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SCIENTIFIC RESULTS OF THE "NAUTILUS" EXPEDITION, 1931

Under the Command of Capt. Sir Hubert Wilkins

Parts IV and V

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CAMBRIDGE, MASSACHUSETTS
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Scientific Results of the "Nautilus" Expedition, 1931, Under the Command of Captain Sir Hubert Wilkins. Parts IV and V.

IV. DIE SCHWEREMESSUNGEN AUF DER "NAUTILUS" EXPEDITION, 1931

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CONTRIBUTION No. 4 FROM THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

Die wissenschaftlichen Arbeiten auf der Wilkins-Nautilus-Expedition 1931 umfassten neben den oceanographischen und erdmagnetischen Untersuchungen die Messungen der Schwerkraft der Erde im Polargebiet. Diese Messungen sind für die Geodäsie—für das Problem der Erdgestalt—von grosser Bedeutung, weil bisher noch keine zuverlässigen Schwerkraftswerte aus dem innerarktischen Gebiet vorliegen und daher die Berechnung der Abplattung der Erde aus der Schwerkraft auf ein sehr unvollständiges Material angewiesen ist. Eine sichere Grundlage für diese Berechnung ergibt erst die Vergleichsmöglichkeit der Schwerkraftswerte im Polargebiet mit denen am Aequator.

Auch für die Untersuchungen über die Lehre der Isostasie d.h. über die Lehre des schwimmenden Gleichgewichts der Erdkruste sind Schwerkraftswerte aus diesem bis jetzt unbekannten Gebiet von grosser Wichtigkeit.

Für die Schweremessungen an Bord des *Nautilus* wurde in Holland ein neuartiger Pendelapparat nach dem System von Professor Vening-Meinesz gebaut, der speziell für U'Boote konstruiert und von ihm auf verschiedenen Fahrten erprobt war.

Schweremessungen auf See mit den allgemein gebräuchlichen Pendelapparaten sind wegen der Störungen durch die ständige, wenn auch noch so kleine Bewegung der See und des Schiffes unmöglich. Um diese Störungen unwirksam zu machen, verwendet Vening-Meinesz zwei zu gleicher Zeit schwingende und in der gleichen vertikalen Ebene aufgehängte Pendel. Jede auf das eine Pendel beschleunigend oder verlangsamend wirkende Horizontalbewegung hat dann die gleiche Wirkung auf das andere Pendel. Durch photographisches Registrieren der Unterschiede der Pendelausschläge wird die Störung ausgeglichen. Die Photogramme enthalten durch Einschaltung zweier Chronometer (eines mittleren Zeit-Chronometers und eines Stern-Zeit-Chronometers) und durch Verwendung mehrerer Hilfspendel noch Zeichen für Zeit und Schwingungsebene. Das ist von grossem Vorteil, weil so die Photogramme erst nach der Expedition ausgemessen und ausgerechnet zu werden brauchen. Der ganze Apparat ist doppelt cardanisch aufgehängt und dadurch im unter-Wasser-fahrenden U'boot verwendbar. Zum Ausrechnen der Messungen sind ausser den Photogrammen nur noch wichtig genaue Aufzeichnungen über Länge und Breite des Standortes, über Geschwindigkeit und Kurs des Schiffes, Richtung und Geschwindigkeit der Strömung, tägl. Gang der beiden Chronometer, Temperatur und Luftfeuchtigkeit im Apparat, Barometerstand, Meerestiefe und Tiefe des Schiffes unter Wasser.

Die Bedienung des Apparates verlangt eine gewisse praktische Begabung und vor allem ein genaues Kennen der Konstruktion in allen Einzelheiten. Zum Einarbeiten dürfte im allgemeinen eine Zeit von 2—3 Wochen genügen, besonders wenn man wie ich das Glück hat, von Prof. Vening-Meinesz selbst eingeführt zu werden.

Längere Uebung erfordert die genaue Ueberwachung der Chronometer durch das Vergleichen der Chronometer mit den wissenschaftlichen Radio-Zeitsignalen (Coincidenzsignalen), da diese Signale oft durch störenden Nebengeräusche oder durch Ueberlagerung anderer signalisierender Radiostationen nur sehr undeutlich zu hören sind. Ich persönlich hatte Zeit genug, mich einzuarbeiten, da *Nautilus* durch die Verzögerungen in Amerika und England 10 Wochen später als vorgesehen in Bergen eintraf. Die Wissenschaftler der Expedition—Professor Sverdrup, Ozeanograph und Chef des wiss. Stabes, der Erdmagnetiker Fl. Soule und ich—waren am 10. Mai in Bergen zusammengekommen, um sich am dortigen Geophysikalischen Institut in die wiss. Untersuchungen einzuarbeiten. Am 28. Mai sollte *Nautilus* von Bergen aus starten, in Wirklichkeit kam das U'boot aber erst am 1. August dort an.

Auf Empfehlung von Vening-Meinesz waren die Chronometer für die Schweremessungen bei der Firma Ulysse Nardin in Le Locle (Schweiz) bestellt worden. Am 15. Mai wurden sie in der Radiostation des Geophysikalischen Instituts in Bergen aufgestellt und von mir täglich verglichen. Als Zeitzeichen verwendete ich die Coincidenzsignale der langwelligen Stationen: Rugby (18750 m Wellenlänge), Bordeaux (19150 m), Nauen (18130 m) und ausnahmsweise auch Paris-Eifelturm (2650 m). Die Chronometer liefen mit grösster Präzision, die mittlere Abweichung vom Mittel der wöchentlichen Periode betrug für die Zeit 18.5.–18.7. beim mittl.-Zeit-Chron. ±0.059 sec., beim Stern-Zeit-Chron. ±0.061 sec.

Am 21. und 22. Juli führten Professor Vening-Meinesz und ich im Keller des Geophysikalischen Instituts in Bergen eine Anschlussmessung an die holländische Station De Bilt aus. Am 21. Juli wurden fünf und am 22. Juli vier Registrierungen von jeweils zweistündiger Dauer vorgenommen. Die Chronometer-vergleichung erfolgte an diesen Tagen je zweimal, am 21. Juli mit Bordeaux 8^{01}–8^{06} und 20^{01}–20^{06} (Greenw. Zeit), am 22. Juli mit Rugby 9^{55}–10^{00} und 17^{55}–18^{00} (Gr. Zt.).

Am 1. August lief *Nautilus* in Bergen ein. Der Einbau der wissenschaftlichen Instrumente—besonders des verhältnismässig grossen Schweremessungsapparates—machte viel Kopfzerbrechen, da der ganze Innenraum des Bootes übervoll war mit Navigationsinstrumenten, Reservemaschinen etc. Schon das Hinunterschaffen durch den Eisenturm war sehr schwierig. Der Pendelkasten selbst ging gerade noch—fast auf den Centimeter genau—hindurch, das Eisengestell für die cardanische Aufhängung aber musste in der Mitte durchgesägt und im Innern des Bootes wieder mit Eisenbändern und Schrauben zusammengesetzt werden.

Der günstigste Platz zum Aufstellen des Schweremessungsapparates ist im allgemeinen der mittschiffs gelegene Zentral-Kontrollraum. Im *Nautilus* war das wegen Ueberfüllung des Raumes mit andern Apparaten unmöglich. Als einzigstes blieb der vorne gelegene sog. wissenschaftl. Raum übrig, in dem ausser dem ganzen wissenschaftl. Gerät noch die Radioanlage, der grosse Eisbohrturm mit den Antriebswinden und fünf Schlafkojen untergebracht waren. Auf zwei starken Eisenschienen am Boden der Kammer wurde das Apparategestell aufmontiert, die Schienen selbst wurden noch verstärkt, damit sich bei starkem Schlingern die Befestigungsschrauben nicht lösen konnten. Sehr bequem war das Arbeiten in dem überfüllten Raum nicht. Der Apparat war nur auf einer Seite frei zugänglich, die drei übrigen Seiten waren mit Kisten zugestellt.

Am 5. August war der Einbau der wissenschaftlichen Apparate beendet und *Nautilus* nahm Kurs nach Norden. Am 15. August wurden in Spitzbergen die letzten Brennstoffvorräte eingenommen. Erst am 18. August konnte der eigentliche Start ins Polareis erfolgen. Die ursprünglich geplante Fahrt quer durch das Polarmeer nach Alaska kam zu so später Jahreszeit natürlich nicht mehr in Frage. Selbst der Nordpol wäre nur noch zu erreichen gewesen, wenn alles auf dem kürzesten Weg und ohne jede Störung vonstatten gegangen wäre. Viel wichtiger aber als eine so riskante Polfahrt war das gründliche Ausprobieren des Bootes in und unter dem Eis, die Feststellung der Leistungsfähigkeit der Eisbohrer und Navigationsinstrumente, das Einsammeln von möglichst zahlreichem Untersuchungsmaterial und vor allem das Erproben der wissenschaftlichen Apparate unter den ganz neuartigen Bedingungen.

Die Expeditionsroute für dieses abgeänderte Programm wurde in das Polarmeer nördlich von Spitzbergen verlegt. Dort sollten am Eisrand die Tauchproben gemacht und die wissenschaftlichen Untersuchungen ausgeführt werden. Der Weg war der Eiskante entlang soweit als möglich nach Osten und dann wieder zurück nach Westen geplant.

Am 19. August wurde nördlich von der Nordwestecke Spitzbergens auf 80° 30′ nördlicher Breite und 12° 00′ östlicher Länge die Eiskante angetroffen. Die Deckaufbauten wurden sofort abmontiert, das Handgeländer weggenommen und die Eisbohrer einer letzten Prüfung unterzogen. Ein plötzlich aufkommender Sturm mit starkem Seegang hinderte uns aber, die angefangenen Arbeiten zu Ende zu führen. Das Treibeis schob sich zusammen und gefährdete das Schiff. Wir mussten schleunigst wieder aus dem Eis herausfahren und einige hundert Meter von der Eiskante entfernt besseres Wetter abwarten. Zwei Tage dauerte der starke Südoststurm mit Schneetreiben an. Das Eis wurde weit nach Norden getrieben und in der Nacht vom 21./22. mussten wir mehrere Stunden nordwärts fahren, um wieder Anschluss an die Eiskante zu bekommen. Erst auf 81° 20′ Nord und 14° 20′ Ost war wieder Eis in Sicht. Als am 22. die Arbeiten zum Tauchklarmachen des Bootes fortgesetzt wurden, stellte der Kapitän des Schiffes fest, dass die Tiefensteuer nicht mehr in Ordnung waren. Der Taucher Crilley wurde unter Wasser geschickt, um festzustellen, was los war. Er kam mit der Meldung zurück, dass das ganze Tiefensteuer von den Trägern abgerissen sei. Wie der Schaden entstanden war, konnte nachträglich nicht mehr einwandfrei ermittelt werden. Sehr wahrscheinlich haben vorbeitreibende Eisschollen auf der Fahrt im Eis das auf beiden Seiten sehr weit überstehende Tiefensteuer erfasst und abgerissen.

In offenem Wasser zu tauchen bezw. untergetaucht zu fahren, war ohne Tiefensteuer ausserordentlich gefährlich. Eine schwache Möglichkeit bestand noch, wenn es gelänge, unter Beibehaltung eines starken Auftriebes aber mit gesenkter Spitze das Boot gewaltsam unter das Eis zu schieben. Ein Versuch wurde beschlossen, und es gelang auch, teilweise unter das Eis zu kommen. Wir konnten so wenigstens Einblick in die Lichtverhältnisse unter dem Eis gewinnen, die viel günstiger waren, als man angenommen hatte.

Da längere Unterwasser-bezw. Untereisfahrten nicht mehr möglich waren, traten die wissenschaftlichen Arbeiten in den Vordergrund. Dabei zeigte es sich, dass das U'Boot besser als jedes andere Fahrzeug für die wissenschaftlichen Untersuchungen geeignet war—ganz speziell für die oceanographischen Arbeiten. Diese wurden nämlich nicht—wie auf den gewöhnlichen Schiffen—vom Deck aus mit der Leine über die Seite ausgeführt, sondern vom sog. Tauchraum im Innern des Bootes aus. Das ist eine geräumige Kammer, ganz vorne im Boot gelegen, die durch eine Schleusskammer luftdicht von den übrigen Räumen abgeschlossen und mit Pressluft gefüllt wurde, bis der Luftdruck im Innern so gross war wie der Wasserdruck von aussen. Eine Falltüre im Boden der Kammer wurde dann herabgelassen, sodass das Meer vollständig frei lag. Unabhängig von Wind und Wetter wurden durch diese Oeffnung Wasserproben aus allen Tiefen des Meeres heraufgeholt, sogar Grundproben vom Meeresschlamm aus Tiefen bis zu 3400 m. Auf diese Untersuchungen hatte glücklicherweise der Verlust des Tiefensteuers gar keinen Einfluss, da sie ebenso gut vom aufgetauchten wie vom untergetauchten Boot aus gemacht werden konnten.

Schwieriger gestalteten sich die Schweremessungen. Unterwasserfahrten in 20 bis 30 m Tiefe kamen für uns nicht mehr in Frage und der Vening-Meineszsche Pendelapparat ist speziell für Fahrten in diesen Tiefen vorgesehen. So musste ich versuchen, die Messungen vom treibenden Schiff aus bei ruhiger See auszuführen. Glücklicherweise sind im Polarmeer die Bedingungen dazu viel günstiger als in jedem andern Meer, da die Eisschollen den Seegang so stark abdämpfen, dass im Innern des Eisgürtels—schon wenige hundert Meter von der Eiskante entfernt—fast jede Dünung aufhört. Unangenehm sind dagegen die mit der Strömung treibenden Eisbrocken, die an das Schiff anstossen und unangenehme Erschütterungen für die Pendel hervorrufen können.

Trotz der erschwerten Umstände gelangen mir in der kurzen Zeit von 8 Tagen sechs einwandfreie Messungen. Die Tagebucheinträge für diese Zeit gebe ich hier wieder:

30. August. Der Wind hat über Nacht nach Norden gedreht und die Dünung am Eisrand hat fast ganz nachgelassen. Ich schlage Sverdrup vor, in den Eisgürtel einzufahren, um eine Schweremessung über Wasser zu versuchen. Auf 81° 50′ Nord und 19° 55′ Ost wird in Lee einer grossen Scholle gestoppt. Schwache, langgezogene Dünung. Nach einigen vergeblichen Versuchen gelingt es mir, den Pendeln die richtige Amplitude zu geben. Nach 10 Minuten Registrierzeit nimmt die Dünung zu. Trotz cardanischer Aufhängung kommen die Pendel in so starke Schwingung, dass ich in der 15. Minute die Messung wegen Gefahr für die Achatschneiden der Pendel abbrechen muss. Zwei weitere Versuche verlaufen ebenfalls ergebnislos.

31. August. Der Nordwind hat über Nacht das Eis weit nach Süden getrieben. Der Eisgürtel ist lockerer geworden, die Aussichten, ein ruhiges Plätzchen für die Messungen zu finden, sind heute günstiger. Gegen 6 Uhr fahren wir tiefer ins Eis hinein. Zwischen zwei grossen Schollen wird Halt gemacht. Die Dünung ist kaum mehr zu spüren. Von 8^{00}–8^{30} (Gr. Zt.) gelingt mir die erste einwandfreie Schweremessung (Nr. 2) im Polargebiet; d.h. wenn ich die Probemessung vom 18. August (Nr. 1) in der Adventbai nicht mitzähle. (Diese Messung hatte ich kurz vor der Abfahrt von Spitzbergen ins Eis angefangen, aber nicht zu Ende führen können, da die Dieselmotoren gestartet wurden, während ich noch registrierte. Wie sich später herausstellte, konnte das Photogramm aber doch noch ausgewertet werden. Wir haben auf diese Weise auch eine Schwerkraftsmessung aus dem Eisfjord in Spitzbergen (Adventbai) bekommen.)

Der Standort während der Messung am 31. August ist 81° 48′ Nord und 19° 25′ Ost. Das Echolot zeigt eine Meerestiefe von 3400 m, wir befinden uns also im eigentlichen Polarbecken. Gleich nach Beendigung der Schweremessung werden die Antennen umgelegt. Schade, dass ich deswegen die 10 Uhr-Zeitsignale von Rugby nicht hören kann und bis zum Abend warten muss. Aber schliesslich sind die Tauchversuche für die Expedition genau so wichtig wie die Schweremessungen. . . . Gegen 17 Uhr ist das Tauchen zu Ende. Die Antennen werden aufgerichtet und die Radiostation in Gang gesetzt. Von 20^{01}–20^{06} höre ich die Coincidenzsignale von Bordeaux, allerdings wegen vieler athmosphärischer Störungen sehr undeutlich. Der tägl. Gang des mittl. Zt. Chron. ist heute −0.39 sec., der des Stern-Zt. Chron. +1.07 sec., Barom. 756 mm, Luftfeucht. 73%, Temp. +4.8° Celsius.

1. Sept. Liegen wegen Nebels an der Eiskante und laden die Akkumulatoren auf. Ich helfe Sverdrup bei den chemischen Untersuchungen der Wasserproben. Abends entwickle ich eine Probe der gestrigen Schweremessung, Resultat gut. Gegen Mitternacht fahren wir der Eiskante entlang ostwärts.

2. *Sept.* Bis 7 Uhr haben wir ca. 50 Seemeilen zurückgelegt. Interessant sind heute die Echolotungen. Innerhalb weniger Meilen steigt der Meeresboden von 3000 m auf 100 m. Der Schelfrand geht hier viel weiter nach Norden, als man bisher geglaubt hat. Wir liegen auf 81° 38′ N. und 24° 45′ O. ringsum von Eis umgeben. Wilkins und Sverdrup arbeiten in der Tauchkammer, ich versuche in der Zwischenzeit kurz hintereinander 2 Messungen, um eine Vergleichsprobe zu haben. Bei der ersten Registrierung von 8^{45}–9^{15} ist die See etwas unruhig, zu allem Ueberfluss fängt mitten drin noch der Elektromotor an zu laufen. Wir sind während des Treibens einer grossen Eisscholle zu nahe gekommen und müssen rasch einige Meter zurückfahren, bevor die Messung zu Ende ist. Ich registriere aber trotzdem weiter, um zu sehen, wie die Pendel auf die Erschütterungen des Ueberwasserfahrens mit den Elektromotoren reagieren. Die zweite Messung (Nr. 3) von 10^{40}–11^{10} klappt vorzüglich. Den tägl. Gang kann ich heute sehr genau nach den Morgen- und Abendcoincidenzen von Rugby feststellen: mittl. Zt. Chr. –0.24 sec., Stern-Zt. Chr. +1.05 sec., Temp. +6.7° C., Meerestiefe: 560 m (Echolot & Draht), Barom. 760. 8 mm., Luftfeucht. 74.2%.

Nachmittags legen wir an einer grossen Eisscholle an und vertäuen das Schiff. Soule macht auf einer sehr grossen Eisscholle eine erdmagnetische Serienbeobachtung, Sverdrup eine genaue Ortsbestimmung mit dem Theodolit.

3. *Sept.* Stark bewölktes, nasskaltes Wetter, nasser Neuschnee. Wir fahren nach Westen zurück, um wieder in tieferes Wasser zu kommen. Um 18^{00} wird auf 81° 44′ N. und 11° 20′ O. gestoppt und auf besseres Wetter gewartet. Ein Schweremessungsversuch scheitert an zu starkem Seegang.

4. *Sept.* Das Wetter hat sich gebessert. Um. 7 Uhr fahren wir in den Eisgürtel hinein. Wilkins und der Kameramann Dored wollen Filmaufnahmen von unserer neuartigen Tauchtechnik machen. Beide werden auf einer Eisscholle abgesetzt. Das Schiff wird zum Tauchen fertig gemacht, die Spitze gesenkt und mit grosser Fahrt unter eine Eisscholle geschoben. . . . 12 Uhr sind die Tauchmanöver zu Ende. Hinter einer grossen Scholle lassen wir das Schiff treiben, um wissenschaftlich arbeiten zu können. Sverdrup arbeitet mit Soule im Tauchraum, ich mache auf 81° 40′ N. und 11° 20′ Ost eine neue Schweremessung (Nr. 4), die aber wegen Wind und leichtem Seegang recht schwierig ist. Ueber eine Stunde brauche ich, bis die Pendel die richtige Amplitude haben. Plötzlich—ich bin glücklicherweise mit der halbstündigen Registrierung fertig—gibt es einen furchtbaren Ruck. Der Apparat schwankt bedenklich hin und her. Ich kann gerade noch die Pendel arretieren und so eine Beschädigung der Achatschneiden vermeiden. Eine riesengrosse Scholle ist mit der Breitseite des U'Bootes zusammen gestossen und hat die vordere Stahlwand verbeult.—Tägl. Gang (mit Rugby verglichen) heute für mittl. Zt. Chr. –0.48 sec., für Stern-Zt. Chr. +0.46 sec. Meerestiefe: 1582 m, Barom. 762.7 mm, Luftfeucht. 74.5%, Temp. +5.0° C. Abends Weiterfahrt in südwestlicher Richtung.

5. *Sept.* Stürmisches kaltes Herbstwetter mit Schneetreiben. Um 7^{30} versuche ich eine Messung während einer oceanographischen Station, aber es ist unmöglich, die Pendel in die richtige Schwingung zu bringen. Nach Beendigung der oceanographischen Arbeiten fahren wir weiter ins Eis hinein, um ruhigeres Wasser zu finden. Auf 81° 23′ Nord und

6° 50′ Ost gelingt mir die Messung (Nr. 5). Es stossen zwar immer kleine Eisstücke an die Schiffswand, ich kann aber die Registrierung doch gut zu Ende führen.

Tägl. Gang (Rugby) für mittl. Zt. Chr. –0.30 sec., für Stern-Zt. Chr. +0.68 sec. Meerestiefe: 775 m, Barom. 762.1 mm, Luftfeucht. 74.8%, Temp. +6.5° C.

6. Sept. Das gleiche kalte stürmische Wetter wie tags zuvor. In der Nacht sind wir der Eiskante nach Südwesten gefolgt. Der Eisrand wird immer dichter. Erst gegen Mittag finden wir eine Bucht, in der wir arbeiten können. Auf 80° 31′ Nord und 1° 05′ Ost mache ich die vielleicht letzte Messung (Nr. 6) im Eis (morgen wollen wir nach Spitzbergen zurüchfahren!), die ohne jede Störung verläuft. Tägl. Gang (Rugby) für mittl. Zt. Chr. –0.40 sec., für Stern-Zt. Chr. +0.70 sec.

Meerestiefe: 3110 m, Barom. 761.9 mm, Luftfeucht. 74.8%, Temp. +6.05° C. Die Echolotungen der letzten Tage sind sehr interessant gewesen. Wir kamen aus dem eigentlichen Polarbecken (von Tiefen bis 3400 m) über ein Unterwassergebirge (Nansenrücken!) (geringste Tiefe 400 m auf 81° 26′ und 7° 55′ Ost) in die norwegische See (mit Tiefen bis 3100 m).

Den ganzen Tag fahren wir in südwestlicher Richtung weiter. Wir begegnen zwei grossen Eisbergen. Die Eiskante wird volkommen fest, nirgends zeigen sich offene Buchten. Bei 80° 02′ Nord und 1° 25′ West geht sie in südlicher Richtung weiter. Wetter sehr stürmisch, hohe Dünung. Wissenschaftliche Arbeiten sind so gut wie aussichtslos. Wir machen kehrt und nehmen Kurs auf Spitzbergen (Crossbai).

7. Sept. Das Schiff schlingert entsetzlich. Wir beobachten Ausschläge bis zu 50° nach einer Seite. Eine Sturzwelle geht über Deck und knickt den vorderen Antennenmast um. Nachmittags laufen wir in die Crossbai ein und stoppen in der Nähe der Südwestspitze von König Haakons Halbinsel auf 79° 13′ Nord und 12° 00′ Ost zur letzten Schweremessung im Polargebiet (Nr. 7). Die Registrierung gelingt gut, nur gegen Ende nimmt die Dünung zu.

Tägl. Gang (Rugby-Bordeaux) –0.31 sec. für mittl. Zt. Chr., für Stern-Zt. Chr. +0.93 sec. Meerestiefe: 29 m, Barom. 759.2 mm, Luftfeucht. 75.5%, Temp. +8° C.

8. Sept. *Nautilus* fährt nach genau dreiwöchentlicher Eisfahrt in den Eisfjord (Adventbai) ein. Da Wilkins beabsichtigt, von hier direkt nach Amerika zu fahren, werden die wissenschaftlichen Apparate ausmontiert und an Bord des Spitzbergen-Kohlendampfers *Inger Elisabeth* verladen, auf welchem Sverdrup, Soule und ich nach Bergen zurück fahren.

26. Sept. Die Rückfahrt von Spitzbergen nach Norwegen mit unserer gesammten wissenschaftlichen Ausrüstung verlief ohne Besonderheit. Ankunft in Bergen am 17. Sept., 3 Tage vor *Nautilus*, der die Rückfahrt nach Amerika wegen schlechten Wetters aufgeben musste und nach Bergen beordert wurde. Die wissenschaftlichen und nautischen Instrumente werden nach dem Geophysikalischen Institut in Bergen gebracht und dort unter Zollverschluss für die nächste Expedition (mit einem neuen Special-Arktis-U'Boot) aufbewahrt.—Vom 19.–23. Sept. entwickle ich die Photogramme der Schweremessungen, die ich auf der Expedition gemacht habe. Mit Ausnahme der Messung vom 30. August (die ich am 31. August wiederholt habe) sind alle Photogramme gut auswertbar.

25. und 26. Sept. mache ich die Anschlussmessungen im Keller des Geophysikalischen Instituts in Bergen—analog den Messungen vom 21. und 22. Juli. An beiden Tagen werden je 6 Messungen von jeweils zweistündiger Dauer durchgeführt. Die Chronometervergleich-

ung erfolgt jeweils 9^{31}–9^{36} und 22^{31}–22^{36} nach den Coincidenzsignalen von Paris-Eifelturm (Welle 2650 m).

Tägl. Gang des mittl. Zt. Chr. am 25. Sept. –0.74 sec., am 26. Sept. –0.87 sec.
Tägl. Gang des Stern-Zt. Chr. am 25. Sept. +0.54 sec., am 26. Sept. +0.42 sec.

Damit schliessen die Tagebucheinträge über die Schweremessungen auf der Nautilusexpedition. Am 5. Okt. wurden die Pendel zur Nachprüfung auf Länge und Gewicht zu Professor Vening-Meinesz nach Holland (De Bilt) gebracht.

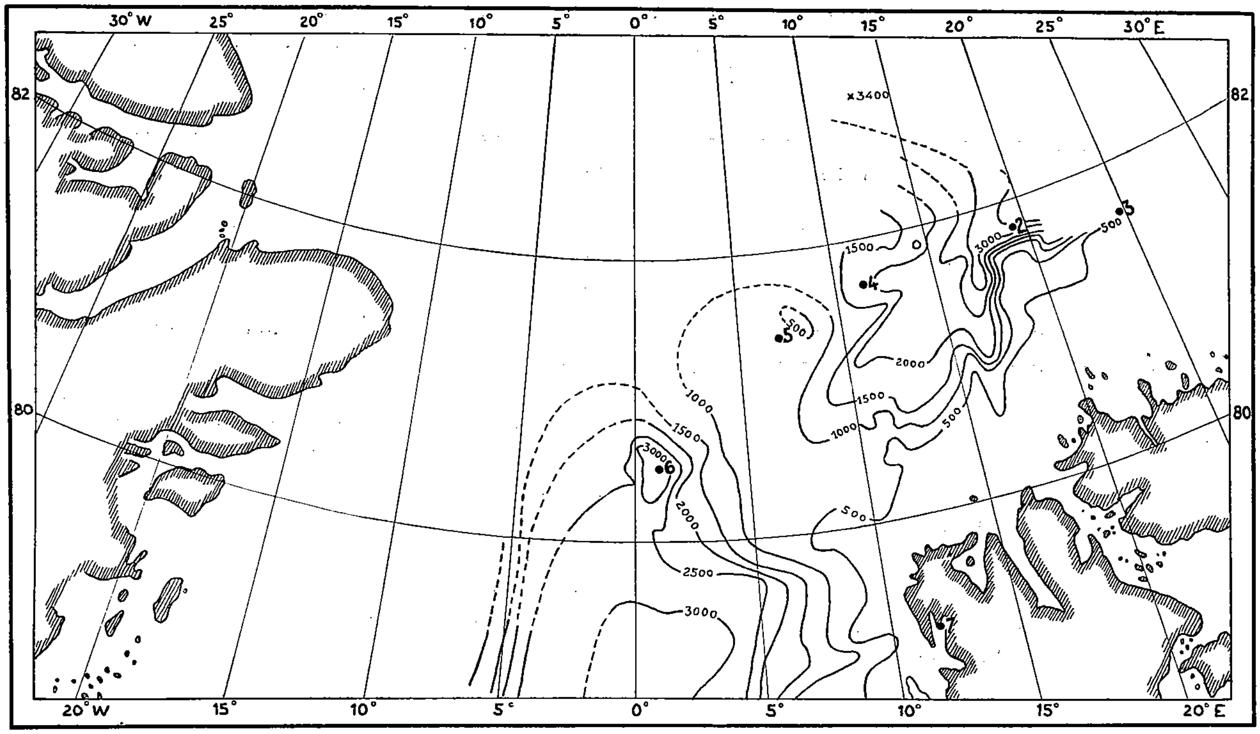

Fig. 47.

Ueber die Berechnung und die Resultate der Messungen geben die beigefügten Tabellen Aufschluss (siehe Tabelle 1 und 2, Anhang 1 und 2 und Anmerkungen zu den Tabellen 1 und 2 bezw. Anhang 1 und 2).

Die auf der Nautilusexpedition gefundenen Schwerkraftswerte geben natürlich noch kein umfassendes Bild über die Abplattung der Erde im Polargebiet. Sie scheinen zwar den Wert von 1/270 zu bestätigen, auf den sich die Formel für den Normalwert der Schwerkraft stützt. Der Wert von 1/270 ist aus dem heutigen Schwerkraftsmaterial und aus den astronomischen Beobachtungen errechnet worden. Doch ist eine sichere Entscheidung bei der geringen Zahl von Messungen noch nicht möglich. Immerhin der erste Schritt ist gemacht. Spätere Expeditionen werden neue Messungen hinzufügen, bis auch das Problem der Erdgestalt im Polargebiet eines Tages gelöst sein wird.

Anmerkungen zu den nachfolgenden Tabellen 1 und 2 und zu Anhang 1 und 2:

1.) Ueber die Art und Weise, wie die Photogramme ausgemessen und berechnet wurden, liegen folgende Veröffentlichungen vor:

Theory and Practice of Pendulum Observations at Sea by F. A. Vening-Meinesz. (Publication of the Netherlands Geodetic Commission—uitgegeven door de Rijkscommissie voor Graadmeting en Waterpassing—Technische Boekhandel en Drukkerij J. Waltman jr.—Delft 1929.)

Publications of the United States Naval Observatory, Second Series, Vol. XIII—Appendix I, Washington, 1930. (Papers from the Geophysical Laboratory, Carnegie Institution of Washington, No. 736.)

2.) Die Konstanten für Temperatur und Luftdichte wurden von Prof. Vening-Meinesz im Winter 1930/1931 in Holland bestimmt. Die Werte betragen:

Temp. Konstante für Pendel Nr. 4 = 43.08 10^{-7} sec.
" " " " Nr. 5 = 46.54 " "
" " " " Nr. 6 = 42.85 " "

Luftdichtekonstante f. Pend. Nr. 4, 5, 6 = 639 10^{-7} sec. pro Dichteeinheit von trockener Luft bei 760 mm Druck und 0° Celsius Temperatur.

3.) Aus der Gangtabelle der beiden Chronometer (siehe Anhang 2) ist zu ersehen, dass der mittl. Zt. Chr. Nr. 2780 einen regelmässigeren Gang hatte als der Stern-Zt. Chr. Nr. 2787. Es wurde daher dem mit Chr. 2780 berechneten Resultat für die Schwingungszeiten dreimal mehr Gewicht gegeben als dem mit Chr. 2787.

4.) Als Basisstation für die Messungen auf der Expedition wurde das holländische geodätische Institut in De Bilt genommen. Der Schwerkraftswert für De Bilt beträgt ($g_{\text{De Bilt}}$ =) 981,268 cm/sec^2.

Für die Stationsvergleichung wurde gefunden:

		d
am 7. Mai 1931	0.5037877	48
am 8. Mai 1931	0.5037895	49
Mittel	0.5037886	48
am 26. Nov. 1931	0.5037870	17
am 27. Nov. 1931	0.5037871	18
Mittel	0.5037871	18

$d = T_6 - T_5$ ist der Unterschied der reduzierten Schwingungszeiten der zwei fiktiven Pendel.

Als Mittel für die Stationsvergleichung wurde 0.5037881 angenommen (wegen Differenzänderung (*d*) wurde der zweiten Reihe nur der halbe Wert der ersten Reihe gegeben).

TABELLE 1

Nr. der Messungen	Datum (1931)	Temp. (Cels.)	Barom. (mm)	Feucht. (%)	$T_6-T_5=d$ (10^{-7} sec.)	v (10^{-7} sec.)	g_0 (cm/sec^2)
Nr. 1	Aug. 18	11.0	759.2	73	102	6	982.988
" 2	" 31	4.8	756.0	73	34	–	983.096
" 3	Sept. 2	6.84	760.8	74	62	– 2	983.169
" 4	" 4	5.1	762.7	74	– 2	–27	983.098
" 5	" 5	6.49	762.1	75	52	–13	983.128
" 6	" 6	6.05	761.9	75	–25	– 4	983.112
" 7	" 7	7.88	759.2	75	118	–22	983.016

d ist der Unterschied der reduzierten Schwingungszeiten der 2 fiktiven Pendel.

v ist der Unterschied der mittl. reduzierten Schwingungszeiten der 2 fiktiven Pendel, berechnet nach dem Chron. Nr. 2870 und nach dem Chron. 2787.

TABELLE 2

Nr. der Messungen	Breite (Nord)	Länge (Ost) (v. Gr.)	Meeres Tiefe (m)	g_0 (cm/sec^2)	γ (cm/sec^2)	Korr. für Topograph. u. Kompens. (milligal)	$g_0-\gamma$ (milligal)	g_0-g_c (milligal)
Nr. 1	78° 14′	15° 37′	40	982.988	983.006	– 6	–18	–12
" 2	81° 48′	19° 25′	3402	983.096	983.116	–74	–20	+54
" 3	81° 38′	24° 45′	560	983.169	983.111	+59	+58	– 1
" 4	81° 40′	11° 20′	1582	983.098	983.112	– 2	–14	–12
" 5	81° 23′	6° 50′	775	983.128	983.104	+29	+24	– 5
" 6	80° 31′	1° 05′	3110	983.112	983.080	–62	+32	+94
" 7	79° 13′	11° 50′	29	983.016	983.040	+10	–24	–34

Für die Korrektionen für Topogr. und Kompens. der Messungen Nr. 2–6 ist eine Unsicherheit von ±10 milligal anzunehmen, da für diese Stationen nur wenige sichere Daten über Meerestiefe und Topographie vorliegen.

γ ist die theoretisch errechnete Schwerkraft nach der Formel von Cassinis, welche von der internationalen geodätischen Assoziation an der Konferenz in Stockholm im Jahre 1930 angenommen wurde.

$$(\gamma = 978.049\,(1+0.0052884\,\sin^2\varphi - 0.0000059\,\sin^2 2\varphi)\,)$$
$$(\varphi = \text{Breite}\qquad)$$

$g_0-\gamma$ ist die unreduzierte Anomalie mit Rücksicht auf die Formel von Cassinis.

g_c ist gleich γ+Korrektion für Topographie und Kompensation nach dem Verfahren der U. S. Coast and Geodetic Survey (siehe Anhang 1).

g_0-g_c ist die isostatische Anomalie mit Rücksicht auf die Formel von Cassinis, reduziert nach dem Verfahren der U. S. Coast and Geodetic Survey.

Die verhältnismässig grossen Schwankungen von d rühren her von den Unsicherheiten in der Berechnung der Korrektionen für Amplitude und für Abweichung von Isochronismus, verursacht durch die grosse Unregelmässigkeit der Pendelschwingungen. Diese Unregelmässigkeit ist die Folge der stärkeren Schiffsbewegung über Wasser. Die mittlere Schwankung von d ist *54 10^{-7} sec.*

Würde das für die Schwerkraftsberechnung benutzte Mittel der Schwingungszeiten der zwei fiktiven Pendel von den Unsicherheiten dieser Reduktionen in korrespondierendem Masse beeinflusst, so wäre der mittlere Fehler dieses Mittels $=1/2.54 \; 10^{-7}$ sec. In Wirklichkeit heben sich aber die Unsicherheiten der Korrektionen im Mittel grösstenteils auf (siehe pag. 25 von "Theory and Practice of Pendulum Observations at Sea"), der mittlere Fehler ist also bedeutend kleiner. Wenn wir dafür zwei Drittel des Wertes $=18 \; 10^{-7}$ sec. annehmen, haben wir ihn bestimmt nicht unterschätzt.

Der Einfluss der Gangunsicherheiten der Chronometer konnte, wie die Zahlen von v zeigen, demgegenüber vernachlässigt werden.

Das gleiche gilt auch von dem Eötvös-Effekt, der die Abänderung der Centrifugalkraft der Erde ausdrückt, die von einer Ostwestgeschwindigkeit des Schiffes während der Fahrt herrührt. Die Eigenbewegung des Schiffes war gleich Null (es lag während der Messungen ohne Fahrt an der Wasseroberfläche) und die Strömung in solch hohen Breiten hat nur ein Sechstel des Einflusses wie am Aequator (er beträgt bei Strömung von 1 Seemeile pro Stunde auf 80° nördl. Breite nur 1, 3 milligal). Die Strömungsgeschwindigkeit und Richtung hätte sowieso nicht geschätzt werden können, da die Ortsbestimmungen und die nachträgliche Berechnung des Gesamtkurses wegen häufiger plötzlicher Kursänderungen im Treibeis zu ungenau waren.

Der oben angegebene Fehler von $18 \; 10^{-7}$ sec. im Mittel der Schwingungszeiten ist im Resultat für g einem mittleren Fehler von 7 *milligal* gleichzusetzen.

ANHANG 1

Corrections for Topography and Compensation, calculated by U. S. Coast and Geodetic Survey
(In units of the fourth decimal place of gals)

STATION No. 1

ZONE	ELEVATION IN METERS	TOPOGRAPHY	COMPENSATION	TOPOGR. AND COMPENSATION	ZONE	TOPOGR. AND COMPENSATION
A	− 46	− 1	0	− 1	18	+ 4
B	− 46	−24	0	−24	17	+ 9
C	− 46	−16	0	−16	16	+12
D	− 44	− 6	0	− 6	15	+18
E	− 37	− 5	0	− 5	14	+21
F	− 20	0	0	0	13	+50
G	+ 57	+ 1	− 1	0	12	+29
H	+115	+ 2	− 2	0	11	+21
I	+257	− 5	− 7	−12	10	+13
J	+439	− 6	−16	−22	9	+ 4
K	+305	+ 2	−16	−14	8	+ 2
L	+166	+ 3	−13	−10	7	+ 1
M	+319	+ 4	−62	−58	6	0
N	+359	− 1	−60	−61	5	+ 2
O	+134	− 4	−22	−26	4	+ 4
					3	+ 5
					2	+ 5
					1	0
			Total (all zones, lettered and numbered)			−55

ANHANG 1

Corrections for Topography and Compensation, calculated by U. S. Coast and Geodetic Survey
(In units of the fourth decimal place of gals)

STATION NO. 2

ZONE	ELEVATION IN METERS	TOPOGRAPHY	COMPENSATION	TOPOGR. AND COMPENSATION	ZONE	TOPOGR. AND COMPENSATION
A	−2091	− 1	+ 0	− 1	18	+37
B	−2091	− 41	+ 1	− 40	17	+35
C	−2091	−107	+ 3	−104	16	+33
D	−2091	−214	+ 8	−206	15	+31
E	−2091	−348	+ 17	−331	14	+31
F	−2079	−368	+ 20	−348	13	+60
G	−2081	−299	+ 25	−274	12	+34
H	−2076	−247	+ 33	−214	11	+21
I	−2057	−241	+ 54	−187	10	+17
J	−1941	−127	+ 71	− 56	9	+ 8
K	−1773	− 85	+ 93	+ 8	8	+ 4
L	−1625	− 49	+128	+ 79	7	+ 1
M	−1428	− 42	+275	+233	6	− 2
N	−1242	− 9	+209	+200	5	+ 1
O	−1120	− 5	+185	+180	4	+ 5
					3	+ 5
					2	+ 5
					1	0
			Total (all zones, lettered and numbered)			−735

STATION NO. 3

ZONE	ELEVATION IN METERS	TOPOGRAPHY	COMPENSATION	TOPOGR. AND COMPENSATION	ZONE	TOPOGR. AND COMPENSATION
A	− 215	− 1	0	− 1	18	+31
B	− 215	−40	0	− 40	17	+28
C	− 215	−68	0	− 68	16	+28
D	− 215	−61	+ 1	− 60	15	+28
E	− 234	−39	+ 2	− 37	14	+30
F	− 252	−17	+ 2	− 15	13	+47
G	− 277	− 9	+ 3	− 6	12	+34
H	− 325	−11	+ 5	− 6	11	+26
I	− 371	−16	+ 10	− 6	10	+17
J	− 419	− 2	+ 15	+ 13	9	+ 9
K	− 464	− 4	+ 24	+ 20	8	+ 5
L	− 568	−13	+ 45	+ 32	7	+ 1
M	− 883	−20	+170	+150	6	−2
N	−1019	−10	+171	+161	5	+ 1
O	− 993	− 9	+164	+155	4	+ 5
					3	+ 5
					2	+ 5
					1	0
			Total (all zones, lettered and numbered)			+590

ANHANG 1

Corrections for Topography and Compensation, calculated by U. S. Coast and Geodetic Survey
(In units of the fourth decimal place of gals)

STATION NO. 4

ZONE	ELEVATION IN METERS	TOPOGRAPHY	COMPENSATION	TOPOGR. AND COMPENSATION	ZONE	TOPOGR. AND COMPENSATION
A	−1076	− 1	0	− 1	18	+36
B	−1076	− 41	+ 1	− 40	17	+36
C	−1076	−102	+ 2	−100	16	+38
D	−1076	−190	+ 4	−186	15	+40
E	−1076	−249	+ 9	−240	14	+40
F	−1076	−201	+ 11	−190	13	+53
G	−1076	−121	+ 13	−108	12	+51
H	−1076	− 97	+ 17	− 80	11	+22
I	−1068	− 68	+ 28	− 40	10	+13
J	−1061	− 39	+ 39	0	9	+ 7
K	−1049	− 35	+ 55	+ 20	8	+ 5
L	− 976	− 27	+ 77	+ 50	7	+ 2
M	− 980	− 18	+189	+171	6	− 2
N	−1222	− 4	+205	+201	5	+ 1
O	−1104	− 2	+183	+181	4	+ 5
					3	+ 5
					2	+ 5
					1	0
			Total (all zones, lettered and numbered)			−25

STATION NO. 5

A	−492	− 1	0	− 1	18	+38
B	−492	− 40	0	− 40	17	+38
C	−492	− 93	+ 1	− 92	16	+35
D	−492	−137	+ 2	−135	15	+35
E	−492	−120	+ 4	−116	14	+34
F	−492	− 65	+ 5	− 60	13	+45
G	−502	− 34	+ 6	− 28	12	+25
H	−507	− 24	+ 8	− 16	11	+17
I	−512	− 15	+ 13	− 2	10	+11
J	−523	− 3	+ 19	+ 16	9	+ 7
K	−527	− 8	+ 28	+ 20	8	+ 5
L	−538	− 11	+ 42	+ 31	7	+ 3
M	−628	− 3	+121	+118	6	− 2
N	−753	− 1	+127	+126	5	+ 1
O	−977	− 1	+162	+161	4	+ 5
					3	+ 5
					2	+ 5
					1	0
			Total (all zones, lettered and numbered)			+289

ANHANG 1

Corrections for Topography and Compensation, calculated by U. S. Coast and Geodetic Survey
(In units of the fourth decimal place of gals)

STATION NO. 6

ZONE	ELEVATION IN METERS	TOPOGRAPHY	COMPENSATION	TOPOGR. AND COMPENSATION	ZONE	TOPOGR. AND COMPENSATION
A	−1845	− 1	0	− 1	18	+34
B	−1845	− 41	+ 1	− 40	17	+33
C	−1845	−103	+ 3	−100	16	+34
D	−1845	−211	+ 7	−204	15	+30
E	−1845	−335	+ 15	−320	14	+23
F	−1845	−342	+ 18	−324	13	+35
G	−1835	−258	+ 22	−236	12	+25
H	−1776	−193	+ 28	−165	11	+18
I	−1697	−165	+ 44	−121	10	+12
J	−1645	− 92	+ 60	− 32	9	+ 7
K	−1568	− 65	+ 82	+ 17	8	+ 6
L	−1409	− 39	+111	+ 72	7	+ 4
M	−1116	− 21	+215	+194	6	− 2
N	−1065	− 5	+179	+174	5	+ 1
O	−1190	− 4	+197	+193	4	+ 5
					3	+ 5
					2	+ 5
					1	0
			Total (all zones, lettered and numbered)			−618

STATION NO. 7

A	− 77	− 1	0	− 1	18	+17
B	− 77	−31	0	−31	17	+21
C	− 69	−28	0	−28	16	+24
D	− 74	−14	0	−14	15	+26
E	− 60	− 7	0	− 7	14	+31
F	− 39	− 2	0	− 2	13	+53
G	− 39	0	0	0	12	+27
H	+ 70	0	− 1	− 1	11	+17
I	+215	− 4	− 6	−10	10	+12
J	+303	− 1	−11	−12	9	+ 6
K	+394	− 5	−21	−26	8	+ 5
L	+366	+ 4	−29	−25	7	+ 2
M	+258	+ 4	−50	−46	6	− 1
N	− 37	− 1	+ 6	+ 5	5	+ 2
O	−299	− 4	+49	+45	4	+ 4
					3	+ 5
					2	+ 5
					1	0
			Total (all zones, lettered and numbered)			+103

ANHANG 2

(*Gangtabelle der beiden Chronometer Nr. 2780 und 2787*)

Datum 1931	Tägl. Gang des Mittl. Zt. Chron. Nardin Nr. 2780	Abweich. v. Mittel der Wöchentl. Periode	Tägl. Gang des Stern-Zt. Chron. Nardin Nr. 2787	Abweich. v. Mittel der Wöchentl. Periode
Aug. 18	−0.81	−0.05	+0.62	+0.30
" 19	−0.91	+0.05	+1.30	−0.38
" 20	−0.91	+0.05	+0.96	−0.04
" 21	−0.88	+0.02	+1.07	−0.15
" 22	−0.80	−0.06	+0.98	−0.06
" 23	−0.86	±0.00	+0.61	+0.31
	Mittel −0.86	±0.04	Mittel +0.92	±0.21
Aug. 24	−0.52	−0.08	+1.33	−0.37
" 25	−0.57	−0.03	+0.92	+0.04
" 26	−0.64	+0.04	+1.28	−0.32
" 27	−0.80	+0.20	+0.86	+0.10
" 28	−0.55	−0.05	+0.55	+0.41
" 29	−0.51	−0.09	+0.93	+0.03
" 30	−0.64	+0.04	+0.84	+0.12
	Mittel −0.60	±0.07	Mittel +0.96	±0.20
Aug. 31	−0.39	−0.01	+1.07	−0.31
Sept. 1	−0.36	−0.04	+0.61	+0.15
" 2	−0.48	+0.08	+0.71	+0.05
" 3	−0.44	+0.04	+0.80	−0.04
" 4	−0.43	+0.03	+0.67	+0.09
" 5	−0.36	−0.04	+0.61	+0.15
" 6	−0.40	±0.00	+0.70	+0.06
" 7	−0.31	−0.09	+0.93	−0.17
" 8	−0.40	±0.00	+0.72	+0.04
	Mittel −0.40	±0.04	Mittel +0.76	±0.12

V. THE BOTTOM DEPOSITS

By H. C. STETSON

CONTRIBUTION NO. 5 FROM THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

This paper presents the data obtained from the eight bottom cores collected by the *Nautilus* on the Wilkins-Ellsworth Expedition of 1931. The writer wishes to express his thanks to Prof. P. E. Raymond for much helpful advice, and to Miss Mary F. Wolfe and Miss C. F. Whitman for assistance in the mechanical analysis.

The stations lie in a crescent approximately 270 miles long, and from 80 to 100 miles off the coast of Spitzbergen. It was hoped that information of some geologic significance might result, but due to the infrequence of the stations and the shortness of the cores there has come out of it little more than a detailed account of the type of bottom deposit encountered in that particular part of the Arctic Basin.

TABLE I

SAMPLE No.	DATE	LAT. N.	LONG. E.	DEPTH, M.	LENGTH OF CORE, CM.
1	Aug. 26	81 54	14 15	1600	42
2	Aug. 27	81 52	13 40	1620	44
3	Aug. 28	81 59	17 30	2660	35
4	Aug. 29	81 51	21 30	3500	36
5	Sept. 2	81 38	24 45	560	Empty glass tube
6	Sept. 4	81 40	11 20	1690	38
7	Sept. 5	81 24	6 50	790	37
8	Sept. 5	81 01	4 15	740	34
9	Sept. 6	80 31	1 10	3100	42

The cores were taken with a *Meteor* type bottom sampler in late August and early September, and were received in Cambridge the following February. They were still moist inside their glass tubes, and could be pushed out without distortion. This process shortened the cores somewhat, and the lengths here given in Tables II and III are those measured after removal from the tube. It must also be remembered that previous to this, the column of sediment probably shortened about one-quarter to one-third of its original length under the impact and friction of the bottom sampler.

PROCEDURE

The procedure adopted was the combined sieve and hydrometer method devised by Dr. Arthur Casagrande, formerly of the Massachusetts Institute of Technology and now of Harvard University. The description of this method, in manuscript form, is now in the hands of the U. S. Bureau of Public Roads. The principal errors of the older methods, such as accumulation of sediment on the bulb, the influence of the diameter of the sedimentation cylinder on the computation of the grain size, and the temperature factor, have been compensated for by various corrections resulting from much experimental work. An improved form of hydrometer, accurately calibrated, is used.

It is, of course, essential to have the sample absolutely free of salt. This was accomplished by repeated washings, the water being drawn off through a Pasteur-Chamberland filter by means of a vacuum pump. This is much more efficient than filter paper, and in addition none of the finer grades is lost. The film of clay readily slides off the porcelain filter tube when back pressure is applied. The sample was never dry until the final weighing, which made mechanical dispersion easy and thorough by means of an electric egg beater. Sodium silicate or ammonia was the dispersing agent used.

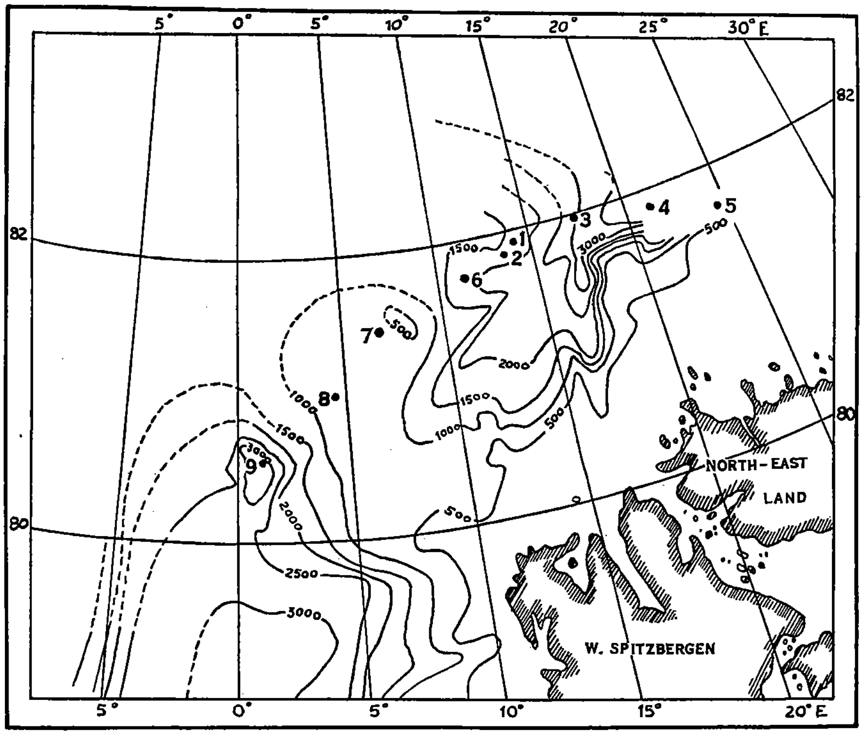

Fig. 1. Position of Bottom Cores.

Since the determination of grain size and the percentage distribution require the solution of equations for every hydrometer reading, Casagrande has devised a nomographic chart which greatly accelerates this process.

Numerous writers, notably Rubey (6), have pointed out the undesirability of presenting the size distribution of clays and silts in the terms of actual diameters. Settling velocities, rather, should be used. Although this is theoretically correct, it causes difficulty in presenting the size distribution when the sample is partly sand, as Trask (11, p. 69) points out. When the sand portion makes up a large fraction of the total, as is the case in most marine sediments except abyssal deposits, presentation of data in terms of diameters is essential if a reasonable picture of the sediment as a whole is to be secured. Furthermore, the comparative value of this data, when treated statistically, is in no way impaired.

In Casagrande's method the sample is separated approximately at the 200 mesh sieve grade by a simple panning process. It makes no difference if the washing does not separate the sample at a definite grade size, as the total dry weights of both the sieve and hydrometer portions of a given sample are involved in the calculations for the curves. Although the sand fraction of the *Nautilus* material is in some cases very small, for the sake of uniformity, and for comparison with other work on marine sediments now being conducted at the Woods Hole Oceanographic Institution, it was decided to apply this procedure.

The presentation of mechanical analyses by means of histograms and curves alone is not particularly satisfactory, not only because of the space involved, but also because the graphic method is not satisfactory for comparative purposes, particularly when dealing with large numbers of samples. Many statistical methods of presenting the important characteristics of size distribution have been put forth, but that described by Trask (10 and 11) seems to be well adapted to the purpose. The following is a brief summary of his method. For full details his papers should be consulted.

Three constants are employed, the median diameter, the coefficient of sorting, and the coefficient of skewness or its logarithm.

"The median diameter indicates the mid-point of size distribution. One half of the weight of the sediment is composed of particles larger in diameter than the median and one half smaller," Trask (11, p. 70). This is the most important single constant, affording a mathematical means of measuring variations in texture. An arbitrary division considers medians of 50–1000 microns as sand, 5–50 microns as silt, 1–5 microns as clays, and less than 1 micron as colloids.

The coefficient of sorting expresses the degree of sorting. It is based on a relationship of the first and third quartiles. Twenty-five per cent by weight of the sample is composed of grains of larger diameter than the first quartile and seventy-five per cent larger than the third quartile. It is derived from the formula $So = \sqrt{Q_1/Q_3}$. From the analysis of many sediments it is found that sorting represented by the coefficient 2.5, or less, is good. If So is greater than 4.5 the sorting is poor; 3 is about average for the samples he analyzed.

The coefficient of skewness measures dissymmetry of size distribution in relation to the median diameter. It shows on which side of the median diameter, and how far from it the mode, or peak, of this distribution lies. It is derived from the formula: $Sk = Q_1Q_3/M^2$. If Sk is greater than 1.0, or log Sk positive, the mode lies on the fine side of the median diameter. If Sk is less than 1.0, or log Sk negative, it lies on the coarse side; if Sk is about 1, or log Sk about 0 the mode corresponds with the median. The logarithm of Sk is given to bring out more clearly the relationship of skewness ratios which may lie on either side of the median, i.e., the amount of their divergence from it. The more Sk diverges from 1.0, or log Sk from 0, the further the position of maximum sorting lies from the median.

Statistical Constants

The cores in the tubes varied from 34 to 44 centimeters in length. They were pushed out, lower end first, in segments 25 millimeters long. Each slice was carefully examined for stratification, and then washed down to remove the sand and foraminifera. Since many of the slices contained cavities and air spaces, and since the effect of smearing must be taken into account in a core of such small diameter (2 cm.), three slices were combined to give an adequate and fair sample for each mechanical analysis. Because of these air spaces and the unequal length of the cores, the top section usually contained more material than the others. It was impossible to predict beforehand how much compression would result during removal from the tube.

The sediments were in general a light, chocolate brown. Variations will be noted below. However, numerous patches of greenish grey often occurred with the brown, and it was noted that in most cases a thin film of water lay between the glass and the core. Upon removal from the tube these grey patches were found to be superficial, none going deeper than 2 or 3 mm. It suggests that alteration of the color of the entire surface of the core might have occurred had sufficient time elapsed. These should not be confused with the grey mud found in the lower part of some of the cores described below, which has a very different appearance.

TABLE II

MECHANICAL ANALYSES

Statistical Constants

	Depth in cm.	Microns			So	Sk	log Sk
		Q_1	M	Q_3			
Core 4							
Section 1	8.0	5.1	1.6	.47	3.3	.93	—.02
Section 2	15.5	6.2	1.6	.43	3.8	1.04	.01
Section 3	23.0	4.2	1.0	.29	3.82	1.10	.04
Section 4	29.8	23.0	3.7	.36	7.98	.60	—.22
Core 3							
Section 1	7.5	9.4	2.3	.62	3.89	1.10	.04
Section 2	15.0	6.2	1.7	.51	3.48	1.09	.03
Section 3	22.5	5.0	1.3	.46	3.3	1.36	.13
Section 4	29.3	30.0	5.8	1.1	5.22	.98	.00
Core 1							
Section 1	6.4	6.8	1.7	.52	3.62	1.22	.08
Section 2	13.9	5.6	2.5	1.1	2.25	.98	.00
Section 3	21.4	5.0	2.2	.9	2.36	.93	—.03
Section 4	28.9	6.0	1.9	.6	3.16	1.0	.00
Section 5	36.4	5.2	1.8	.68	2.77	1.08	.03
Core 6							
Section 1	5.0	6.0	3.4	1.1	2.3	.57	—.24
Section 2	12.5	7.8	2.5	.47	4.07	.58	—.23
Section 3	20.0	8.3	3.7	1.8	2.15	1.05	.02
Section 4	27.5	6.0	1.4	.5	3.46	1.52	.18
Section 5	35.0	5.2	1.2	.46	3.36	1.66	.22
Core 7							
Section 1	10.8	9.4	3.0	.62	3.89	.64	—.18
Section 2	18.3	9.6	2.2	.52	4.3	1.03	.01
Section 3	25.8	7.2	1.6	.46	3.96	1.29	.11
Section 4	33.3	36.0	5.1	.66	7.39	.91	—.04

TABLE II—Continued

MECHANICAL ANALYSES

Statistical Constants

	DEPTH IN CM.	MICRONS			So	SK	LOG SK
		Q_1	M	Q_3			
Core 8							
Section 1	8.0	22.5	7.2	.8	5.31	.35	—.45
Section 2	15.5	12.0	4.0	.38	5.63	.20	—1.55
Section 3	23.0	13.0	3.7	.7	4.31	.66	—.18
Section 4	30.5	26.0	4.3	.6	6.58	.84	—.07
Core 9							
Section 1	9.3	4.7	2.0	.42	3.35	.49	—.30
Section 2	16.8	4.7	2.0	.22	4.62	.25	—.58
Section 3	24.3	5.5	1.7	.42	3.62	.79	—.09
Section 4	31.8	4.8	1.3	.37	3.6	1.09	.03
Section 5	38.3	7.3	1.7	.19	6.0	.48	—.31

From Table II it is obvious that the various sections are not comparable, one with another. It is not to be expected that a given layer observed in one core will be found at the same distance below the surface 50 or 60 miles away. The inequalities of deposition would prevent it. The trend of the constants throughout each core must be followed, and it is this factor on which all comparisons must be based. Certain general resemblances are very apparent.

In cores 4 and 3, which lie farthest to the east, the median diameters show a definite tendency to be finer in the middle sections than at the top, followed by a very considerable coarsening at the bottom. In sections 1, 2, and 3 of these two cores the sorting is normal, but in section 4 the sorting is very poor. Log *Sk* indicates that the peak of size distribution lies in general near the median, on the fine side, except in core 4, sections 1 and 4 and core 3, section 4.

This emphasizes the conclusion that the median gives the best single index to the nature of the sediment, for the skewness may be the same in coarse or fine grained deposits. The high coefficient of sorting in section 4 in both cores, at once indicates the adventitious nature of the large particles in these fractions.

Further to the west are two more cores, 7 and 8, which show the same tendencies. They are taken on the relatively shallow ridge connecting Spitzbergen and Greenland in a little more than 700 meters, whereas 3 and 4 come from what is definitely a part of the deep Arctic Basin. In core 7 the middle sections are again finer than the top, with a definite coarsening in section 4. Core 8 shows the same trend, although the top section is the coarsest of all. The sorting in core 7 is about as in 3 and 4, and the peak of the size distribution in every case lies on the coarse side of the median.

The other type of core is represented by 1, 6, and 9. Cores 1 and 6 lie in 1600 and 1690 meters in the Arctic Basin, but 9 lies on the Greenland Sea side of the ridge connecting Greenland and Spitzbergen, in 3100 meters. The median diameters of all three cores are fine throughout, and in all of them the bottom sections have finer medians than the top. Core 1 is fairly uniformly sorted from top to bottom, and the position of maximum size distribution is very near the median. Core 6 is not quite so well sorted and the mode lies farther from the median. The sorting in core 9 is about normal, and except for section 4, the mode lies on the coarse side of the median. The lower 10 mm. of 9 and the lower 18 mm. of 1 were not used. In the first case a limonitic cement made complete dispersion impossible, and in the second instance, the lower part was full of dried paint, and therefore was not in its original condition and could not be considered a fair sample.

Descriptive Data

The survey of the physical characteristics that lie behind the statistical constants is best carried out by reference to Table III, which shows each section split up into arbitrary divisions of sand, silt, clay and colloid. As stated above each section was divided, in most cases, into slices approximately 25 mm. long, which were washed down separately.

TABLE III

SIZE FRACTIONS

Based on percentage of total weight

Section	Depth in Centimeters	Sand 0.05-1 mm.	Silt 0.005-0.05 mm.	Clay 0.001-0.005 mm.	Colloid 0-0.001 mm.
			Core 4		
1	8.0	4.4	21.1	36.4	38.1
2	15.5	5.3	23.4	30.1	41.2
3	23.0	5.0	17.2	30.3	47.5
4	29.8	24.5	21.0	20.2	34.2
			Core 3		
1	7.5	7.6	19.1	39.8	33.5
2	15.0	5.6	22.1	33.9	37.5
3	22.5	9.0	15.5	33.4	42.1
4	29.3	24.5	21.7	31.6	22.2
			Core 1		
1	6.4	1.4	29.1	31.6	37.9
2	13.9	2.0	23.3	48.1	40.9
3	21.4	.5	23.1	30.2	46.2
4	28.9	3.5	24.9	25.8	45.8
5	36.4	3.2	22.8	26.1	47.9
			Core 6		
1	5.0	4.0	36.0	28.3	32.0
2	12.5	6.4	29.6	29.0	34.0
3	20.0	6.0	34.0	29.7	33.3
4	27.5	4.5	23.0	32.4	40.1
5	35.0	6.4	19.1	30.9	43.6

TABLE III—Continued

SIZE FRACTIONS

Based on percentage of total weight

Section	Depth in Centimeters	Sand 0.05-1 mm.	Silt 0.005-0.05 mm.	Clay 0.001-0.005 mm.	Colloid 0-0.001 mm.
Core 7					
1	10.8	6.5	32.1	30.5	30.9
2	18.3	8.4	28.3	28.4	34.9
3	25.8	8.1	22.9	27.0	42.0
4	33.3	27.4	22.8	19.8	29.8
Core 8					
1	8.0	7.6	45.9	18.7	27.8
2	15.5	11.9	33.2	28.4	26.5
3	23.0	9.8	35.8	26.4	28.0
4	30.5	20.0	26.6	23.3	30.1
Core 9					
1	9.3	0.0	21.6	44.0	35.0
2	16.8	6.0	13.6	43.7	36.7
3	24.3	4.2	21.9	35.4	38.5
4	31.8	2.6	22.4	30.9	44.1
5	38.3	12.0	19.6	25.4	43.0

Core 4. The top section is of a chocolate-brown color, no stratification is apparent, and there is very little sand, except a few large, rounded quartz grains. The texture is well expressed by the median diameter. The middle slice of section 2 has a layer of fine sand 2 mm. thick, but except for this, and some well rounded quartz in slice 3, section 3, the middle two sections are very like the top. The percentage of sand, silt, clay, and colloid in each section checks well except for the increase in colloid in section 3. The lowest and middle slices of section 4 each show a band of fine, grey sand about 1 mm. in thickness. The top slice shows nothing. A large amount of sand, the grains having diameters up to .5 mm., is scattered throughout each slice, as is shown by the value of 24.5% for the section as a whole. This is also reflected in the median diameter. There is some weak cementation by limonite in the middle slice of this section. Except for the sand layers mentioned above there was no other evidence of stratification in the wet core.

Core 3. Sections 1, 2, and 3 are very similar to the corresponding sections in core 4, a fact which is borne out by inspection as well as by the data in Tables II and III. The topmost slice is an exception, containing rather more clay than usual. It should be noted that the same increase in the colloid fraction occurs in section 3 accompanied by a decrease in the silt, as was found in core 4, section 3.

The bottom section shows a sharp increase in the sand fraction. In addition, the two bottom slices contain numerous limonitic pellets. The middle slice contained what appeared to be fragments of a silty layer about 1 mm. thick, firmly cemented by limonite, which was broken up as the sampler went through it. No other stratification was found. This core is very similar to core 4.

Core 7. Keeping the same order as above, we will skip to cores 7 and 8. According to the statistical constants these two cores are very similar to cores 3 and 4, although coming apparently from a different environment, namely, the relatively shallow ridge between Spitzbergen and Greenland. The median diameter is larger than we have yet encountered in a surface section, due to the presence of a large amount of silt. There is nothing noteworthy about section 2. Section 3, however, shows distinct stratification in its lower part, with alternate bands of brown and grey about 2–3 mm. in thickness. The middle slice has a laminated appearance due to discontinuous bands of minerals large enough to be visible. This slice, and the one above it, contain much bright red limonite, both as a coating on the individual grains and in pellet-like particles. Section 4 is mostly grey in color and the contact between this material and the usual chocolate brown at the top of the section is very sharp. The grey segment is about 73 mm. in length. The sand fraction is heterogeneous in composition and contains many fragments of rock, some igneous and some schistose in appearance, as well as many large angular quartz grains. The largest sizes are up to 1 mm. in diameter. The top slice of this section contains less of this material than the lower two, although it is still present. The percentage of sand is very large and reflects in the median diameter, while an *So* of 7.39 indicates that the material is scarcely sorted at all.

Core 8. The upper 12 cm. of this core is rusty brown in color, the lower 22 cm. is grey. When observed the contact was not sharp. Considerable smearing seems to have resulted when the sampler cut through. The material in the upper 12 cm. is definitely stratified, the bands showing by small differences in the shades of brown.

Section 1 has the largest median diameter of any surface sample encountered. This is caused by a great increase in the silt fraction at the expense of the clay, rather than by any large amount of sand. The sorting is only fair. However, it is much better than in section 4 and in core 7, section 4, which contained large quantities of sand and rock fragments. The color is rusty brown, and the middle slice has a dark chocolate-brown band across the middle a fraction of a millimeter in width. The top slice of section 2, about 5 mm. below the base of section 1, definitely marks the transition between the reddish brown and the grey. Five millimeters of the transition zone had streaks of rusty brown through it. Limonite pellets are common, and they continue throughout the section but are masked by the grey color. The sorting is poor, probably due to the limonitic material, although the median diameter is lower than the surface section. There is no real stratification. Section 3 continues with the same grey material with one thin reddish layer in the upper part of the middle slice, and also great numbers of fæcal pellets. Section 4 grows progressively coarser towards the bottom. The soft grey mud continues, and many fragments of rock were found in it, particularly in the bottom slice. The rock was mostly a dark grey to black schist, although some of the fragments were igneous. These large fragments were removed before analysis. In addition there was some rounded, and much angular, quartz present. The increase of the coarse material is clearly shown by the percentage of the sand fraction.

This section is similar in every way to core 7, section 4, except that the rock fragments are larger.

Core 1. This core is one of the most uniform in the whole series. The median diameters are small, and the sorting good throughout. Each section is very like every other. The color is chocolate brown, except for the bottom 5 cm. which are rather more greenish grey than brown. This should not be confused with the material making up the bottoms of cores 7 and 8, as it is quite a distinct shade, and totally different material. It seems more like the type of grey color produced by chemical alteration, after sealing up in the tube. Superficial grey patches were noted above.

The sand grade percentage is lower, and the colloid fraction correspondingly higher, than in any other core. The bottom slice of section 4 contains some very well rounded sand, but that seems to be the only detail worthy of special notice. The lowest 18 mm., which was in a second tube, was full of flakes of dried paint. This obviously could not be considered a fair and undisturbed sample, and therefore was not considered. No stratification was observed anywhere.

Core 6. This core is also fairly uniform, and the median diameter of section 1 is due to a large amount of silt and not to an increase in the sand percentage. The bottom of the core is finer than the top. The color is chocolate brown, except for the lowest 4 cm., which are greenish grey, exactly as in core 1. The middle slice of section 5 shows indistinct lines of dark minerals, but there is no other evidence of stratification anywhere in the core.

Core 9. This core is the longest of all, and it is also as fine grained as core 1, though not so well sorted. Like cores 1 and 6 the bottom is somewhat finer than the top. The color is chocolate brown except for the lowest 10 mm., which is a bright rusty red. Section 1 contains no sand at all. Numerous fæcal pellets are present. Sections 2, 3, and 4 are very similar as to characteristics. Section 4 contains one angular piece of rock about 7 mm. in largest diameter. This was not considered in the weight per cent. There is no stratification apparent. The top slice of section 5 shows distinct interstratification of very thin dark bands with lighter ones. The latter are about .5 mm. thick and the dark bands about one quarter that. Under the binoculars the material in both layers seems to be about the same size. The middle slice contains a large pebble about 10.5 mm. in its largest dimension. The bottom 10 mm. is a bright rusty red in color and the contact between it and the chocolate brown of slice 5 is sharp, with a distinct parting plane. The material was considerably cemented by iron, and for this reason a proper dispersion could not be secured. Inspection, however, shows it to be definitely coarser than any of the other sections. Many grains of quartz and flakes of mica, up to .5 mm., were washed out, as well as numerous rusty pellets. The colloid fraction of the core as a whole shows a tendency to increase from the surface downwards, as is the case with cores 1 and 6, in contrast to the other cores which have a coarse bottom section.

ORGANIC REMAINS

Dr. Joseph A. Cushman very kindly undertook to study the foraminifera. He examined the cores section by section, but found only the normal, Arctic, bottom-living foraminifera of the present day. Although changes occur from section to section, it is not thought worth while to make a detailed list, as nothing is known about the factors which control the changes.

A few general observations seem pertinent to the problem in hand, however. In the first place there is no progressive increase or decrease in the abundance of foraminifera from top to bottom. Great numbers and variety, or absolute barrenness, may occur anywhere in the core. This indicates that the past environmental controls were probably local in character, as at present, for no widespread change is recorded. Secondly, the present surface samples, with two exceptions, are characterized by the same dominant forms, with Globigerina far in the lead, and possibly Pyrgo second. The number of individuals and the general assemblage varies greatly, however. As might be expected, the exceptions in the surface sections are the two shallow cores, 7 and 8. Here arenaceous forms replace Globigerina as the dominant group. Thirdly, below the surface Globigerina is also the dominant form in most cases, but Pyrgo is not found. The total population, and accessory forms likewise, change considerably from section to section. Lastly, the three westernmost cores, namely 7, 8, and 9, are characterized by a zone in which Cassidulina is dominant. This begins 22–25 cm. from the surface and continues to the bottom.

In contrast to the comparative abundance of foraminifera is the singular lack of diatoms and radiolarians. Each section was examined under the binoculars, but no siliceous skeletons were observed. It is possible that an occasional individual, or a fragment of one, may have escaped notice, but even so their rarity is very remarkable, taking into account the fact that they are obtained in surface tows. An occasional sponge spicule and worm tube was found, but their distribution has no significance. No coccoliths were found. Bøggild (1) noted a similar lack of siliceous organisms in working up the samples from the *Fram* expedition.

CALCIUM CARBONATE CONTENT

The calcium carbonate content is very closely tied up with the actual numbers of foraminifera present. It frequently happens that one slice of a core contains an abundance of calcareous tests, and a centimeter above or below very few are found. It is evident that abrupt and meaningless fluctuations of the $CaCO_3$ content must follow. If there were any chemically precipitated $CaCO_3$, its presence would be masked, or false conclusions reached. The same would be true of sediments derived from limestone rocks. When calcium carbonate is present in as small quantities, as in the sediments under consideration, it is negligible from a limestone-forming point of view, and unless chemically precipitated has little geologic significance.

From inspection under low power binoculars it was possible to forecast whether or not a given sample would run relatively high or low in $CaCO_3$, because broken fragments of the calcareous tests were recognized down to the limit of magnification. An attempt was made to minimize the effect of the presence of the foraminifera as much as possible, by analyzing only the material used in the hydrometer determinations. This eliminated most of the whole specimens as well as the sand grades. Even so, samples which originally contained an abundance of foraminifera yielded a higher $CaCO_3$ content than those which yielded a few. For this reason it was not thought necessary to analyze every section. Enough analyses were made to show that the $CaCO_3$ content was quite in line with other samples taken in the Arctic, and with samples in bathyal environments taken elsewhere in temperate latitudes. Furthermore, position in the core, texture, and sorting had no observed influence—the controlling factor is the quantity of organic remains.

The percentage of $CaCO_3$ ranges from 6.44 to .24. The following instances are typical. An example of variability is shown by section 4 in cores 1 and 9. Here the median, coefficient of sorting, and even the skewness, indicate that the samples are as nearly alike as it is possible for any pair to be. In addition they are at the same depths in their respective columns. Inspection shows that they are the same chocolate-brown material, yet section 4, core 1 has 3.21 per cent $CaCO_3$ and section 4, core 9 has only .61. The former contains the zone, mentioned above, characterized by numerous Cassidulina, whereas the latter contains only a few Globigerina. Another illustration is afforded by the bottom section in cores 7 and 8. This, it will be remembered, is the grey mud zone, full of rock fragments. The statistical constants show the same tendencies, and inspection indicates that the zone is identical in the two cores. Core 8 has 3.50 per cent and core 7 only 1.46. Foraminifera are more numerous in the first instance. The top of core 4 had more foraminifera (Globigerina) than any other section, and showed 6.44 per cent $CaCO_3$. The bottom of core 3 contained almost exclusively arenaceous forms, and had .34 per cent.

Bøggild (1) in his report on the samples taken by the *Fram* states that one of his samples ran up to 4.5 per cent $CaCO_3$, and that all the others had one to two per cent or less. He did not state whether or not the whole foraminifera were included, but even if they were, as seems probable, the two sets of results check closely. The pecentages of $CaCO_3$ derived from analyses of blue mud in the Atlantic run, on the average, considerably higher. Murray and Chumley (5, p. 225) report a mean percentage of 16.99 for the entire series, which ranged from 0–50 per cent. Depth had no apparent influence. Thorp (8) reports approximately similar results. The mean percentage of the *Nautilus* samples analyzed is 2.03. The Atlantic is, of course, a more favorable environment for organisms than the Arctic Ocean, and many remains other than foraminifera enter into the calculations as Murray and Chumley state. In addition, pelagic foraminifera are found here but are entirely absent from the Arctic. It seems, therefore, that the $CaCO_3$ content is very largely dependent on the amount of organic remains present.

ORGANIC CONTENT

Core 2 was analyzed for organic content by Dr. S. A. Waksman who reports as follows:

TABLE IV
MARINE HUMUS IN MUD ON BASIS OF DRY MATERIAL
CORE 2

DEPTH OF MUD CM.	ORGANIC CARBON PER CENT	TOTAL NITROGEN PER CENT	C/N
0–14	0.852	0.080	10.65
15–28	0.672	0.054	12.44
29–42	0.468	0.044	11.10

"A comparison of the abundance of organic matter in this mud with that of other marine muds (Waksman, 12) brings out the fact that although the total amount of organic matter is fairly low, still it is within the range of results obtained for certain muds in the vicinity of Woods Hole and elsewhere; the ratio of carbon to nitrogen in this mud is quite similar to that found for other marine muds. The rapid drop of organic matter content found with an increase in the depth of the core may be somewhat more precipitous than that reported for other cores of marine mud, as those taken in the Gulf of Maine. Although it is impossible to draw any definite conclusions from the analysis of one core, since the organic matter content of the mud may vary considerably, as shown by Waksman, still one is justified in stating here that the organic matter in the marine mud obtained by the *Nautilus* expedition possesses the general characteristics of muds commonly found not far from shore."

PETROGRAPHY

The petrographic analysis was undertaken by C. J. Roy and his report follows below. One core of each type was taken in addition to No. 9 from the Greenland Sea.

TABLE V

	Total weight of sand in grs.	Percentage of heavies.	PROPORTION OF EACH MINERAL ON THE BASIS OF 100 GRAINS																
			Hornblende	Augite	Olivine	Garnet	Tourmaline	Zoisite	Titanite	Zircon	Biotite	Muscovite	Staurolite	Epidote	Andalusite	Hypersthene	Calcite	Opaque Minerals	Rock frags.
CORE No. 1.																			
Section 1	.152	2.1	13	17	4	4	2	1	1	1	0	2	0	1	0	2	0	2	2
Section 2	.188	0.5	23	13	1	1	0	0	1	1	2	1	+	3	1	3	2	6	0
Section 3	.251	6.0	16	11	2	3	0	0	0	2	+	0	1	2	2	4	+	11	+
Section 4	.548	12.3	22	6	4	4	3	1	2	1	1	0	0	+	0	+	3	4	+
Section 5	.751	10.5	25	8	3	2	1	0	2	1	+	+	1	3	0	2	3	7	3
CORE No. 4.																			
Section 1	.736	2.3	25	6	28	2	1	0	0	0	2	1	0	+	0	3	2	30	0
Section 2	.827	3.5	32	11	8	4	2	0	1	+	1	2	0	3	0	5	0	31	0
Section 3	.715	6.8	36	10	12	3	+	0	+	1	2	1	0	2	0	6	0	27	0
Section 4	5.214	5.2	18	8	9	2	1	1	+	+	2	2	0	1	0	16	+	32	+
CORE No. 8.																			
Section 1	.386	1.7	23	11	4	5	2	+	1	1	1	2	0	2	0	2	0	46	+
Section 2	.405	2.3	26	12	3	4	+	0	+	+	3	2	0	3	0	2	+	37	3
Section 3	.667	5.2	28	14	5	3	2	0	1	2	1	+	0	2	0	3	+	42	2
Section 4	2.893	3.6	23	6	7	4	1	0	0	3	1	1	0	2	+	2	0	44	6
CORE No. 9.																			
Section 1	.190	1.0	24	9	2	3	2	0	1	1	1	1	0	2	0	3	0	37	0
Section 2	.227	1.5	23	14	4	5	3	1	3	4	2	3	0	3	0	4	0	16	3
Section 3	.718	1.5	27	16	3	4	3	0	2	3	1	+	0	4	0	2	0	13	0
Section 4	.540	2.0	27	17	6	4	1	1	1	+	2	1	+	3	0	3	0	17	1
Section 5	1.514	3.2	19	11	1	1	2	0	+	1	1	2	0	1	0	1	+	6	4

"The sand portions of four cores, numbers 1, 4, 8, and 9, were examined microscopically. All foraminifera were removed before these samples were received and thus are not mentioned in the mineralogical analysis given below.

The cores were studied in sections as shown in Table V. The sand of each section was separated in bromoform, specific gravity 2.89, in order to study the heavy minerals as distinct from the light. Index oils were used as media in which to determine the minerals. No attempt was made to determine the size of the mineral grains. Such information is given in the size analysis.

In general the sands are fresh, and the grains are, for the most part, angular. Well rounded grains are almost entirely absent. The most abundant ferro-magnesian minerals, hornblende, augite, and olivine, show minor amounts of decomposition. The feldspars are fairly fresh with indications of slight kaolinization. Cleavage fragments of calcite found in the sand appeared perfectly fresh. The presence of this calcite seems to indicate a short distance of transport, and slight effects of chemical weathering. This indication is further supported by the angularity and freshness of all the minerals.

Table V shows the percentage of the heavy minerals in the sand samples, the suite of minerals identified, and the proportion of each mineral. The proportion of each mineral was determined by counting the grains in the microscope field, under low power, and calculating the results on a basis of 100 grains. A plus sign in the table indicates that the mineral was identified in slides for that section of the core, but did not appear in three or more counted areas.

As indicated by the table, hornblende, augite (pyroxene), and olivine are the most abundant constituents. The hornblende is mainly the green variety with occasional clear or brown grains. The augite is mainly clear, but many grains contain small black inclusions. The olivine is a minor constituent in most of the cores, but is very abundant in number 4, especially in section 1. Here it occurs as large, fresh, angular grains.

The opaque minerals consist of magnetite and illmenite with occasional sulfide grains. Some fragments of manganiferous worm tubes were probably considered as opaque minerals in sections where the complete specimens were scarce or absent.

The following minerals were identified in the light portion of the samples: quartz, orthoclase, plagioclase, microcline, glauconite, chlorite, carbonate (granular aggregates), calcite (cleavage fragments), and rock fragments. The quartz grains are angular and for the most part clear. Some show black irregular inclusions. The feldspar grains, both orthoclase and plagioclase, are angular and mostly fresh. Some grains show effects of slight kaolinization, and some contain black inclusions. The carbonate aggregates are probably fragments of foraminiferal tests or of shells of other animals. The calcite cleavage fragments are apparently detrital. Most of the sections contain fragments of mineral aggregates, some of which could be classified.

The only section containing large fragments was core 8, section 4. In this material several fragments from 1–7 mm. in diameter were found. Without exception they were fragments of igneous and metamorphic rocks. Granite, schist, and perhaps slate were recognized. Under the microscope the finer materials showed what appeared to be fragments of these same rocks, and also of quartzite.

The percentage of heavy minerals naturally increases downwards as the total sand increases. No distributional trends of any kind are apparent. Each section is very similar to the next, and the cores themselves closely resemble each other."

Stratification

Bradley (2), in a recent paper, describes certain laminated sediments, past and present, under the name of non-glacial marine varves. They consist of alternating dark and light colored layers, with organic matter concentrated in the dark ones. He finds that in most cases the grain size is essentially the same in the organic-rich and the organic-poor layers, but that in some cases the clay is concentrated in the former. The boundaries of the dark layers are sharp, and the upper boundary is usually the better defined of the two. These varves are to be distinguished from glacial varves in which the grain size diminishes upwards from one varve to the next. Among the ancient sediments cited are: the Genesee shale of central New York, in which the couplets of laminæ average .025 mm. in thickness, the Hartshorne sandstone of Pennsylvania, in which the couplets average .178 mm., the Hannibal shale of Illinois with couplets .14 mm. thick, and the Modolo formation of southern California, in which the couplets average .025 mm. They range from fine-grained, silty shales to coarse siltstones. In all of them shaly structure (fissility) is poorly defined. Several recent fresh water lakes are cited in which this type of stratification occurs, as well as the ancient sediments of the Green River formation. Applying the analogy of these fresh water examples, Bradley concludes that the concentration of organic matter in alternate layers, which makes the laminations visible, was caused by the annual plankton cycle. With this in mind, all cores taken at the Woods Hole Oceanographic Institution were examined. Most of them came from the continental shelf proper, including some of the siltier parts, such as deep holes in the Gulf of Maine and Cape Cod Bay. Two cores were taken, however, off the New Jersey coast in the blue mud zone in 1000 and 1800 meters of water. None of them showed the slightest trace of any seasonal rhythms or stratification. Subsequently the writer was informed by Dr. R. MacDonald, of Harvard University, that in certain cores taken by him from the Cumbræ Deep of the Clyde Sea, which had remained for some months in their glass containers, stratification eventually appeared which was not at first visible. This consisted of alternate dark and light bands, with the organic matter concentrated in the dark layers. The pairs of bands were fractions of inches in width rather than fractions of millimeters, as in the case of the ancient sediments described above.

Fig. 2. Bottom of core 2, showing laminæ after drying. 3X.

All the *Nautilus* cores were examined for stratification with the results noted above. There were several indefinite approaches to varving, but the only clear cut case was the top of core 8, in which the laminations were faint but regular. It so happened that in core 2, which was set aside for determination of organic content, a small piece was left in the tube. Eighteen months had elapsed since the core was taken. Upon removal it was broken lengthwise, and part of it was found to show laminæ with remarkable clearness, as can be seen in Figure 2. The couplets of laminæ average about .80 mm. If we apply Bradley's maximum compression factor, i.e. compaction to 1/10 of the original thickness, we find that a pair of laminæ would measure .08 mm. if this sediment becomes a shale. The laminæ in this case show up because they have different shades of rusty brown, and not through any concentration of carbonaceous matter. The coloring matter seems to be limonite or some limonitic compound. That the Arctic bottoms are not deficient in carbonaceous material, as compared to other marine deposits, is shown by Waksman in Table IV. It is curious that the successive layers are not colored black as in the examples described above. The regularity of stratification indicates that some sort of sedimentary rhythm, or cycle is involved, but whether this could be due to the annual deposition of plankton is not clear, in view of the apparent lack of carbonaceous matter. Neither is it clear why the bottom of the piece in question is unlaminated, or why most of the cores show no traces of laminæ whatsoever. In a personal communication Bradley offers the following as a possible explanation.

"Two possible explanations occur to me for these laminations which showed up on standing in the laboratory. The first is that inasmuch as they are limonitic stains they may be due to diffusion banding or rhythmic segregation of iron salts which were at first uniformly distributed through the mud. This sort of lamination would of course be quite independent of any rhythms in the sedimentation, but as iron stains of this sort are so very common in sediments it would be well to examine them rather critically to see whether this is the plausible explanation. Diffusion bands of this sort would be more or less systematic in their variations in spacing and they might also be oriented at some systematic angle, or system of angles, with respect to the walls of the containing vessel. On the other hand, there is some theoretical reason for expecting that the laminations which you observed may represent a real rhythm in sedimentation. For example, decomposing organic matter in these muds is very prone to concentrate iron sulphides in the thin layers where organic matter has accumulated. If, then, this organic matter were all decomposed and only the minutely granular iron sulphides were left, they could easily escape detection in the cores until after standing for a long time, when the iron had oxidized to the more conspicuous limonitic stain which you describe. If these limonite stains really represent cycles of sedimentation, I should expect them to be separated by intervals which were not systematic, and further that the width of the limonite layers themselves should not vary systematically within the core. Also, I should expect them to be nearly normal to the long axis of the core except for a moderate amount of upturning at the edges, due to the shearing along the walls of the sampling device."

As nearly as can be determined by inspection under the binocular microscope, the grain size is uniform from layer to layer, exactly as in the majority of cases cited by Bradley. Numerous quartz grains, up to a half millimeter in diameter, are scattered throughout the finer material, but their distribution is entirely accidental, and has no connection with either the light or the dark bands.

ORIGIN

The most striking characteristic of the sediments from the Arctic Basin is the fineness of the grain and the uniformity of texture over large areas, which is unusual in a sediment, terrigenous in origin. This fact was also noted by Bøggild (1) in the samples collected by the *Fram* north of the position of the *Nautilus* stations. The two sets of samples are similar in color and composition. They both fall into the large and heterogeneous group of the "Blue Muds." However, they differ in certain respects from Blue Muds collected in other parts of the world in that they are mostly clays, whereas this type of sediment found elsewhere in the bathyal environment near the continental masses is usually a silt.

The older technique was entirely inadequate for the separation of the finer fractions, so that only rough comparisons can be made in many cases. In the table giving the percentages of "fine washings" Murray and Chumley (5, p. 229) find that the material under .05 mm. averages 63.56 per cent for the Blue Mud. Just how significant this figure is in view of the great ranges involved is questionable. These "fine washings" would correspond to the sum of the silt, clay, and colloid grades as shown for the *Nautilus* cores in Table III. It is obvious that the percentage obtained is much larger than Murray's average, also that the ranges involved are smaller. From the histograms given by Thorp (8, pp. 14 and 17) for Blue Mud from the western North Atlantic we find that the silt grade runs considerably higher than in the Arctic Ocean, and that the percentage of clay and colloid is very much lower, even though the samples are taken, in most cases, in deeper water. The data from a core taken by *Atlantis*, station 1088, N. Lat. 38.04, W. Long. 73.22, in 1800 meters, is given below for the sake of comparison.

TABLE VI

SIZE FRACTIONS

Based on percentage of total weight

Section	Depth of Section in Centimeters	Sand	Silt	Clay	Colloid
1	11.5	10.0	55.7	14.4	19.9
2	32.0	7.0	39.6	26.5	26.9
3	56.0	6.2	36.6	30.0	27.2

MECHANICAL ANALYSES

Statistical Constants

Section	Microns			So	Sk	log Sk
	Q_1	M	Q_3			
1	30	14.0	2.5	3.47	.382	—.42
2	13	5.0	1.1	3.44	.572	—.24
3	11	3.5	.9	3.50	.812	—.09

This is in the belt of terrigenous sediments lying outside the continental slope. The core was 58 centimeters long and the slices were taken at the top, middle and bottom. The top slice has the coarsest texture of all, and the percentage of size distribution shows that it is very similar to the Blue Mud analyzed by Thorp. The middle and bottom slices, however, particularly the latter, show a higher percentage of clay and colloid.

Trask (11, Table G) gives a valuable statistical review of sediments from all types of environments. These are summarized in Tables 19 and 20 on pages 87 and 92. From these data he concludes that there does not seem to be any definite arrangement of texture according to depth of water or distance from shore. Fine sediments will accumulate in quiet water no matter what the depth, and coarse sediments in agitated waters. The data also indicate that the deep water clays tend to be well sorted with an average *So* of 2.5, and the small limits for log *Sk*, —.14 to .27, indicate a symmetrical size distribution. The average log *Sk* is .02.

Turning again to the *Nautilus* cores, we find that the median diameters indicate that they belong to the clay group for the most part. The average *So* for the top sections, however, is 3.4, and that for all sections is 3.8. Average log *Sk* for top sections is —.12, and for all sections .06. The range is from —.30 to .22. Only those sections having medians of 1–5 microns were considered. From the above it is evident that these Arctic Basin sediments do not check well, in regard to statistical constants, with other deep water clays. If we take the average figures for deep water clays as given in Table 20, *So* = 4.0 and log *Sk* = .24, the correspondence is closer but not exact. However, the more mathematical processes are applied to the statistical data, and the more they are averaged, the more the individual characteristics of the sediment in question tend to disappear. If we turn to Table G, mentioned above, in which the constants for the shallow water clays in each sample are given separately, and not as averages, we find a striking similarity. Chief among the shallow water clays in this table are the sediments from Lake Maracaibo, the Gulf of Venezuela, the Orinoco delta, several bays along the Texas coast, Georgia Strait, Monterey Bay, Pamlico Sound, the Potomac estuary, and the Mississippi delta. These clays are to a large extent fluviatile in origin. Most of them show small medians, as in the deep water clays, but *So* and log *Sk* are often fairly large and fluctuating. For example: sample 221A, Lake Maracaibo, $M=2.8$, $So=3.3$, log $Sk=.02$, in sample 224B, $M=3.3$, $So=3.52$, log $Sk=-.13$; from the Gulf of Venezuela, sample 246A, $M=2.2$, $So=5.56$, log $Sk=.51$, sample 247A, $M=2.5$, $So=2.64$, log $Sk=00$. From the Orinoco delta, sample 255A, $M=3.2$, $So=2.92$, log $Sk=-.08$, sample 255C, $M=3.2$, $So=5.01$, log $Sk=.40$, sample 260B, $M=1.0$, $So=2.19$, log $Sk=.11$. From Nueces Bay, Texas, sample 268A, $M=1.2$, $So=7.60$, log $Sk=1.03$. From Pamlico Sound, sample 477, $M=3.2$, $So=2.46$, log $Sk=.07$. The above illustrations, to which many more could be added, are sufficient to show the characteristics of shallow, as distinguished from deep, water clays, which are much more regular in their constants, and do not exhibit such wide fluctuations. The constants for the *Nautilus* cores show the trends of the former.

We have become so accustomed to associating the rafting of detritus by bergs formed in continental ice sheets and glaciers, that we are apt to forget the rôle that sea-ice may play, although it has been noted by several writers. Fuchs and Whittard (3) are the latest to comment on this point. While the Cambridge Expedition of 1929 was frozen in the East Greenland ice-pack, numerous occurrences of silt and clay resting on the surface of the ice were noted. In some cases shells were associated with the sediments. They state that sediment alone had been previously noted by several others in different parts of the Arctic, notably by Nordenskiold, Nansen, Nathorst, and Andrée. Gray, Stappers, and DeLong commented on its association with shells. Kindle (4) describes observations on the North American side, where conditions are somewhat different from the Eurasian side, and do not directly concern the problem at hand.

The source of the mud is of course involved with the origin of the ice. Smith (7) gives a good summary of the literature on the sea-ice of the Arctic, and the currents which move it. In winter, ice forms over the whole of the wide continental shelf of Siberia, because it is shallow, and because the sea water is diluted by the large Siberian rivers. This fast-ice, so called because the inner edge of the sheet is frozen solidly to the shore, forms all around the borders of the Arctic Ocean, but other localities are secondary to the huge sheet north of Eurasia. The ice-foot is frozen solidly to the shore and is unmoved by the tides during the winter. Melting starts along Arctic shores during May. Smith (7, p. 24) states that, "the land snow in melting flows out on top of the fast-ice, collecting in large pools and lagoons of 'off-shore water.' The fast-ice platform, for a few weeks, holds tightly until the heat from the sun penetrating downward opens up the floes and allows these pools to drain away. Then sand and detritus from the land, now bare, honeycomb the ice. Soon the sheet gains a slight movement along the coast, uncovering a lane of open water which persists then for the entire summer." Fuchs and Whittard (3, p. 424) cite other illustrations. During the spring freshets, the Lena River carries much sediment out onto the ice. This condition is intensified by floods which occur when the huge ice jams burst. Another flooding often occurs in mid-winter, due to "hydraulic pressure upstream which raises the ice-bed and finally bursts it open; and the water continues to overflow until the pressure has been relieved." Such conditions in a lesser degree doubtless obtain at the mouths of the smaller rivers and streams of the coast. It is apparent, therefore, that there is abundant opportunity for sediment to get out upon the fast-ice.

The fast-ice, on being loosened from the shore, forms pack-ice, and drifts away to join the permanent polar ice cap (Smith, 7). The main drift of this polar cap is anti-cyclonic, with the opening between Spitzbergen and Greenland affording the main road of escape into the Atlantic. Although no detailed account of its movement has as yet been published, the drift of ships, wreckage, and other *dêbris* is sufficient to establish the general direction. The important thing from the point of view of the *Nautilus* cores is that much of this Siberian ice eventually has to pass to the north of Spitzbergen, and in summer considerable sediment may be dropped, due to melting, as the ice goes by. Striking evidence as to the amount of melting even in high latitudes is given by Fuchs and Whittard (3, footnote p. 419) who state that enough fresh water is supplied by the melting of the massive polar ice to maintain a permanent stratum of fresh water below the ice sheet, which in turn damps any wave oscillations which would cause mixing. This layer supports a strictly fresh-water fauna which drifts along with the ice, and is of course destroyed when entire melting occurs. As was stated above, the Arctic clays do not resemble other deep sea clays, but have more of the characteristics of shallow water clays, deposited in protected situations, and closely associated with rivers. Uniformity of material over a large area also favors the hypothesis of deposition by sea-ice. The place in which we would expect the least accumulation would be the ridge between Spitzbergen and Greenland. Trask (9) has shown that ridges are subject to current scour even in deep water. It is significant that on the ridge the sampler in two cores punched through the homogeneous, chocolate-brown material, and reached a totally different stratum which it did not penetrate, namely, the grey clay zone full of small fragments of crystalline rocks.

Land ice can be eliminated as a source of supply for this sediment. No such uniformity and fineness of texture could ever be produced by direct deposition from bergs of glacial origin, or from continental ice sheets. The heterogeneous character of such deposits on land is of course familiar to every one. Coarseness and poor sorting is the rule for bottom sediments off glaciated coasts, unless extensively reworked by wave action and other currents. In addition, the type of bottom changes rapidly, and great variations of texture are encountered within short distances, as is shown by the mechanical analysis of samples from Davis Strait (Trask, 10, Table 1). Large ranges in the constants are encountered and often clay, sand, and pebbles are found in the same sample. The same conditions obtain in the Gulf of Maine, where at the same depth of water, and only a short distance apart, a sediment may be a silt, sand, or gravel, well or poorly sorted.

It is of course impossible to tell the exact amount of material deposited by sea-ice, but the inference is strong that its rôle is considerable. It seems very probable that enough of this ice-borne sediment is being mixed with the material added to the sea bottoms from erosion of shore line and land surface, to change the characteristics which such deposits should normally show. If these deep Arctic clays had been deposited by marine agencies alone, we would expect a better degree of sorting. If this hypothesis is correct, the Arctic Basin is receiving more sediment than would be the case with similar environments in other parts of the world, but even if to deposition and distribution by sea-ice, we add that normally carried on by currents alone, the accumulation of sediment in such deep water must necessarily be slow. The fact that 30 to 40 centimeters of very homogeneous material can accumulate in such an environment indicates that geologic conditions have been stable in the Arctic over a long period of time.

SUMMARY

1. The samples are in the main a chocolate-brown clay, uniformly distributed over the area covered. On the whole they are moderately well sorted. Fluctuations occur in all the constants. The plasticity is poor.

2. The material is entirely terrigenous in origin and there is no trace of any of the pelagic oozes.

3. In general the percentage of sand tends to increase downwards, as is reflected by the increase in the median diameters. There are no definite trends in the other grade fractions.

4. The foraminifera are all normal, Arctic, bottom-living forms of the present day. There is nothing in their distribution suggestive of past geologic changes.

5. The $CaCO_3$ content is directly dependent on the relative abundance of calcareous foraminifera.

6. The organic content of these sediments is comparable to other marine sediments from similar environments.

7. In general the minerals are fresh and angular, although minor amounts of decomposition are shown by some of the ferro-magnesian group, and slight kaolinization has taken place in some of the feldspars.

8. Stratification, suggestive of varving, is present in the cores in a few cases. It showed out very clearly in a portion of core which was accidentally left in the container for a long time (Fig. 2).

9. The statistical constants indicate a closer relationship with shallow-water, near-shore clays of fluviatile origin, than with true deep-water clays.

10. Sea-ice is suggested as an important transporting agent, the clay being washed out upon the fast-ice during the spring freshets of the rivers of the Siberian coast.

11. As a clay in deep water must accumulate very slowly, the evidence seems to point to the existence of stable conditions over a long period of time in the Arctic regions.

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