly well explored, but little definite information is available regarding the bottom deposits, although the gold-bearing beach sands have attracted much attention at Nome. Most of the sea floor near land, is a fine gray sand; the black sands are in part of volcanic origin, as there are several active volcanoes in the Aleutians. No separation has been attempted on the map. Agassiz and Murray's map shows a tongue of deep-sea diatom ooze stretching up the depression north of the islands, to a depth of 500 fathoms, the remainder of the sea being simply classed as "ferrugeous". The border between the sand and mud is very irregular, varying in

* Prof. Martin and the writer were present when one of these was actually discovered as forecasted above. Haha!

depth from 25 to 100 fathoms, and presenting two marked embayments of mud into the sand. The northern one of these is not marked by any corresponding hydrographic feature; but the southern is associated with the depression north of the Islands. Isolated areas of mud, or muddy sand, occur within the sandy area; while conversely, areas of sand or gravel often occur far from land, amidst the mud, as on the bank in lat. 56-30, long. 173, where yellow muddy gravel and gray sand are recorded.

The Kuskokwim is the most northerly river into which large glaciers drain, but no data is available as to the deposits off its mouth; they are presumably muddy, like those described in Cook Inlet. Bristol Inlet is, however, free from mud; the rivers entering it largely come from lakes, and so must be clear. At the mouth of the Yukon, and in Norton Sound, much mud or silt is found; but the charts are rather unsatisfactory. Some irregular sand patches, like the bar at Cape Nome, occur. Yukon?

The deeper parts, and the Siberian coast of Bering Sea, have been little explored. In deep water, blue and brown oozes of terrugenous or volcanic origin are found, while the shallow waters have sands similar to those on the eastern coast. The existence of Bower's Bank, in lat.55, long. 181, is suggestive of a second but more broken Aleutian range; Pribilof Islands and the bank west of them support this idea.

sp?

Arctic Ocean. Little is known of the ice-covered and slightly frequentad Arctic Ocean. It is very shallow as far north as Wrangle Island. Most of the bottom is muddy, but sand stretches a long way out to the west of Point Barrow. The reasons for this preponderance of mud will be explained later.

sp

Tentative?

THEORETICAL CONCLUSIONS.

Agents of the Supply of Sediment. The methods by which sedi-

sediment is supplied to the sea, are too well known to require any but brief mention.

The action of the waves has been emphasized by the English geologists, who saw their country being steadily cut away by the ocean, but it is doubtful that this process could proceed very far into a continent without the help of subsidence; after the profile of equilibrium had been established, it would be very slow.

Rivers are probably more important, especially at the present time, when the continents are almost wholly out of water. When the epicontinental seas were very extensive, however, the balance was undoubtedly against them.

Wind is generally of little importance, except in the case of lagoon deposits, where the amount of sand blown from the beach may be very considerable (Shaler). Adjacent to desert regions the wind may supply a substantial amount of material.

Springs doubtless bring much material in solution. They occur in the ocean at many points in the West Indies, off Cuba, Florida, and many other limestone coasts (Hitchcock). Delesse ascribed some importance to them, as some others have done (Daubree).

Eruptions also can make important contributions, both in the form of fragmental material and solutions. Delesse was inclined to emphasize their effects, and in more recent times Van Hise and Leith have suggested their importance in the formation of the unique ferrous silicate and carbonate rocks of the Lake Superior regions.

<u>Agents of the Distribution of Sediment.</u> The forces which work to sort and distribute the sediment brought to the sea, are different forms of motion of its waters, i.e. waves, and currents. These are effective over the forces of the land in the shape of the location of rivers and shape of the coast, in proportion as the

shore is exposed to waves, subject to currents, or the land is small in extent or low, or the drainage from it is slight from any cause.

Waves. The action of waves in sorting and moving sediment according to size and specific gravity is well known. The resulting wear of particles is accompanied with chemical action, which tends to leave only the stable end products, sand and clay, together with a few other stable minerals such as magnetite, zircon, garnet, etc. Wear by water is less effective than by air, as the material loses in weight when submerged, and is protected by an adhering layer of water. Moreover the movements of water average much slower than those of air by reason of its greater density. For this reason there is a lower limit (about .1 mm.), below which grains are not worn; but in the process it is obvious that a large amount of fine dust must be formed which unites with the kaolin to form clay. This subject of the wear of sands has been considered by Reade and Holland, while Sorby long ago pointed out the importance of the microscopic study of sand grains.

The depth to which sands are disturbed during storms, or even the average limit of depth at which sand is found, are a measure of the depth of wave action. In general, this transition is marked by a break in the bottom formed by the edge of the cut and built terrace; but so many exceptions have been noted on the charts, that little can be told from this source. Probably 60 fathoms is about the limit of effecient action, which agrees substantially with the results of Hunt, 4, who found broken shells and other signs of wave power in 40 fathoms. Many observers (Stirrip, Austen) state that after gales the sea bottom is built up in places, and worn down again in calm weather. It has already been mentioned that the lower limit of sand drift in large quantities, is less than 20 fathoms along the Atlantic coast. In the Grand Banks the bottom is disturbed by storms in 25 fathoms or more.

It is now thought that the diagonal attack of waves on the coast, which is most effective at high tide, is the dominating cause of the drift of sediment along shore (Breon, Dall, Pourtales, 5, Shaler, 1, 6, Thoulet, Austen, Harrison, and others). Good examples of this process are furnished by both coasts of Florida, and the English Channel. The trades and "northers" appear to be the cause in the former case, aided on the east coast, where it is more pronounced, by back eddies of the Gulf Stream; in the English Channel, it is only the westerly winds which can be effective, and so the drift is towards the east. Other instances are the sands north of the mouth of the Columbia, the muds north of the Yukon, and west of the Mississippi. The prevailing winds will be found well shown in Bartholemew's Atlas of Meteorology.

<u>Tidal Currents</u>. The efficacy of tidal currents as agents in the distribution of sediment, is a vexed question. Their oscilatory character tends to neutralize their effects. Many engineers and geologists (Davis, Harrison, Krümel, Reade, Wheeler) have believed that the tidal wave was dominant; on the other hand, Mitchell and Harris of our Coast Survey minimize its efficiency. Turning to observations, there is no doubt that tidal currents are widely distributed and often very swift, swifter in fact than most rivers (Krümmel), and that in shallow water, especially on bars, the bottom velocity is not much less than that at the surface. Reade mentions bouys drawn down to the bottom by the currents of the Little Minch, west of Scotland, in 80 fathoms, as well as the cutting of a cable in 500 fathoms off Gibralter. Austin does not mention tide ripples or discolored water on banks deeper than 60 fathoms. Wharton, however, says that right in many of the dreaded breakers of the Pacific, supposed to indicate reefs, the

surveying ships of the Admrilty often found several hundred fathoms of water, the inference being that these are only tide rips. Delesse mentions "ripple marks" nearly 100 fathoms. These were probably the result of currents rather than waves.

There can be no question that tidal currents are effective in estuaries and harbors, as has been abundantly proved by experiment and experience. Their influence is greater upon lagoon and estuarine sedimentation than upon truly marine deposition. Much information on this point may be found in any work on harbor design, and the reports of the Army Engineers. On the other hand, the tidal wave is by no means a wave of translation (rev. of Wheeler), and probably diminishes in velocity with depth, where flowing freely. It should also be considered that in order to carry sediment, a current must do work which requires a loss of velocity and therefore no current can maintain the same velocity to the bottom, except on a shoal or weir. We need much more data in the way of current meter observations at various depths, for it is probable that more reverse currents exist below than has been suspected. Especially is such work desirable in the so-called submarine valleys which Chamberlin and Salisbury think may be kept open by the action of the tides (vol. III).

Forms of Shoals. The forms of shoals like those off the Atlantic coast, do not seem to be wholly explainable by wave action. The most complex forms, as has been mentioned, are confined to less than 20 fathoms of water, and are especially developed near the mouths of large rivers where the depth of water off the beach is much less than elsewhere (Fenneman). They also occur where the water is, very shallow and tidal currents are strong, as on George's Bank. From this limitation of irregular forms and steep slopes to 20 fathoms or less, it would appear that cross-bedded marine formations must in general have been formed in water of less than that depth. Deposition along the edge of the wave-built terrace, as described by Austin and Blake, would not account for cross-bedding, but rather for the inclination of strata, producing deceptive thickness, as explained by Chamberlin and Salisbury (vol. II). More detailed observations on these localities is much to be desired. It seems clear, however, that true "sand bars" with bedding like that of stream deposits can be formed in the sea.

Oceanic Currents. The influence of oceanic or permanent currents upon sedimentation, has been seen to be slight at the present time. Even the classic example of the Gulf Stream has had to be given up, following the results of recent current meter observations, though the evicence of the clean bottom is still to be considered. It is possible that the southward drift along the Atlantic Coast is in part explained by the influence of the Labarador current.

How much work oceanic currents may have had in past times, is another question, for then there were broad shallow seas, and the currents may well have controlled the distribution of limestone-forming organisms both by affecting the termperature and food supply. The question of non-sedementation is considered below.

Flotation. Some observers have mentioned instances of floating beach sand far from land; this process may be seen on our lakes, when the water is still enough, but it is unlikely that it was ever an important factor in sedimentation (Agassiz, 1, p. 247).

Methods of Sedimentation. The agents by which sediment may be deposited, may be classified as follows:

Mechanical: settling of material from moving water into still, or from suspension.

Chemical:

Physical-chemical: flocculation; concentration of solutions.

Chemical: reactions producing insoluble substances.

Organic-chemical: formation of insoluble matter by agency of life.

These methods need little further description. As waves aided by currents are the most efficient sorting agents it follows that deposition by mechanical means is most important. Material is reworked by these means in proportion as the power of the waves is sufficient to handle the less associated material worn from the coasts and brought in by rivers. Organic deposits consist of the remains of both plants and animals. (The former being nearly all soft matter are generally either cast up on the beach or go to pieces from decay.) Occasionally, expecially in the tropics much land vegetation finds its way to the sea. The shells of mollusks are everywhere found, they being most abundant on sandy bottoms (Delesse). They thrive best where wave action is not too strong but the shells are often transported some distance and broken up by the waves. Often this comminuted shell matter is a considerable proportion of the bottom deposit (Delesse) At the present time pure calcareous deposits are confined to warm waters and are very limited in extent compared with those of Paleozoic times. Prof.

Needs revision.

<u>Classification of Sediments</u>. The following classification of shallow water sediments is by Herdman and Lomas, and is one of the best:

	Slaty gravel -- mainly inorganic.
	Sand " "
	Slaty gravel with shells -- mainly inorganic.
	Muddy sand " " " "
Terrigenous:-	Mud and clay " "
	Shelly gravel -- shells and stones equal.
	Shells and sand-- about equal.
Neritic ----	Shell deposit -- almost all large shells.
	Nullipore " " " nullipores.
	Neritic sand -- small organic material.
	Concretions.

<u>Resulting Distribution of Sediments</u>. The usual distribution of sediments in zones parallel to the shore, and in order of specific gravity, was long ago described by Rutot. As we have seen, the usual form of these zones of gravel, sand, and mud is that of a terrace with the mud below the break; but there are so many exceptions that the ordinary diagrams which ignore this c vertical distribution are perhaps not far from the truth. To what an extent a wave-cut terrace existed in the shallow seas of ancient times, is hard to say.

Some of these exceptions to the general rule are cases of non-sedimentation or sedimentation at a different level of the water; the presence of sandy spots, not always shoals, within large expanses of mud, being hardest to account for. The distance of continuously coarse deposits from land may, however, be very great, as in the North Sea (Murray, 3), which is almost entirely sandy bottom. It has been argued from experiments by Reade and Holland, Thoulet, 3 and others that the finer material which forms the muds settles so slowly that very slight currents may carry it far to sea. There is more or less of a sharp break in size between this argillacious matter and the finest sand, thus accounting for the shape of the terrace of deposition. This raises the question of the possibility of muds accumulating in an open sea with a depth less than wave base; currents would also be very effective in such a body of water. In protected seas, like the Irish Sea, wave base is naturally higher; Herdman and Lomas state that muds are found there below 50 fathoms, except in the main channels of tidal flow, where there is rock bottom (Reade).

Mud holes in shallow water near shore are readily explained: they occur either in hollows among the shoals, or off the mouths of rivers, where locally the river silts overload the sorting power of the waves. Instances of this kind have been cited in the description of shore drift, the most notable ones being the Yukon and Mississippi. In the case of the latter, however, the clayey character of the coast to the west may help to explain the preponderance of mud in that direction.

Littoral and Shallow Water Deposits. The deposits of the littoral zone are of comparatively little importance for as shown by Barrell they are seldom preserved. With regard to size, large fragments especially of an angular shape are confined closely to the foot of cliffs. Boulder beaches or indeed extensive deposits of boulders are confined to glaciated regions where they are often washed out of till in large quantities. The coarsest deposit is found at the foot of the undertow slope, not the beach. However, where protected by seaweeds growths assortment is not always complete and muddy gravels are often found close in shore. Stones Meaning in this connection? are often moved by the action of storms on the attached sea-weeds. S/i These conditions are, however, of the estuarrene rather than the true marine class. Alternations of conditions by reason of storms also cause a more marked mixing of sediments in this zone than somewhat farther out. The presence of even a slight amount of clay retards drying between tides and thus hinders the formation of sand dunes on the beach (Delesse).

As explained in a previous paragraph, the bottom forms close shore are not wholly explainable by wave action. Dune-like sand bars are common and are due to one direction of the tidal currents being more powerful or running in a different direction than the other. In sheltered hollows small patches of mud may also occur. The same also occurs where rivers bring in a greater amount of sediment than the sea can carry off and sort. Closer studies of such mixed and cross-bedded deposits are needed in order to discover definite criteria by which they may be discriminated from fluviatile deposits. The conditions of this zone are rather unfavorable for shell fish and hence sparingly fossils ferous ~~fewer~~ formations may accumulate.

Off-shore Deposits. Outside of the zone of active wave work the bottom is stirred only by currents and in violent storms. As the conditions for the development of most forms of marine life are therefore better. The sea bottom shows a much greater quantity of remains of shell fish. The bottom is very regular in form indicating that horizontal strata of wide lateral extent are formed instead of the more irregular stratification with some cross-bedding which appears to be characteristic of shallower or current-swept waters, close to the supply of sediment. As explained above, muds are sorted out and carried into deep and quiet water where the forces of the sea are sufficiently powerful to care for the amount of sediment offered. An inspection of the Paleozoic marine series will quickly show the results of the process of marine sorting when carried to its fullest development in the shallow epicontinental seas of those days. Limestones greatly predominate and are associated with clean quartz sandstones more frequently than with shales, whereas were there no such clean separation the last should greatly predominate as shown by Mead and others. Obviously the muds were sorted from the sands and carried out into the deep seas whence they have never been raised. As a proof of this, it is found that in northern waters like Hudson Bay where sorting is checked by ice, there is a great preponderance of mud over sand, (Delesse). A good instance of present-day sedimentation under conditions comparable to those of Paleozoic times, is the coast of Florida. On the east coast silicious sands are now overlapping with probably a slight "unconformity" an old coral reef. These sands have been brought from considerable distances (though not all from Cape Hatteras nor altogether at the present stage of sea level, but rather as a result of a series of similar movements in the past) On the west coast marly limestone and swamp deposits grade to the north into contemporaneous quartz sands. Little or no clay is found.

Deposits not related to Depth. The exceptions to the above outline of the distribution of sediments may now be discussed. These may be classed under two heads: 1- Deposits too coarse; and 2- Deposits too fine for the depth. Under the first head we may note the frequent gravels and stones ~~noted~~ in quite deep water. In all regions of floating ice, boulders and gravel are quite common in all depths. In warmer latitudes deposits of pebbles in deep water usually mean a change of sea-level. Sand may however be carried out by active currents as is probably the case off Hatteras and at points on the Pacific coast. As mentioned above, a minor cause for the transportation of large stones into deeper water is the attachment of sea weeds which give the waves a hold on them. Debris is also carried in the roots of trees. Local action of currents may account for some patches of sand within muddy areas.

Deposits too fine to correspond to the usual arrangement according to depth may be ocassioned by 1- dominance of supply of muds by rivers over the power of the sea, 2- sub-marine erosion of deposits formed under different conditions and, 3- shelter due to irregularities in the bottom or the growth of sea weeds.

<u>Non-Sedimentation</u>. The question of non-sedimantation is an important and vexed one. That all of the sea bottom is not receiving sediments is as clear as that all of the land is not undergoing erosion. As long ago shown by Delesse there are large areas of sea which are not receiving deposits at present. These are marked by 1- bare rocks or 2- material too coarse or too fine to accord with present conditions of deposition or 3- strong currents. In short, all areas which are above the profile of equilibrium are subject to erosion or at least non-deposition. The same applies to areas swept by powerful currents either permanent or alternating. This of course, neglects the effects of subsidance or of a greater supply of sediment from rivers than the sea can care for. Submerged rocks are by no means then protected from either mechanical or chemical action. The work of boring mollusks on soft rocks may also be cited.

A few instances of non-deposition or erosion over considerable areas may be dited. The ridge across the Gulf of Maine is probably typical. It appears to be undergoing erosion for the most part although in places like Nantucket shoals deposition is probably taking place. The Block Island clays are another. Lindenkohl regarded them as of Tertiary age. Their surface is reddened by oxidation. The English Channel is said to have shown permanence of depth since the earliest surveys whowing at least very slow deposition, while Delesse, Reade, Jukes-Browne and others mention many other instances largely due to currents. In all probability the Grand Banks are not receiving sediments.

<u>Relation of Life to Deposits</u>. The close relation of the

Moreover, ++ clear & needs extreme modification.

fauna to the character of the bottom, has been pointed out by many investigators (see bibliography). There is also a zonal arrangement controlled by depth alone. Life is most abundant where there is support for fixed forms and sufficient protection from waves and violent currents; less strong ones may be important in furnishing a food supply (Agassiz, 1). This results in a greater abundance on pebbly mud, sand, and rock bottoms. (Agassiz, Herdman and Lomas, Pourtales). Sea weeds are most abundant where the water is not too much disturbed, but by attaching themselves to fragments of rock they help to move them during storms (Jukes-Browne).

Shell banks are common to all waters (Delesse), but are almost entirely on sandy bottom. The shells are carried away from where they were when alive, and deposited at a considerable distance; littoral shells are sometimes found 50 miles from land (Herdman and Lomas, Austin). In the process the shells are very much broken and often mixed with sand. The remains of the smaller forms of life are also important in forming calcareous sand (Pourtales, 5). Delesse, 1 mentions calcareous dunes along the coast of Brittany, but shell material is too weak to form extensive accumulations. It should be mentioned that marine shells in an unbroken state are sometimes blown into the dunes or lagoons.

Delesse worked out the distribution of this shell deposit, which is termed "traëz" by DeLapparent, and the relation of the animals forming it to the supply of lime from the adjacent land; but it seemed impossible to do this for the coasts now under consideration. It appears improbable that any extensive marine deposits could ever be entirely unfossiliferous before severe anamorphism (Grabau, Kindle). However, shallow water deposits might well be very sparringly fossiliferous.

Calcareous Deposits. Although deposits of calcium carbonate are not the main subject of the present investigation, their relation to detrital accumulations must be considered. They are by no means confined to great depths, but it is very hard to tell from present data whether the limestone banks of the Bahamas, Florida, and Yucatan are now being built up or dissolved. No geologists now agree with Agassiz's, 1) conclusion that they are growing, for the results of drilling show that the recent limestone is only a thin crust. It would be interesting to bore into the Pourtales Plateau for instance. Even there it is improbable that there is anything but a crust of recent shells. Calcareous dune deposits (Agassiz, Nelson) are worthy of consideration; they are consolidated by rain and spray into a sort of oolite? The ? waste from limestone shores seldom seems to be important (Herdman and Lomas); when reduced below a certain size, the fragments are either dissolved or carried away in suspension (Reade and Holland, Delesse). There are, however, detrital limestones such as are formed behind the Florida Keys (Sanford).

As has been stated, shell deposits are often found in sandy areas; they would form lenses of limestone in the resulting sandstone. Excellent examples of the transgression of silicious sands over slightly older limestone are found on both coasts of Florida. These localities are also instances of sedimentation controlled by the sea, and largely independant of the character of the adjacent land. Southern Florida is a locality more closely approximating to conditions like those of Paleozoic times than any other region which is readily accessible. It will be seen from the analyses cited, that muds are often highly calcareous, although for the most part few shells are found on mud bottom, and the transition to limestone-forming ooze is too gradual to be traced. The smaller organisms, globergina, etc. are more important in furnishing this material than the larger shell fish of shallow and clear water.

Resulting Accumulation of Sediments. We have seen that all kinds of sediments are accumulating simultaneously, and that there are sharp transitions, both in directions perpendicular and parallel to the adjacent shore. If the water level should remain constant with respect to the land, sedimentation would go on only beyond the edge of the cut and built terrace, as pointed out by Austin and Blake who noted that the oldest surveys of the English Channel do not differ essentially from modern ones. By this process the zones of sediment would broaden and coarse material come to be deposited above fine. If it were not for the smoothing irregularities in the horizontal form of the shore, shore erosion would soon slacken. Prof

As is generally the case, however, the form of the shore line is changed, so that the currents may sweep along it with a minimum of resistance and distribute sediment equally. Headlands are cut back and bays bridged, so that the former become places of little or no deposition, as is shown by the common occurence of rock bottom off headlands (Delèsse).

If the level of the sea rises with respect to the land, and the shore travels inland, the zones of sedimentation travel in that direction, as demonstrated by Rutot and Van den Broeck. Thus, finer deposits come to be deposited above coarse, and we have the sequence of deposits commencing with the "gravel of immersion" (Rutot); then sand, and finally mud, or limestone. Two types of transgression may be distinguished: over a shore steeper than the average of the profile of equilibrium, and over a slope of less than that amount. In the first case, a cliff will in general result, and by combining the factors of cutting and susidence, it will be seen that an inclined plane of marine denudation will be formed, and covered with the succession of deposits outlined above. In the case that the slope is less than that needed to form a beach, a rampart is built (Fenneman, Gulliver, Shaler, 1). This barrier incloses lagoons in which deposits, generally of clay and peat are formed. As subsidence goes on, this barrier will travel landward (Barrell, 1), accompanied by a zone of non-deposition in front, and thus a plain of denudation will be formed, excluding, of course, esturarine deposits in depressions below the level of the foot of the beach slope. If filling along shore takes place, however, this plane of erosion may leave part of the lagoon, and terrestrial accumulation, and therefore slow subsidence favors their preservation, unless the movement should be rapid enough to carry them down intact. Experience shows that where there are receding barriers that the estuarine or lagoon deposits are generally destroyed. The same conditions may cause the preservation of parts of the old land surface almost intact. This is believed to be the case beneath the Cambrian of Wisconsin.

Rutot laid great stress on the alternate movements of the sea level. The phenomena of regression are similar to those of filling out from the shore, so that coarse material comes to cover fine, ending in a gravel beach forming the "gravel of emersion" (Rutot, Van den Broeck). This gravel must necessarily be less well developed than that of immersion and ~~is~~ might frequently be composed only of rolled shells.

<u>The Sedimentary Cycle</u>. The sedimentary cycle of mechanical sediments, as described by Rutot, is a succession comprising, as seen in section: gravel of immersion, sand, clay, sand, and gravel of emmersion. This ideal succession is only realized when either all of the material is derived from cliff cutting, or the state of the land remains essentially constant during the later stages, ~~and~~ otherwise

so the upper two members will be lacking. Rutot considered various combinations of sedimentary cycles, complete and incomplete in development, but ignored this influence of the physiographic state of the land and climatic changes. In this connection we must consider that the examples of sedimentation that we have considered have largely been along the shores of fairly high or even mountainous lands, where there was cliff cutting, and the streams were able to bring in both sand and mud so that complete series might be formed. ¶ On the other hand, the coasts of Florida are an example of the dominance of the sea in bringing sediment long distances and depositing it where it is not at all related to the adjacent land. Thus we get alternation of sandstone and limestone instead of sandstone and shale. Is this statement correct? If the amount of land was less in proportion to the area of deposition, then physiographic changes, the destruction of certain strata, and climatic changes would certainly be recorded in the nearby sediment. This matter is considered by Willis in a paper on the conditions of sedimentary deposition.

Planes of Equal Time. We will now consider the relation of of the beds in this cycle of sediments, for it is the object of stratigraphic study to discover the age of the deposits investigated. These planes are evidently the profiles of the sea bottom at each given time. On th~~is~~e sea bottom ~~the~~ different kinds of deposits ~~were~~ are being simultaneously laid down, each with its appropriate fauna part of which ~~would~~ will become fossilized. As time goes on, evolution and migration often due to changes in ocean currents, etc. would change these faunas so that in recurring strata of the same lithologic character in the same section, the character of the fossil fauna would be different. Thus the character of each fauna of fossils of animals appropriate to the different kinds of bottom, will vary from one plane of equal time to the next. This will bring it about that in following a formation of a given lithologic character we will find fossils indicating a different age at different places. The planes then cut the formations at a low angle, dipping away from the old shore as does the sea bottom. This angle is so slight that the bedding planes which follow it cannot serve as a guide. This fact that a stratum of the same lithologic character is not of the same age throughout, has not been appreciated by many geologists and numerous errors have resulted, especially when some of the formations are barren. Thus, some consider that because the fossils of the limestones overlying the St. Peter sandstone indicate different ages at different localities, there was a period of erosion, or at least of non-deposition. That this does not follow is now realized (Berkey); for as the St. Peter is almost barren, the fact that it is of different ages at different places cannot be seen; we should not speak of the St. Peter time, but simply of the St. Peter formation. The fact that faunas vary with changes of deposits is now well recognized.

Overdrawn.

n/ all?

Two ideas here are confused.

<u>Settling and Induration</u>. The effects of settling and induration have been little studied except sometimes in connection with coal seams. Sorby states that a newly-settled clay was found to contain 89% of water. Obviously the process of induating such a deposit to shale would involve a large volume change. The work of Shaw on the "mud lumps" of the Mississippi delta shows clearly the effects of settling and sliding. Such sliding may take place along very slightly inclined planes as has been found even on land at Panama and elsewhere. Even in Wisconsin such instances occur while Grabau mentions several instances of sub-lacusterine slumping in Europe. Without doubt some of the

peculiar folds and irregularities of bedding which now puzzle the geologist would be readily explained were the true extent of sliding and slumping appreciated. With regard to the settling of marine sands there is less to be said. Where slopes are steep, slumping may occur but in general it is undoubtedly much less likely to occur. Many sea sands are so limy from the presence of shells that but little time would be necessary to indurate indicate them. Carcareous deposits are frequently indurated below water and are readily hardened by percolating waters when uplifted. The subject of volume changes due to recrystalization has not been considered.

Locally the deposits of submarine springs may be important in consolidating sediments without uplift (Delesse).

<u>Summary</u>.- It has been shown that on the bottoms of the seas adjacent to the coasts of the United States we have a wide variety of deposits being laid down at the present time. For the most part, however, the conditions differ considerably from those existing in the Paleozoic seas. The deposits are forming close to rather high lands and on coasts exposed to the full sweep of the ocean waves, and where the depth becomes great at a moderate distance from the shore. The supply of sediment is moreover, largely furnished by rivers. On the Atlantic coast the forces of the sea predominate for the most part, resulting in a clean separation of the mud from the sand. In Florida particularly we find sands now transgressing over coral reefs and associated calcium carbonate deposits just as they did so frequently in Paleozoic seas. There we find little mud or clay, nearly all the fine material being carried out to deep water by the waves and currents of the sea.

In the Gulf of Mexico, however, we find the forces of the land triumphant. The great volume of mud brought by the Mississippi as well as the occurence of older clay formations along the Texan coast, results in overburdening this quieter sea with its slight tides, so that muds are accumulating in quite shallow water. In arctic waters, also, marine sorting is slight because the waves are checked by ice on both beach and sea. Here, then we have the opposite extreme and may conclude that, in a marine series, shales of extensive thickness mean either a very considerable depth of water or the predominance of the forces of the land for any cause, climatic or physiographic, so that either the supply of sediment is too great to be effectually sorted or the forces of the sea are weak.

<u>Bedding of Marine Deposits</u>. It has been shown that on open coasts regular and horizontal bedding is formed in the sands laid down in water deeper than 20 fathoms. In shallower water and where tidal or other currents are strong or near a large source of supply from a river, less regular bedding or even cross-bedding often of the current or sand-bar type, together with intercalated mud lenses will result. Very close studies should be made of such conditions since they much resemble those existing in rivers, and might give rise to nearly or quite unfossiliferous sandstones.

<u>Color of Marine Deposits</u>. The colors of marine deposits are nearly always gray, brown, green, yellowish, or blue. In other words the iron although often in the ferric state is seldom in the state of free ferric oxide or hematite. It is either a
w/ silicorte as in glauconite and perhaps in some clays or a hydrate-sulphide, or sulphate or in the ferrous form. This result is to be ascribed to the reducing action of organic matter and the presence of water. The only notable exception is the red mud found off tropical rivers like the Amazon. In this case the

climatic conditions favor the formation of oxidized lateritic soils which is brought to sea in such quantities that the marine agencies are unable to bleach it completely. Occasionally, however, muds of red color are found in higher latitudes where it is possible they are due to former subaerial exposure of the present sea bottom.

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The other more theoretical conclusions with regard to the sedimentary cycle of clastic deposits need no repetition. They are for the most part not entirely original with the writer. The importance of settling and slumping especially of clays has been noted.

--- Finis ---