B.—Account of Sums granted from the Donation Fund in 1870.

1. Mr. Warren De La Rue, for the enlarging of certain Solar Negatives obtained at the Kew Observatory	£11 11*s*.
2. Dr. Carpenter, for the purchase of a specimen of Pentacrinus Caput Medusæ	25
3. Mr. Edward Waller, for the exploration of the Sea-bed on the North-western coast of Ireland by means of the Dredge, in continuation of the researches made last year in H.M.S. 'Porcupine'	100
4. Mr. J. P. Gassiot, to defray expense of making six prints from the Negatives of Sun-pictures taken at the Kew Observatory during the years 1862–72, with the view of presenting them to the Royal Society, the Royal Astronomical Society, the Imperial Academy of Sciences of Paris and of St. Petersburg, the Royal Academy of Sciences, Berlin, and the Smithsonian Institution, Washington (£120 in two payments)	60
5. Mr. William Saville Kent, in aid of a Zoological Dredging-expedition in a private yacht off the west coast of Spain and Portugal..	50
6. Dr. Bastian, for carrying on certain experiments with a Digester capable of sustaining high Temperatures................	10
	£256 11*s*.

December 8, 1870.

General Sir EDWARD SABINE, K.C.B., President, in the Chair.

The President announced that he had appointed the following Members of the Council to be Vice-Presidents :—

The Treasurer.
Sir Philip Grey-Egerton, Bart.
Mr. Francis Galton.
Dr. Huggins.

The following communication was read :—

"Report on Deep-sea Researches carried on during the Months of July, August, and September 1870, in H.M. Surveying-ship 'Porcupine.'" By W. B. Carpenter, M.D., F.R.S., and J. Gwyn Jeffreys, F.R.S. Received December 2, 1870.

[At the time at which this Report was presented, it was hoped that the General Summary of Results, of which it then consisted, could be amplified by the insertion of the requisite details, within the time at which the publication of the Proceedings would be due. It has been found, however, that in working out these details so many new points arose suggestive of further inquiries (especially requiring careful comparison of Temperature observations) that, though devoting to them all the time he could command, the Member of the Expedition who is responsible for the whole, save the Narrative of the First Cruise, has found himself unable to complete his portion of the Report at an earlier date. Whilst expressing his regret for the delay which has hence arisen, he ventures to hope that some compensation for it will be found in the greater completeness which the Report now possesses; especially in that Section of it which treats of the Causal Relation between the double currents of the Straits of Gibraltar and Baltic Sound, and the General *vertical* Oceanic Circulation.—W. B. C.]

INTRODUCTION.

Preliminary Proceedings.

The following Extracts from the Minutes of the Council of the Royal Society set forth the origin of the 'Porcupine' Expedition of 1870, and the objects which it was designed to carry out.

March 24, 1870.

A Letter was read from Dr. Carpenter, addressed to the President, suggesting that an Exploration of the Deep Sea, such as was carried out during 1868 and 1869 in the regions to the North of the British Islands, should now be extended to the South of Europe and the Mediterranean,

and that the Council of the Royal Society should recommend such an undertaking to the favourable consideration of the Admiralty, with a view to obtain the assistance of Her Majesty's Government as on the previous occasions.

Resolved,—That a Committee, consisting of the President and Officers, with the Hydrographer, Mr. Gwyn Jeffreys, Mr. Siemens, Professor Tyndall, and Dr. Carpenter, with power to add to their number, be appointed, to consider the expediency of adopting the proposal of Dr. Carpenter, and the plan to be followed in carrying it out, as well as the instruments and other appliances that would be required, and to report their opinion thereon to the Council; but with power previously to communicate to the Admiralty a draft of such report as they may agree upon, if it shall appear to them expedient to do so in order to save time.

April 28, 1870.

Read the following Report:—

"The Committee appointed on the 24th of March to consider a proposal for a further Exploration of the Deep Sea during the ensuing summer, as well as the scientific preparations which would be required for a new expedition, beg leave to report as follows:—

"The general course proposed to be followed, and the chief objects expected to be attained in a new expedition, are pointed out in the following extract from the letter of Dr. Carpenter, read to the Council on the 24th ult., which was referred to the Committee.

"'The plan which has been marked out between my Colleagues in last year's work and myself is as follows:—

"'Having reason to hope that the 'Porcupine' may be spared towards the end of June, we propose that she should start early in July, and proceed in a S.W. direction towards the furthest point to which our survey was carried last year; carefully exploring the bottom in depths of 400 to 800 fathoms, on which, as experience has shown us, the most interesting collections are to be made; but also obtaining a few casts of the Dredge with Temperature-soundings at greater depths, as opportunities may occur.

"'The course should then be nearly due South, in a direction of general parallelism with the coast of France, Spain, and Portugal, keeping generally within the depths just mentioned, but occasionally stretching westwards into yet deeper waters. From what has been already done in about 400 fathoms' water off the coast of Portugal, there is no doubt that the ground is there exceedingly rich. When approaching the Straits of Gibraltar, the survey, both Physical and Zoological, should be carried out with great care and minuteness; in order that the important problem as to the currents between the Mediterranean and Atlantic Seas, and the relation of the Mediterranean Fauna to that of the Atlantic (on which Mr. Gwyn Jeffreys

is of opinion that the results of our last year's work throw an entirely new light), may be cleared up.

"'Mr. Gwyn Jeffreys is prepared to undertake the scientific charge of this part of the expedition; and if Prof. Wyville Thomson should not be able to accompany him, it will not be difficult to find him a suitable assistant.

"'The ship would probably reach Gibraltar early in August, and there I should be myself prepared to join her, in place of Mr. Jeffreys, with one of my sons as an assistant. We should propose first to complete the survey of the Straits of Gibraltar, if that should not have been fully accomplished previously; and then to proceed eastwards along the Mediterranean, making stretches between the coasts of Europe and Africa, so as to carry out as complete a survey, Physical and Zoological, of that part of the Mediterranean basin as time may permit. Malta would probably be our extreme point; and this we should reckon to reach about the middle of September.

"'It is well known that there are questions of great Geological interest connected with the present distribution of Animal life in this area; and we have great reason to believe that we shall here find at considerable depths a large number of Tertiary species which have been supposed to be extinct. And in regard to the Physics of the Mediterranean, it appears, from all that we have been able to learn, that very little is certainly known. The Temperature and Density of the water, at different depths, in a basin so remarkably cut off from the great ocean, and having a continual influx from it, form a most interesting subject of inquiry, to which we shall be glad to give our best attention, if the means are placed within our reach.'

"Considering the success of the two previous Expeditions, and especially that of the 'Porcupine' last year, the Committee are persuaded that no less important acquisitions for the furtherance of scientific knowledge would be gained by the renewed exploration as now proposed; and they accordingly recommend that a representation to that effect be made to the Admiralty, with a view to obtain the aid of Her Majesty's Government as on the previous occasions.

"The Committee approve of a proposal made by Mr. Gwyn Jeffreys to accept the services of Mr. Lindahl, of Lund, in the expedition as unpaid Assistant Naturalist.

"As regards scientific instruments, the Committee have to report that those employed in last year's voyage will be again available for use; and Mr. Siemens hopes to render his electro-thermal indicator of more easy employment on ship-board.

"The Committee, having learned that Dr. Frankland has contrived an apparatus for bringing up the deep-sea water charged with its gaseous contents, have resolved to add his name to their number; and they request leave to meet again in order to complete the arrangements and make a final report to the Council."

Resolved,—That the Report now read be received and adopted, and that the Committee be requested to continue their Meetings and report again on the arrangements when finally decided on.

Resolved,—That the following draft of a Letter to be addressed to the Secretary of the Admiralty be approved, viz.:—

"SIR,—I am directed by the President and Council of the Royal "Society to acquaint you, for the information of the Lords Commissioners "of the Admiralty, that, considering the important scientific results of the "Physical and Zoological Exploration of the Deep Sea carried on in 1868 "and 1869 through the aid of Her Majesty's Government, they deem it "highly desirable that the investigation should be renewed during the "ensuing summer, and extended over a new area.

"The course which it would be proposed to follow in a new Expedition, "the principal objects to be attained, and the general plan of operations, "are sketched out in the inclosed extract from a Letter addressed to the "President by Dr. Carpenter, and have in all points been approved by the "Council.

"The President and Council would therefore earnestly recommend such "an undertaking to the favourable consideration of My Lords, with the "view of obtaining the assistance of Her Majesty's Government so libe-"rally accorded and effectively rendered on the previous occasions.

"The scientific conduct of the expedition would, as in the last year, be "shared by Dr. Carpenter, Professor Wyville Thomson, provided that "gentleman is able to undertake the duty, and Mr. Gwyn Jeffreys. It is "also proposed that Mr. Lindahl, a young Swedish gentleman accustomed "to marine researches, should accompany the expedition as Assistant "Naturalist.

"I have to add that whatever appertains to the strictly Scientific equip-"ment of the Expedition will, as formerly, be at the charge of the Royal "Society.

"W. SHARPEY, *Secretary.*"

A sum of £100 from the Government Grant was assigned for the Scientific purposes of the Expedition.

May 19, 1870.

Read the following Letter from the Admiralty:—

"Admiralty, 10 May, 1870.

"SIR,—Having laid before My Lords Commissioners of the Admiralty your letter of 2nd inst., requesting that further researches may be made of the deep sea, I am commanded by their Lordships to acquaint you that they will spare Her Majesty's Steam-vessel 'Porcupine' for this service, and that the Treasury have been requested, as on the former occasion, to

defray the expense of the messing of the scientific gentlemen composing the Expedition.

"I am, Sir,
"Your obedient Servant,
"VERNON LUSHINGTON."

"*To W. Sharpey, Esq., M.D.,*
Secretary of the Royal Society,
Burlington House."

EQUIPMENT.

1. The equipment of the 'Porcupine' for the previous Expedition had been found so complete and satisfactory that nothing more was considered necessary to prepare her for the work of the present season than the overhauling of her gear, and the manufacture of new dredges, sieves, and other apparatus, on the patterns of those which had already proved most serviceable. We had the advantage of the same excellent Commander, now promoted to the rank of Staff-Captain, with his able staff of Officers; and we would take this opportunity of again expressing our deep sense of obligation to them all for their hearty co-operation in our scientific work, and for the unvarying personal kindness by which our voyage was rendered a most agreeable one. A considerable part of the Crew, also, consisted of the same steady and experienced men. The Meteorological Department supplied eight of the protected Miller-Casella Thermometers, including the two with the performance of which we had been so thoroughly satisfied last year; and we usually employed one of these in conjunction with one that had not been used in the previous Expedition.

2. At the request of the Committee, Mr. Siemens undertook to devise an Apparatus for testing the depth of Sea-water to which Light, or at least the Actinic rays, can penetrate. The foundation of the apparatus which he constructed for this purpose is a horizontal wheel with three radii, each of them carrying a glass tube in which a piece of sensitized paper is sealed up. The rotation of this wheel round a vertical axis brings each of the tubes in succession out of a dark chamber in which it ordinarily lies, exposes it to light in an uncovered space, and then carries it into darkness again. This movement is produced by a spring; but it is regulated by a detent that projects from the keeper of an Electro-magnet, which is made and unmade by the completion or breaking of a circuit that connects it with a Galvanic battery. When the magnet is made, it lifts the keeper with its projecting detent; and this allows the wheel to be carried by the spring through one-sixth of its rotation, whereby the first of the tubes is brought out into the open space. There it remains until the circuit is broken, whereby the magnet is unmade; the keeper then falls, and the wheel is allowed to move through another sixth of a rotation, so as to carry on the tube into the dark chamber. A repetition of the making and unmaking of the magnet brings out the second tube, and shuts it up again;

and another repetition does the like with the third tube. This apparatus, with a deep-sea lead attached to it, is suspended by an insulating cable that contains the wires whereby it is connected with the battery in the vessel. Being lowered down to any desired depth, the circuit is completed, the magnet made, and one of the tubes exposed for as long a time as may be wished; the circuit is then broken, the magnet unmade, and the tube shut up again. The second tube may be exposed for a longer time in the same place, or the apparatus may be lowered to a greater depth, at which the experiment may be repeated; and the third tube may then be dealt with in like manner.—The Committee having been satisfied with the performance of Mr. Siemens's apparatus, it had been arranged that trial should be made of it, and also of his Differential Thermometer, now provided with an improved Galvanometer; and he had undertaken to send out a qualified Assistant to take charge of these instruments during the Mediterranean Cruise. The declaration of war between France and Germany, however, unfortunately interfered with this arrangement; the Assistant (a German) being recalled to his own country, and no other competent person being available on a short notice. Under these circumstances it was thought better that the Differential Thermometer should not be sent out; but it was hoped that such a trial might be given to the Photometric Apparatus as should at any rate determine whether satisfactory results might be anticipated from its use, or whether any modifications in its construction might be needed. The apparatus was sent out to Gibraltar under charge of Dr. Carpenter, and was got into working order by his Son and himself in Gibraltar Harbour. It proved, however, that the action of sea-water on the bearings,—increased as this was by the galvanic current arising out of the contact of iron and brass in them,—so embarrassed its Mechanical arrangements, that no fair trial could be made of its Photometric efficiency. But the experiment served the important purpose of showing the weak points of the apparatus; and neither Mr. Siemens nor Dr. Carpenter entertains any doubt that it may be so reconstructed as to answer the purpose for which it was devised.

3. The work of this year's Expedition was divided, according to the plan originally marked out, into two Cruises: the *first* to examine the Deep-sea bottom between Falmouth and Gibraltar; the *second* to make the like examination of the western basin of the Mediterranean between Gibraltar and Malta, and to determine its Physical and Biological relations to the Atlantic, with special reference to the Gibraltar Current.—The First Cruise was under the scientific direction of Mr. Gwyn Jeffreys, who was accompanied by a young Swedish Naturalist, Mr. Josua Lindahl, of the University of Lund, as Zoological Assistant; whilst Mr. W. L. Carpenter, as before, took charge of the Chemical department,—his special work, on this occasion, being the determination, by Volumetric analysis, of the proportion of Chlorine in samples of Atlantic water taken from the surface, the bottom, and from intermediate depths, so as to serve as a basis of com-

parison with similar determinations of Mediterranean water.—In the Second Cruise it had been arranged that Dr. Carpenter and Prof. Wyville Thomson should co-operate as before; but the latter being unfortunately prevented by serious illness from taking part in it, the whole charge of this Cruise rested with Dr. Carpenter. He was fortunately able to retain the assistance of Mr. Lindahl; and the Chemical work was continued (as in the Third Cruise last year) by Mr. P. H. Carpenter. Mr. Laughrin throughout acted as dredger and sifter.

NARRATIVE.

First Cruise.

4. After leaving Falmouth on the 4th of July, a thick fog and contrary wind delayed our voyage to such an extent that Captain Calver considered it advisable to put into Mount's Bay, as we could make but little way, and were uselessly expending coal. We remained there at anchor all the next day. The wind having moderated, we started at daybreak on the 6th, and steamed westward. During the day we used a towing-net (constructed on a plan of Lieut. Palmer), while the vessel was going at a speed of between five and six knots an hour, and caught myriads of a small oceanic Crustacean, *Cetochilus Helgolandicus*.

5. In the evening of the next day (7th of July) we reached that part of the slope extending from the entrance of the British Channel to the Atlantic deeps, which appeared from the chart and our sounding to be promising ground; and here our first dredging was made in 567 fathoms (Station 1). There being little or no wind, the contents of the dredge were very small, but proved extremely interesting. Among the Mollusca were *Terebratula septata, Limopsis borealis, Hela tenella, Pecchiolia* (or *Verticordia*) *abyssicola,* and a fine species of *Turbo,* which we were subsequently enabled to identify with *Trochus filosus* of Philippi, of which his *T. glabratus* is a variety. The last-named species and its variety are only known at present as Tertiary fossils of Calabria and Messina. The three species first named likewise occur in the Pliocene beds of Southern Italy; and these, as well as the *Pecchiolia* or *Verticordia,* live in the Norwegian seas. The other species of Mollusca now dredged are also northern, with the exception of *Ringicula ventricosa* (one of our Crag fossils), which was obtained in last year's expedition, not far from our present position, in 557 fathoms. The Rev. Mr. Norman notices among the Crustacea new species of *Ampelisca* and of six other genera. Of Echinoderms the pretty *Echinus elegans* was the most conspicuous. We lay-to at nightfall, so as to keep near the same ground.

6. On the 8th the weather was very fine; but there was not sufficient wind to give the necessary driftway for dredging. Our first attempt in 305 fathoms (Station 2) was almost a failure. Later in the day dredgings in 690 fathoms (Station 3) and about 500 fathoms produced some important results, viz. Mollusca: *Rhynchonella Sicula,* Seguenza MS. (a Sicilian

fossil), *Pleuronectia* sp. n., *Actæon* sp. n., besides *Limopsis borealis, L. aurita, Dentalium abyssorum, Puncturella noachina, Hela tenella, Rissoa Jeffreysi, Natica Montacuti, Admete viridula, Pleurotoma carinata,* and other northern species. CRUSTACEA: Mr. Norman reports as to the 690 fathoms (No. 3), "A most important dredging; the results among the Crustacea being more valuable than all the rest put together—at any rate of the First cruise. It contains almost all the choicest of the new species in last year's expedition, and four stalk-eyed Crustaceans of great interest, three of which are new, and the fourth (*Geryon tridens*) is a fine Norwegian species." And he adds that "with these are associated two forms of a more southern character, *Inachus Dorsettensis* and *Ebalia Cranchii,* which I should not have expected at so great a depth." ECHINODERMATA: *Cidaris papillata* (from which, according to Professor Wyville Thomson, *C. hystrix* is not specifically distinct), *Echinus elegans, Astropecten arcticus, A. Andromeda, A. Pareli,* and *A. irregularis*. ANNELIDA: Dr. M'Intosh notices, as a species supposed to be specially northern, *Thelepus circinnatus* of Fabricius from 690 and 500 fathoms. HYDROZOA: a new and beautiful tree-like form of a deep orange-colour. SPONGIA: *Holtenia Carpenteri* in considerable numbers and of all ages. Professor Wyville Thomson is fully convinced that the *H. Grayi* of Kent is only a variety of this species. The dredges did not fill; and most of the above results were obtained by means of the "hempen tangles," which were in 1869 for the first time attached to the dredge, and used with such wonderful success.

7. July 9th. Dredged all day; but the wind was too light, and the drift therefore insufficient for effective work. We began dredging in 717 fathoms (Station 4), and afterwards shifted the ground, getting 358 fathoms (Station 6), when we left off. This was about 185 miles from Cape Clear and Ushant, and 165 miles from the Scilly Isles. The Fauna was generally of a northern character, and included among the Mollusca *Terebratella Spitzbergensis* (Arctic and Japanese), *Pecten vitreus, P. aratus, Leda pernula, Axinus eumyarius, Rissoa turgida, Trochus suturalis* (a Sicilian fossil), *Odostomia nitens* (Mediterranean), *Taranis Mörchi, Defrancia* sp. n., and *Pleurotoma hispidula* or *decussata*=*P. concinnata*, S. Wood (Sicilian fossils, the last being Coralline Crag also), *Ringicula ventricosa, Actæon* sp. n., and *Bulla propinqua*. Some species were common to the North Atlantic and the Mediterranean. Among the Echinoderms was a fine specimen of *Brisinga endecacnemos*; and the Corals were represented by *Amphihelia oculata* and *Desmophyllum crista-galli*. Among the Annelids were *Pista cristata* of O. F. Müller, and *Trophonia glauca* of Malmgren, both Arctic species.

8. We lay-to on Sunday the 10th; and the next day we resumed our soundings and dredgings on the Channel slope at depths ranging from 257 to 690 fathoms (Stations 8, 9), occasionally changing the ground. The Fauna was everywhere northern, with a few exceptions. As to the Mollusca may be mentioned *Terebratula septata* (intermediate in shape between the typical kind and *Waldheimia Floridana*), *Leda* (*Yoldia*) *obtusa*,

Pecchiolia granulata, Trochus suturalis, T. reticulatus, Rissoa subsoluta (the last four Sicilian and Calabrian fossils), *Scalaria* sp. n., *Solarium fallaciosum, Fusus Berniciensis, F. fenestratus, Pleurotoma hispidula,* and *Bulla propinqua.* The Crustacea included *Cyclaspis longicaudata* (Norwegian) and *Polycheles typhlops* (Mediterranean), besides some new and peculiar species. A stony Coral of an undescribed genus and species also occurred, together with *Caryophyllia cyathus*, var. *clavus*. In the evening we steamed southwards, with a leading wind, for the deepest water in this part of the North Atlantic. We were afraid to continue the dredgings on the Channel slope towards the French coast, because the submarine telegraph-cable between Brest and North America might possibly be injured, and no information had been given, or could be obtained, as to the line of its direction.

9. July 12. On reaching the trough in the Bay of Biscay (or rather in that part of the Atlantic which lies outside the Bay), the sea became too high and the wind too strong for either sounding or dredging. This was from 250 to 300 miles south of the Scilly Isles, and about 200 miles north of Vigo. Our object was to get a cast in the greatest depth; and we lay-to all the day, waiting patiently for the chance of more favourable weather. But the wind did not take off at sunset, and the prospect did not improve; so it was determined not to lose any more time. At 10.30 P.M. steam was got up, and we went on towards Vigo. Rain fell at night; and the sea was brilliantly illuminated by the phosphorescent *Noctilucæ* and other animals. Some of these, especially the smaller oceanic Hydrozoa, gave a much brighter and steadier light than the rest; so that they might fancifully be compared to planets among stars. The next day (13th) was fine overhead; but there was too much swell to have carried out our intention of dredging in the deepest water.

10. Thursday, July 14, passed Cape Finisterre, and dredged in 81 fathoms (Station 10), about nine miles from the coast of Spain. Fauna mostly southern; although Mr. Norman notices among the Crustacea a new species of *Mysis*, and the following British and Norwegian kinds, *Galathea Andrewsi* and *Crangon nanus*; and Dr. M'Intosh gives *Terebellides Strœmii* and *Praxilla gracilis*, both Norwegian Annelids. We then steamed out, and dredged in 332 fathoms (Station 11). The bottom was rocky or stony; and the dredge fouled. On the tangles were two specimens (one adult and the other young) of that singular Echinoderm, or soft sea-urchin, belonging to the *Diadema* family, which was procured last year in nearly 60 degrees of North Latitude. It will be soon described by Professor Wyville Thomson under the name of *Calveria hystrix*. With this Echinoderm were the arms of *Brisinga endecacnemos*, and a specimen of a northern Mollusk, *Rissoa Jeffreysi*. Another dredge being put down on the same ground, was unfortunately lost, with some rope.

11. The following day (15th) we sounded in 128 and 232 fathoms (Stations 11, 12) about forty miles from Vigo, but used tangles only in consequence of the rocky nature of the bottom. The only noticeable Mollusk

was *Rissoa Jeffreysi*; and we also got an undescribed Polyzoon (*Idmonea Hispanica*, Busk), which was afterwards found in the Mediterranean.—16th. Dredged twice in Vigo Bay, at a depth of about 20 fathoms. This may be almost called "classical" ground; for it was the scene of Mr. M'Andrew's dredging-operations in the spring and autumn of 1849. We obtained a few species of Mollusca new to this locality; and two of these (*Tellina compressa* and *Nassa semistriata*) are interesting, as having been described and figured by Brocchi from the Subapennine Tertiaries. The latter species is one of our Crag fossils, under Mr. J. Sowerby's name of *Buccinum labiosum*. Mr. Busk mentions *Lepralia unicornis*, a Polyzoon previously known as from the Coralline Crag and Italian Pliocene, as well as Mediterranean. Vigo was our first anchorage after leaving England; and on Sunday we attended Divine Service, and dined with the late Capt. Burgoyne, on board his ill-fated but noble vessel the 'Captain,' which also had just arrived, after encountering some rough weather on her way out.

12. We left Vigo Bay at daybreak on Monday the 18th. It blew strong from the north-east; and after going about forty miles westward, and trying in vain to sound, we drifted along till the evening, and then steamed slowly in the direction of Lisbon, which was distant about 200 miles. The following day (19th) we sounded and dredged at depths of 100 and 220 fathoms (Station 13) from thirty to forty miles west of Cape Mondego, on the coast of Portugal. The Fauna at the lesser depth was southern and local, and at the greater depth comprised the following interesting species of Mollusca:—*Terebratula cranium, Limopsis borealis, L. aurita, Dentalium abyssorum, Trochus amabilis, T. suturalis, Trophon costifer* (Coralline Crag), *Fusus antiquus*, monstr. *contrarium, F. fenestratus*, and *Pleurotoma carinata*. Among the Foraminifera were specimens of the beautiful *Orbitolites tenuissimus* (sp. n., Carp.) found last year on the north-west of Ireland (Report, par. 36), and some other peculiar forms.

13. Wednesday, July 20th. Dredged all day with considerable success at depths of from 380 to 994 fathoms (Stations 14–16), the wind and sea having now gone down; and we took with the scoop-net a few living specimens of *Clio cuspidata*. The dredgings in 380 and 469 fathoms yielded among the Mollusca *Leda lucida* (Norwegian, and a Sicilian fossil; probably included in Philippi's description of *Nucula pellucida*), *Axinus eumyarius* (also Norwegian), *Neæra obesa* (Spitzbergen to the west of Ireland), *Odostomia* sp. n., *O. minuta* (Mediterranean), and *Cerithium* sp. n.; and among the Echinoderms were *Brisinga endecacnemos* and *Asteronyx Loveni*. But the results of the Dredging in 994 fathoms were so extraordinary as to excite our utmost astonishment. It being late in the evening, the contents of the dredge could not be sifted and examined until daylight the next morning. We then saw a marvellous assemblage of Shells, mostly dead, and consisting of Pteropods, but comprising certain species which we had always regarded as exclusively Northern, and others which Mr. Jeffreys recognized as Sicilian Tertiary fossils, while nearly forty per cent. of the entire number of species were undescribed, and some of them repre-

sented new genera. The following is an analysis of the Mollusca (perfect and fragmentary) taken in this one haul:—

Orders.	Total number of species.	Recent.	Fossil.	New or undescribed.
Brachiopoda	1	1		
Conchifera	50	32	1	17
Solenoconchia	7	3	..	4
Gastropoda	113	42	23	48
Heteropoda	1	1		
Pteropoda	14	12	..	2
	186	91	24	71

The Northern species above referred to are 34 in number, and include *Mytilus* (*Dacrydium*) *vitreus*, *Nucula pumila*, *Leda lucida*, *L. frigida*, *Pecchiolia abyssicola*, *Neæra jugosa* or *lamellosa*, *N. obesa*, *Tectura fulva*, *Fissurisepta papillosa*, *Cyclostrema* sp. n., *Torellia vestita*, *Pleurotoma turricula*, *Admete viridula*, *Cylichna alba*, *Cylichna ovata*, Jeffr. MS. = *Bulla conulus*, S. Wood, not Deshayes (Coralline Crag), and *Scaphander librarius*. *Leda lucida*, *Neæra jugosa*, *Tectura fulva*, *Fissurisepta papillosa*, *Torellia vestita*, and the undescribed species of *Cylichna*, as well as several other known species in this dredging, are also fossil in Sicily. Nearly all these Shells, as well as a few small Echinoderms, Corals, and other organisms, had evidently been transported by some current to the spot where they were found; and they must have formed a thick deposit, similar to those of which many Tertiary fossiliferous strata are composed. It seemed probable also that the deposit was partly caused by tidal action, because a fragment of *Melampus myosotis* (a littoral Pulmonibranch) was mixed with deep-water and oceanic Pectinibranchs and Lamellibranchs. None of the shells were Miocene, or of an older period.

14. This remarkable collection, of which not much more than one half is known to Conchologists, notwithstanding their assiduous labours, teaches us how much remains to be done before we can assume that the record of Marine Zoology is complete. Let us compare the vast expanse of the seabed in the North Atlantic with that small fringe of the coast on both sides of it which has yet been partially explored, and consider with reference to the dredging last mentioned what are the prospects of our ever becoming acquainted with all the inhabitants of the deep throughout the globe! We believe, however, that a thorough examination of the newer Tertiaries would materially assist us in the inquiry; and such examination is feasible and comparatively easy. Much good work has been done in this line; but although the researches of Brocchi, Bivona, Cantraine, Philippi, Calcara, Costa, Aradas, Brugnone, Seguenza, and other able Palæontologists in the South of Italy have extended over more than half a century, and are still energetically prosecuted, many species of Molluscous shells are con-

tinually being discovered there, and have never been published.—Besides the Mollusca in this dredging from 994 fathoms, Professor Duncan informs us that there are two new genera of Corals, and *Flabellum distinctum,* which last he regards as identical with one from North Japan. It coincides with the discovery on the Lusitanian coasts of two Japanese species of a curious genus of Mollusca (*Pecchiolia* or *Verticordia*), both of which are fossil in Sicily, and one of them in the Coralline Crag of Suffolk. Professor Wyville Thomson notices undescribed Sponges from the same dredging. The weather was very hot, and the sea quite smooth, at 10 P.M.

15. Thursday, July 21st. On deck at 5 A.M. Dredged all day in from 600 to 1095 fathoms (Stations 17, 17 *a*) with extraordinary success. Together with many of the new and peculiar species of Mollusca obtained at Station 16 (994 fathoms), some of which were here alive, occurred—*Nucula delphinodonta, Leda* (*Yoldia*) sp. n., *L. abyssicola, Axinus eumyarius, Siphonodentalium vitreum* (the first being North-American and Norwegian, and the last three Arctic and Norwegian), *S. coarctatum* (a well-known Subapennine fossil), *Dischides* sp. n., *Chiton albus* (northern), *Molleria costulata* (Arctic), *Trochus reticulatus* (a Calabrian fossil), *Omphalius monocingulatus,* Seg. MS. (a Sicilian fossil), *Hela* sp. n., *Eulima* sp. n., *Scalaria frondosa* (a Leghorn and Crag fossil), and *Trachysma delicatum* (a Sicilian fossil). Of Crustacea, there were *Apseudes spinosa* (Norwegian and British), *A. grossimanus* (sp. n.), and *Paranthura elongata* (sp. n.). Of Polyzoa, *Cellepora abyssicola,* sp. n. (Busk, MS.). Of Corals, *Cænocyathus* sp. n., and an undescribed species of an unknown genus allied to *Bathycyathus. Holtenia Carpenteri* and other rare Sponges, with *Brisinga endecacnemos* and various Echinoderms equally interesting, formed part of our treasures; but the greatest prize of all was a noble *Pentacrinus,* about a foot long, of which several specimens came up attached to the tangles. This discovery of a true *Pentacrinus* in the European seas crowned the day's work. Mr. Jeffreys has named it *P. Wyville-Thomsoni*; Dr. Carpenter will describe it, and give its zoological and geological relations, as he is especially acquainted with this group of the Echinoderms by having worked out the structure of *Antedon* in the Philosophical Transactions for 1866. We may remark that our *Pentacrinus* was dragged up from soft mud or ooze, and that its base was entirely free. Portions of the arms occurred in several other dredgings on the Lusitanian coasts; and joints of apparently the same species have been found by Professor Seguenza in the Zanclean formation or older Pliocene near Messina.

16. July 22nd. We tried to dredge among the Berling Isles, but could do nothing. The ground was rocky, and the charts were incorrect. The sounding-lead was deeply indented, and a water-bottle torn away and lost. A dredge was afterwards put down twice in a trough or gulley between 900 and 1000 fathoms deep; each time it came up empty. We then steamed for Lisbon, where we arrived the next day.

17. On the 25th (Monday) we got to Cape Espichel. The wind had in-

creased so much that, after fruitlessly endeavouring to dredge, we anchored in the evening for shelter in Setubal Bay. We there dredged, with no special result. Professor Bocage had kindly given us at Lisbon a letter of introduction to the coast-guard Officer at Setubal, who was said to know the only place where the deep-sea Shark and the *Hyalonema* are taken by the fishermen; but the state of the weather unfortunately prevented our availing ourselves of it.

18. July 26th. Although the wind was rather high and the sea rough, we contrived (owing to the admirable management of Captain Calver) to dredge off Cape Espichel in 740 fathoms (Station 20); and later in the day, having stood out further to sea, in 718 fathoms (Station 22.). Deeper water is sometimes found to be near land than at a distance from it. The Mollusca were mostly of the same kind as those from No. 16 (994 fathoms), but included *Leda pusio*, *Limopsis pygmæa* (Sicilian fossils), and *Pecchiolia acuticostata*. The last-named species is extremely interesting in a geological as well as geographical point of view. It is a fossil of our Coralline Crag and the Sicilian pliocene beds; and it now lives in the Japanese archipelago. Some Japanese Brachiopods and Crustacea also inhabit the Mediterranean. It may be difficult to account for this migration to or from Northern Asia, except through the Arctic ocean; but we would again venture to call attention to the suggestion made by Mr. Jeffreys as to the communication which probably existed, at a period subsequent to the Middle Tertiary or Miocene epoch, between the North Atlantic and the Mediterranean, in the direction of the Languedoc canal or Canal du Midi, from the Bay of Biscay to the Gulf of Lyons. The Straits of Gibraltar do not appear to afford the means of such migration or transport of any northern Fauna to the Mediterranean, because the current which flows into it from the Atlantic is superficial only, and does not reach the bottom, which the *Pecchiolia* inhabits. This Mollusk has no power of swimming, like many univalves; nor does its fry rise to the surface and become for a short time oceanic, as in certain species of *Trochus* and *Dolium*. Any current which flows out of the Mediterranean at its bottom into the Atlantic would transport the fry of the *Pecchiolia* southwards, or at any rate could not withstand the great northern current which brings Arctic mollusca to the Lusitanian seas. Now the greatest height above the sea in the line of the Canal du Midi from Bordeaux to Narbonne is stated to be 189 mètres, or about 615 feet. M. Reboul, in his "Mémoire sur les Terrains de comblement tertiaire" (Mém. Soc. Géol. de France, 1834) mentions, as to the district in question, marine tertiary shells which had been deposited by a sea higher by about 200 mètres than the present sea; and he says that M. Deshayes considered these shells to be among the most recent of the Tertiary period. No lists of the shells, or any definite particulars of the deposits, however, have been published by French geologists; and it is to be hoped either that this deficiency will be supplied by them, or that Mr. Prestwich may be able to investigate the matter with his usual

ability, and give us some satisfactory and reliable information. In the dredging (Station 22) at 718 fathoms, Mr. Norman reports new species of Crustacea belonging to four genera.

19. July 27th. Dredged a few miles north of Cape St. Vincent, in 292 and 374 fathoms (Stations 24, 25). Ground rocky; and in the evening a dredge, with 400 fathoms of 3-inch rope, was unavoidably lost. The last haul yielded two Siliceous or Vitreous Sponges of an enormous size, one of them measuring nearly 3 feet in diameter at the top, of the kind called "Neptune's Cup" (*Askonema Setubalense*, Kent), besides that lovely sponge, *Aphrocallistes Bocagei*. The Mollusca were mainly northern, and included fresh-looking fragments of the gigantic *Lima excavata*, besides *Limopsis minuta* (distinct from *L. borealis*), *Pecchiolia acuticostata*, *P. granulata*, *Trochus suturalis*, and *Pleurotoma hispidula* or *decussata*, all of which are Sicilian fossils. Two undescribed species of Crustacea, which Mr. Norman proposes to name *Amathia Jeffreysi* and *Ethusa mirabilis*, were here obtained.—At night we steamed slowly south, and doubled Cape St. Vincent. The electric telegraph-cable between Falmouth and Gibraltar sadly hampered our movements in this part of the cruise, by occupying the ground which we were most desirous of exploring. It was not considered safe to dredge within eight or ten miles on either side of it. This was a serious drawback; since it obliged us to dredge either in water which is too deep for systematic or continued exploration, or in comparatively shallow water near the coast, where the ground is rocky and the dredge liable to be lost.

20. July 28th. Dredged several times off Cape Sagres in from 45 to 58 fathoms. Fauna southern. *Venus multilamella*, *Tellina compressa*, and *Halia Priamus* occurred living; and Dr. M'Intosh says that two Annelids (*Glycera capitata* and *Praxilla prætermissa*) had not been hitherto observed south of the track in last year's expedition. The sea being rough and wind high, we anchored off Lagos.

21. July 29th. Steamed south, and dredged in 364 and 322 fathoms (Stations 26, 27). The water was of an indigo-blue colour. Weather fine, but rather windy. For the first dredging 700 fathoms of rope were payed out, and two weights of 100 lbs. were attached at 350 fathoms from the dredge. The Mollusca comprised some of the new and remarkable species procured in Station 16 (994 fathoms) and other dredgings, as well as *Terebratula vitrea*, *T. cranium*, *Pholadomya* sp. n., *Trochus amabilis*, *Pyramidella plicosa* (Belgian and Coralline Crag), *Tylodina Dubeni* (Norwegian), *Cancellaria mitræformis*, *C. subangulosa* (both Coralline Crag), *Pleurotoma galerita*, and *Actæon pusillus*. The Crustacea of most interest were *Pagurus platycheles* (sp. n.), and an undescribed species of *Munna*. The Corals were *Flabellum distinctum* (the same as in Station 16) and *Amphihelia oculata*. The Hydrozoa in 364 fathoms included a new and beautiful species of *Plumularia*. But the most remarkable novelty here obtained was a large collection of thin sandy disks, from 0·3 to

0·4 inch in diameter, with a slight central prominence; for these proved on subsequent examination to contain an entirely new type of Actinozoon, extraordinarily flattened in form, and entirely destitute of tentacles. Dr. Carpenter, by whom this curious organism will be described, has assigned to it the name of *Ammodiscus Lindahli.*

22. July 30th. Sounded and dredged at two stations on our way to Cadiz in 304 and 280 fathoms (Stations 28, 28*a*). At the first of these stations *Flabellum distinctum* and a new species of *Caryophyllia* occurred. At the latter station we got the same undescribed species of *Pholadomya,* being the second species known in a recent or living state; the other is extremely rare, and West Indian. With the *Pholadomya* were *Trochus crispulus* and *Odostomia plicatula* (Sicilian fossils), and *Actæon exilis,* besides undescribed species of *Poromya, Mitra,* and *Marginella.* Anchored off Cadiz, near H.M.S. 'Cruizer;' where we had at first some difficulty in being allowed to land, in consequence of our not being provided with a bill of health, and there being no surgeon on board.

23. Left Cadiz on Tuesday, 2nd August, and steamed west, so as to get on the seaward side of the provoking cable. Dredged in 227 and 386 fathoms (Stations 29, 30). There was an admixture of northern and southern species, including a fragment of *Fusus antiquus,* var. *carinata*; and the *Ammodiscus* here also presented itself, with a test composed of coarser sand-grains than before, and frequently including Foraminifera.

24. Aug. 3rd. Dredged at three more Stations (31, 32, 33), in 477, 651, and 554 fathoms, across the entrance to the Straits of Gibraltar, and towards the Morocco coast; and we shifted our ground at night. The Fauna was northern, but scanty; the bottom being stiff clay, and nearly unproductive. Undescribed species of *Cioniscus* and *Bulla* were among the Mollusca; a remarkable Sponge, eighteen inches long, which Prof. Wyville Thomson considers the type of a new genus allied to *Esperia* (*Chondrocladia virgata,* Wyv. Th. MS.), another new and exquisitely graceful Sponge of the *Holtenia* group, and provisionally named by him *Pheronema? velatum,* and *Aphrocallistes Bocagei*; two new species of a compound stony Coral (*Cænocyathus*); and a few Crustaceans and Annelids were taken. Part of a large Ribbonfish (*Regalecus gladius*) was caught floating on the surface of the sea, the remainder having been apparently bitten off and devoured by a Shark or Swordfish.

25. Aug. 4th. Dredged again off the Straits and on the coast of Africa in from 414 to 72 fathoms (Station 34). In the greater depths was the same stiff and nearly azoic clay; and in the lesser depths were broken and dead shells of southern species. The Fauna in the former was chiefly northern, and comprised *Rissoa turgida* (Norwegian) and *Holtenia Carpenteri.* Capt. Spratt suggests that the clayey bottom may have been formed by continual deposits from the great and muddy rivers Guadalquiver and Guadiana. Such deposits would to a considerable extent inter-

fere with the existence and growth of marine animals. An easterly wind having sprung up, we hove-to off Cape Spartel, between thirty and forty miles from Gibraltar.

26. Aug. 5th. Steamed into Tangier Bay, after ineffectually trying to dredge in 190 fathoms (Station 37) off Cape Spartel. The bottom in this part of the Straits is everywhere rocky; and there is reason for believing that it must be swept by the undercurrent in the middle, and by the tide at the sides. Sargasso or Gulf-weed was found floating off the Cape. In Tangier Bay we dredged twice at a depth of about 35 fathoms. Fauna principally British, with a few more southern forms: the last include, among the Mollusca, *Pythina? Macandreæ, Cyclostrema sphæroïdeum* (Coralline Crag), *Rissoa sculpta* and *R. substriata* (Calabrian and Sicilian fossils), *Adeorbis supranitidus* (Coralline Crag); and among the Polyzoa, *Cupularia Canariensis*, which inhabits Madeira and the Canaries, and occurs in the Coralline Crag as well as other tertiaries of the same age. *Sphenotrochus intermedius* (a Coralline Crag Coral) was the only other acquisition worth notice.

27. On the following day (6th August) we arrived at Gibraltar. Mr. Jeffreys was there succeeded by Dr. Carpenter; and the former went on to Sicily *viâ* Malta, for the purpose of examining the newer tertiary formation in the south of Italy, and the collections of fossil shells at Catania, Messina, Palermo, and Naples, in connexion with the results of his cruise.

28. The quantity and variety of Zoological materials is so great that we have distributed it as follows:—*Crustacea*, Rev. A. M. Norman and Mr. George S. Brady; *Polyzoa*, Mr. Busk; *Annelida*, Dr. M'Intosh; *Corals or Stony Anthozoa*, Professor Duncan; *Horny or Flexible Anthozoa*, Mr. Kent; *Hydrozoa*, Dr. Allman; *Echinodermata and Sponges*, Professor Wyville Thomson. The *Mollusca* will be worked out by Mr. Jeffreys; and the *Pentacrinus, Ammodiscus*, and *Foraminifera* by Dr. Carpenter, who also undertakes to discuss the Physical results.

29. Throughout the whole of this Cruise the Temperature of the *Sea-bottom* was taken by the protected Miller-Casella Thermometers in nearly every Sounding, with the results tabulated in p. 220. As, for the reason already mentioned (§ 9), no extreme depths were sounded, and as the general rate of the diminution of temperature on the margin of the North-Atlantic basin seemed to have been established by the Serial Soundings taken in the Expedition of the preceding year, it was not thought necessary to repeat these; more especially as the variety of depths at which the *Bottom*-temperatures were ascertained gave adequate data for comparison with the results then correlated. It will be shown hereafter (§ 79) that this comparison leads to some very interesting conclusions, fully confirming the view advanced in the last Report (§ 119) as to the slow northward movement of an upper stratum of warm water 700 or 800 fathoms in depth, and of the southward movement of the whole deeper stratum, bringing water of an almost icy coldness from the Arctic basin into the Temperate and even the Intertropical Zone.

30. During the whole of this Expedition the Temperature of the *surface* of the Sea was ascertained and recorded every two hours, both by day and by night; as were also the readings of the Dry and Wet-bulb Thermometers, which were placed in a small penthouse on deck, in which they were freely exposed to the surrounding Air, but secluded from direct or reflected Solar heat.—The Temperature of the *surface-water*, from the time of our leaving the British Channel in Lat. 48° N. to our turning the corner of Cape St. Vincent in Lat. 36° 50′ N., increased at a rate which bore a pretty regular proportion to the Southing. Thus, at the "chops of the Channel," it averaged 62° for five days; whilst by the time we approached Cape St. Vincent it had gradually risen to above 69°. After passing that point, however, we found both the *surface-* and the *bottom*-temperatures to present certain variations, which, though not considerable in themselves, proved to be of great interest when taken in connection with the peculiar condition of the *embouchure* of the Strait of Gibraltar. These points, however, will be more fitly discussed hereafter (§ 73 *et seq.*); and we shall now only notice a sudden *rise* in Surface-temperature of about 3° which showed itself as we turned the corner of Cape St. Vincent and entered the *north side* of the embouchure, and a sudden *fall* of nearly 6° (to 66°·4) which was encountered when we entered the mid-stream of the narrower part of the Strait as we proceeded towards Gibraltar.

31. In the course of the First portion of the Cruise between Falmouth and Lisbon (beyond which point Mr. W. L. Carpenter was unable to proceed), thirty-six quantitative determinations were made, by Volumetric analysis, of the amount of Chlorine in as many samples of Atlantic water, taken (1) from the surface, (2) from the bottom at various depths, and (3) from various intermediate depths. The greater part of these, as will be shown hereafter (§ 84), exhibited a very close conformity to a uniform standard of density, as indicated by a Specific Gravity of 1·0268, and a Chlorine proportion of 19·84 per 1000*; the chief departures being observable in the *lower* density of the *deepest* waters, and in the occasional *excess* of density in the surface-waters. The former is doubtless attributable to the fact that the *deepest* water is essentially *Polar*, and therefore derives its more dilute character from that source. The latter we are inclined to attribute to the influence of slight concentration by evaporation.

Second Cruise.

32. Leaving Gibraltar early in the morning of Monday, Aug. 15, we steamed out into the middle of the Strait, for the purpose of commencing our experiments on the Gibraltar Current. The point selected by Capt. Calver (Chart of Strait of Gibraltar, Station 39) lay midway between Point Carnero, which forms the south-eastern boundary of Gibraltar Bay,

* The proportion here adopted,—the number of Grammes of Chlorine to 1000 Cubic Centimètres of Water,—is that employed by Prof. Forchhammer in his elaborate Memoir on the Composition of Sea Water (Philos. Transact. 1865).

and Jebel Musa or Apes Hill, which lies opposite to it, at a distance of only 8 geographical ($9\frac{1}{4}$ statute) miles, on the African coast, the Strait being here nearly at its narrowest: and it was also that at which the greatest depth (510 fathoms) was indicated by the Soundings marked on the Chart. With this depth our own Sounding, which gave a bottom at 517 fathoms, agreed very closely; and having thus at once found the position most advantageous for our work, that position was precisely determined by angles taken by sextant from the Ship between conspicuous objects on the shore. The *bottom*-temperature obtained in the first sounding was between 5° and 6° *higher* than that which had been met with at corresponding depths on the bed of the Atlantic about 100 miles to the westward; whilst the *surface*-temperature was *lower* by from 5°·3 to 6°, as will be seen by the following comparative statement:—

	Station.	Depth.	Surface-temperature.	Bottom-temperature.
			°	°
Strait of Gibraltar..	39	517	66·0	55·5
Atlantic	31	477	71·3	50·5
Atlantic	32	651	71.5	50·0
Atlantic	33	554	72·0	49·7
Atlantic	34	414	71·7	50·0

33. This striking difference led us to take a set of *serial* soundings at intervals of 50 fathoms; and these gave a result which, though it appeared anomalous at the time, was afterwards fully explained, and proved to be of unexpected import. The Temperature fell, at 50 fathoms from the surface, to 56°; at 100 fathoms it was 55°·7; at 150 it was 55°·5; and from that depth to the bottom, at 517 fathoms, there was *no further descent*. Now it will be shown hereafter (§ 88) that the thermal condition which here so much surprised us by its contrast with that of the Atlantic waters, is that universally met with in the Mediterranean; the Temperature of which, whatever may be its surface-elevation, falls to within 1° Fahr. above or below 56° at a depth of 50 fathoms, to a degree or two lower at 100 fathoms, and then remains uniform down to the greatest depth (1743 fathoms) at which we examined it. And it thus appears that whilst the *surface*-water in this part of the Strait is certainly derived from the Atlantic, the *deeper* water, partaking of the thermal condition which so remarkably characterizes that of the Mediterranean basin, may be fairly regarded as belonging to the latter.

34. This inference is in harmony with another fact ascertained on the same occasion, viz. the great excess in Salinity shown by water brought up from the depth of 250 fathoms over the water of the surface. Whilst the Specific Gravity of the latter was found to be 1·0271, that of the former was 1·0293; and whilst the proportion of Chlorine in the latter was 20·324 per 1000, it was 21·775 in the former. Now in these particulars the Surface-water agreed well with what had been found to be the condition

of the water of the Atlantic; whilst the water at 250 fathoms agreed equally well with what proved to be the condition of the bottom water in the adjacent part of the Mediterranean (§ 43). We were not a little surprised, however, to find that the water here taken from the *bottom* (517 fathoms) was of much *less* density, as indicated both by Specific Gravity and by Chlorine percentage, than that of the *intermediate* stratum; its Specific Gravity being 1·0281, and its proportion of Chlorine 21·465. This apparent anomaly (the existence of which was confirmed by observations made on our return voyage, § 61) pointed to the existence of an *out*-current in the *intermediate* stratum as the probable explanation of the overlaying of the lighter by the heavier water. The Specific Gravity of the *bottom*-stratum closely corresponded, as we subsequently found, with that of the bottom-water over the *deepest* part of the area of the Western basin of the Mediterranean (§ 93).

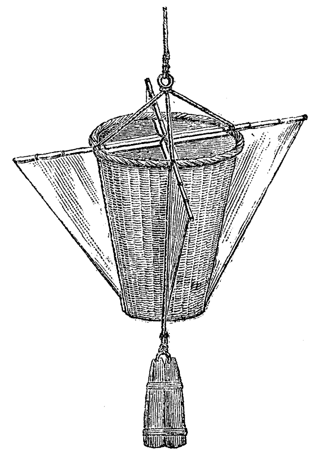
35. These data having been obtained by the examination of the several parts of the vertical column at one and the same point, and this point being in the centre of nearly the narrowest part of the Strait, and at the deepest part of the channel, we proceeded to test the *actual movement* of water on the surface and at different depths beneath it.

36. The rate of *surface*-movement was easily determined. The precise position of the Ship having been ascertained in the manner already stated, a small flat basket, presenting no such elevation above the water as would cause it to be influenced in any considerable degree by a moderate wind*, was sent adrift, so as to be freely carried along by the current; it was allowed to float for a determinate time, throughout which it was followed by the ship; and when it was taken up at the expiration of that time, the place of the ship was again ascertained as before. The space between the two points being then determined trigonometrically, the rate of the flow per hour, and its precise direction, could be readily calculated. Thus on the morning of August 15th the float was followed by the ship for fifteen minutes, during which it was found to have moved 4377 feet in the direction E. by S. $\frac{3}{4}$ S., or at the rate of 2·88 miles per hour (§ 40).

37. For the determination of the *movement of the water at different depths below the surface*, a "current-drag" (see figure, p. 165) had been constructed by Capt. Calver on a plan suggested by his previous experience, which had led him to the conclusion that a submerged basket lined with sailcloth, which of course fills itself with water, presents a better resisting surface than any vessel of wood or metal. Such a basket being made the basis (so to speak) of the apparatus, its resisting surface was augmented by fixing two pairs of arms at right angles to one another across

* It is obvious that the movement of the Ship itself would be liable to be considerably affected by even a slight breeze, on account of the large surface of resistance presented by its transverse section (especially by its paddle-boxes) above the water. This would cause its drift to be *more* rapid than the current, if the direction of the wind should be *with* that of the current, and *less* rapid if the wind should be opposed to it.

its upper end, and by stretching a piece of sail-cloth between each arm and the side of the basket; which device caused a uniform resisting surface to be presented to the current, whatever the manner in which the sails might meet it. To the lower part of this "drag" a couple of sinkers, of 112 lbs. each, were attached; and the whole apparatus was supported by cords meeting in a ring above it, to which the suspending line was secured.



Current-drag.

38. This "current-drag" having been transferred to a boat, was lowered down by a couple of men placed in her, to the desired depth; and the boat was then left entirely free to move, being lightened by the return of the men into the ship. The motion of the boat would be the composite result of (1) the action of wind (if any) upon the transverse section of the part of of the boat above the water; (2) the action of the surface-current upon the transverse section of the immersed part of the boat; (3) the action of the upper current upon the suspending line; and (4) the action of the current in which the "drag" is suspended upon the drag itself. Putting aside the *first* of these agencies, which will be of very little account if (as in the experiment now narrated) the boat be small and the breeze be light, it is obvious that the relative influence of the *second* and *third* to that of the *fourth* will depend upon the proportion between the surfaces presented by the boat, the line, and the "drag" respectively, and the strength of the current acting upon each. The surface given to the "drag" being larger than that of the boat and line taken together, the force acting on the "drag" will dominate, if it hang in an opposing current superior, equal, or even somewhat inferior in rate to that which acts on the boat and line; so that the boat would be carried along by the drag *against* the surface-stream, at a rate proportioned to the excess.—If, again, the rate of the undercurrent should be greatly inferior to that of the surface, its action upon the "drag" might still be sufficient to neutralize that of the surface-current upon the boat and line, and the boat would then remain *stationary* or nearly so.—A still further reduction in the rate of the opposing undercurrent would make its action upon the "drag" *less* powerful than that of the surface-current upon the boat and suspending line; and the boat would then move *with* the surface-current, but at a rate of which the great retardation would indicate an antagonistic force beneath.—Supposing, again, the water of the stratum in which the "drag" is suspended to be stationary, the action of the surface-current upon the boat and line would be opposed by the resistance offered by the deeper water

to the movement of the drag; and the retardation of the movement of the boat would be less, though still considerable.—If, again, the stratum in which the "drag" is suspended should itself be moving in the direction of the surface-current, but at a reduced rate, there will still be a resistance to the movement of the "drag" at the more rapid rate of the surface-current; and this resistance will produce a proportional retardation in the motion of the boat.—Finally, if the stratum in which the "drag" is suspended, with the intermediate stratum through which the suspending line passes, move at the same rate with the surface-current, the motion of the boat with the whole suspended apparatus will have the same rate as that of the simple float.

39. Putting these respective cases conversely, it may be affirmed (1) that if the boat, having the "current-drag" suspended from it, should move *with* the surface-current and *at the same rate,* the stratum in which the "drag" hangs may be presumed to have a motion nearly corresponding with that of the surface-current; (2) that if the rate of movement of the boat *with* the surface-current should be *retarded,* a diminution of the rate of the stratum in which the "drag" hangs, to a degree *exceeding* the retardation of the movement of the boat, may be safely predicated; (3) that when this retardation is so considerable that the boat moves *very slowly* in the direction of the surface-current, it may be inferred that the stratum in which the "drag" is suspended is either stationary or has a slow movement in the opposite direction; (4) that if the boat should remain *stationary,* a force must be acting on the "drag" which is equal and in the *contrary direction* to that of the upper current upon the boat and suspending line; so that the existence of a counter-current is indicated, having a rate as much *less* than that of the surface-current, as the resisting surface presented by the "drag" is *greater* than that offered by the boat and upper part of the suspending line; (5) that if the boat should move in a direction *opposed* to that of the surface-current, a motion is indicated in the stratum in which the "drag" hangs which will correspond in *direction* with that of the boat, and which will *exceed* it in *rate,* the effect of the "drag" upon the boat being partly neutralized by the antagonistic drift of the surface-current.

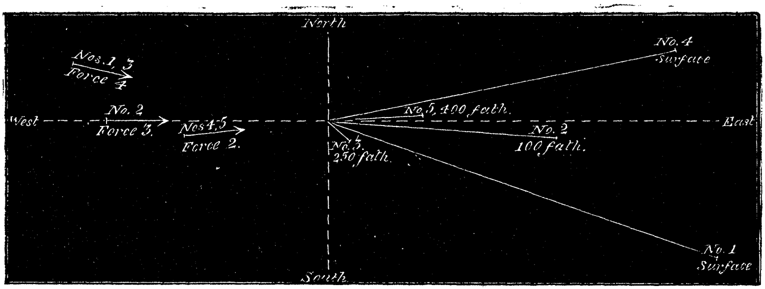
40. Now our first set of experiments (Station 39) with the "current-drag" gave the following results:—

I. The surface-movement being first tested in the manner already described (§ 36), its rate was found to be 2·88 nautical miles per hour, and its direction E. by S. $\frac{3}{4}$ S. The wind was W. by N., with a force of 4.

II. The "drag" having been lowered down to a depth of 100 fathoms, the rate of movement of the boat from which it was suspended was reduced to 1·550 mile per hour, or *rather more than half* the surface-movement. Its direction was E. $\frac{1}{3}$ S. Taking into account the action of the wind and surface-current on the boat, it may be safely affirmed that at 100 fathoms the rate of the current was reduced to *less than one half.*

III. The "drag" having been lowered down to a depth of 250 fathoms, the boat remained nearly stationary, its *rate* of movement being reduced to 0·175 mile per hour, while its direction (S.E. ¼ E.) was slightly altered to the southward, though still easterly. From this we felt ourselves justified in inferring that the 250-fathoms' stratum had a movement in the *reverse*

Station 39.



Rate (per hour) and Direction of Movement of Surface-float, and of Current-drag at different Depths; with Force and Direction of Wind.

direction, acting on the current-drag with a force almost sufficient to neutralize the action of the upper stratum on the boat and suspending line. And this inference, which was strengthened by the indication already shown to be afforded by the extraordinary density of the water of this stratum (§ 34), was fully justified by the results of the experiments which we made on our return voyage (§ 62).

41. While these experiments were in progress, we had the pleasure of seeing the Channel Fleet, which was expected to meet the Mediterranean Fleet at Gibraltar, come in sight beyond Cape Tarifa; its approach having been indicated, long before even the tops of the masts of the vessels composing it showed themselves above the horizon, by the number of separate puffs of smoke which the experienced eye of our Commander enabled him to distinguish. As soon as all possibility of doubt was removed by the appearance of the masts, Capt. Calver communicated "Fleet in sight" by signal to the Admiral in Gibraltar Harbour, our position being such that *we* could be seen by him, though the Fleet could not. In due time, the massive hulls of the Ironclads rose above the horizon; and whilst we continued at our work, all passed us in sailing order at a distance of not more than a couple of miles,—the ill-fated 'Captain' being the chief object of interest. A few hours later, the 'Monarch,' which had been detained for repair, but whose passage had been made in a shorter time by the free use of her steam-power, came in sight; and passed on in solitary grandeur to join the Fleets now united in Gibraltar Bay.

42. The whole of our first day having been consumed without our being able to work the "current-drag" in the deepest stratum, we anchored for the night near Point Carnero, with a view to resuming our experiments on

the following morning. We then ran out to a spot almost precisely identical with that which had been our starting-point on the previous day; and commenced, as before, by testing the rate and direction of the surface-movement. Its rate proved rather slower, being 2·40 miles per hour, instead of 2·88; and its direction was E. by N., instead of E. by S. $\frac{3}{4}$ S. Both differences seemed to be accounted for by the difference in the force and direction of the wind; which, having been W. by N. with a force of 4 on the previous day, was now W. $\frac{1}{2}$ S. with a force of only 2. The "drag" was then lowered to a depth of 400 fathoms; but our expectation that it would there encounter a westerly (or outward) current sufficiently strong to carry the boat in that direction in spite of the antagonistic movement of the easterly (or inward) surface-current, was not verified on this occasion; for the boat slowly drifted in an E. $\frac{1}{3}$ N. direction, its rate being 0·650 mile per hour. Whether this result should be taken to indicate a stationary condition of the deep stratum, or a slight movement in either direction (§ 39), could scarcely be affirmed with positiveness; but from the indication afforded by the Specific Gravity of the water taken up from this depth (§ 34), it seemed probable that the general movement of this stratum was at this time rather *westerly*, or in conformity with that which we attributed to the intermediate stratum, though at a slower rate.—It will be shown hereafter (§ 62) that a decisive proof of such a movement was obtained on a subsequent occasion.

43. Thinking it expedient to postpone the further prosecution of this inquiry until our return voyage,—when we should be able to repeat our experiments, not only at this narrow end of the Strait, but also at that shallowest portion to the westward where the Strait opens out into the Atlantic,—we put steam on before mid-day, and entered the basin of the Mediterranean, directing our course in the first instance to the spot (Lat. 36° 0′ N., Long. 4° 40′ W.) at which the sample of bottom-water had been obtained by Admiral Smyth, which, when analyzed by Dr. Wollaston, was found to possess the extraordinary Specific Gravity of 1·1288, and to yield a percentage of 17·3 of Salt *. As we were within sight of both shores, and could distinguish several remarkable mountain-summits which were accurately laid down on our Charts, the bearings of these enabled the situation of the Ship to be determined with great precision; and Capt. Calver undertook to place her within a mile of the point at which Admiral Smyth's observation had been taken. Having reached this (Station 40) we took our first Sounding in the Mediterranean; and awaited the result with no little interest. The depth proved to be 586 fathoms, or 84 fathoms less than that given by Admiral Smyth's sounding; but as the latter was not taken on the improved method now adopted, and as its correctness may have not improbably been affected by the strength of the easterly current which is here very perceptible, the discrepancy can scarcely be considered as of any real account as showing that the two points were otherwise than nearly

* Phil. Trans. for 1829, p. 29; and Admiral Smyth's 'Mediterranean,' pp. 128–130.

coincident *. The specimen of bottom-water brought up by our bottle was found to have a Specific Gravity of 1·0292, whilst that of the surface-water was 1·0270. The volumetric determination of the Chlorine gave 21·419 per 1000 for the bottom-water, as against 20·290 per 1000 for the surface-water. A decided excess of salt is thus indicated in the bottom-water, as compared on the one hand with the surface-water of the same spot, and on the other with the bottom-water of the Atlantic, which had been generally found to show a rather smaller proportion of Chlorine than the surface-water. But this excess is extremely small in comparison with that indicated by Dr. Wollaston's analysis. For, assuming his factor of ·134 as representing, when multiplied by the excess of Specific Gravity above that of distilled water, the total percentage of Salt, that percentage is only 3·91, instead of 17·3 as stated by Dr. Wollaston.

44. This result accorded so closely with that obtained by Dr. Wollaston himself from the analysis of two other samples of bottom-water taken up by Admiral Smyth, the one in Long. 1° 0′ E. from a depth of 400 fathoms, and the other in Long. 4° 30′ E. from a depth of 450 fathoms,—as well as with our own determinations of the Specific Gravities and Chlorine percentages of a great number of samples taken in different parts of the Western basin of the Mediterranean,—that we cannot hesitate in regarding it as representing the *ordinary* condition of the bottom-water at this spot. And it seems to us far more probable that the sample furnished by Admiral Smyth to Dr. Wollaston had been concentrated by evaporation in a badly stopped bottle, in the three years during which it had remained in Admiral Smyth's possession, than that any extraordinary discharge of salt from a brine-spring at the bottom (a sort of *Deus ex machinâ* invoked by Admiral Smyth to account for the occurrence) should have given rise, in the spot at which his Sounding was taken, to an exceptional condition of which no indication whatever was presented in our own.

45. The Temperature-phenomena presented at this Station proved of singular interest. The *surface*-temperature, 74°·5, was higher than any that had been encountered on the Atlantic side of the Straits, even in a latitude half a degree further south; and the observations, which had been regularly taken every two hours, showed that it had increased nearly *ten degrees* as we proceeded eastwards from Station 39, between 10 A.M. and 2 P.M. A part of this increase was doubtless due to the heating effect of the mid-day sun; but as the temperature of the air had not increased quite *six* degrees during the same time, and as it will be shown hereafter (§ 86),

* Thus Admiral Smyth states (Mediterranean, p. 159) the depth in mid-channel between Gibraltar and Ceuta to be 950 fathoms; whereas it is now known to be but little more than 500 fathoms. "A little further to the eastward," he says, "there is no bottom with 1000 fathoms of line up-and-down (*upwards of* 1300 *payed out*);" whereas the greatest depth as far east as Malaga Bay is now known not to exceed 750 fathoms. These errors are noticed in no invidious spirit, but merely to prevent their perpetuation. Admiral Smyth doubtless made the very best use of the means at his disposal; but a far more satisfactory method has now entirely superseded that formerly adopted.

by a comparison of the diurnal averages of the surface-temperature of the Mediterranean with those of the Atlantic, that the latter are at least four or five degrees higher than the former, it may be fairly assumed that at least half the increase was due to the passage from the colder Atlantic water of the mid-channel into the warmer water of the Mediterranean basin, the temperature of the latter being even here somewhat reduced by the inflow of the former.—The *bottom*-temperature was found to be here 55°; and this corresponded closely with that which we had met with in the Strait (§ 32), while it was at least 5° higher than had been obtained at corresponding depths on the Atlantic side. Being desirous of determining the rate of its diminution, we took *serial* soundings at intervals of 10 fathoms down to 50, and then at 100 fathoms, with the following remarkable result:—

		°	°
Surface	....	74·5	
			diff. 5·2
10 fathoms	....	69·3	
			diff. 4·3
20 ,,	....	65·0	
			diff. 2·0
30 ,,	....	63·0	
			diff. 1·3
40 ,,	....	61·7	
			diff. 2·0
50 ,,	....	59·7	
			diff. 4·6
100 ,,	....	55·1	
			diff. 0·1
586 ,,	(bottom) ..	55·0	

Thus there was a fall of 9°·5 in the first 20 fathoms, of 5°·3 in the next 30 fathoms, and of 4°·6 in the next 50 fathoms; whilst from 100 fathoms to the bottom at 586 fathoms there was no further descent.

46. Whilst we were prosecuting these inquiries, we found ourselves surrounded—the surface of the Sea being extremely calm—by great numbers of the beautiful floating *Velellæ*, which are occasional visitors to our own Coast, accompanied by the *Porpitæ*, which are more exclusively restricted to warmer seas. With these was a great abundance of a small species of Firoloid (*Firoloïdea hyalina*, D. Chiaje?), about 0·4 inch in length, the extreme transparence of which enabled every part of its organization to be readily studied microscopically, its Nervous System being specially distinguishable. Of this very interesting *Heteropod*, a full description will be hereafter published by Dr. Carpenter.

47. The result obtained by our first Temperature-sounding in the Mediterranean was fully borne out by that of the Temperature-soundings taken during three subsequent days, which show an extraordinary uniformity of *bottom*-temperature at depths from 162 to 845 fathoms *:—

* This uniformity, as we have since learned, had been previously observed by Capt. Spratt, in his Soundings in the Eastern Basin of the Mediterranean; but owing (it seems probable) to the want of "protection" in his Thermometers, he had set the uniform temperature too high, namely 59°. (See his 'Travels and Researches in Crete,' vol. ii. Appendix II.)

Station. No.		Depth, in faths.	Surface-temp.	Bottom-temp.
			°	°
41	....	730	74·5	55·0
42	....	790	74·0	54·0
43	....	162	74·7	55·0
44	....	455	70·0	55·0
45	....	207	72·7	54·7
46	....	493	73·5	55·5
47	....	845	69·5	54·7

It will be observed that the surface-temperature varied between 69°·5 and 74°·5 ; and that whilst the highest temperatures were shown at Stations near the African Coast, the lowest presented itself between Cape de Gat and Cartagena. Now the Gibraltar inflow is very sensibly felt at Cape de Gat, where the current usually runs at the rate of a mile an hour; and of the strength of this current we had unpleasant experience. For on the 19th of August, as we were crossing from Station 46 towards the Spanish coast, we encountered a strong N.E. breeze, which, meeting the current, worked up a considerable swell; this prevented us from taking even a Temperature-sounding on that day, and gave our Ship a peculiar twisting or screwing movement, from which we were glad to escape by the subsidence of the breeze during the following night. During this day the Surface-temperature of the Sea came down from the average of 72°·2, which it had maintained on the 18th, to 66°·9. Had the weather been calm we might have attributed this reduction to the colder Gibraltar in-current; but as the average temperature of the Air also fell from 73°·8 to 69°·8, and as the strong N.E. breeze must have had a cooling effect upon the surface of the sea, we should have deemed it probable that the reduction of Surface-temperature was due at least as much to the latter as to the former of these causes, had it not been that a set of Serial soundings which we took at Station 47 showed that the reduction extended very far down, as will be apparent on comparing the following results with those given in § 45 :—

		° Fahr.
Surface	....	69·5
10 fathoms	....	59·0
20 ,,	....	57·5
30 ,,	....	56·5
40 ,,	....	55·7
50 ,,	....	55·3
100 ,,	....	54·7
845 ,, (bottom)	....	54·7

It will be seen hereafter that the observations made on our return voyage gave more distinct evidence of the cooling influence of the Gibraltar in-current (§ 86).

48. At most of these Stations we explored the bottom by means of the Dredge, with results much less profitable than we had anticipated. Except

near the Coast, on either side, where the ground was rocky and unequal, the bottom was found everywhere to consist of a tenacious mud, composed of a very fine yellowish sand mixed with a bluish clay,—the former predominating in some spots, the latter in others. Large quantities of this mud were laboriously sifted, often without yielding any thing save a few fragments of Shells, or a small number of *Foraminifera*; and in no instance was it found to contain any considerable number of living animals of any description. Our disappointment at this unexpected paucity of life was not small; and it was destined, as will hereafter appear, to continue through the whole of our Dredging-exploration of the deeper portions of the Mediterranean basin. The operation of Dredging in the shallower portions nearer shore was rendered difficult by the rocky nature of the bottom, on which the dredge continually "fouled;" and after the loss of two more dredges and a considerable quantity of rope, Capt. Calver came to the conclusion that the "tangles" only should be used where the inequality of the soundings indicated danger to the Dredge. Now the "tangles," whilst gathering Polyzoa, Echinoderms, Crustacea, and the smaller Corals, sometimes even better than the Dredge, pick up but few Shells; and hence our collection of Mollusca is altogether a scanty one. Nevertheless many of the types we did obtain were of considerable interest. Thus at Station 45, at a depth of 207 fathoms, we got *Turbo Romettensis*, Seguenza, MS. (Sicilian fossil); *Scalaria plicosa* (Sic. foss.); *Odostomia obliquata*, Ph.; *Philine*, two undescribed species; and an interesting Coral (*Dendrophyllia corrugosa*).

49. On the afternoon of Saturday, Aug. 20th, we anchored in Cartagena Bay, in which we got *Taranis Mörchi*, Malm (northern), and *Pleurotoma decussata*, Ph. (Sic. and Cor. Cr. foss.). We left this harbour on the following Monday morning, and proceeded to a point (Station 48) at which we expected to find deeper water than any we had previously sounded in this year's work. Bottom was here struck at 1328 fathoms; and its temperature, 54°·7, proved still conformable to the uniform standard previously observed. The density of the water was not as great as we had found it on a shallower bed, its Specific Gravity being 1·0282, and its proportion of Chlorine 21·32. The specimen of the bottom brought up by the Sounding-apparatus was not promising; and when the dredge was hauled in, filled with stiff mud, but without any sign of Animal life, we experienced the truth of the beatitude "Blessed are they who expect nothing, for they shall not be disappointed." Large quantities of this mud were washed and sifted without yielding more than a few comminuted fragments of shell; and we were reluctantly driven to the conclusion that there was "nothing in it." The like result attended the exploration we made the next day at another Station (49), where we found the depth to be 1412 fathoms, and the Temperature and Density of the bottom-water to be almost exactly the same as at the last Station. We then steamed towards the Algerine Coast, and took a dredging in shallow water 5–51 fathoms, which gave us a few Shells of considerable interest:—*Venus multilamella*, Lamarck (Monte

Mario foss.); *Solarium pseudoperspectivum*, Brocchi (Sic. foss.); *Mitra zonata*, Marryat (Sic. foss.); *Mytilus incurvatus*, Ph. (Sic. foss.); *Sportella Cailleti*, Conti (Monte Mario foss.).

50. During the night we again steamed out into Deep water, and on the morning of Aug. 26th found at Station 45 a depth of 1415 fathoms, with a bottom-temperature of 54°·7. The Density of the Bottom-water was almost exactly the same as that of the two previous deep-water samples. Our dredging was here more successful, the following species of Mollusca being obtained:—*Nucula*, sp. n. (*quadrata*); *N. pumila*, Asbjörnsen (northern); *Leda*, sp. n. (Portuguese also); *Pecchiolia granulata*, Seg. (Sic. foss.); *Hela tenella*, Jeffr. (northern, and Sic. foss.); *Trochus gemmulatus*, Ph. (Sic. foss.); *Rissoa subsoluta*, Aradas (Sic. foss.); *Natica affinis*, Gmelin (northern, and Sic. foss.); *Trophon multilamellosus*, Ph. (Sic. foss.); *Nassa prismatica*, Br. (Sic. foss.); *Columbella haliæeti*, Jeffr. (northern, and Sic. foss.), ?=*Buccinum acuticostatum*, Ph.; *Pleurotoma carinata*, Cristofori and Jan (northern, and Sic. foss.); *P. torquata*, Ph. (Sic. foss.); *P. decussata*, Ph. (Sic. foss.); *Planorbis glaber*, Jeffr. (fresh-water!); *Spirialis physoïdes*, Forbes, =*S. recurvirostra*, A. Costa.

51. Directing our course again towards the Algerine Coast, we kept nearly parallel to it during the greater part of the next day, occasionally sweeping the bottom with the "tangles," which gave us abundance of Polyzoa, Echinoderms, &c. of well known types, without any specimens of novel or peculiar interest, except (at Station 50, in 7–51 fathoms) a specimen of *Trochus biangulatus*, Eichwald, *fide* Hornes, =*T. ditropis*, S. Wood, a Miocene and Coralline Crag shell. We reached Algiers on the afternoon of the 26th; and as it was necessary to take in coal, we remained in harbour until the 29th, when we resumed our easterly course, still keeping near the Coast. The weather now began to be oppressively hot, the Surface-temperature of the Sea rising to 76° or 78°, and that of the Air being often several degrees higher. Wishing to see what would be the point at which the effect of this extreme superheating would cease to manifest itself, we took a set of Serial soundings at Station 53, with the following result, which we incline to consider typical of the condition of the proper Surface-water of the Mediterranean in the Summer season:—

	° Fahr.
Surface	77
5 fathoms	76
10 ,,	71
20 ,,	61·5
30 ,,	60
40 ,,	57·3
50 ,,	56·7
100 ,,	55·5

Thus the amount of heat lost in the first 20 fathoms is no less than 15°·5; and as much as 9°·5 of this loss shows itself between 10 and 20 fathoms.

Somewhat nearer the shore, at a depth of from 40 to 80 fathoms, we got the following Mollusca:—*Pecchiolia,* sp. n. (Sic. foss.); *Solarium pseudo-perspectivum* (Sic. foss.); *Nassa semistriata,* Brocchi (Sic. foss., and Coralline and Red Crag)=*N. labiosa,* S. Wood, =*N. trifasciata,* H. Adams; and *Bulla,* sp. n.

52. Again proceeding into deep water we perseveringly explored the bottom with the Dredge; and from a bottom of 1508 fathoms we brought up some hundredweights of the same barren mud as had previously given so much trouble and to so little profit. The sieve and the washing-tub again returned for answer "barren all." Disappointing as this negative result was to us as Zoologists, there are aspects under which it may be viewed that may give it no small value to Geologists. On these, however, we can more fittingly enlarge hereafter (§ 102). Once more, shifting our ground a few miles, we put down our dredge in 1456 fathoms' water, and brought it up loaded with a similar profitless freight.

53. We now determined to keep closer to the Shore, and worked for several days along the African Coast, for the most part using the "tangles," the ground being too rocky for the dredge. Here we came upon a small fleet of Coral-fishers; and were not a little interested in finding that they employed "tangles" similar to our own as their most effective method of collecting. We swept the shore with these very assiduously, usually between 50 and 100 fathoms; and although we obtained Polyzoa, Echinoderms, and Corals in considerable abundance, there were not many of special interest. We may note, however, that several of the *Polyzoa* which occurred in the region in which the Red Coral is found, had, when fresh, a red colour nearly as brilliant as that by which it is characterized; but this colour, in the Polyzoa, was quite evanescent. At Station 55 we obtained the following Mollusca:—*Leda acuminata,* Jeffr. (Sic. foss.), *Dentalium abyssorum,* Sars (northern), and *Turritella subangulata,* Brocchi (Sic. foss.).

54. The extreme heat of the weather having produced an exhausting effect upon our crew, especially on the engineers and stokers, Capt. Calver considered it desirable to give them rest; and we accordingly made for the Bay of Tunis, which we reached at mid-day on Saturday, Sept. 3rd. The town itself is situated at the head of a shallow lagoon or salt-lake, that communicates with the sea by a narrow channel; and at this entrance there is a small sea-port named the Goletta, having a basin for vessels of moderate size. The lake, although about six miles long, has only from six to seven feet of water at its deepest part; and when the water is unusually low, a small Steamer, which plies between the Goletta and Tunis, is not always able to run, as happened at the time of our visit. Owing to the great evaporation, and the absence of any stream of fresh water, the water of this lake is usually very salt; but when heavy rains fall, the level is considerably raised, and the saltness is diminished. Thus the condition of this lake in regard to that of the sea outside is sometimes that of the Mediterranean in regard to that of the Atlantic (§ 122), and some-

times that of the Baltic towards the German Ocean (§ 123); and we would suggest whether it might not be possible, through our Consulate (which has an office at the Goletta), to have a regular series of observations made upon the relative densities of the water of the lake and that of the sea, and upon the direction of the upper and under current in the channel of communication between them, that might furnish valuable data for the complete elucidation of the subject of currents occasioned by excess of evaporation. We availed ourselves of this short rest to visit the town of Tunis, which, for the most part, retains its genuine Moorish characters; as well as the ruins of Carthage, a few miles off, the most remarkable part of which consists of a series of immense reservoirs for water, supplied by an aqueduct that brought it from a range of mountains at no great distance, from which also the modern town of Tunis is supplied.

55. Quitting Tunis at mid-day on Tuesday Sept. 6, we resumed our Dredging-explorations on more productive ground,—the shallow between the Eastern and Western basins of the Mediterranean, that extends between the African coast and Sicily, and is termed the "Adventure Bank," from having been first discovered by Admiral Smyth when surveying in H.M.S. 'Adventure.' The depths here range from about 30 to 250 fathoms. When passing Cape Bon, we fell in with another small fleet of Italian Coral-fishers; and were surprised at the large outlay incurred for such small returns as they seemed to be obtaining. We here found, between 25 and 85 fathoms, the following species of MOLLUSCA: *Trochus suturalis*, Ph. (Sic. foss.); *Xenophora crispa*, König (Sic. foss.); *Cylichna striatula*, Forb. (Sic. foss.); *C. ovulata*, Brocchi (Sic. foss.). And seven miles off the point called Rinaldo's Chair, between 60 and 160 fathoms, we obtained *Tellina compressa*, Brocchi (Sic. foss.), a species possessing the following synonyms—*Tellina striatula*, Calcara; *T. strigilata*, Ph.; *Psammobia Weinkauffi*, Crosse; and *Angulus Macandrei*, Sowerby: also an interesting ANNELID, *Praxilla prætermissa*, Malmgren (northern). Here, again, we brought up a great abundance of *Polyzoa*; and many of these have proved of great interest. One, in particular, of a beautiful, very open reticular plan of growth, is the type of a new genus, of which another species had been previously obtained by Mr. Busk from the Canary Islands, and which he will describe under the name of *Climacopora*. Many of the species obtained had been previously known only as Tertiary Fossils. A complete account of them will be published by Mr. Busk hereafter. Abundance of Shells were here found; among them we obtained a considerable number of living specimens of *Megerlia truncata*, including a whole series in various stages of growth, the youngest of which presented a very remarkable character,—a set of *setæ* projecting from the margin of the shell, the length of which exceeded its own long diameter. Among other species of interest were:—*Kellia*, sp. n. (Sic. foss.); *Gadinia excentrica*, Tiberi; *Rissoa*, sp. n.; *Scalaria frondosa*, J. Sow. (Sic.&Cor.Cr.foss.); *Odostomia unifasciata*, Forbes; *Pyramidella plicosa*, Bronn (Sic. & Cor. Cr. foss.)=*P. læviuscula*, S. Wood; and *Actæon pu-*

sillus, Forb. (Sic. foss.). Among the *Annelida* was an interesting Northern form, *Hyalinæcia tubicola,* Müller. The *Echinodermata* were in considerable abundance, but were mostly well-known Mediterranean types. The *Cidaris hystrix* was especially frequent; and a comparison of the series of specimens obtained in this and the preceding Cruise, with those obtained last year in the Northern area, has enabled Prof. Wyville Thomson to satisfy himself that *C. hystrix, C. papillata,* and *C. affinis* are specifically identical. The *Corals* found on the Adventure Bank have proved peculiarly interesting; and will be the subject of a special Report by Prof. Duncan. Among the *Hydrozoa* were two undescribed species of *Aglaophenia.* Although no new *Foraminifera* here presented themselves, yet it was very interesting to obtain (as we had previously done at several points on the African coast) specimens of the beautiful *Orbitolites tenuissimus* first discovered last year in the Atlantic (Report, § 36), of which we had ventured to predicate the existence in the Mediterranean from having discovered an extremely minute fragment of it in one of Captain Spratt's Ægean dredgings; also peculiarly large and elaborately finished specimens of the great Nautiloid *Lituola,* first met with last year, the "test" of which is built up of sand-grains united by a ferruginous cement, with passages extending from the principal chambers into their walls, forming what is known as the "labyrinthic structure," of which the greatest development is found in the two gigantic Fossil types (*Parkeria* and *Loftusia*) recently described by Dr. Carpenter and Mr. H. Brady*.

56. This part of our work having brought us to the neighbourhood of the Island of Pantellaria, we landed on it with the view of visiting, if possible, a cavern which had the reputation of being "of icy coldness." As we found, however, that a whole day's delay would be involved, we gave up the idea; and we afterwards obtained elsewhere the information we desired (§ 89).—The continuance of the very hot weather having brought a large part of our Crew to a state of such exhaustion as to render a continuation of our operations undesirable, Captain Calver considered it expedient to proceed to Malta without further delay; and we anchored in the Harbour of Valetta on the morning of Saturday, Sept. 10th. Here we found it necessary to remain for ten days, the illness of our Chief Engineer, which we at first hoped might be only temporary, proving sufficiently serious to require that a substitute should be found for him. Our time was passed very pleasantly in visits to the various objects of interest in which the Island abounds, and in the enjoyment of the kind hospitality of His Excellency the Governor, Vice-Admiral Key, and other Officers.—The time was too short for any careful examination of the Geology of the Island; but one point which struck us as of special interest in relation to the deposit at present forming on the Mediterranean bottom will be specially noticed hereafter (§ 102).

57. As the instructions which we received at Malta required us to

* Philosophical Transactions, 1869.

proceed homewards without unnecessary delay, and as Capt. Calver was desirous of avoiding, if possible, the necessity of going into port for coal between Malta and Gibraltar, we found ourselves obliged to relinquish the hope we had entertained of being able to resume our Dredging-explorations in deep water along a different line on our return voyage. But, desiring to gain what addition we could to the information already acquired respecting the Physical condition of the Mediterranean, we arranged so to shape our course on leaving Malta as to enable us (1) to obtain a deep Sounding in the Eastern basin, and (2) to ascertain the Bottom-temperature on an area of Volcanic activity.

58. Quitting Valetta Harbour at mid-day on September 20th, we steered in a N.E. direction towards a point about 70 miles distant, at which a depth of 1700 fathoms was marked on the Chart. This we reached early the next morning (Station 60); and a Sounding being taken, 1743 fathoms of line ran out. As this was the greatest depth we had anywhere met with in the Mediterranean, and as the Basin in which the Sounding was taken is cut off by the shallows between Sicily and Tunis from all but superficial communication with the Western basin, we watched the heaving in of the Sounding-apparatus and its accompaniments with no little interest. The Thermometers recorded a Temperature of 56°, which was one degree *higher* than that which we had met with in our two deepest Soundings (1456 and 1508 fathoms) in the Western basin. The sample of the bottom brought up in the tube of the Sounding-apparatus indicated the prevalence of a yellowish clayey deposit so similar to that which had elsewhere proved so disappointing, that we could not feel justified in pressing Capt. Calver for the sacrifice of nearly a whole day, which would have been required for a single cast of the Dredge at this depth. The specimen of Bottom-water brought up by our Water-bottle surprised us by its very small excess of Density above the Surface-water; the Specific Gravity of the former being only 1·0283, whilst that of the latter was 1·0281; and the proportion of Chlorine per 1000 being 21·08 in the former, whilst that of the latter was 20·77. The Surface-water being here *more* dense than the average, the Bottom-water was *less* dense—a result which a good deal surprised us at the time, but which subsequent comparison with the densities of specimens taken from the greatest depths we had sounded in the Western basin (§ 93) showed to be by no means exceptional; and when we came to reason out the mode in which surface-evaporation may be presumed to operate in augmenting the density of the water beneath, we found it to be quite in accordance with *à priori* probability, that the *deepest* water should show the *least* excess of density above the water at its surface (§ 94).

59. Having thus satisfied ourselves, so far as we could do by a single set of observations, that the Physical conditions which we had found to prevail in the Western basin of the Mediterranean present themselves also in the Eastern, we steered for the Coast of Sicily; and in a few hours

came in sight of Syracuse, with the lofty mass of Etna as a magnificent background in the remote distance. The clouds which lay upon its summit during the earlier part of the day gradually dispersed as we approached it, so that we could distinctly trace the outline of its cone, save where this was obscured by a constantly shifting semitransparent cloud. Whether this was a light smoke given off from the crater, or a film of vapour condensed by the contact of a current of warm moist air with the colder surface of the mountain-summit, we were unable to distinguish, though we watched it with great interest during the whole afternoon.—We steamed quietly along the Sicilian coast during the night, so that sunrise the next morning found us in the narrowest part of the Strait of Messina, between Messina and Reggio; and we shall not easily forget the beauty of the spectacle we then beheld on either shore. Passing through the once-dreaded Charybdis, the dangers of which are rather poetical than real, and leaving on our right the picturesque castle-crowned rock of Scylla, we passed out of the "Faro," which narrows at its northernmost extremity to about $3\frac{1}{2}$ miles, into the open sea to the North of Sicily, studded by the Lipari Isles, and steered direct for Stromboli, stopping at 10 A.M. to take a Sounding (Station 61). This gave us a depth of 392 fathoms, and a Bottom-temperature of 55°·7, which afforded no indication of unusual elevation. Here again we found the Density of the Bottom-water scarcely in excess of that of the Surface-water; and it was even lower than that of the Surface-water in another Sounding taken somewhat further on (Station 62), and at the depth of 730 fathoms, which gave a Bottom-temperature of 55°·3.

	Sp. Grav.	Chlorine.
Surface..................	1·0281	21·32
Bottom, 392 fathoms	1·0282	21·36
Bottom, 730 fathoms	1·0280	21·22

60. This result, again, surprised us much at the time; but we are now inclined to attribute it to the decrease of surface-evaporation consequent upon the marked decrease in the heating-power of the Sun, which showed itself in the change of the relative Temperatures of the Sea and Air; for whilst, for some days before we put into Malta, the Surface-temperature of the Sea had ranged between 76° and 78°, and the Temperature of the Air had been usually about 1° *higher*, we now found that while the Surface-temperature of the Sea ranged between 73°·6 and 76°·6, the Temperature of the Air was between 2° and 4° *lower*. This difference continued to show itself nearly all the way to Gibraltar; the daily averages of the Surface-temperature of the Sea ranging between 73°·1 and 75°·6, whilst those of the temperature of the Air ranged between 68°·5 and 72°. We now approached the rugged cone of Stromboli, from the summit of which there was constantly issuing,—as has been the case since the time when the neighbouring island of Hiera was fabled to be the workshop of Vulcan,—a cloud

of smoke, indicative of active changes in the molten depths beneath. Of this activity, however, we had found no special indication in the Temperature-soundings taken nearest to the island. Whether the *general prevalence* in the neighbourhood of Sicily of a Bottom-temperature averaging about a degree above that of the Western part of the Mediterranean is due to Subterranean heat, is a question which can only be determined by a larger number of observations than we had the opportunity of making. As we neared Stromboli, we were much struck with the height to which the energetic industry of its inhabitants had carried the vine-cultivation all round the cone, save on two slopes looking N.W. and S.E., over one or other of which there is a continual discharge of volcanic dust and ashes. Although no flames were visible during daylight, we could distinctly perceive occasional flashes as night came on.—Our course was now laid straight for Cape de Gat, which we passed on the 27th of September, arriving at Gibraltar on the evening of the 28th. The only Scientific observations which we had the opportunity of making during this part of our voyage were confirmatory of those which we had made at the commencement of our Mediterranean Cruise, as to the lower Temperature and inferior Density of the Surface-water, both which we attribute to the inflow from the Atlantic. (See §§ 86, 92).

61. Having taken in at Gibraltar as much coal as we could carry, we left the harbour at 9 A.M. on the 30th Sept., and proceeded at once towards the scene of our previous observations. We thought it worth while, however, to take a Sounding in our way towards this, near the 100-fathom line (Station 63), for the sake of ascertaining the Temperature and Specific Gravity of the bottom-water. The depth was found to be 181 fathoms, showing that the slope from the shallow to the deep portion of the channel is here very rapid. The bottom-temperature was 54°·7, that of the surface being 68°; and the Specific Gravity of the bottom-water was 1·0280, that of the surface being 1·0271. This bottom-water thus agreed closely in both particulars with that of the *deep* mid-channel, as ascertained in our first set of observations (§ 34), which were afterwards confirmed by our second. We then steamed out to a point (Station 64) nearly identical with that from which our previous investigations had been carried on; and commenced our work with a Temperature-sounding. The surface-temperature (65°·6) proved to be here *less* by 2°·4 than it had been found to be at Station 63; and this although it was taken an hour later in the forenoon, when an increase might have been expected. It thus corresponded closely with what had been previously found to be the average temperature of the Strait in mid-channel, both during the first approach to Gibraltar from the westwards (§ 30), and during our own experiments at the commencement of the Mediterranean Cruise (§ 32); and the continuation of the like observations during the remainder of the day and ensuing night (§ 65) gave the same remarkable result, the *rationale* of which will be considered hereafter (§ 74). The depth was somewhat less than at the neighbouring Station 39,

being 460 fathoms instead of 517; but the bottom-temperature was a little lower, being 54°·7 instead of 55°·5. The respective Specific Gravities of the Surface- and Bottom-waters, and of that of the Intermediate stratum of 250 fathoms, were found to coincide almost exactly with those previously determined, as the following comparative statement shows:—

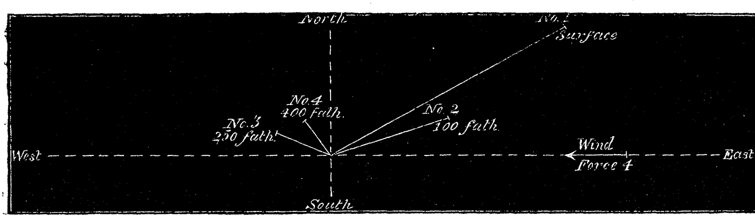
	Specific Gravity. Station 39.	Specific Gravity. Station 64.
Surface	1027·1	1027·1
250 fathoms	1029·3	1029·2
Bottom	1028·1	1028·3

Now the density of the *bottom*-water here corresponds so exactly with that which prevails over the *deeper* bottom of the Western basin of the Mediterranean, whilst it so considerably exceeds that of the *bottom*- as well as of the *surface*-water of the Atlantic, that we cannot fail to recognize it as belonging to the Mediterranean basin; so that, if it has any motion at all, we should expect that motion to be from east to west. Still more certainly may this be affirmed of the *intermediate* stratum, the density of which corresponds with that of the bottom-water of the *shallower* part of the Mediterranean basin; the greatest depth (586 fathoms) at which such water was obtained being at Station 40, the nearest point to the Strait from which a specimen of bottom-water was obtained (§ 43). And it may be further predicated that a stratum of water of a density of 1029·3 could not overlie water of the density of 1028·1, unless it *moved over* the stratum below,—that is, unless (1) the two strata were moving in opposite directions, or (2) were moving at different rates in the same direction, or (3) the upper stratum were in motion in either direction, and the lower stratum were stationary. It will presently appear that the second of these conditions is the one which obtains in the present case.

62. We now proceeded to repeat our experiments with the "current-drag," with the view of obtaining, if possible, unequivocal evidence of the existence of that Westerly undercurrent which so many considerations combined to render probable.—The direction of the Wind during this set of experiments was from the East, or opposite to that of the surface-current; and its force (3 to 4) was sufficient, by its *meeting* the current, to produce a considerable swell, which necessitated the employment of a larger boat, and rendered it unsafe to allow her to drift without men. The sectional area of the boat was therefore greater than on the former occasion, giving the in-current a stronger hold upon her; but, on the other hand, the surface she presented to the wind was also greater; and as this acted in the opposite direction, the latter increase might be considered to neutralize the former, or even rather to exceed it, so as to render the boat more capable of being carried westwards by the "current-drag," if this should be acted on by an outward undercurrent. The rate of surface-movement was tested as before (§ 36), and proved to be 1·823 mile per hour, its direction

being N.E. by E. ½ E. This was a retardation of more than a mile per hour, as compared with the former observation; and that it was not attributable to the mere surface-action of the easterly wind, was clear from the result of the next observation, which showed that the retardation extended to a depth far below the influence of surface-action.—The "current-drag" having been lowered to 100 fathoms' depth, the drift of the boat was reduced to 0·857 mile per hour, or *less than half* its surface-drift; its direction was nearly the same as that of the surface-current, viz. E. by N. ½ N. The "current-drag" was then lowered to a depth of 250 fathoms; and in a short time the boat was seen to be carried along by it in a direction (W.N.W.) *almost exactly opposite* to that of the middle *in*-current of the Strait. The rate of outward movement of the boat was 0·400 mile per

Station 64.



Rate (per hour) and Direction of Movement of Surface-float and of Current-drag at different Depths; with Force and Direction of Wind.

hour; but from the considerations formerly stated (§ 39), it is clear that the actual rate of the undercurrent must have exceeded that of the boat on the surface.—The "current-drag" was then lowered down to a depth of 400 fathoms; and again the boat was carried along in nearly the same direction as in the previous experiments, namely N.W. ½ N.; but more slowly, its rate of movement being 0·300 mile per hour.

63. Thus, then, our previous deductions were now justified by a *conclusive proof* that there was at this time a return-current in the mid-channel of this *narrowest* part of the Strait, from the Mediterranean towards the Atlantic, flowing beneath the constant surface-stream from the Atlantic into the Mediterranean; and it will be shown hereafter (§ 115), by a comparison of all the results of our observations, that a strong presumption may be fairly raised for the *constant* existence of such a return-current, though its force and amount are liable to variation.

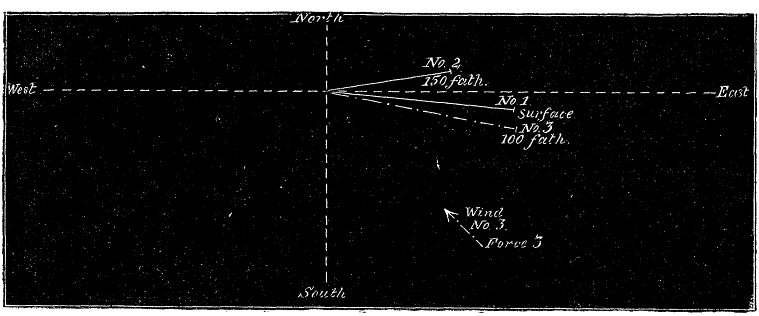
64. As the determination of the boundaries of this return-current, and of the amount and conditions of its variation, could only be effected by multiplied simultaneous observations at different points, with ample license as to time, neither of which fell within the scope of the present Expedition, we were obliged to content ourselves, as regards this locality, with what we had found ourselves able to accomplish; and at the conclusion of this day's work we proceeded westwards under easy steam, so as to be able

to resume our experiments the next morning in the *shallowest* part of the Strait.

65. The average Surface-temperature of the Mid-stream during our outward passage through the Strait proved to be 66°, thus corresponding exactly with what we had found it to be on our inward passage seven weeks previously (§ 30). This depression, as compared with the surface-temperature of the Strait itself nearer the shore, both north and south, and with the temperature of the Mediterranean to the eastward and that of the Atlantic to the westward, is extremely remarkable. We shall hereafter inquire how it is to be explained (§ 74).

66. The breadth of the Channel between Capes Spartel and Trafalgar (Chart II.) is about 23 nautical or $26\frac{1}{2}$ statute miles. Its northern half is much shallower than the southern, as is shown in Section B B; the 100-fathom line off the Spanish coast running at about twelve miles' distance from Cape Trafalgar, whilst along the African coast it keeps much nearer the shore, being at only two miles' distance from Cape Spartel. Between these two lines, the greatest depth marked in the Chart is 194 fathoms; and this occurs off Cape Spartel, at less than a mile from the 100-fathom line. Between this and the opposite border of the deeper channel, the depths vary from 130 to 180 fathoms; the abruptness of the differences at neighbouring points indicating a rocky bottom, of which we soon had unpleasant experience.

Stations 65, 66.



Rate (per hour) and Direction of Movement of Surface-float and of Current-drag at different Depths; with Force and Direction of Wind in No. 3. (No Wind in Nos. 1, 2.)

67. We commenced our observations on the morning of Oct. 1st at the point of greatest depth (Station 65). The temperature of the surface at 6 A.M. was only 63°, which was at least eight degrees lower than the average temperature at that hour within the Mediterranean. The bottom-temperature at 198 fathoms was 54°·5, and the Specific Gravity of the bottom-water was 1028·2. The coincidence both in temperature and Sp. Gr. with the bottom-water at Station 64 was thus very close. The place of

the Ship having been determined by angles taken with the shore, the rate of the surface-movement was tested as on former occasions, and was found to be 1·277 mile per hour, its direction being E. ½ S. The "current-drag" was then sunk to 150 fathoms, the greatest depth at which it was thought safe to use it; and the boat from which it was suspended moved E. ¾ N. at the rate of 0·840 mile per hour. This observation indicated a very considerable retardation in the rate of *in*flow, but gave no evidence of an *out*flow. It did not, however, negative the inference deducible from the Temperature, and still more from the Specific Gravity, of the water beneath, that an outflow takes place in that lowest stratum which we could not test by the "current-drag."

68. We then steamed across the deep channel towards the Spanish side; and passing a bank of 45 fathoms which rises near its middle, we sounded again at Station 66, about six miles to the northward of Station 65. The surface-temperature at 9 A.M. was here found to have risen to 69°; and since not more than half this increase could be attributed, according to our general experience, to the increase of direct solar radiation at this period of the day, the cause of the additional elevation has to be sought elsewhere (§ 78). The length of sounding-line run out was 147 fathoms; but on attempting to reel it in, the lead was found to have fixed itself between rocks; and all Capt. Calver's skill in the management of his ship proved inadequate to free it. As we were thus anchored by our sounding-line, it was requisite to set *ourselves* free, by putting a breaking strain upon it; and we thus lost, with the lead, one of our Water-bottles, and a pair of Thermometers, one of which was specially valued by us as having been used throughout the 'Porcupine' Expedition of 1869, in which the Temperature-soundings had proved of peculiar importance. The "current-drag" was here let down to 100 fathoms; and the boat from which it was suspended moved along in the direction of the surface-current, and at the rate of 1·280 mile per hour, which was almost precisely that of the surface-current in the previous observation.

69. Deeming it important to obtain the Temperature and Specific Gravity of the bottom-water on the Spanish side of the deeper portion of the channel, we slightly shifted our ground, and again let down our lead, with Thermometers and Water-bottle, at Station 67, where the depth proved to be 188 fathoms. On beginning to reel in the line, we found the lead to have anchored as before, and for some time feared that we should sustain a second loss of the Water-bottle and Thermometers attached to it. The means taken by Capt. Calver for its extrication, however, proved on this occasion successful; and we had the satisfaction of seeing the whole apparatus safely brought up,—the lead bearing evident marks of having been jammed between rocks and then violently strained. The Temperature of the bottom proved to be 55°·3, that of the surface being 73°; and the Specific Gravity of the bottom-water was 1028·1, that of the surface being 1026·8. Here again, therefore, the evidence afforded by the Tem-

perature and Specific Gravity of the *bottom*-water was conclusive as to its Mediterranean character. Its Density corresponded rather with that of the *bottom*-water than with that of the *intermediate* stratum, at the opposite end of the Strait; but the more rapid Westerly motion of the latter (§ 62) would seem to indicate that the water which here flows over the "ridge" is derived from it, rather than from the deeper layer, and that its diminution in density is due to the dilution it sustains in its course. In either case the denser Mediterranean water discharged by this undercurrent must flow *up-hill*; but the incline is so gradual that a very small force, if constantly sustained, would suffice to produce the elevation needed to carry it over the ridge.

70. Whilst we were prosecuting these inquiries, our attention was attracted by the long chains of *Aggregate Salpæ* which were floating close to the Ship near the surface of the very calm sea. We were able to collect four or five different species of these, and to submit them, during life, to Microscopic examination. The reversal of the direction of the Circulation took place in all at more regular intervals than we have usually found to be the case in the Compound Ascidians; and we were able to distinguish an unmistakable rudimentary *eye*, which had not, we believe, been previously noticed. We hope to be able hereafter, by the detailed study of these specimens, to make some additions to the knowledge previously acquired of this very interesting group.—As the nature of the bottom put it out of the question to attempt to dredge on this ridge, our only means of investigating its Zoology lay in the use of the "hempen tangles." A "sweep" taken with these brought up a few Echinoderms and Polyzoa of no special interest; but with these there was a new species of *Amphihelia*, allied to *A. oculata*.

71. We now took our final leave of the Mediterranean basin with mingled feelings of disappointment and satisfaction. The Zoological results of our Cruise had been by no means equal to our expectations; but, on the other hand, we could console ourselves with the belief that our determination of the peculiar Physical conditions of this great Inland Sea, and in particular our elucidation of the mystery of the Gibraltar current, would be fairly regarded as a success; and we venture to think that this will be admitted by such as may follow us through the discussion of General Results to which we shall presently proceed.

72. As Capt. Calver considered himself bound not to make any unnecessary delay in returning homewards, and to take every advantage of the continuance of the fair weather and favourable breeze which we enjoyed during nearly the whole remainder of our voyage, we were reluctantly compelled to give up the idea of prosecuting any further researches in the Deep Sea; and devoted ourselves to the examination of the specimens previously collected, and to the correlation of our Temperature and other results,—specially directing our attention, however, to the Surface-temperature of the *embouchure* of the Strait, with the view of ascertaining whether a sudden *fall* would be observable on quitting it, corresponding to the *rise* which had

been noticed on the outward voyage on entering it (§ 30). This change proved to be very decided. As we kept along the Southern Coast of Portugal towards Cape St. Vincent, the Surface-temperature averaged 73°·5. At 6 P.M. we were turning the corner of the Cape, and found the Surface-temperature 72°·5; and at 8 P.M., when we were fairly in the Atlantic, we found that the Surface-temperature had fallen to 69°, thus showing a difference of 4°·5. On the following day, when we were off Lisbon, the Surface-temperature was 69°·5; and it gradually diminished as we proceeded Northwards from that point.—Although the season of the year led us to expect a rough passage across the Bay of Biscay, the weather continued remarkably fine until we reached the "Chops of the Channel," where we fell in with a rather fresh breeze; this did not interfere, however, with our anchoring at Cowes on the afternoon of the next day (Oct. 8th), after an absence of just two months, during which a greater number of most important Public events had occurred than had ever before been crowded within so short a period.

GENERAL RESULTS.

Temperature and Composition of Atlantic Water.

[*For this portion of the Report Dr. Carpenter is alone responsible.*]

73. *Surface-Temperature.*—The Temperature of the surface-water at the Chops of the Channel (Stations 1–9) averaged 62° for five days; and it rose gradually in conformity with the Southing, until at Cape St. Vincent it stood at 69°. The Temperature of the *Air*, which averaged 63°·4 in the former locality, rose to about 69° in the latter; but it is specially noteworthy that whilst, as we crossed the Bay of Biscay and drew southwards along the coasts of Spain and Portugal, the temperature of the Air was almost always higher by from 2° to 5° than that of the Sea, this difference ceased to show itself as we neared Cape St. Vincent, and was even replaced by a slight difference in the contrary direction. The excess in the Surface-temperature of the Sea above the temperature of the Air became still more marked after we had passed the Cape, and had changed our course to the East; a *sudden rise* of from 2° to 4° then showing itself in the former, whilst the latter did not rise by more than half that amount. Thus on July 30, between Stations 27 and 28, on our way to Cadiz, in about Lat. 36½° N. and Long. 7½° W., the surface-temperature of the Sea exceeded 74°, whilst the temperature of the Air was only 72°. The like condition showed itself after leaving Cadiz, on August 2, between Stations 29 and 30; the surface-temperature of the Sea being 73°·2, whilst the temperature of the Air was 71°·4. That this excess did not depend upon a reduction of evaporation, consequent upon a peculiarly damp condition of the atmosphere, appeared from the fact that the Wet-bulb thermometer during this period stood at from 3° to 4° below the Dry a difference fully equal to

the general average of our observations.—Having thence crossed the *embouchure* of the Strait of Gibraltar, so as to approach the coast of Africa, the three following days were passed in Latitudes averaging about a degree further *south* than those in which the previous observations had been noted ; yet the surface-temperature of the Sea then *fell* again to an average of 72°, whilst that of the Air averaged 73°·7, thus nearly restorin gthe usual ratio between the two.—It was not a little perplexing to find, when we had fairly entered the Strait and were proceeding along the *mid-channel* towards Gibraltar, that the surface-temperature of the Sea *fell* still further to 66°·4, whilst the temperature of the Air *rose* to 76°·6, thus showing the then unprecedented difference of 10°·2 between the two.

74. These remarkable phenomena caused us to give particular attention to the Surface-temperature in the *mid-stream* of the Strait, and on the northern side of its *embouchure*, on our return voyage ; when our first series of observations derived full confirmation from another series taken with the greatest care nearly two months afterwards. For when we left Gibraltar Harbour on the morning of September 30th, we found, on proceeding into the mid-stream, that the surface-temperature *fell* from 70°·7 to 65°·6, although the latter observation was made towards noon ; that it remained at nearly the same point through the remainder of that day and the succeeding night, during which we were slowly proceeding eastwards,—still in the mid-current ; and that it stood as low as 63° at six o'clock on the following morning (Oct. 1), when we had reached Station 65, in the deepest part of the channel over the ridge not far from the African coast. Having thence moved towards the Spanish coast, we found the surface-temperature at Station 66 to have risen to 69° ; and a little further, at Station 67, it was found to have risen to 73°.—These observations make it clear that in the line of the strongest surface-*in*set, the temperature of the current is *several degrees lower* than that of the surface-water of the Atlantic from which it is directly derived ; and the fact would seem to indicate either that the water of which this current consists is drawn from a part of the Atlantic at least as far north as Lisbon, or (which may be thought more probable) that it is derived from a stratum of the neighbouring ocean *somewhat beneath the surface*, so as to have received less of the solar superheating than the actual surface-water.—It would be a matter of much interest to trace this colder current to its source, and thus to ascertain how it makes its way through a sea at least five degrees warmer than itself.

75. Our second series of observations upon the Surface-temperature of the Northern side of the wide *embouchure* of the Strait were also quite confirmatory of the inference to which the first seemed to point,—that there is a *surface-outflow* of Mediterranean water along the Spanish coast, by which the Temperature is kept up above the ordinary standard of Atlantic water in that latitude ; for during the remainder of Oct. 1, the following night, and the greater part of the next day, the surface-temperature was between 70° and 72°·5, being a degree or two *higher* than the temperature

of the Air: at 4 P.M. it was 73°·5; at 6 P.M., when we were passing Cape St. Vincent, it was 72°·5; and at 8 P.M., when we were fairly in the Atlantic, it was at 69°. The average of the next two days, while we were proceeding steadily Northwards, was maintained at nearly the same point; and the surface-temperature of the Sea was now pretty constantly *lower* than that of the Air.

76. The most probable explanation of this excess seems to lie in the fact that, besides the mid-current almost invariably setting eastwards, there are two lateral streams, of which the direction is sometimes reversed under tidal influences (§ 106); and that warmer water from the Mediterranean basin thus finds its way outwards, chiefly along the Spanish shore. —That the surface *in*draught is greatest on the African side of the Strait, and that the surface *out*flow is greatest on the Spanish side, is, we understand, a fact well known to those who are in the habit of navigating it, though we do not find it mentioned in the 'Sailing Directions;' and this is just what our observations of surface-temperature in the *embouchure* of the Strait would lead us to infer.

77. It is a circumstance worthy of remark, that an abnormally low temperature showed itself during the whole of our first stay in Gibraltar Bay, from Aug. 7 to Aug. 14; the surface-temperature of the Water ranging between 64°·1 and 65°·6,—being apparently that of the mid-strait to the eastward,—whilst the temperature of the Air ranged between 72°·9 and 77°·2, the greatest difference between the two being 12°·5. During most of this time the wind was easterly, and the wet-bulb thermometer ranged from 4°·1 to 8°·2 below the dry; but the increased evaporation that would result from the atmospheric condition thus indicated, could scarcely have produced the marked depression observable in the surface-temperature of the water; more especially as our general experience was that the surface-temperature in the comparatively shallow water of a Harbour was rather higher than in the deeper sea outside.—No such depression presented itself on our return voyage. On approaching Gibraltar from the Mediterranean side, there was a gradual reduction from 74°, which had been the average of several previous days, to 72°, apparently in consequence of the influx of the colder Atlantic water; the water in the Bay itself had an average surface-temperature of nearly 71°; and the surface-temperature did not fall until we came out into the mid-channel, where we encountered the colder indraught as already described (§ 61). Hence the depression observed during our first visit must be occasional only; and may perhaps be attributable to a deflexion of the mid-current into the Bay, by the opposing influence of the easterly wind which then prevailed.—This is one of the points as to which further inquiries, such as may be easily instituted by the Government authorities at Gibraltar, would doubtless furnish information of great interest.

78. *Bottom-Temperature.*—The Temperature-soundings taken during the Atlantic Cruise (see p. 220) may be arranged in three sets:—

I. Those taken in the "Chops of the Channel," about Lat. 48° N., corresponding closely in geographical position with several of those of the Second Cruise of 1869.

II. Those taken off the Atlantic Coast of Spain and Portugal, between Lat. $42\frac{1}{2}$° N. and Lat. 37° N.

III. Those taken within the *embouchure* of the Strait of Gibraltar, extending westerly as far as Cape St. Vincent and Tangier, and lying between Lat. 37° N. and $35\frac{1}{2}$° N.

79. The first two sets may be advantageously compared with each other, and with a Set of Bottom and Serial (No. 42) Soundings taken last year nearly in the same locality as the first; these are presented in the following Table.

Temperature of the Sea at different Depths near the Western margin of the North-Atlantic Basin.

I. Chops of the Channel, 1869.				II. Chops of the Channel, 1870.				III. Coast of Spain and Portugal			
No.	Depth, in fathoms.	Surface-Temp. ° Fahr.	Bottom-Temp. ° Fahr.	No.	Depth, in fathoms.	Surface-Temp. ° Fahr.	Bottom-Temp. ° Fahr.	No.	Depth, in fathoms.	Surface-Temp. ° Fahr.	Bottom-Temp. ° Fahr.
34.	75	66·0	49·7	7.	93	61·0	51·3	10.	81	60·5	53·5
35.	96	63·4	51·3	5.	100	62·3	51·5	12.	128	61·5	52·5
42.	250	62·6	50·2	8.	257	60·7	50·0	19.	248	64·7	51·7
42.	300	62·6	49·6	2.	305	61·5	48·7	11.	332	60·5	51·5
42.	350	62·6	49·1	6.	358	62·0	50·3	17.	340	67·0	50·5
42.	450	62·6	47·6					14.	469	69·7	51·5
39.	557	63·0	47·0	9.	539	64·0	48·0				
42.	600	62·6	45·5					21.	620	67·3	50·5
36.	725	63·9	43·9	4.	717	61·5	45·5	22.	718	66·5	50·5
								15.	722	67·5	49·7
42.	750	62·6	42·5					17*a*.	740	66·7	49·0
42.	800	62·6	42·0					23.	802	66·5	49·3
42.	862	62·6	39·7					16.	994	69·5	40·3
38.	1000	64·0	38·3					18.	1065	65·0	39·7
38.	1250	64·0	37·7					17.	1095	68·0	39·7

Between Nos. I. and II., as might be anticipated, the accordance is extremely close; and this accordance extends to the upper stratum (excluding the actual surface) in No. III., allowance being made for difference of Latitude. Notwithstanding that the *surface*-temperatures in No. III. range as high as 69°·7, the average excess at depths between 81 fathoms (at which the *super*heating of the surface has but little effect, § 87) and 350 fathoms is not above 2°, the reduction of temperature encountered in descending this upper stratum being very small in each case. But whilst this slow rate of reduction continues in No. III. down to 800 fathoms,—the bottom-temperature at 802 fathoms being 49°·3,—the reduction is more rapid in Nos. I. and II., so that the temperature of 45°·5 is reached in the one at 600 fathoms, and in the other at 717; whilst at 800 fathoms in No. I. the temperature has fallen to 42°. Below 800 fathoms, how-

ever, in No. III., the temperature undergoes so extraordinarily rapid a depression, that it is reduced *nine degrees* within the next 200 fathoms; the water at 994 fathoms being only 2° warmer than it is at 1000 fathoms in No. I. A slight further reduction of temperature is noticeable in the two deepest Soundings taken in the Atlantic Cruise of 1870, the temperature found at nearly 1100 fathoms being just 2° higher than that found at 1250 in No. I.

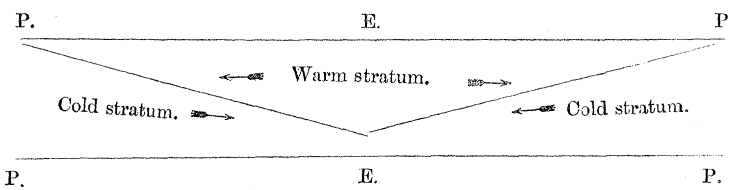
80. Considering these facts in the light thrown upon the Temperature phenomena of the Atlantic Basin by those of the "Cold Area" explored in 1869, it appears clear that we have in the Latitude of Lisbon the same distinct separation between an *upper warm* and a *lower cold* stratum as presented itself in the channel between the Shetland and the Faroe Islands; but whilst the "stratum of intermixture" in the latter lies between 150 and 300 fathoms, it lies in the former between 800 and 1000 fathoms. It seems perfectly clear that the *lower* stratum must have had a Polar source; but there is at present no distinct evidence that the *upper* stratum is derived from any source nearer the Equator. Its temperature, indeed, is *lower* by 4 or 5 degrees than that of the Mediterranean in the same parallel of Latitude at corresponding depths; and since the temperature of the latter may be considered as the *normal* of the Latitude,—this great Inland Sea being virtually excluded from participation in the general Oceanic Circulation,—it would seem that the effect of that circulation is rather to lower than to raise the temperature of the upper stratum of this portion of the Atlantic. Its *surface*-temperature also, as already shown (§ 45), is decidedly lower than that of the Mediterranean under the same parallel; and the limitation of the *super*heating to its most superficial layer is in entire accordance with our Mediterranean observations upon this point (§ 87).—Hence it seems a justifiable conclusion that neither the superficial layer nor any portion of the upper stratum of the Atlantic water that laves the coasts of Spain and Portugal receives any accession of heat from the extension of the Gulf-stream into its area*.

81. When, however, we compare the Temperatures of this upper stratum at different depths with those which are met with at Stations much further North (as tabulated in Par. 110 of the Report for 1869), there is found to be a remarkable correspondence in the *general rate of reduction* with depth, except in this particular,—that the influence of the cold stratum beneath begins to be decidedly marked much nearer the surface; so that instead of a very slight reduction between 500 and 800 fathoms, and then a very rapid passage through a "stratum of intermixture" of 200 fathoms, as in the

* It may be said that this conclusion, though it may be true as regards the *summer* temperature of this marine area, is "not proven" as regards its *winter* temperature. The data furnished, however, by the comparison of the Winter climates of stations along the Atlantic Sea-bord, with those of Mediterranean Stations in corresponding Latitudes, indicate that it is as true for Winter as for Summer. (See 'Proceedings of the Royal Geographical Society' for Jan. 9, 1871.)

Southern stations, there is a more gradual reduction of about the same amount (9°) between 500 and 1000 fathoms. Now this resul tis in remarkable conformity with what might be anticipated on the hypothesis advanced in the last Report. For if the whole *upper* stratum of Oceanic water be slowly moving *northwards* from the region with which we are now concerned towards that explored in the Third Cruise of 1869, whilst the *lower* stratum is slowly moving *southwards* beneath this, it might be expected that the further North the warm stratum advances, the more would it show the influence of the colder stratum beneath, in the lowering of the Temperature of the portion that immediately overlies it. And conversely, in proportion as the cold stratum advances Southwards, we might anticipate that the temperature of *its* upper layer would be gradually raised, so that even when the "stratum of intermixture" has been entirely passed through, we should find the Temperature at corresponding depths somewhat higher than at stations further north,—which is just what seems actually to be the case*.

82. The data at present in our possession seem to point to the inference that the relation between the *upper warm* and the *lower cold* strata of the Ocean, on different parts of the surface of the Globe, is such as may be diagrammatically expressed thus :—



At the Poles (P P, P P) the cold stratum occupies the whole depth, from the surface to the bottom ; but as we pass towards the Equator we find it lying further and further down, its surface forming an inclined plane on which the warm stratum rests. The warm stratum, on the other hand, has its maximum depth at the Equator, and gradually thins-off towards the Poles.—This is just what would be expected on the hypothesis of a General Vertical Circulation (§ 124 *et seq.*); since in the Polar-Equatorial flow of the cold stratum its surface would be continually gaining heat by contact with the warm stratum above, so that its superficial portion would be (so to speak) progressively transferred to the warm stratum ; whilst, on the other

* Prof. Wyville Thomson, in his Lecture on "Deep-Sea Climates" ('Nature,' July 28, 1870), has expressed the opinion that the cold stratum in the North Atlantic is derived rather from the *Antarctic* than from the Arctic basin. Putting aside the difficulty of accounting for a constant *in*flow of Antarctic water into the Northern Hemisphere, without a corresponding *out*flow, a strong argument against it may be drawn from the facts stated above. For if the *cold* stratum have a Southern source, we should expect its own temperature to be lower, and its effects upon the superincumbent stratum to be more marked, the further *south* it is examined,—the contrary of which proves to be the case.

hand, in the Equatorial-Polar flow of the warm stratum its lower layer would be gradually reduced in temperature by moving over with the cold stratum beneath*. Moreover as its surface would be exposed to a lower and yet lower Atmospheric temperature the further North it moves, each superficial layer as it is cooled will descend into the colder stratum, of which the thickness will be progressively augmented at the expense of that which overlies it.

83. The *Third* group of *Bottom*-temperatures, which includes those taken within the *embouchure* of the Strait of Gibraltar (Nos. 25–28, p. 220), presents some peculiarities which are worthy of notice, when taken in connection with the fact already stated as to the constant Temperature of about 55° found in the water of the Mediterranean at depths greater than 100 fathoms. For if we compare the Bottom-temperatures of Stations 25, 28, 29, 30, and 38, with those of Stations 31, 32, 33, and 34, we find in the former a distinct *elevation* above the latter. Thus at Stations 25 and 28 the temperature was 53°·5, at 374 and 304 fathoms respectively; at Station 29 it was 55° at 227 fathoms; at Station 30 it was 52°·7 at 386 fathoms; and at Station 58 it was 54° at 503 fathoms: whilst at Station 31 it was 50°·5 at 477 fathoms; at Stations 32 and 34 it was 50° at 651 and 414 fathoms respectively; and at Station 33 it was 49°·7 at 554 fathoms. This difference seems fairly attributable to the influence of the undercurrent which is now known to carry out the warmer Mediterranean water to mingle with the colder water of the Atlantic, and which, after flowing over the ridge between Capes Trafalgar and Spartel (§ 69), may still for a time maintain its distinctness on the descending slope of the Atlantic basin. It would probably not be difficult to trace its further course by a sufficient number of observations on the Temperature and Specific Gravity of the bottom-water to the west of the Strait; and it would be very interesting thus to ascertain how far this undercurrent makes its way before blending with the general mass of Atlantic water.—If a detailed examination of the phenomena of the double current should be undertaken by the Authorities at Gibraltar, this point should not be neglected.

84. *Density*.—In order to determine the Salinity of the water of the Atlantic Ocean as a basis for comparison with that of the Mediterranean Sea, the proportion of Chlorine in 34 samples of the former, taken between Falmouth and Lisbon, was determined by Volumetric analysis. Of these samples, 12 were of surface-water, 12 of bottom-water from various depths down to 1095 fathoms, and 12 of intermediate water. The results are expressed in Grammes per 1000 Cubic Centimetres of water.

* It was long ago shown by Dr. Arnott, in his 'Elements of Physics,' that if two layers of water originally of different temperatures, separated by a good conductor, *move in contrary directions*, they will gradually *exchange temperatures*; and this principle is now applied in the construction of Coolers for Breweries and Distilleries, in which a *hot* liquid which it is desired to cool is made to impart nearly all its heat to a *cold* liquid whose temperature it is desired to raise.

	Surface-water.	Intermediate water.	Bottom-water.
Average......	19·94	19·85	19·75
Maximum....	20·19	19·94	19·98
Minimum....	19·81	19·70	19·46

It appears from these Analyses that there is a slight excess of Salinity in the *surface*-water of the Atlantic, as had been previously observed by Forchhammer *; the excess, however, being so small as not to neutralize the excess of Density which the deeper water derives from its lower Temperature and from the Pressure of the superincumbent column. Five determinations of the Chlorine contained in samples taken at the same spot, from the Surface, and from 10, 25, 50, and 100 Fathoms, gave the following results :—

Surface................	20·013
10 fathoms............	19·909
25 ,, ...	19·909
50 ,, ...	19·909
100 ,, ...	19·805

A comparison of these seems to indicate that the excess of density, being limited to a mere superficial film, is entirely due to evaporation; and the reason why this more concentrated film does not sink, as it does in the Mediterranean (§ 90), is that its excess of Salinity is so small, that even at the depth of 10 fathoms its effect on Specific Gravity is neutralized by the greater density arising from reduction of Temperature.—The difference between the *maximum* and *minimum*, which in Surface-water is only 1-52nd part of the whole, and in Intermediate water only 1-83rd part of the whole, is in Bottom-water 1-38th of the whole; and the *minimum* of the whole series, namely, 19·46, presented itself in a specimen of Bottom-water taken from a depth of 994 fathoms. This proportion might have been presumed to represent the inferior Salinity of the Polar stream, from which the Temperature of the sample indicated its derivation, were it not that another sample from a depth of 1095 fathoms was found to yield 19·73, or nearly the average proportion, of Chlorine. Two samples, taken respectively from 700 and 322 fathoms, gave 19·63; and the maximum of 19·98 occurred in a sample from 717 fathoms. These anomalies are somewhat perplexing, yet the whole range of variation is really very small. Similar anomalies presented themselves in the results of Dr. Frankland's Analyses of samples of Bottom-water collected in the Cold area (Report for 1869, p. 489); for whilst the proportion of Chlorine in a sample (No. 64) taken from a depth of 640 fathoms, at a Temperature of 29°·6, was 19·88, that of the Surface at 49°·7 being 19·96, it was 20·14 in another sample (No. 54), which, though taken at little more than half the depth (363 fathoms), was shown by its Temperature to have been brought up

* See his Memoir on the "Composition of Sea-water" in the Philosophical Transactions for 1865, p. 247.

from the Polar stream, that of the Surface at 52°·5 being 20·17. Possibly, as suggested by Dr. Forchhammer (*loc. cit.*), the several parts of the Polar stream may vary in density, according to the amount of nearly fresh water which each may have derived from the icebergs that have liquefied in it.

85. *Specific Gravity.*—As the determination of Specific Gravity by observations taken with the Hydrometer on board ship is open to two sources of error,—that of the *instrument*, and that of the *reading* (which, when the vessel is unsteady, cannot be precise),—we deem it safer to depend upon the more exact determination of the Specific Gravity of a smaller number of samples by means of the Balance, and to estimate that of others by the Chlorine-determinations. In this manner we arrive at a range of from 1·0261, the Specific Gravity of the sample of Bottom-water of *minimum* density, to 1·0269, the Specific Gravity of the sample of Surface-water of *maximum* density; the average of all being 1·0265. This agrees very well with the results obtained by Forchhammer.

Temperature and Composition of Mediterranean Water.

86. *Surface-Temperature.*—With only two days' exception, the range of the daily average Surface-temperature of the Mediterranean, between the 16th August on which we entered it, and the 28th September on which we quitted it, was between 73° and 79°. The increase at once experienced as we passed into it from Gibraltar Strait was extremely marked (§ 45); and this was maintained for the next two days. On the 19th, however, the average of the day fell from 72°·2 to 66°·9, the average of the Air being 69°·8; and on the 20th it was 68°·9, the average of the Air being 74°·3. On the first of these days we were crossing from the African towards the Spanish coast, and experienced very strongly the effect of the in-current on the movement of our vessel (§ 47); and it can scarcely be doubted that the low surface-temperature was due to the colder stratum introduced from the Atlantic. On the following day we were between Cape de Gat and Cartagena; and were still within the influence of the cold in-current, which is known to flow past Cape de Gat at the rate of about a mile per hour. On leaving Cartagena, we came into a surface-stratum of true Mediterranean water, as indicated by its temperature of 73°; and the daily average never afterwards fell below this. The greatest heat was experienced in the neighbourhood of the Tunisian coast, when for several days the average Surface-temperature was 78°. The average Temperature of the Air during the greater part of our Mediterranean Cruise was from 1° to 2° *above* that of the Sea; but during our return from Malta towards Gibraltar, between the 20th and 26th September, the temperature of the Air averaged about 3°·5 *below* that of the surface of the Sea, the former having fallen, while the latter remained nearly stationary until we neared the Strait of Gibraltar. As we approached

it, a progressive reduction was observable, from 74°, which had been the average of several previous days, to 72°, with a further reduction to 71° when we entered Gibraltar Harbour. The *scorching* power of the Sun's rays was often very strongly felt; and we much regretted that we were not provided with a Thermometer having a range sufficiently high to enable us to estimate the influence of *direct* solar radiation*. There can be no question that the effect of this radiation upon the surface must be to produce a rapid evaporation, especially when the air is dry. The difference between the Dry- and Wet-bulb thermometers averaged about 4°, but rose occasionally to above 8°; we could not, however, trace any relation between this difference and the Surface-temperature of the Sea.

87. *Temperature of the Upper Stratum.*—Finding that the reduction in Temperature with depth was so extremely rapid as to show that the direct influence of Solar radiation is limited to a comparatively thin stratum of surface-water, we took *Serial* soundings at three Stations, at intervals near enough to show the rate of diminution. The *first* of these Stations (Stat. 40), although the nearest to the Strait, seems to have been out of the direct influence of its cold in-current, which is shown very strongly in the *second* (Stat. 47); the *third* (Stat. 53) may perhaps be taken as representing most characteristically the thermal condition of the upper stratum of the water of the Mediterranean during the season of greatest heat:—

	I.		II.		III.	
	° Fahr.	Diff.	° Fahr.	Diff.	° Fahr.	Diff.
Surface	74·5		69·5		77·0	
5 fathoms		5·2		10·5	76·0	6·0
10 ,, ...	69·3		59·0		71·0	
20 ,, ...	65·0	4·3	57·5	1·5	61·5	9·5
30 ,, ...	63·0	2·0	56·5	1·0	60·0	1·5
40 ,, ...	61·7	1·3	55·7	0·8	57·3	2·7
50 ,, ...	59·7	2·0	55·3	0·4	56·7	0·6
100 ,, ...	55·1	4·6	54·7	0·6	55·5	1·2

Taking No. III., therefore, as the standard of comparison, we observe that while the Thermometer fell only 1° in the *first five* fathoms, it fell 5° in the *second five*, and no less than 9°·5 between 10 and 20 fathoms, below which depth the reduction was very slow. In No. I., with a lower surface-temperature, the reduction in the first ten fathoms was nearly the same; but it was much less between 10 and 20, so that for depths between 20 and 50 it was between 3° and 4° higher than at corresponding depths in No. III.; at 100 fathoms, however, the two were brought to an almost precise accordance by the larger reduction which took place in No. I. between 50 and 100 fathoms. In No. II., on the other hand, the great

* We learned from Colonel Playfair, the Consul General at Algiers, that whilst he was at Aden, a Thermometer with a blackened bulb having been laid upon a black surface, and exposed to the full glare of the Sun, had risen to 215°.

reduction showed itself in the uppermost stratum of 10 fathoms; but though the further reduction took place at a very slow rate, the temperatures at this Station were decidedly below those at the other two, down to 100 fathoms, at which there was not a difference of 1° among the three.

88. *Bottom-Temperature.*—The uniformity which showed itself in the Temperature of the bottom (see Table, p. 221), *at all depths* below 100 fathoms, was very remarkable. The *lowest* bottom-temperature we anywhere met with was 54°; and this presented itself at a depth of 790 fathoms. The *highest* we anywhere met with was 56°·5; and this presented itself in three instances, at depths of 266, 390, and 445 fathoms. But that the trifling elevation was not in any way dependent upon the smaller depth of these Soundings, was obvious from two considerations:—first, that our deepest sounding gave a temperature of 56° on a bottom of 1743 fathoms, whilst we found 55° at depths of 1456 and 1508 fathoms; and second, that the slight variations observable among the *bottom*-temperatures occurred also between the temperatures taken at 100 fathoms. In fact, *whatever the temperature was at* 100 *fathoms, that was the temperature of the whole mass of water beneath, down to the greatest depth explored.* In that part of the Western basin of the Mediterranean which lies between Gibraltar and Sardinia, the bottom-temperature ranged between 54° and 55°·5, the *average* being 54°·9. East of this, in the neighbourhood of Sicily, the bottom-temperature ranged between 55° and 56°·5, the *average* being 55°·8. It was because we thought it possible that the slight excess of Bottom-temperature on this area might be due to Volcanic heat beneath, that we directed our homeward course by way of Etna and Stromboli, for the purpose of ascertaining if the near neighbourhood of a constantly active Volcano has any influence in raising the temperature of the bottom. No such influence, however, was perceptible; the Temperatures obtained at Stations 61 and 62,—namely 55°·7 at 392 fathoms, and 55°·3 at 730 fathoms,—being rather *below* than above the average.

89. The remarkable contrast thus presented to the slow but continuous reduction of temperature encountered in the successive strata of Oceanic water in the great Atlantic basin, and to the sudden fall which presents itself as the Thermometer descends to its lower depths (§ 79), excites enquiry into the cause of the difference. It is now clear that no amount of *surface*-heat has power *directly* to affect the temperature of sea-water to a greater depth than 100 fathoms, the elevation of temperature it produces below 30 fathoms being very slight; and it seems also clear that the uniform temperature of from 54° to 56°·5 encountered below the 100 fathoms' stratum, represents the *permanent temperature* of the great mass of water which occupies the Mediterranean basin. Now this mass is entirely cut off from the influence of the General Oceanic Circulation, the surface-inflow through the Strait of Gibraltar having no other effect than slightly to lower the general temperature at the western extremity of the basin. And the uniform permanent temperature of the mass of Mediterranean water may

thus be considered as representing the mean temperature of the Earth in that region, slightly raised, perhaps, by a *downward convection* of heat from the surface in the manner to be presently described (§ 90). With such an allowance it corresponds closely with the determinations of the mean temperature of the Crust of the Earth, made by sinking Thermometers into the ground to such a depth as to seclude them from the direct influence of Summer heat or Winter cold, but not to bring them within the direct influence of the Internal Heat of the earth. Thus Quetelet found that a Thermometer sunk to a depth of 24 feet at Brussels showed an annual average of 53°·4, the range of variation being only 2°·5; and Bischoff found a Thermometer sunk to a depth of 36 feet at Bonn give an annual average of 51°, with a range of only 1°·5. The Temperature of deep Caves gives another set of data of the like kind, which accord very closely with the foregoing. Thus we have been informed by Mr. Pengelly that the temperature in the part of Kent's Hole at Torquay which is furthest from its entrance varies but little from 52° throughout the year. There is a cave in the island of Pantellaria, lying between Sicily and the African Coast, which is reputed to be of "icy coldness;" but Lieut. Millard, of H.M.S. 'Newport,' who has lately been making a careful survey of the Island, informed us that, although he felt it "very cold" on passing into it out of a very hot sunshine, its actual temperature, taken by Thermometer, was 54°. And we have also learned on good authority that this is the temperature of the bottom of the deepest tanks in which water is stored up in Malta, provided that these are excavated (as is very commonly the case) beneath the houses, or are in any other way secluded from the direct rays of the sun.

90. Now let it be supposed that the superficial stratum of the water of the Mediterranean had been cooled down by a severe winter to the uniform temperature of the depths below; we have to enquire in what manner it would be affected by the heating-power of the summer sun. This, it is obvious, can be only exerted *directly* upon the actual surface; for the *conducting*-power of water is so small that very little downward transmission of heat would take place through its agency. Further, as the application of heat at the surface will render the superficial layer specifically lighter, no such *convection* will take place in the *downward* direction as takes place *upwards* when heat is applied at the bottom. But another agency comes into play in the case of Sea-water. The rapid evaporation produced by powerful solar radiation, especially when aided by the hot dry winds of Africa, occasions such a concentration of the surface-film, that, in spite of its elevation of temperature, it becomes specifically heavier, and descends,—to be replaced by a fresh layer. In this manner it will carry down an excess of heat, which diffuses itself through the subjacent layer, of course producing the greatest elevation of temperature in the stratum nearest the surface. The continual repetition of this process through the hot season will carry the elevation of temperature further and further

down; but so soon as the temperature of the Air falls much *below* that of the Sea, the surface-layer being cooled will become heavier and sink, and will thus carry down *cold* instead of heat, so as to lower the temperature of the stratum below. In no instance, however, so far as we can learn, has the surface-temperature of the Mediterranean ever been seen so low as 56°, even in midwinter.

91. That it is by this sinking of the surface-films successively concentrated by evaporation that the Solar heat, which acts so powerfully on the Mediterranean basin during the summer, is transmitted downwards, appears certain from the fact, of which the particulars will be presently given, that the Salinity of the water of the Mediterranean is greater *below* the surface than *at* the surface, instead of diminishing as it does in the Atlantic (§ 84); and we thus see how important an influence is exerted by that Salinity in diffusing the heat imparted to the surface through the waters beneath. In the great *fresh*-water lakes of Switzerland, the deeper water retains all through the year a temperature but little above 39°, the small excess being probably derived from the warmth of its bed; for the whole mass of water down to the bottom must be cooled to this degree in winter before any ice can form on its surface; and as the heating of the surface in summer makes all the water affected by it specifically lighter, none of it will descend and carry heat downwards, as it does in the Mediterranean.

92. *Density.*—The determination of the actual Salinity of the water of the Mediterranean basin, alike at the Surface and at various Bottom-depths, was one of the special objects of our inquiries; for although various Analyses had been previously recorded, they had been made upon samples of water which had been kept in bottles for a more or less considerable period; and the depths from which those samples had been collected were not by any means the greatest known to exist in this basin.—The number of Chlorine-determinations of *Surface*-water was 25; and their Geographical range was from the Strait of Gibraltar to the edge of the Eastern basin (Station 60). A marked difference in density was observable between the Surface-waters of the Western and of the Eastern portions of this area; for whilst those of the latter invariably showed a considerable excess in Salinity above the *maximum* of Atlantic water, that excess was so much reduced in some of the samples taken nearer to the Strait, as almost certainly to show that the surface-stratum there consists in great degree of Atlantic Water. Thus at Station 47, in which a like indication was given by the Temperature of the Surface-water (§ 87), we found the proportion of Chlorine to be 20·46, or only 0·27 above the maximum we had encountered in Atlantic water; and when we crossed to the neighbourhood of the opposite Algerine Coast (where, however, the density of the Surface-water was probably reduced by the entrance of River-water), we found the proportion of Chlorine as low in one case as 19·69, and in another as 19·99. When approaching the Strait on our return voyage, we took a series of five samples

for the purpose of testing the reality of this difference; and we found the proportions of Chlorine to be respectively 20·77, 20·67, 20·56, 20·51, and 20·47. The *mean* of these five determinations, together with the one previously taken at Station 47, but excluding the two taken on the coast of Algiers, is 20·57; and the mean Specific Gravity was 1·0274. On the other hand, at the Sicilian end of the basin, where the water was that of the Mediterranean proper, the *mean* of ten Chlorine-determinations was 21·05, with a corresponding Specific Gravity of 1·0280. The *maximum* of Chlorine was there 21·32, with Specific Gravity 1·0284; and the *minimum* 20·77, with Specific Gravity 1·0277. The combination of these 16 observations gives a *mean* of 20·87 for the Chlorine, and 1·0278 for the Specific Gravity, of the Surface-water of the Mediterranean generally *.

93. The number of Chlorine-determinations of *Bottom*-water taken in the proper Mediterranean basin, at depths between 207 and 1700 fathoms, was 20. They show a general excess of Salinity over the Surface-water, the *mean* of the whole being 21·38 (as against 20·87), with a *maximum* of 21·88 (Sp. Gr. 1·0292) and a *minimum* of 21·08 (Sp. Gr. 1·0281). On grouping them into three Series according to their depth, we arrive at a curious result:—

Fathoms.		Chlorine.	Sp. Gr.
200 to 400,	Mean of 7 observations......	21·53	1·0287
400 to 800,	„ 7 „	21·38	1·0285
1300 to 1700,	„ 6 „	21·21	1·0283

94. Thus it appears that the excess of Salinity is greatest in the *shallower* water, and that it gradually diminishes with the depth. This is also shown most strikingly by comparing the sample taken from the *least* depth (207 fathoms) with that taken from the greatest depth (1703 fathoms); for it was the former that showed the *maximum* of 21·88, and the latter that showed the *minimum* of 21·08.—Now this fact, though at first unexpected (since we had supposed that the heaviest water would gravitate to the greatest depths), seems not difficult to account for, if we consider the mode in which the concentration of the surface-film will be likely to affect the water below. For it can be shown experimentally, by pouring a strong saline solution tinged with colour upon the top of a weaker colourless solution, that the former will in the first instance sink "bodily," but will gradually impart its excess of salt to the liquid through which it falls; the descent of the coloured stratum becoming slower and slower, and its

* This *mean* accords closely with that of 20·845 obtained by Prof. Forchhammer from his examination of samples collected at different times and by different persons from various parts of the surface of the Mediterranean (Phil. Trans. 1865, p. 252). His *maximum* of Chlorine, 21·718, was higher than ours; but this seems to have been an exceptional case; and the sample may have undergone some concentration in keeping. On the other hand, his *minimum* was lower, being only 20·16; but this sample, having been taken in the Strait of Gibraltar, contained a large proportion of Atlantic water.

colour being more and more imparted to the general mass of the liquid. The proportion of salt will in time be made uniform throughout the whole column by "diffusion." Now it is obvious that if each column rests (so to speak) on its own base, the degree in which the Salinity of the whole mass is raised by the addition of a more concentrated solution will depend *cæteris paribus* upon its height; and thus where the depth of the Mediterranean basin is only between 200 and 400 fathoms, we should expect the Specific Gravity of its water to be more raised by the successive concentration of its surface-films, than where the depth ranges from 1300 to 1700 fathoms.

95. Since this proves actually to be the case, the further conclusion appears justifiable—that there is *an extremely small amount of movement in the abyssal waters of the Mediterranean basin.* The uniformity of Temperature throughout the whole of it, and the restriction of seasonal changes in temperature to its upper stratum, will prevent it from being subjected to any thing like the *vertical circulation* which is produced in the great Oceanic basins by the antagonistic action of Heat and Cold on the Equatorial and Polar areas (§ 125). And from any *horizontal displacement* they would seem altogether excluded by the depth at which they lie; for the action of winds cannot disturb more than that comparatively superficial stratum which is affected by the Gibraltar current. The inflow of lighter surface-water through the Strait, and the outflow of denser water from the comparatively shallow stratum of the neighbourhood, will probably produce no change whatever at depths greater than 500 fathoms. And the same may be said of the supply of fresh water brought in either by rain or rivers; for this will at once go to make up the loss produced by surface-evaporation; and whilst helping to maintain the purity of the upper stratum inhabited by fishes &c., will do nothing for the waters of the abyssal depths. If these waters were continually subject to horizontal displacement, it might be expected either that the heaviest water would gravitate to the greatest depths, or that the density of the entire contents of the deeper portion of the basin would be equalized; neither of which happens. On the contrary, as just shown, the density varies with the depth in so marked a degree, as to indicate that the water in each part of the basin retains its distinctness from the rest through long periods of time.

96. *Solid Matter in Suspension.*—The water of the Mediterranean is distinguished from that of the Atlantic, not only in the larger proportion of Saline matter which it holds in *solution,* but also in having diffused through its whole mass, in a state of *suspension,* particles of solid matter in an extremely fine state of division. This statement may seem strange to those who are familiar, either by personal observation, pictorial representation, or verbal description, with the (apparently) clear deep blue of the Mediterranean Sea. But the two phenomena will be presently shown not only to be compatible, but to stand to each other in the relation of cause and effect.

97. Our attention was drawn to this point, in the first instance, by finding that the bottom-water brought up by the Water-bottle was nearly always turbid, and that this turbidity was with difficulty removed by filtration. The bottom-water brought up from sandy or gravelly bottoms is always clear; and though that which was brought up from the area covered by the "Atlantic mud" was often turbid, it was readily cleared by passing through filtering-paper, the deposit on which was found to consist of very minute *Globigerinæ*, which had been apparently floating in the stratum immediately above the Sea-bed. As the clearing of the Mediterranean water was requisite for our Chlorine-determinations, it was passed twice or thrice through the filter, and the solid matter left upon the paper consisted entirely of Inorganic particles of extreme minuteness. Now it is a fact well known to Chemists and Physicists, that the length of time required for the deposit of a precipitate increases with the fineness of the division of its particles, notwithstanding that the material of which they are composed may be of very high Specific Gravity. Thus it was shown by Faraday that precipitates of Gold may not subside for a month; and Mr. Babbage has calculated that, in the case of lighter substances, a period of hundreds of years may be required for the gravitation of very finely divided particles through a considerable mass of fluid.

98. Taking into account, therefore, that the deep waters of the Mediterranean are not only cut off from the General Oceanic Circulation, but that they are almost entirely destitute of *vertical* circulation amongst themselves (§ 95), it may be fairly considered that the perceptible turbidity of the bottom-water is due to the imperceptible diffusion of the same finely divided matter throughout the entire mass of superincumbent water. And that this is really the case, is shown by two different methods of proof. We learned from the Engineer of the Peninsular and Oriental Company's Steam-ship by which we proceeded to join the 'Porcupine' at Gibraltar, that the deposit removed from the boilers after working in the Mediterranean differs from that left by Atlantic water, not only in its larger proportion of *salt*, but in having a very finely divided *mud* diffused through it, which is, of course, derived from the evaporation of *surface*-water. The result of this large-scale experiment harmonizes exactly with that of Prof. Tyndall's examination of a small sample of the surface-water of the Mediterranean by the Electric light; for he found it to be highly charged with minute particles in suspension, as is also the water of the Lake of Geneva. And he has further shown that it is in each case to the presence of these particles that we are to attribute the peculiar intensity of the blue colour by which both these waters are characterized *.

* See 'Nature,' Oct. 18, 1870.—We may take leave to mention that the same idea of the agency of the suspended particles in intensifying the blue colour of the water had previously occurred to ourselves, and had been made the subject of conversation on our voyage home, the probable community of the source of the suspended particles in the Mediterranean and the Lake of Geneva respectively having especially presented

99. But further, when we come to enquire into the source of these suspended particles, the progressive subsidence of which gives rise to the fine muddy deposit that covers all the deeper parts of the Mediterranean, we find that (so far, at least, as the Western basin is concerned) they have been in all probability brought down into it by the Rhone. The upper part of that river, as is well known, is constantly transporting a vast mass of sedimentary matter into the Lake of Geneva; and while the deposit of the coarser particles of the sediment at the upper end of the Lake is causing a progressive formation of alluvial land, the water which passes off at the lower end, though apparently clear, is still charged with particles in a finer state of division. "Scarcely," says Sir C. Lyell*, "has the river passed out of the Lake of Geneva, before its pure waters are again filled with sand and sediment by the impetuous Arve, descending from the highest Alps, and bearing along in its current the granitic sand and impalpable mud annually brought down by the glaciers of Mont Blanc. The Rhone afterwards receives vast contributions of transported matter from the Alps of Dauphiny and the primary and volcanic mountains of Central France; and when at length it enters the Mediterranean, it discolours the blue water of that sea with a whitish sediment for the distance of between six and seven miles, throughout which space the current of fresh water is perceptible."—Thus the Western basin of the Mediterranean stands in the same relation to the lower part of the Rhone and to the tributaries which discharge themselves into it, that the Lake of Geneva does to its upper part. And a like universal diffusion of fine sedimentary particles through the Eastern basin is probably effected by the transporting agency of the Nile.

100. The very slow, but constant, subsidence of these minute sedimentary particles, then, is the source of a large part of the material of that fine tenacious Mud which, mingled with a larger or smaller proportion of Sand, partly calcareous and partly siliceous, constitutes the deposit at present in progress on the deeper parts of the Mediterranean sea-bed. The source of the Calcareous sand, which is itself in a state of very minute subdivision, is probably to be found in the abrasion of the Calcareous Tertiaries which form the shore-line round a large part of the Western basin. This abrasion is specially noticeable at Malta, where, for the security of the fortifications, it has has been found necessary to check it by artificial means. The singular barrenness of this deposit in regard to Animal life forced itself upon our attention during the whole of our dredging-operations in the Mediterranean (§§ 48–52); and whilst disappointed as Zoologists in not meeting with the novelties we hoped to encounter, we venture to hope that

itself to us: and it was with great satisfaction, therefore, that we found our notion so fully confirmed by Prof. Tyndall's investigations; whilst it was not a little interesting to him to find that our independent inquiries had led us to affirm the presence of these suspended particles through the whole mass of Mediterranean water, and to attach so much importance to the fact in its Geological and Biological relations.

* Principles of Geology, 10th ed. vol. i. p. 427.

the negative result of our sedulous investigations may have an important Geological bearing.

101. It will be borne in mind that our previous researches have fully demonstrated the fact that the Depth of from 600 to 1200 fathoms is not *per se* inconsistent with the existence of a varied and abundant Fauna; and that the reduction which shows itself at from 1200 to 2435 fathoms seems to depend as much on depression of Temperature, as on increase of Depth. Hence it was fairly to be expected that a varied and abundant Fauna—probably containing a number of Tertiary types supposed to have been long extinct—would have been found between 500 and 1500 fathoms, on a bottom of which the temperature seems never to fall below 54°. Now the question as to the cause of the deficiency of Animal Life on this bottom naturally connects itself with the old Geological difficulty, of which the inquiries of Prof. Edward Forbes were long supposed to afford a satisfactory solution; viz. the existence of vast thicknesses of sedimentary strata, almost or entirely destitute of Organic Remains. The explanation which has been accepted for many years,—that these deposits were formed in Seas too deep to allow of the existence of Animals on their bottom,—having been now shown to be untenable, the old difficulty recurs; and it is obvious that if it can be shown that a condition prejudicial to Animal Life now prevails on the Mediterranean bottom, which also prevailed when other azoic deposits were formed, a great step will have been gained. Such a condition is to be found—we are disposed to think—in the *turbidity of the bottom-water*. All Marine animals are dependent for the aeration of their fluids on the contact of water either with their external surface, or with special (branchial) prolongations of it. Now if this water be charged with suspended particles of extreme fineness, the deposit of these particles upon the respiratory surface will interfere with the aerating process, and will tend to produce asphyxia. This is not a mere hypothesis. It is well known that Oyster-beds cannot be established in situations to which fine mud is brought by any fluvial or tidal current. And our Colleague Mr. Jeffreys, when dredging some years ago in the neighbourhood of Spezzia, having on one occasion passed a little out of the Bay, from a sandy bottom rich in Animal life to a muddy bottom (this mud being doubtless a part of the Rhone deposit), without any considerable increase of depth, was forcibly struck by the barrenness of the latter.

102. It will be for Geologists to say how far this explanation can be applied to the case of the azoic sedimentary deposits of former epochs. One very notable case of the kind has been communicated to us by Dr. Duncan, that of the Fleisch, a stratum not less than 6000 feet thick, extending from Mont Blanc to the Styrian Alps, which must have been deposited in the condition of extremely fine arenaceous mud, and in which there is an almost entire absence of Fossils. We are disposed to believe, also, from the results of such inquiries as we have been able to make, that the extremely fine Calcareous sandstone of Malta, though reputed to be

rich in Fossils, will be found to contain these fossils, for the most part, in its coarser beds; which were probably deposited in shallower waters, like those which we found rich in Animal life along the shores of the Mediterranean. The extremely fine stone that is used for carved work,—so entirely wanting in "grain" that carvings executed in it look like casts in Plaster of Paris,—contains, we were assured, few fossils except Sharks' teeth, which, of course, dropped into it from above. We commend this enquiry to the attention of Maltese Geologists, as one having an important bearing on the solution of a problem of the highest interest.

103. There is another condition, however, which may be not less potent in restraining within very narrow limits the Animal Life of the deeper parts of the Mediterranean Basin,—namely, *the stagnation produced by the almost entire absence of Vertical Circulation.* In the great Oceanic basins, if our doctrine (§ 124 *et seq.*) be correct, every drop of water is in its turn brought to its surface and exposed to the purifying influence of prolonged exposure to the air. From this movement, the water of the Mediterranean may be said to be virtually excluded; and, as has been already shown (§ 95), the deeper part of the basin has no Circulation of its own, either horizontal or vertical, which will have the effect of bringing its water to the surface. It is difficult, in fact, to conceive of *any* agency that can disturb the stillness of the abyssal depths of a basin which is completely shut in by a wall that rises more than 10,000 feet from its bottom. How far this affects the condition of such depths, in respect to the diffusion of the Organic matter and the Oxygen required for the support of Animal life, must be a matter of future inquiry.

Gibraltar Current.

104. The term "Strait of Gibraltar" is usually applied to that space between the coast-lines of Spain and Morocco which is bounded on the west by Capes Trafalgar and Spartel, and on the east by the two "Pillars of Hercules,"—namely Europa Point, which forms the southern extremity of the Rock of Gibraltar, and Jebel Musa or Apes Hill on the Barbary side. As Admiral Smyth justly remarks*, however, we may correctly include in the Strait the whole of that funnel-shaped entrance from the Atlantic, of which the western boundary is formed by a line from Cape St. Vincent on the north to Cape Cantin on the south, the whole of the water within this entrance being affected by the surface-draught into the Mediterranean. It was considered by Major Rennell that there is a general "set" of Atlantic water between Lat. 30° and 45° N., and from 100 to 130 leagues off the land, towards the entrance of the Strait, the rate of movement being as much as from 14 to 17 miles per day. This estimate, however, is regarded by Admiral Smyth (*loc. cit.*) as excessive; although he thinks that such an indraught may possibly occur during the long pre-

* The Mediterranean, p. 158.

valence of particular winds. We have been informed by Admiral Ommaney that, according to his own experience, the *inset* is most considerable towards the African coast, while the *outset* occasionally observed (§ 106) is most decided on the Northern coast; and this statement derives very remarkable confirmation from the Thermometric observations already detailed. For these show that the lower temperature of the *in*-current is specially noticeable near Cape Spartel (§ 73); whilst the higher temperature, which is traceable westwards along the Spanish and Portuguese coasts as far as Cape St. Vincent, and there suddenly falls to the ordinary standard of the Atlantic, seems to be derived from an *efflux* of the Mediterranean water (§ 75).

105. The length of the narrower portion of the Strait (see Chart II.), sometimes distinguished as the Gut, is about 35 miles. Its width, which is about 22 miles between Capes Trafalgar and Spartel, gradually diminishes to somewhat more than 9 miles between Tarifa and Alcazar point; and then increases until it reaches 12 miles between Gibraltar and Ceuta, eastward of which the Strait terminates abruptly in the wide basin of the Mediterranean. The deepest portion of the Strait is at its eastern extremity; its depth between Gibraltar and Ceuta reaching 517 fathoms, and averaging about 300 (Section C D.). From this the bottom gradually but irregularly slopes upwards (Section A B) as far as the western extremity of the Gut, where the shallowest water is to be found. The northern half of the channel across the section between Capes Spartel and Trafalgar (Section E F) scarcely anywhere exceeds 50 fathoms; whilst its southern half does not seem anywhere to reach 200, and may be considered to average 150 fathoms. On the Atlantic side of this ridge the bottom gradually slopes downwards, until it reaches, at 40 miles westward, a depth about equal to that which it has between Gibraltar and Ceuta. This ridge, therefore, constitutes a kind of marine "watershed," separating the Inland basin of the Mediterranean from the great Oceanic basin of the Atlantic.

106. Through the central part of this Strait a current almost invariably sets eastward, or from the Atlantic into the Mediterranean. This current is most rapid in the narrower part of the Gut, where the *in*flow usually has a rate of from *two* to *three* miles an hour; this rate sometimes rising to *four* miles, or even occasionally (as stated by Gibraltar pilots to Admiral Smyth) to *five*; whilst the current is sometimes so reduced in speed as to be scarcely perceptible, even giving place (though very rarely) to a contrary movement or *out*flow from the Mediterranean towards the Atlantic. These variations are partly due to Tidal influence, which is here very decided, and which may either concur with or oppose the general current. When the tide is *flowing*, its motion is *westwards*, or in opposition to the current; and at spring-tide this motion may be sufficiently powerful to check the current, or even to reverse its direction for a short time. When the tide is *ebbing*, on the other hand, its motion is *eastwards*, or in the direction of the current; and it is to the ebb of spring-tides that the occasional augmentation in the rate of the current to 5 miles an hour is probably

attributable. These effects will, of course, be most marked when the tidal movement is augmented by a strong wind in its own direction *.—The constant current does not occupy by any means the entire breadth of the Strait. In its narrowest part the rapid central in-current is said by Admiral Smyth not to average more than 4 miles in width; and on either side the stream when moving inwards is usually much less rapid, its rate, independent of tide, being about 1 mile per hour in the neighbourhood of Tarifa, and 2 miles an hour on the coast of Africa. These lateral currents are much more affected than the central current by the Lunar tide, which produces a complete periodical reversal of them; the flood at springs running *westwards* off Tarifa at the rate of from 2 to 3 miles per hour, whilst even at neaps it runs westwards at 1 mile per hour. The ebb, on the other hand, concurs with the general current, and augments both its volume and its rate. Thus, when the water is falling, the whole stream is running eastwards; but when it is rising, the tide on either shore sets westwards. By taking advantage of this periodical westerly flow in the lateral streams, it is possible for sailing-vessels to make their way outwards † in opposition to a continued westerly wind.

107. The rate of the general in-current diminishes immediately that it discharges itself into the Mediterranean basin, over the surface of which it seems to spread itself, in virtue of its lower Specific Gravity (§ 92). But the influence of its motion is sensibly experienced along the Spanish Coast as far as Cape de Gat, and along the African Coast even as far as the Bay of Tunis,—its force and direction, however, being greatly affected by the prevalent winds.

108. Various hypotheses have been put forward at different times to account for this continual influx of Atlantic water into the Mediterranean. The motion of an undercurrent flowing in the opposite direction was very early suggested by Dr. Smith ‡; but he did not attempt to show in what way motion is given either to the surface inflow or to the deep outflow. Quite recently the extraordinary hypothesis has been seriously put forward, that the influx through the Strait may be due to a gradual depression of the bottom *now going on* §. The explanation usually received is that first offered by Dr. Halley ||, who attributed it to the excess of evaporation from the surface of the Mediterranean Sea over the whole amount returned to its basin either directly by rainfall or by the rivers which discharge themselves into it; so that the level would be progressively lowered, if not kept up by an inflow from the Atlantic. The obvious objection to this explanation is, that as the water which passes off by evaporation leaves its Salt behind it, and as the water which enters through the Strait is

* Admiralty Sailing Directions, p. 309.
† See Admiral Smyth's 'Mediterranean,' p. 176.
‡ Philosophical Transactions, vol. xiv. p. 364.
§ Mr. George Maw in Geological Magazine, December 1870, p. 550.
|| Philosophical Transactions, vol. xvi. p. 366.

charged with the ordinary proportion of salt, there must be a progressive increase in the density of the water of the Mediterranean until it reaches the point of saturation. This objection has been met by another hypothesis, viz. that although the surface-water of the Mediterranean shows very little excess of density, there may be a great increase in the proportion of salt held in solution in the waters of its abyssal depths; and it has even been surmised that a deposit of salt is taking place on its bottom.

109. This hypothesis seemed to derive support from the analysis made by Dr. Wollaston in 1828*, of a sample of bottom-water brought up by Admiral Smyth from a depth of 670 fathoms, at a point about 50 miles within the Strait; which analysis gave the extraordinary percentage of 17·3 parts of Salt, with a Sp. Gr. of 1·1288,—the proportion of Salt in ordinary sea-water being about 3·5 per cent., and its usual Sp. Gr. about 1·027. But as Dr. Wollaston's analyses of two other samples of Mediterranean water, taken respectively from depths of 450 and 400 fathoms, at distances of 680 and 450 miles eastward of the Strait, showed that their density but little exceeded that of ordinary sea-water, it was pretty clear that the first result was anomalous, and that in whatever way it was to be accounted for†, it did not represent the general condition of the deep water of the Mediterranean. (See §§ 43, 44.)

110. The inquiries detailed in the previous Section of this Report have conclusively shown (1) That there is a general excess of Salinity in the water of the Mediterranean over that of the Atlantic; (2) That this excess does not pass beyond very narrow limits; (3) That it is *least* in *surface*-water the proportion of salt in which is only about 4·7 per cent. above that contained in the surface-water of the Atlantic; (4) That it is *greatest* in *bottom*-water the proportion of salt in which may reach about 9 per cent. above that contained in the bottom-water of the Atlantic, this last *not* being *more*—and apparently somewhat *less*—dense than the surface-water of the same ocean. Our inquiries were almost entirely limited to the Western basin, in which bottom-water of the highest density seemed to prevail at the shallower depths (§ 93). The single sounding which was taken in the Eastern basin, at a depth greater than any elsewhere reached, gave us a sample of which the excess was 6·7 per cent.

111. From these results it seems a justifiable inference that the evaporation from the water of the Mediterranean basin is in excess of the amount of fresh water returned into it, occasioning an increase of its density; but that this increase, notwithstanding the constant influx of salt water from the Atlantic, is in some way kept in check, probably through an efflux of the denser water by an undercurrent, as originally suggested by Dr. Smith in 1673. This is the view adopted by Sir John Herschel (Physical Geography, 1861, p. 28); and it has been considered to derive support from

* Philosophical Transactions, 1829, p. 29.

† It was suggested by Admiral Smyth ('Mediterranean,' p. 131) that a brine spring might have been struck upon.

accounts that have been recorded of vessels sunk in the narrower part of the Strait having floated up near Tangier*. But to these accounts no great importance is assigned by Admiral Smyth†, who seems inclined to attribute the occurrences—if they really took place as narrated—to the action of the lateral Surface-outflow.

112. The only objection that has been advanced, so far as we are aware, to the hypothesis of a westerly undercurrent, is based on the existence of the comparatively shallow ridge which (as already stated) crosses the western end of the Gut between Capes Trafalgar and Spartel. The existence of this ridge, in the opinion of Sir Charles Lyell ‡, "has dispelled the idea which was once popular that there was a counter-current at a considerable depth in the Straits of Gibraltar, by which the water which flows in from the Atlantic is restored to that ocean."—But the validity of this objection has been disputed, and we think successfully, by Captain Maury, who, after citing many cases in which a deep current comes up to near the surface, concludes as follows:—"To my mind the proofs derived from reason and analogy are as clear in favour of this undercurrent from the Mediterranean, as they were in favour of Leverrier's planet before it was seen through the telescope at Berlin" §.

113. The analogy of the Red Sea and the incurrent through the Strait of Babelmandeb, which is adduced by Capt. Maury in support of this view, is a very cogent one. The evaporation from the Red Sea is well known to be enormous, its annual amount being estimated by Dr. Buist as equal to a sheet of water eight feet thick, corresponding in area with the whole expanse of that sea. Of the whole amount of *fresh* water thus drawn off, scarcely any is returned either by rivers or rains. But the level is kept up by a strong current that continually sets in through the Strait of Babelmandeb; and as this current brings in *salt* water, there would be a continual and very rapid accumulation of salt in the trough of the Red Sea if the denser water were not carried off by an outward current beneath. Now since all the observations hitherto made upon the density of the water of the Red Sea show it to be very little greater than that of the Indian Ocean ||, there would seem no escape from the conclusion that such a reverse undercurrent must really exist.

114. We shall now present, in a concise and connected form, the General Results of the inquiries we have ourselves made to determine this question; the particulars having been detailed, as they presented themselves, in the preceding Narrative. These results were of a twofold character. It was our object, (1) to detect if possible by *mechanical* means any *movement* which may be taking place in the lower stratum of water in opposition to

* Philosophical Transactions, vol. xxxiii. p. 192.

† Mediterranean, pp. 154–157.

‡ Principles of Geology, 10th edit. vol. i. p. 563.

§ Physical Geography of the Sea, 1860, pp. 194–196.

|| Transactions of Bombay Geographical Society, vol. ix. p. 39.

the surface inflow; and (2) to determine, by the *Temperature*, the *Specific Gravity*, and the *Composition* of samples of water taken up at different points and from different depths, whether they had been drawn from the Atlantic or from the Mediterranean basin.—The *mechanical* method was entirely devised and carried out, with the practical ability for which he is eminently distinguished, by our excellent friend Staff-Captain Calver (see § 37). The *physical* and *chemical* observations, which were made under our own direction, gave results which harmonize completely with those of the mechanical, where both could be employed together; and supply a deficiency which the impossibility of applying the mechanical test on the uneven bottom of the shallow ridge would otherwise have left, in the proof of the outflow of Mediterranean water over it.

115. Our investigations were first made in the mid-stream between Gibraltar and Ceuta, at nearly the narrowest part of the Strait, where its depth exceeds 500 fathoms (Chart II. Section C D). The decided retardation of the boat by the "current-drag" at 100 fathoms in both sets of experiments (§§ 40, 62) showed that the in-current at that depth has *less than half* the velocity of the surface-current. When the "current-drag" was lowered to 250 fathoms, there was in the First set of experiments simply a further increase of retardation, the boat being kept almost in a stationary position: we felt justified, however, in inferring that the strain of the "current-drag" could not have so nearly neutralized the action not only of the surface-current, but also of the wind, upon the boat from which it was suspended, if it had not been itself acted on by a counter-current. And this view derived very strong confirmation from the evidence afforded by the Temperature, the Specific Gravity, and the Density of the water in the 250 fathoms' stratum. For, in the first place, the surface-temperature being 66°, and the temperature at 100 fathoms having fallen to 55°·7, no further reduction showed itself below that stratum; the water at 250 fathoms, like the bottom-water at 517 fathoms, having exactly the same temperature as the water at 100 fathoms. This, as we have seen, is the uniform rule in the Mediterranean, whilst far otherwise in the Atlantic. Further, the Specific Gravity and the proportion of Salt in the water at 250 fathoms indicated a density which no Atlantic water possesses, and which was not exceeded in any sample obtained from the Mediterranean. There could be no question, therefore, that the stratum at 250 fathoms must be Mediterranean water; so that, if not absolutely stationary, it must be moving westwards. Now this westerly movement was distinctly demonstrated in our Second set of experiments, by the motion of the boat from which the "current-drag" was suspended (§ 62); and since the observations on the Temperature, Specific Gravity, and Salinity of the water in this stratum, which were then repeated, gave results almost precisely identical with those made on the previous occasion, it seems fair to conclude that there was a westerly current in this stratum in the First, as well as in the Second instance, though its effect on the current-drag was masked by the stronger antago-

nistic forces acting on the boat.—The same observations apply to the 400 fathoms' stratum. In the First set of experiments, the boat moved *with* the surface-current, but at little more than *a quarter* its rate; and this retardation, taken in connection with the distinct Physical and Chemical indications that the 400 fathoms' stratum was Mediterranean and not Atlantic water, might fairly be taken as evidence that the force acting on the "current-drag" was antagonistic in its direction to the surface-forces acting on the boat, though less powerful than in the 250 fathoms' stratum. This inference also was justified by the results of the Second set of experiments (§ 62), which showed us the boat carried *westwards,* though at a less rate than when the "drag" hung in the 250 fathoms' stratum.—It was not a little remarkable to find in both sets of observations, that the water of this *lower* stratum is of *less* density than that which overlies it at 250 fathoms, though still unmistakably Mediterranean; and it may hence be pretty certainly inferred that the denser *middle* stratum is drawn by current-action from some intermediate part of the Mediterranean basin at which the maximum density prevails (§ 93), and that it is flowing with a gradual upward inclination, so as at last to pass over the ridge at the opposite extremity of the Strait. On no other hypothesis does it seem possible to explain the persistence of this condition,—supposing it to be uniform, as the close conformity of observations made after an interval of six weeks would indicate that it is.

116. Although we should have been very glad to repeat our experiments at some intermediate Section, yet, as our time did not allow of our carrying them out in more than one other locality, we considered it desirable to proceed at once to the western extremity of the Strait, where its breadth greatly increases, whilst its depth is yet more than proportionally reduced. As already stated (§ 66), the bottom is here characterized by great inequalities; channels of from 150 to 190 fathoms' depth existing in the immediate neighbourhood of shallows of not less than 50 fathoms (see Section E F). In accordance with the greater breadth of this part of the Strait, the easterly surface-current flows at a much lower speed than in its narrower channel; its rate being reduced from nearly 3 miles to little more than $1\frac{1}{4}$ mile per hour. The use of the "current-drag" at 100 fathoms from the surface, in a part of the channel of which the depth was 147 fathoms, did not indicate any reduction in this rate; but a decided reduction was shown when the "drag" was lowered to 150 fathoms in a part of the channel of which the depth approached 200 fathoms (§ 67). As Capt. Calver deemed it inexpedient to lower the "current-drag" to a greater depth, since it would have been certain to foul against the rocky bottom, we were unable to ascertain by Mechanical means that the stratum of water *immediately* overlying that bottom has an *outward* movement; but whilst the existence of such an outflow may be regarded as a necessary inference from the existence of a powerful outward undercurrent at the opposite extremity of the Strait, valid evidence of it was afforded by the

fact that both the Temperature and the Density of the bottom-water brought up at two stations (Nos. 65 and 67), from 198 and 188 fathoms respectively, unmistakably indicated its derivation from the Mediterranean basin. Although its density corresponded rather with that of the 400 fathoms' stratum than with that of the 250 fathoms' stratum at the other end of the Strait, yet it may be very well conceived to be the water of the 250 fathoms' stratum reduced in density during its outward flow through the Strait by intermixture with the less dense water of the in-current.

117. It now no longer then admits of doubt that the water of the deeper part of the Mediterranean basin, which has undergone concentration by evaporation, is continually flowing outwards into the Atlantic, notwithstanding that in doing so it has to be brought nearer the surface, so as to pass over the ridge; and that the increase of density in the Mediterranean water, which would otherwise go on without check so long as the loss by evaporation is in excess of the fresh water returned into the basin, is thus kept within a very narrow limit.

118. The essential phenomena of the Gibraltar Current having been thus determined, we have to consider how they are to be accounted for; that is to say, to inquire (1) what is the power which gives motion to the enormous body of water continually flowing from the Atlantic into the Mediterranean; (2) what it is which not only gives motion to the undercurrent flowing from the Mediterranean to the Atlantic, but draws up the heavier water from the depths of the former to the comparative shallow of its limiting ridge; and (3) in what way the power is generated in each case.

119. These questions have been answered—as we believe correctly—by Captain Maury*, on the hypothetical assumption of the existence of an undercurrent, which has now been verified. He shows that in each case *Gravity* is the impelling power; and that in both cases this power originates from a common source—the excess of evaporation beyond the return of fresh water by rain and rivers, which produces at the same time a *reduction of the level*, and an *increase in the density*, of the water within the Mediterranean basin; the former drawing in surface-water by gravitation from the higher level outside, whilst the latter forces out deeper water by the excess of pressure of the superincumbent column. As the *vertical circulation* thus occasioned has not yet, so far as we are aware, been formularized under First Principles, and as these principles have a much more extended application than Capt. Maury himself seems to have supposed, we shall now present them in a systematic form.

120. The following appear to be self-evident propositions:—

I. That wherever there is a difference of *level* between two bodies of Water in free communication with each other, there will be a tendency towards the equalization of their levels by a *surface-flow* from the height towards the lower.

* Physical Geography of the Sea, 1860, pp. 194–196.

II. That so long as the difference of level is maintained, so long will this flow continue; and thus any agency which permanently keeps the level of one body of water below that of the other (unless it directly antagonize the downward pressure of the higher water*), will maintain a permanent surface-flow from the higher towards the lower. This constant *tendency to equalization* will keep the actual difference of level within very narrow limits.

III. That wherever there is a *want of equilibrium* arising from *difference of density* between two columns of water in communication with each other, there will be a tendency towards the restoration of equilibrium by a flow from the *lowest stratum* of the denser column towards that of the lighter, in virtue of the excess of pressure to which the former is subjected.

IV. That so long as the like difference of density is maintained, so long will this flow continue; and thus any agency which permanently disturbs the equilibrium in the same sense, either by increasing the density of one column, or by diminishing that of the other, will keep up a permanent flow from the lower stratum of the denser towards that of the less dense.—This constant *tendency to restoration of equilibrium* will keep the actual difference of density within definite limits.

V. That if there be at the same time a *difference of level* and an *excess of density* on the side of the shorter column, there will be a tendency to the restoration of the *level* by a *surface*-flow *from the higher to the lower*, and a tendency to the restoration of the *equilibrium* by an *under*-flow in the opposite direction *from the heavier to the lighter* column.

VI. That so long as the *difference of level* and the *difference of density* are maintained, in the same sense, so long will each flow continue; and thus a *vertical circulation* will be kept up by any continuous agency which alters at the same time both the *level* and the *density* of the two bodies of water,—provided that the *excess of density* is on the side of the *lower* column.

VII. That the rate of each flow, where it is not confined within definite limits, will depend simply upon the amount of disturbance, in the one case of *level*, and in the other of *density*; and when this disturbance is small, it may be so slow as to be almost imperceptible, though not less real and effective. But if the communication between the two bodies of water take place through a long narrow channel, the rate of movement will increase so as to produce a decided current in each direction; since the

* Thus it has been shown by Archdeacon Pratt, that in consequence of the local attraction produced by the high land of Asia, with nothing but Ocean to the southward, the sea-level at the mouth of the Indus is no less than 515 feet above that at Cape Comorin (Philosophical Transactions, 1859, p. 795). So, again, if Barometric pressure be *lower* over any Oceanic area than on other parts of the surface, there will be an *elevation* of the water-level in that area, equilibrium being reached when the *excess* of Water-pressure becomes equal to the *deficiency* of Air-pressure. (See Mr. T. G. Brent in Philos. Transact. 1867, p. 5.)

moving force will then act as a *constantly accelerating* one, until any further increase in rate is prevented by the opposing influence of friction, &c.

121. Now such an agency as that which is required by Principles VI. and VII. to maintain a double current in a narrow Strait actually exists in the cases of the Mediterranean and the Red Sea. It must be borne in mind in considering these, that whilst their basins are limited, the Ocean-basins at the other end of their respective Straits are practically unlimited; so that the levels and densities of the latter may be regarded as constant. Now as the excess of evaporation in the Mediterranean basin at the same time lowers the level and increases the density of the water which remains, the reduction of the level gives rise to a continual surface-inflow. But, on the other hand, the restoration of the level by an inflow of salt water, the density of the contents of the Mediterranean basin being already in excess, occasions a constant want of equilibrium between the columns of water at the two extremities of the Strait; and as the lighter water of the Atlantic cannot balance the heavier water of the Mediterranean, a portion of the latter is forced outwards as an undercurrent,—thus again producing a depression of the level, to be again restored by a surface-inflow from the Atlantic.—Thus the *original* moving force of both currents is the *heat of the Sun.*

122. The case may perhaps be made still plainer, by considering the effect of changes in its conditions. If the whole amount lost by the evaporation from the surface of the Mediterranean were replaced by the *fresh* water of rain and rivers, there would be neither lowering of its surface nor increase of its density; and there would be neither influx nor efflux through the Strait of Gibraltar. If, again, with the present excess of evaporation, the Atlantic were to supply *fresh* water instead of salt, the influx through the Strait of Gibraltar would be only that required to maintain the level, and thus to supply the loss by excess of evaporation; and as the columns at the two extremities of the Strait would remain in constant equilibrium, there would be no efflux. But as the water which flows in from the Atlantic is salt instead of fresh, and is itself rendered still more dense by concentration in the Mediterranean, the constantly renewed excess in the weight of the Mediterranean column can only relieve itself by as continual an efflux: this efflux, by lowering the surface-level, in its turn occasions an indraught to maintain it; and thus the in-current has to replace not only the fresh water lost by excess of evaporation, but also the denser water forced out by its excess of weight. These two agencies, like the perturbations of the Planets, are so balanced against one another, as to maintain a constant mean. If the evaporation were to increase, more Atlantic water would flow in; but the increase of density in the Mediterranean water would cause more of it to flow out, which again would occasion a larger indraught of the less dense water of the Atlantic. And thus the excess of density would be kept down to a very moderate amount,—as is actually found to be the case in the Red Sea, notwithstanding that the enormous

loss by evaporation from its surface is scarcely at all replaced by fresh water either from rain or rivers.

123. Now if it can be shown that a similar *vertical circulation* is maintained in the opposite direction, when the conditions of the case are altogether reversed, the explanation above given may, it is submitted, be regarded as having a valid title to acceptance. Such a converse case is presented by the Baltic, an inland basin which communicates with the German Ocean by three channels—the Sound, the Great Belt, and the Little Belt—of which the Sound is the principal. The amount of fresh water discharged into the Baltic is largely in excess of the quantity lost from its surface by evaporation; and thus its *level* would be continually *raised*, if it were not kept down by a constant surface-current, which passes outwards through the channels just mentioned. But the influx of fresh water *reduces* the *density* of the Baltic water; and as the water which the outward current is continually carrying off contains a large quantity of salt, there would be a progressive reduction of that density, so that the basin would at last come to be filled with *fresh* water, if it were not for a deeper inflow. Such an inflow of denser water might be predicted on Principle VI. as a Physical necessity, arising from the constant want of equilibrium between the *lighter* column at the Baltic end of the Sound and the *heavier* column at its outlet in the German Ocean; and that such an undercurrent *into* the Baltic has an actual existence, was proved two hundred years ago by an experiment of the same kind as that by which we have recently proved the existence of an undercurrent *out of* the Mediterranean. This experiment is cited by Dr. Smith (*loc. cit.*) in his discussion of the Gibraltar Current, as supplying an analogical argument for his hypothesis of the existence of an undercurrent in the Strait of Gibraltar; but he does not make any attempt to assign a Physical cause for the movement in either case*.—The condition of the Euxine is precisely parallel to that of the Baltic; and a surface-current is well known to be constantly flowing outwards through the Bosphorus and the Dardanelles, carrying with it (as in the case of the Baltic) a large quantity of salt. Now as the enormous volume of fresh water discharged into the Euxine by the Danube, the Dnieper, and the Don would in time wash the whole of the salt out of its basin, it is obvious that its density can only be maintained at its constant amount (about two-fifths that of ordinary sea-water) by a continual inflow of denser water from the Ægean,—the existence of which inflow, therefore, may be predicted on the double ground of *à priori* and *à posteriori* necessity.

General Oceanic Circulation.

124. The difference as to Level and Density between two bodies of sea-water, which produces the vertical circulation in the Strait of Gibraltar

* Prof. Forchhammer fully confirms Dr. Smith's statement; and further shows that the water which thus returns to the Baltic has the density of Sound water, the surfaces current being formed of the much lighter Baltic water.

and the Baltic Sound, may be brought about otherwise than by the excess of evaporation which maintains it in the one case, or by the continual dilution with fresh water which maintains it in the other. It may be easily shown that a constant and decided *Difference of Temperature* must have exactly the same effect. Let the Mediterranean basin be supposed to be filled with water of the same density as that of the Atlantic, and up to the same level; and to be then cooled down below the freezing-point of fresh water by the withdrawal of Solar heat, whilst the surface of the Atlantic continues to be heated, as at present, by the almost tropical sunshine of the Gibraltar summer. The cooling of the Mediterranean column, reducing its bulk without any diminution of weight, would at the same time lower its level and increase its density. An indraught of Atlantic water must take place through the Strait to restore that level; but this indraught would augment the weight of the column, giving it an excess above that of the column at the other end of the Strait; and to restore the equilibrium a portion of its deeper water must be forced out as an undercurrent towards the Atlantic, thus again reducing the surface-level of the Mediterranean. Now so long as the warm Atlantic water which comes in to maintain that level is in its turn subjected to the same cooling, with consequent lowering of level and increase of density, so long would the vertical pressures of the two columns, which would be speedily restored to equilibrium if both basins were subjected to the same heat or the same cold, remain in a constant state of inequality; and so long, therefore, on Principles V. & VI. (§ 120), must this *vertical circulation* continue.

125. Now the case thus put hypothetically has a real existence. For the Mediterranean cooled down by the withdrawal of Solar heat, let us substitute the Polar Basin; and for the Atlantic, the Equatorial Ocean. The antagonistic conditions of Temperature being constantly sustained, a constant interchange between Polar and Equatorial waters, through the seas of the Temperate Zone, must be the result. The reduction in the temperature of the Polar column must diminish its height whilst augmenting its density; and thus a flow of the upper stratum of Equatorial water must take place towards the Poles, to maintain the level thus lowered. But when the column has been thus restored to an equality of *height*, it will possess such an excess of *weight* that its downward pressure must force out a portion of its deeper water; and thus an underflow of ice-cold water will be occasioned from the Polar towards the Equatorial areas.

126. The agency of Polar Cold will be exerted, not merely in reducing the bulk of the water exposed to it, and thereby at the same time *lowering its level* and *increasing its density*, but also in imparting a *downward movement* to each new surface-stratum as its temperature is reduced, whereby a continual indraught will be occasioned from the warmer surface-stratum around. For the water thus newly brought under the same cooling influence will descend in its turn; and thus, as the lowest stratum will

be continually flowing off, a constant motion from above downwards will continue to take place in the entire column, so long as a fresh stratum is continually being exposed to the influence of surface-cold.

127. On the other hand, the agency of Equatorial Heat, though directly operating on only a thin film of surface-water, will gradually pump-up (so to speak) the Polar water which has reached its area by creeping along the deepest parts of the intermediate Oceanic basins. For since, as already shown, an indraught of the upper stratum surrounding the Polar basin must be continually going on, the place of the water thus removed must be supplied by water drawn from a still greater distance; and thus the movement will be propagated backwards, until it affects the upper stratum of the Equatorial area itself, which will flow off Pole-wards, bearing with it a large measure of Heat. The cold and dense Polar water, as it flows in at the bottom of the Equatorial column, will not directly take the place of that which has been draughted off from the surface; but this place will be filled by the rising of the whole superincumbent column, which, being warmer, is also lighter than the cold stratum beneath. Every new arrival from the Poles will take its place below that which precedes it, since its temperature will have been less affected by contact with the warmer water above it. In this way an *ascending movement* will be imparted to the whole Equatorial column, and in due course every portion of it will come under the influence of the surface-heat of the Sun. This heat will of course raise the level of the Equatorial column, without augmenting its absolute weight; and will thus add to the tendency of its surface-stratum to flow towards the lowered level of the Polar area. But as the *super*-heating extends but a short way down, and as the temperature of the water beneath, down to the "stratum of intermixture" (§ 80), is very moderate, whilst the water below that stratum is almost as cold as that of the Polar basin, it is evidently in the latter that the force which maintains this *vertical circulation* chiefly originates.

128. Here, then, we have a *vera causa* for a General Oceanic Circulation, which, being sustained only by the unequal distribution of Solar Heat, will be entirely independent of any peculiar distribution of Land and Water, provided always that this does not prevent the free communication between the Polar and Equatorial Oceanic areas, at their depths as well as at their surface. That this agency has been so little recognized by Physical Geographers, we can only attribute to the prevalence of the erroneous idea of the uniform deep-water temperature of 39°, of which the Temperature-observations made in our Expeditions of 1868 and 1869 have shown the fallacy. Until it is clearly apprehended that *Sea-water becomes more and more dense as its temperature is reduced*, and that it consequently continues to sink until it freezes, the immense motor power of Polar Cold cannot be apprehended; but when once this has been clearly recognized, it is seen that the application of *cold at the surface* is, in the case of Sea-water, precisely equivalent as a moving force

to the application of *heat at the bottom*, the motor power of which is universally admitted,—being practically utilized in keeping up the circulation through the hot-water Warming-Apparatus now in general use *. The movement thus maintained would not, on the hypothesis, be a rapid one, but a gradual *creeping* flow; since the absence of limit would prevent the power which sustains it from acting as an *accelerating force*, as it would do if the Equatorial and Polar areas were connected only by a narrow channel, like the Atlantic Ocean and the Mediterranean Sea (§ 120, Princ. VII.).

129. That the Vertical Circulation here advocated on *à priori* grounds actually takes place in any mass of Salt water of which one part is exposed to surface-Cold and another to surface-Heat, is capable of ready experimental proof:—Let a long narrow trough with glass sides be filled with salt water; and let heat be applied at one end (the Equatorial) by means of a thick bar of metal laid along the surface, with a prolongation carried over the end of the trough into the flame of a spirit-lamp; whilst cold is applied at the other (the Polar) by means of a freezing-mixture contained in a metallic box made to lie upon the surface, or (more simply) by means of a piece of ice wedged in between the sides of the trough. A circulation will immediately commence in the direction indicated by the theory; as may be readily shown by introducing some *blue* colouring liquid at the Polar surface, and some *red* liquid at the Equatorial surface. The blue liquid, as it is cooled, at once descends to the bottom, then travels slowly along it until it reaches the Equatorial end of the trough, then gradually rises towards the heated bar, and thence creeps along the surface back to the Polar end; the red liquid first creeps along the surface towards the Polar end, and then travels through exactly the same course as the blue had previously done †.

130. That such a Vertical Circulation really takes place in Oceanic Water, and that its influence in moderating the excessive Cold of the Polar Areas and the excessive Heat of the Equatorial region is far more important than that of any surface-currents, seems to us a legitimate deduction from the facts stated in the Report of the 'Porcupine' Expedition for 1869. For, on the one hand, it was shown (§§ 116–118) that there is a general diffusion of an almost glacial temperature on the bottom of the deep Ocean-basins,

* The only scientific writer who has even approached what appears to us the truth on this point is Captain Maury, who has put forward the doctrine of a general interchange of water between the Equator and the Poles, resulting from a difference of Specific Gravity caused *inter alia* by difference of Temperature. But, as Mr. Croll remarks, "although Capt. Maury has expounded his views on the cause of Ocean-currents at great length in the various editions of his work, yet it is somewhat difficult to discover what they really are. This arises from the generally confused and sometimes contradictory nature of his hydrodynamical conceptions." See Mr. Croll's Paper "On the Physical Cause of Ocean-currents" in the Philosophical Magazine for October, 1870.

† This experiment has been exhibited, by the kindness of Prof. Odling, at the Royal Institution and at the Royal Geographical Society.

which, at depths exceeding 1000 fathoms, are occupied by Polar water, more or, less diluted by admixture according to the length of the course it has had to travel; whilst between this stratum and that other stratum of warmer water which (on the hypothesis) is slowly moving Pole-wards, there is a "stratum of intermixture," in which there is such a rapid change of Temperature as might be expected from the relation of the upper and lower masses of water. This "stratum of intermixture" showed itself in a most marked manner in the Atlantic Temperature-observations of the present Expedition (§ 80); the descent of the Thermometer, which had been very slow with increase of depth between 100 and 800 fathoms, becoming suddenly augmented in rate; so that between 800 and 1000 fathoms it fell *nine degrees*, namely from 49°·3 to 40°·3.

131. On the other hand, it was shown in the previous Report (§§ 119–121) that there is evidence of the slow Pole-ward movement of a great upper stratum of Oceanic Water, carrying with it a warm temperature; which movement cannot be attributed to any such local influences as those which produce the Gulf-stream or any other currents put in motion by *surface*-action. Of such a movement, it was contended, we have a marked example in that north-easterly flow which conveys the warmth of Southern latitudes to the West of Ireland and Scotland, the Orkney, Shetland, and Faroe islands, Iceland, Spitzbergen, and the Polar basin generally. This flow, of whose existence conclusive evidence is derived from observations of the Temperature of these regions, is commonly regarded as a prolongation of the Gulf-stream; and this view is maintained not only by Dr. Petermann*, who has recently collected and digested these observations with the greatest care, but also by Prof. Wyville Thomson †, as well as by Mr. Croll ‡. Having elsewhere fully stated our objections to this doctrine, and discussed the validity of the arguments adduced in support of it §, we shall here only record the conclusions which a careful examination of the present state of our knowledge of the subject has led us to form:—

I. That there is no evidence, either from the Surface-temperature of the Sea or from the temperature of sea-bord Stations along the western coast of Southern Europe, that the Climate of that region is ameliorated by a flow of Ocean-water having a temperature higher than that of the Latitude,—the surface-temperature of the Mediterranean Sea, which is virtually excluded from all Oceanic Circulation, being higher than that of the eastern margin of the Atlantic in corresponding latitudes, and the Climate of sea-bord Stations on the Mediterranean being warmer than that of Stations corresponding to them in Latitude on the Atlantic Coast; and this not merely in summer, but also in winter. This Oceanic region may therefore be designated the *neutral area*.

* Geographische Mittheilungen, 1870, p. 201.

† Lecture "On Deep-sea Climates," in Nature, July 28, 1870.

‡ Memoir "On the Physical Cause of Ocean-Currents," in Phil. Mag. Oct. 1870.

§ Proceedings of the Royal Geographical Society, for Jan. 9, 1871.

II. That the evidence of Climatic amelioration increases in proportion as we pass Northwards from the *neutral area*, becoming very decided at the Orkney, Shetland, and Faroe islands; but that, as was shown by the 'Porcupine' Temperature-soundings of 1869, the flow of warm water which produces this amelioration extends to a depth of at least 700 fathoms.

III. That this deep stratum of Warm water can be shown, by the correspondence in the rate of its Diminution of Temperature with depth, to be derived from the neutral area to the south-west; where, as is shown by the 'Porcupine' temperature-soundings of 1870, it is separated by a distinct "stratum of intermixture" from the deeper stratum that carries Polar waters towards the Equator.

IV. That the slow north-easterly movement of such a mass of water cannot, on any known Hydrodynamical principles, be attributed to propulsive power derived from the Gulf-stream; the last distinctly traced edge of which is reduced to a stratum certainly *not exceeding* 50 fathoms in depth, and not improbably less.

V. That, on the other hand, this slow Pole-ward movement of the upper warm layer of the North Atlantic, down to the "stratum of intermixture," is exactly what might be expected to take place as the *complement* of the flow of glacial water from the Polar to the Equatorial area, the two movements constituting a General *vertical* Oceanic Circulation.

VI. That there is a strong probability that the quantity of Water discharged by the Gulf-stream has been greatly over-estimated, in consequence of the rate of the surface-current having been assumed as the rate of movement through the whole sectional area, which is contrary to all analogy; whilst there is also a strong probability that there is a *reverse* undercurrent of *cold* water through the Narrows, derived from the Polar current that is distinctly traceable nearly to its mouth. The upper stratum of this southerly current comes to the surface between the Gulf-stream and the coast of the United States; whilst its deeper and colder stratum underlies the Gulf-stream itself *.

VII. That there is a strong probability that the quantity of Heat carried off by the water of the Gulf-stream has been greatly over-estimated; the Temperature-soundings taken during the Cruise of the 'Porcupine' in the Mediterranean having shown that the very high temperature of the surface extends but a little way down, whilst the Temperature-observations in the Atlantic show that the descent into a cold stratum beneath

* That there is a slow southerly movement of Arctic water beneath the Gulf-stream is indicated by the fact that icebergs have been seen moving southwards in direct opposition to its surface-flow, their deeply immersed portion presenting a larger surface to the lower stratum than their upper part does to the more superficial layer,—as in the case of our "current-drag." And similar evidence is afforded by the southward drift of the buoy which was attached to the Atlantic Cable of 1865, but which broke away from it, apparently carrying with it a great length of the wire rope by which it had been attached.

may be very rapid. Hence the average of 65° assumed by Mr. Croll on the basis of observations made at considerable intervals of depth is altogether unreliable.

VIII. That the most recent and trustworthy observations indicate that the edge of the Gulf-stream to the north-east of the Banks of Newfoundland, is so thinned out and broken up by interdigitation with Polar currents, that its existence *as a continuous current* beyond that region cannot be proved by observations, either of Temperature or Movement.

IX. That the Gulf-stream and other local currents put in motion by the Trade-winds or other influences acting on the *surface* only, will have as *their* complement in a *horizontal* circulation return *surface*-currents; and that the horizontal circulation of which the Atlantic Equatorial Current and the Gulf-stream constitute the first part, is completed—so far as the Northern Hemisphere is concerned—partly by the direct return of one large section of the Gulf-stream into the Equatorial Current, and, as to the other section, by the *superficial* Polar currents, which make their way southwards, the principal of them even reaching the commencement of the Gulf-stream.

132. In conclusion it may be added that the doctrine of a General Vertical Oceanic Circulation is in remarkable accordance with the fact now placed beyond doubt by the concurrent evidence of a great number of observations, that whilst the Density of Oceanic water, which is lowest in the Polar area, progressively increases as we approach the Tropics, it again shows a decided reduction in the Intertropical area. It has been thought that an explanation of this fact is to be found in the large amount of rainfall, and of inflow of fresh water from great rivers, in the Intertropical region; but it is to be remembered that the surface-evaporation also is there the most excessive; so that some more satisfactory account of the fact seems requisite. Such an explanation is afforded by the doctrine here advocated, the Polar water which flows towards the Equator along the bottom of the ocean-basins being there (so to speak) pumped up and brought to the surface *. And it is not a little confirmatory of the views advanced in this Report, that in a recent elaborate discussion of the facts relating to the Comparative Density of Oceanic Water on different parts of the Earth's surface, the doctrine of a General Vertical Circulation is advocated as affording the only feasible rationale of them †.

* That water of a *lower* should thus underlie water of a *higher* degree of Salinity, in travelling from the Pole to the Equator, is not difficult to account for, when the relative Temperatures of the two strata are borne in mind.

† "Densité Salure et Courants de l'Océan Atlantique," par Lieut. B. Savy, Annales Hydrographiques, 1868, p. 620.

FIRST CRUISE OF THE 'PORCUPINE' (Chart I.).

Station No.	North Latitude.		West Longitude.		Depth in Fathoms.	Surface Temperature, ° Fahr.	Bottom Temperature, ° Fahr.
	°	′	°	′			
1.	48	38	10	15	567	....	....
2.	48	37	10	9	305	61·5	48·5
3.	48	31	10	3	690	....	....
4.	48	32	9	59	717	61·5	45·3
5.	48	29	9	45	100	62·3	51·5
6.	48	26	9	44	358	62·0	50·3
7.	48	18	9	11	93	61·0	51·3
8.	48	13	9	11	257	60·7	50·0
9.	48	6	9	18	539	64·0	48·0
10.	42	44	9	23	81	60·5	53·5
11.	42	32	9	24	332	60·5	51·5
12.	42	20	9	17	128	61·5	52·5
13.	40	16	9	37	220	64·5	52·0
14.	40	6	9	44	469	65·3	51·5
15.	49	2	9	49	722	67·5	49·7
16.	39	55	9	56	994	69·5	40·3
17.	39	42	9	43	1095	68·0	39·7
17*a*.	39	39	9	39	740	67·5	49·3
18.	39	29	9	44	1065	65·0	39·7
19.	39	27	9	39	248	64·7	51·7
21.	38	19	9	30	620	67·3	50·5
22.	38	15	9	33	718	66·3	52·0
23.	37	20	9	30	802	66·5	49·3
24.	37	19	9	13	292	67·5	52·7
25.	37	11	9	7	374	69·7	53·5
26.	36	44	8	8	364	71·7	52·7
27.	36	37	7	33	322	73·0	51·3
28.	36	29	7	16	304	71·5	53·3
29.	36	20	6	47	227	73·3	55·0
30.	36	15	6	52	386	73·0	52·7
31.	35	56	7	6	477	71·3	50·5
32.	35	41	7	8	651	71·5	50·0
33.	35	33	6	54	554	72·0	49·7
34.	35	44	6	53	414	71·7	50·0
35.	35	39	6	38	335	73·5	51·5
36.	35	35	6	26	128	75·0	55·0
37.	35	50	6	0	190	72·0	53·7
38.	35	58	5	26	503	71·7	54·0

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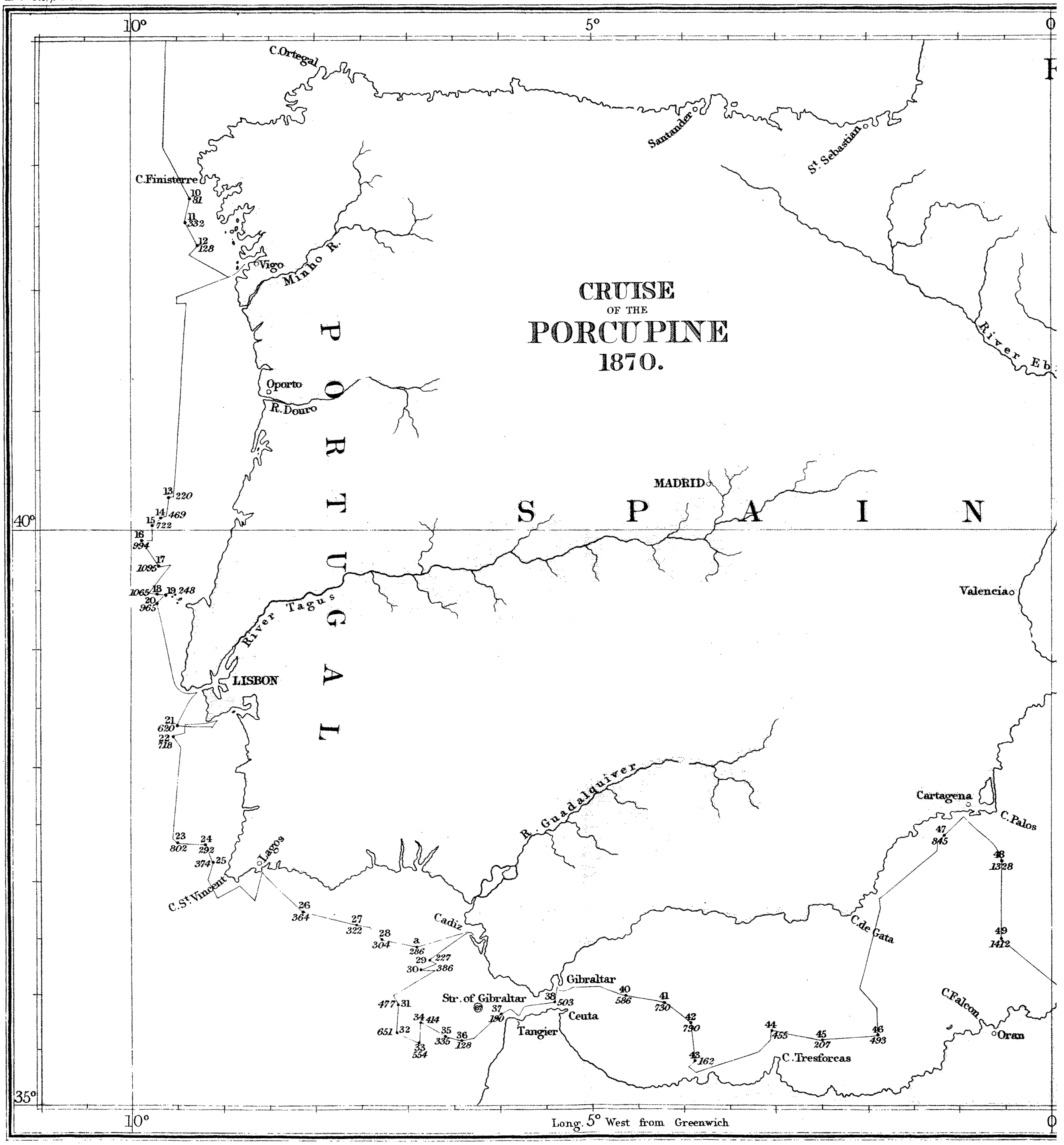

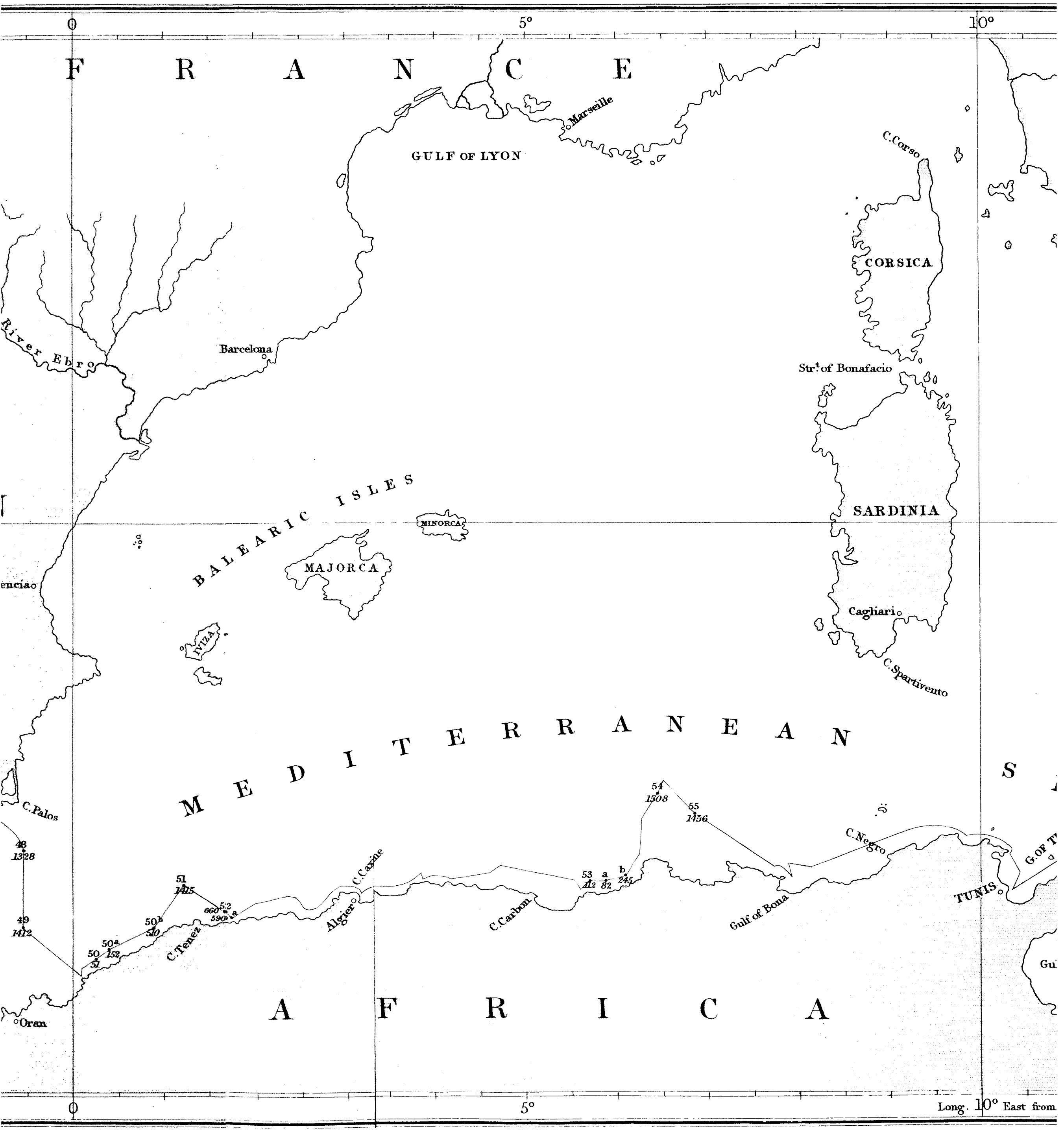

FRANCE
GULF OF LYON
Marseille
C. Corso
CORSICA
Str.t of Bonafacio
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Cagliari
C. Spartivento
River Ebro
Barcelona
BALEARIC ISLES
MINORCA
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MEDITERRANEAN
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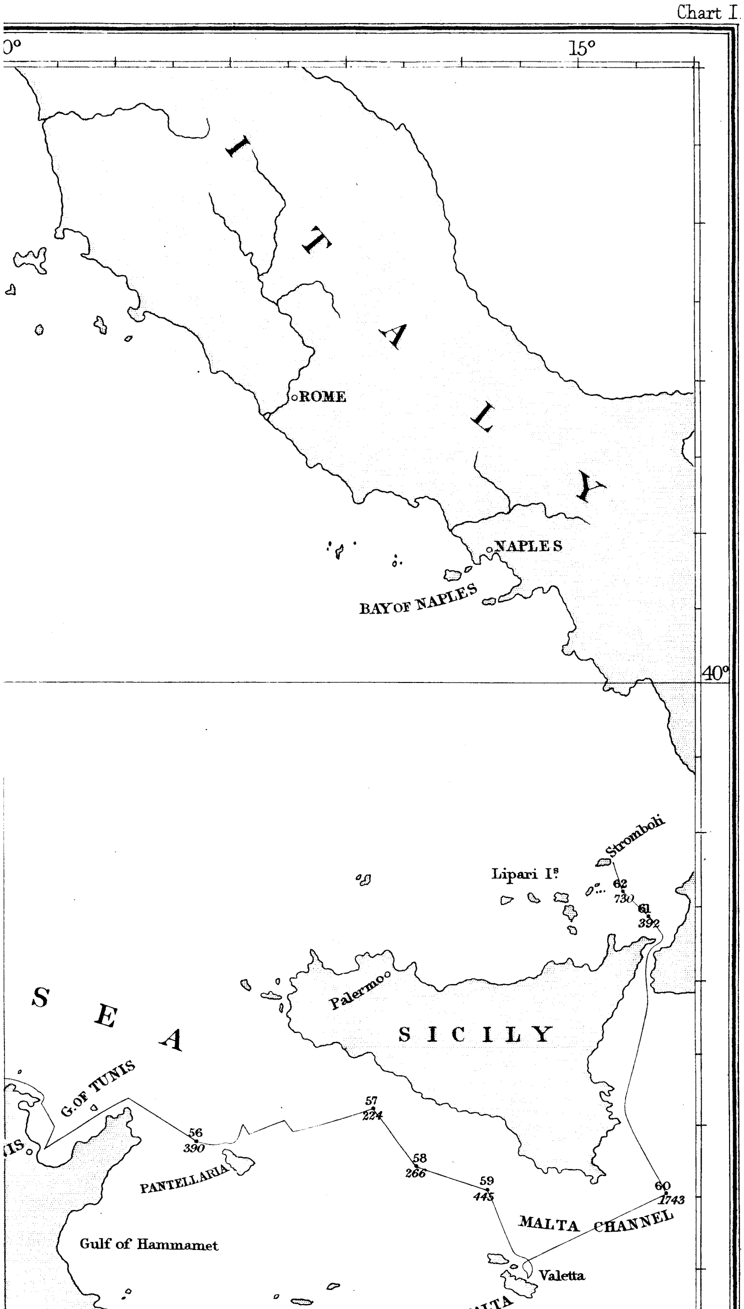
Chart I.



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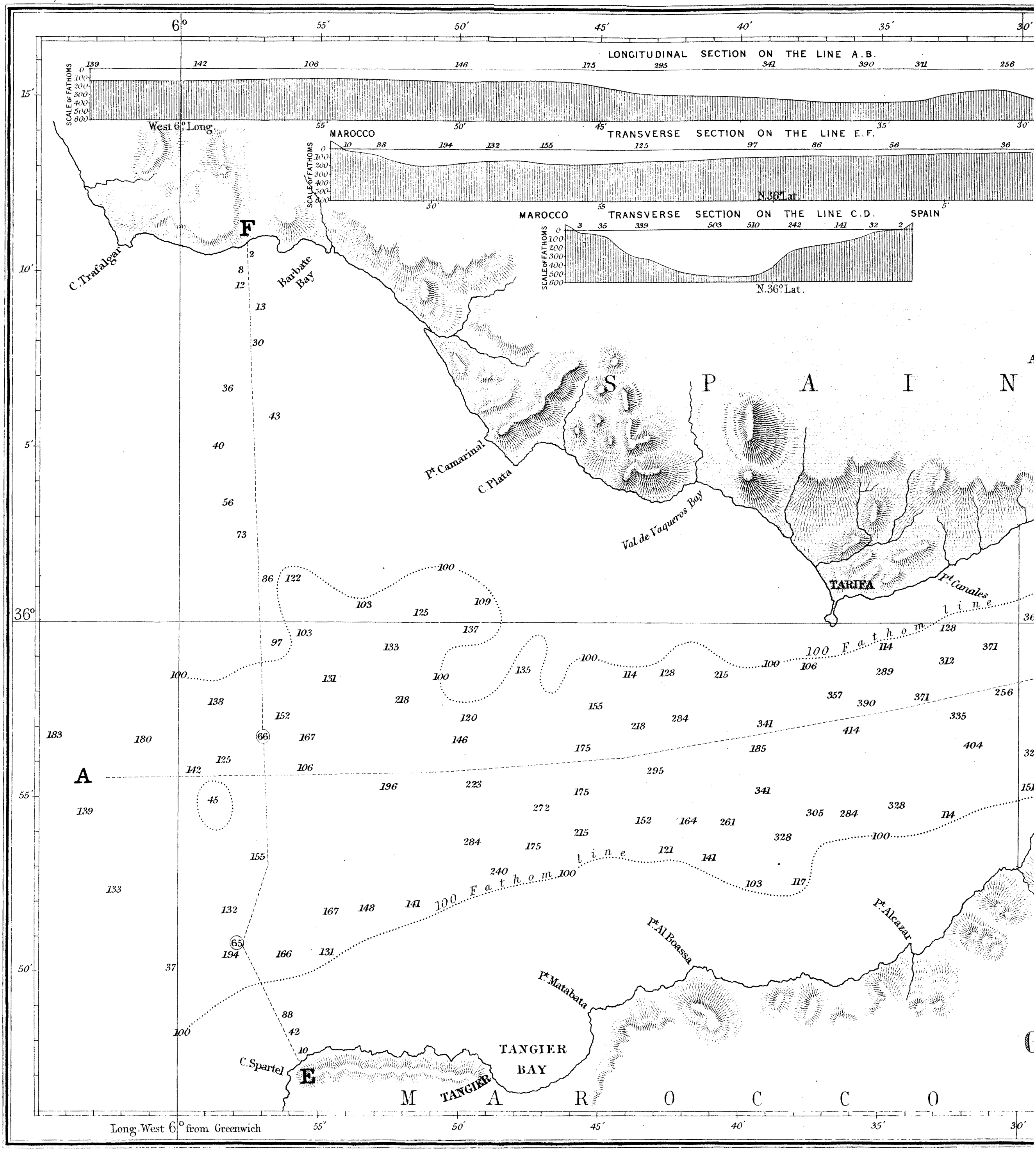

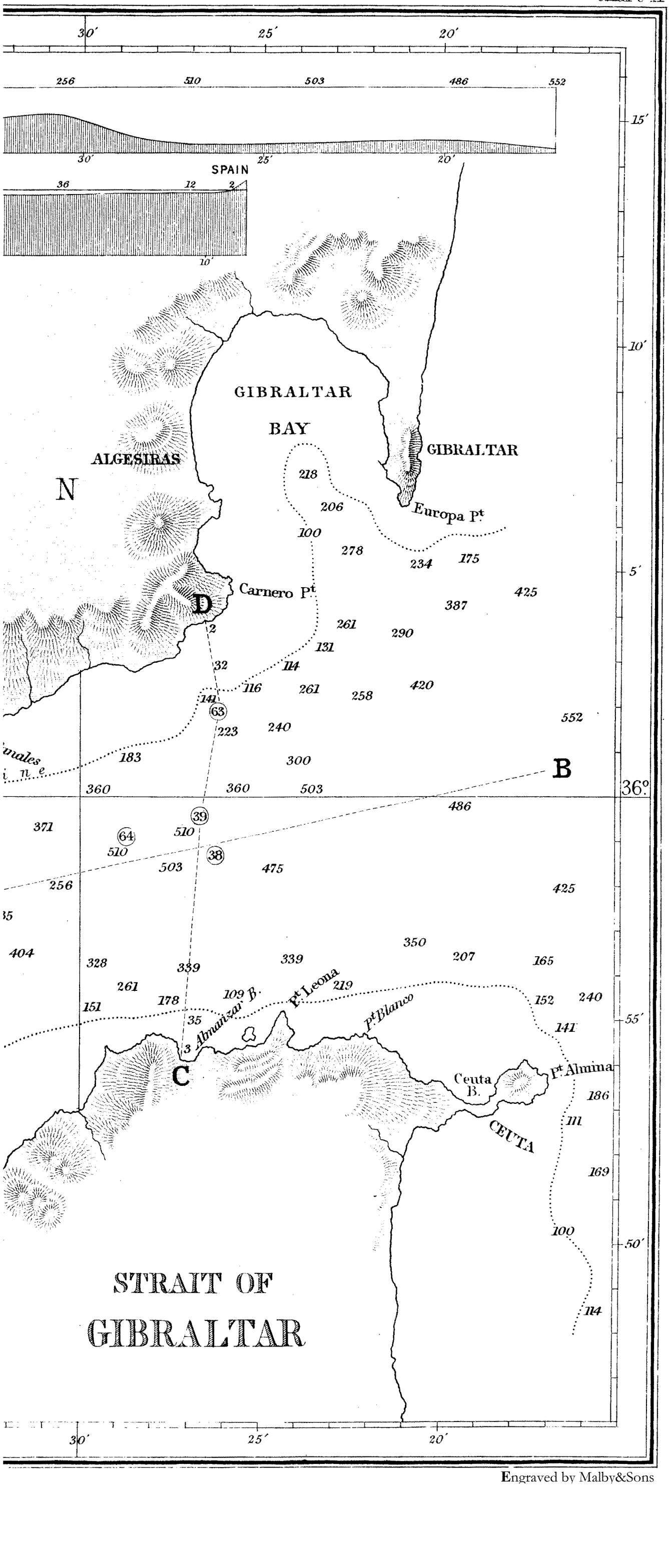

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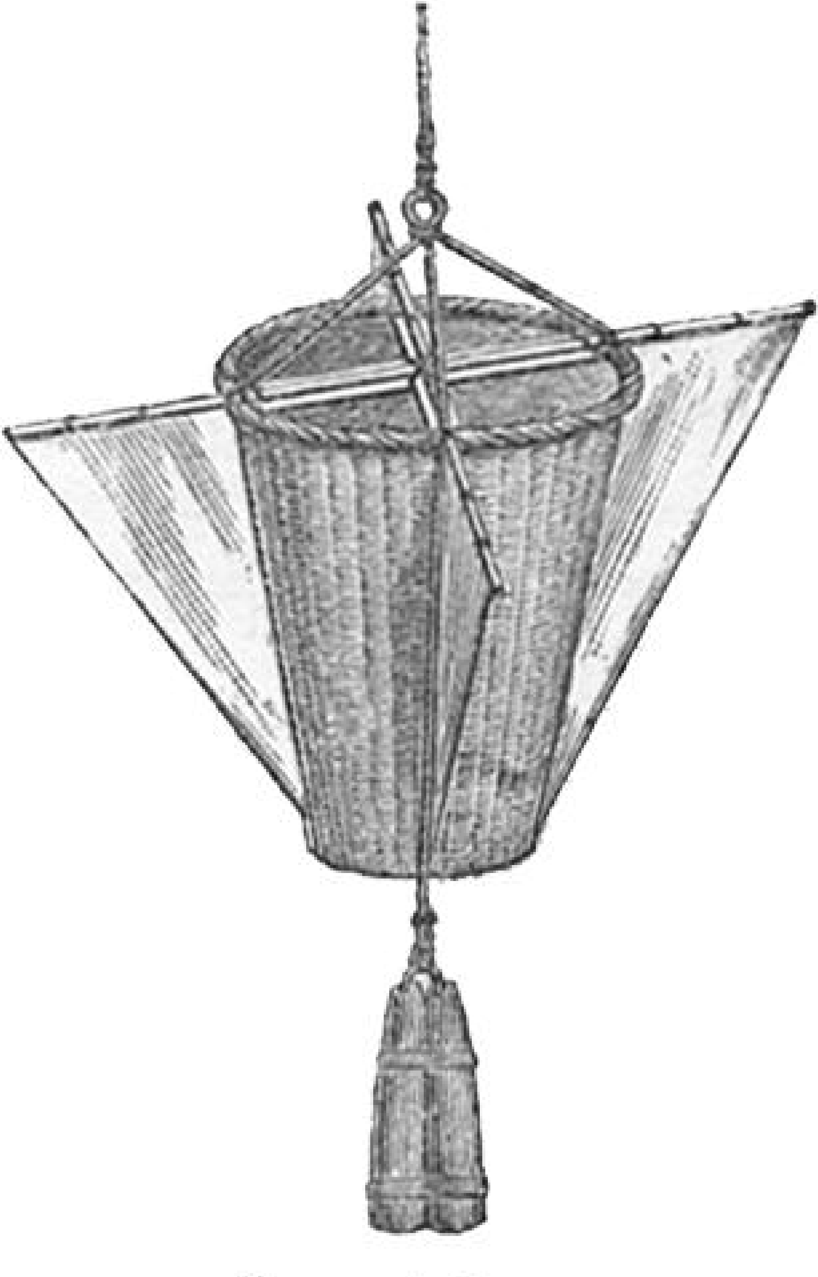
SECOND CRUISE OF THE 'PORCUPINE' (Charts I. and II.).

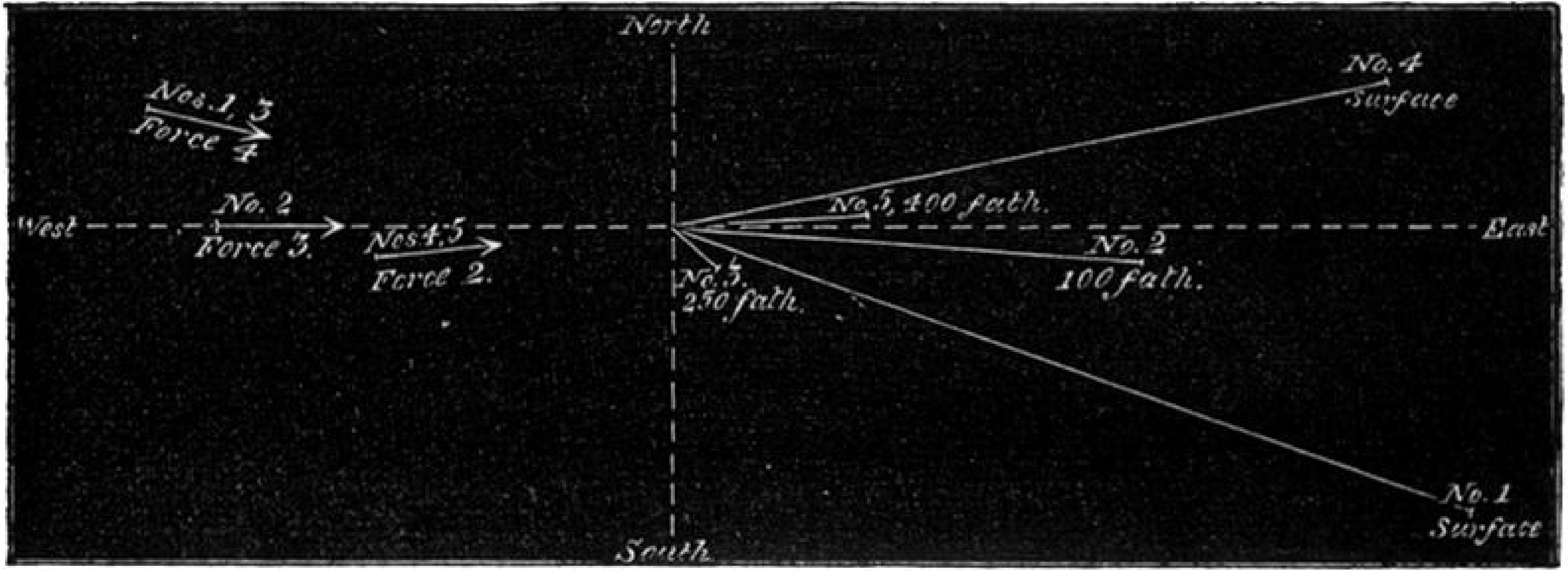
Station No.	North Latitude.	Longitude.	Depth in Fathoms.	Surface Temperature, ° Fahr.	Bottom Temperature, ° Fahr.
39.	35° 59′	5° 27′ W.	517	66·0*	55·5
40.	36 0	4 40 W.	586	74·5	55·0
41.	35 57	4 12 W.	730	74·5	55·0
42.	35 45	3 57 W.	790	74·0	54·0
43.	35 24	3 54 W.	162	74·7	55·0
44.	35 42	3 1 W.	455	70·0	55·0
45.	35 36	2 29 W.	207	72·7	54·7
46.	35 39	1 56 W.	493	73·5	55·5
47.	37 25	1 10 W.	845	69·5	54·7
48.	37 11	0 31 W.	1328	73·5	54·7
49.	36 29	0 31 W.	1412	71·5	54·7
50.	Algerine Coast	....	51	74·4*	
50*a*.			152		
50*b*.			510		
51.	36 55	1 10 E.	1415	75·0	54·7
52.	Algerine Coast	....	660	76·2*	
52*a*.			590		
53.	36 53	5 55 E.	112	77·0	55·5
54.	37 41	6 27 E.	1508	76·0	55·0
55.	37 30	6 51 E.	1456	76·5	55·0
56.	37 3	11 36 E.	390	78·0	56·5
57.	36 6	13 10 E.	224	76·8*	
58.	36 43	13 36 E.	266	75·5	56·5
59.	36 32	14 12 E.	445	76·5	56·5
60.	36 31	15 46 E.	1743	74·0	56·0
61.	38 26	15 32 E.	392	72·5	55·7
62.	38 38	15 21 E.	730	72·5	55·3
63.	Strait of Gibraltar	....	181	68·0	54·7
64.			460	65·6	54·7
65.			198	63·0	54·5
66.			147	69·0	Therm. lost
67.			188	73·0	55·3

* These temperatures are the *averages* of the day.



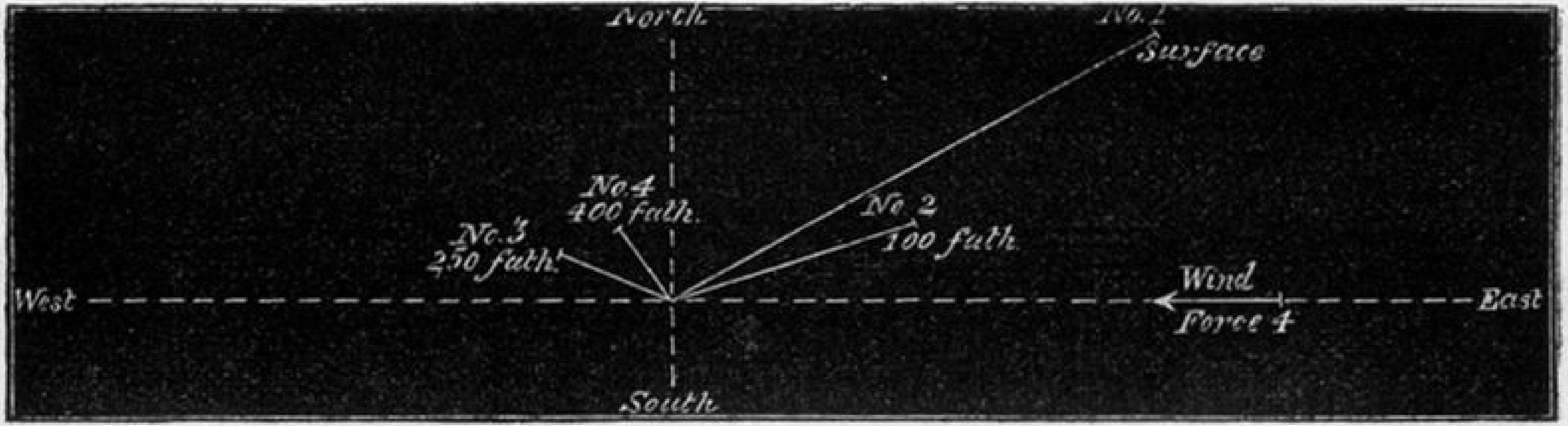
Current-drag.

Station 39.



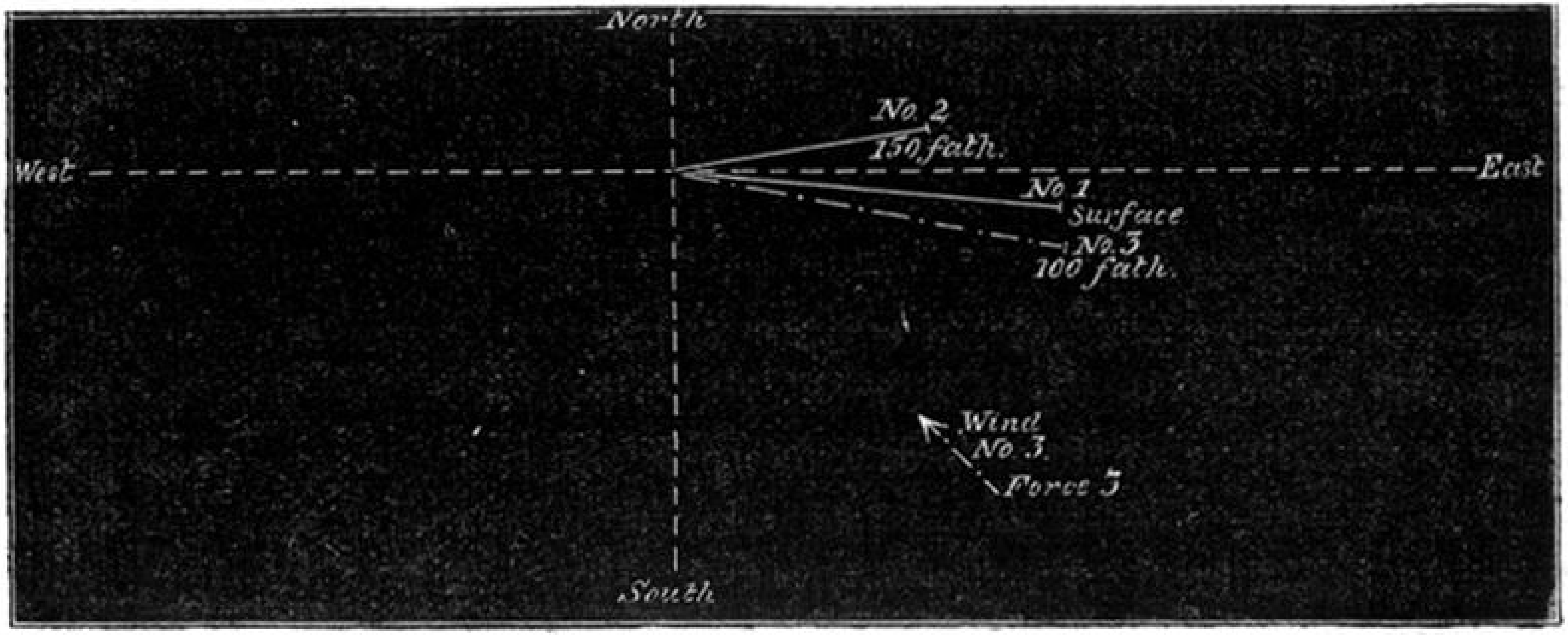
Rate (per hour) and Direction of Movement of Surface-float, and of Current-drag at different Depths; with Force and Direction of Wind.

Station 64.



Rate (per hour) and Direction of Movement of Surface-float and of Current-drag at different Depths; with Force and Direction of Wind.

Stations 65, 66.



Rate (per hour) and Direction of Movement of Surface-float and of Current-drag at different Depths; with Force and Direction of Wind in No. 3. (No Wind in Nos. 1, 2.)

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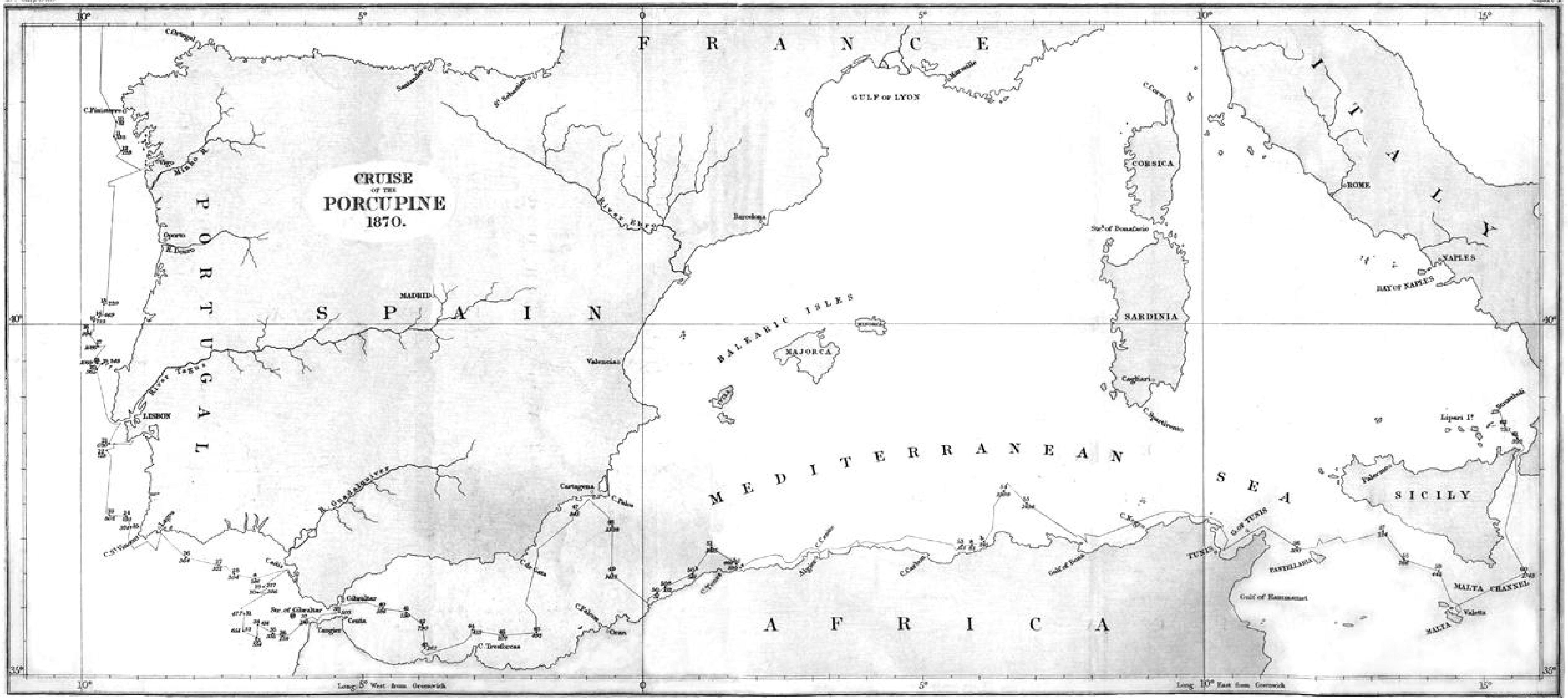
Chart I.



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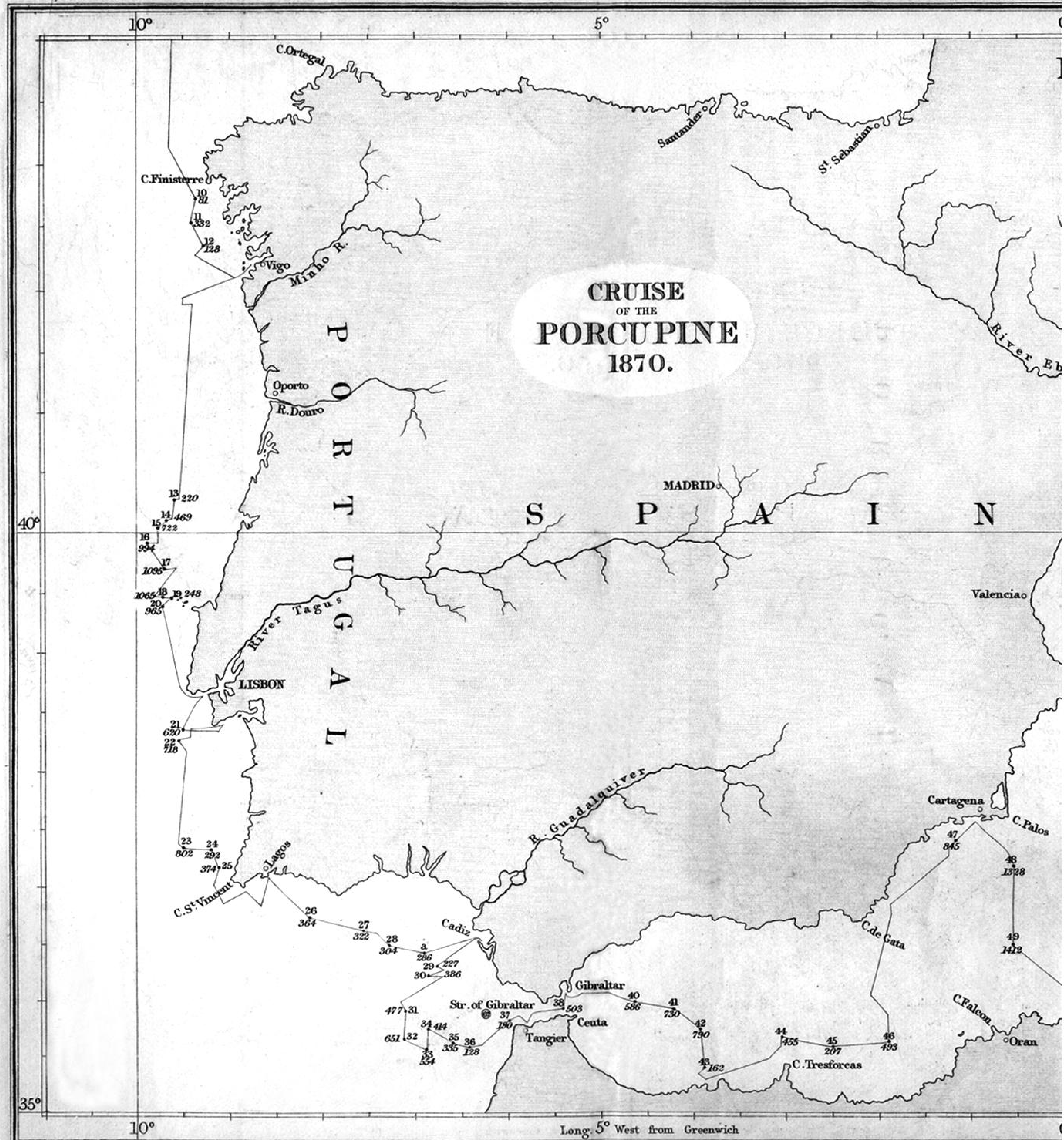

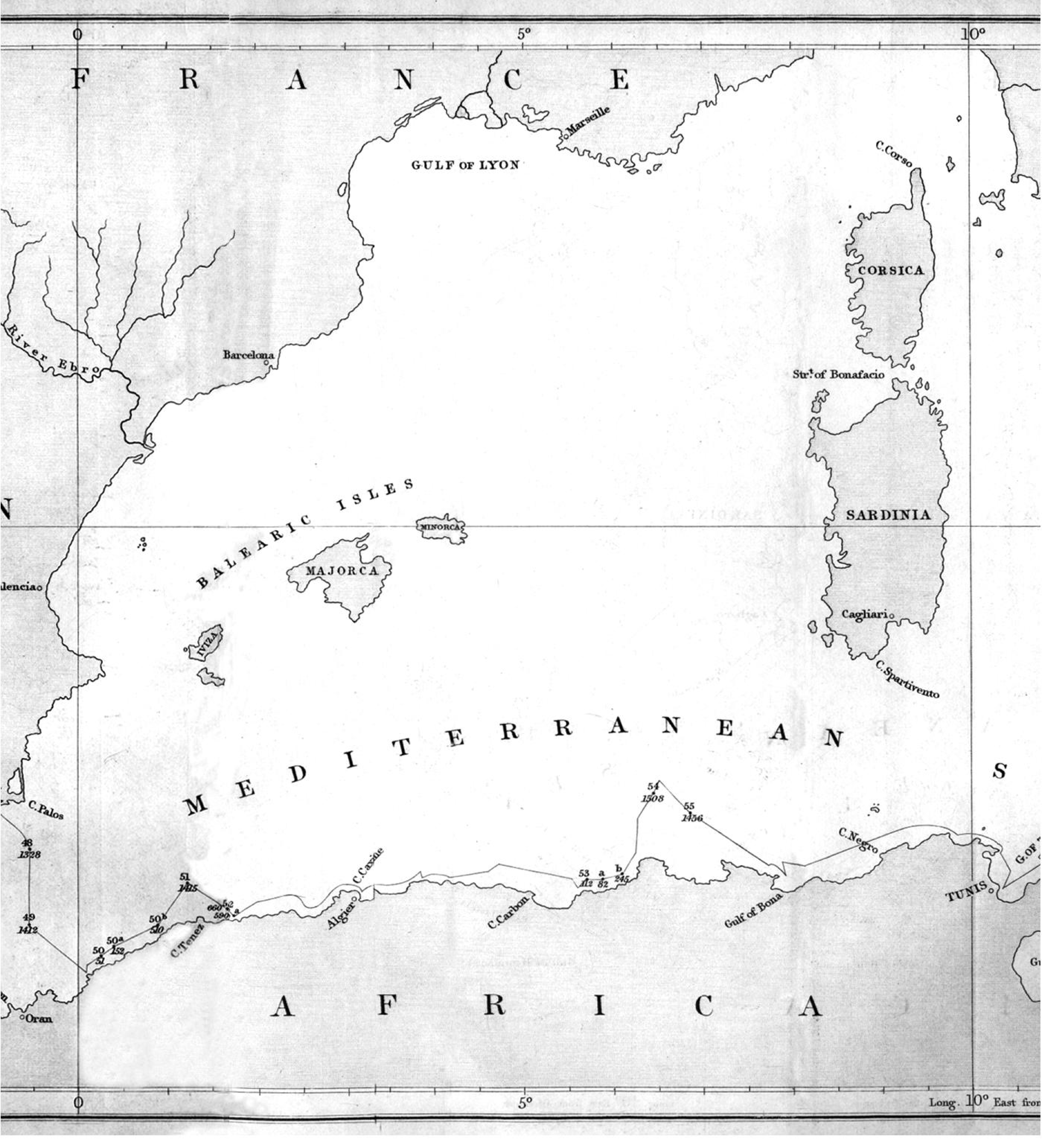

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5°
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GULF OF LYON
C.Corso
CORSICA
River Ebro
Barcelona
Str.t of Bonafacio
SARDINIA
BALEARIC ISLES
MINORCA
MAJORCA
IVIZA
Valencia
Cagliari
C.Spartivento
MEDITERRANEAN S
C.Palos
48
1328
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50b
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51
1415
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660
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a
C.Tenez
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112
a
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b
245
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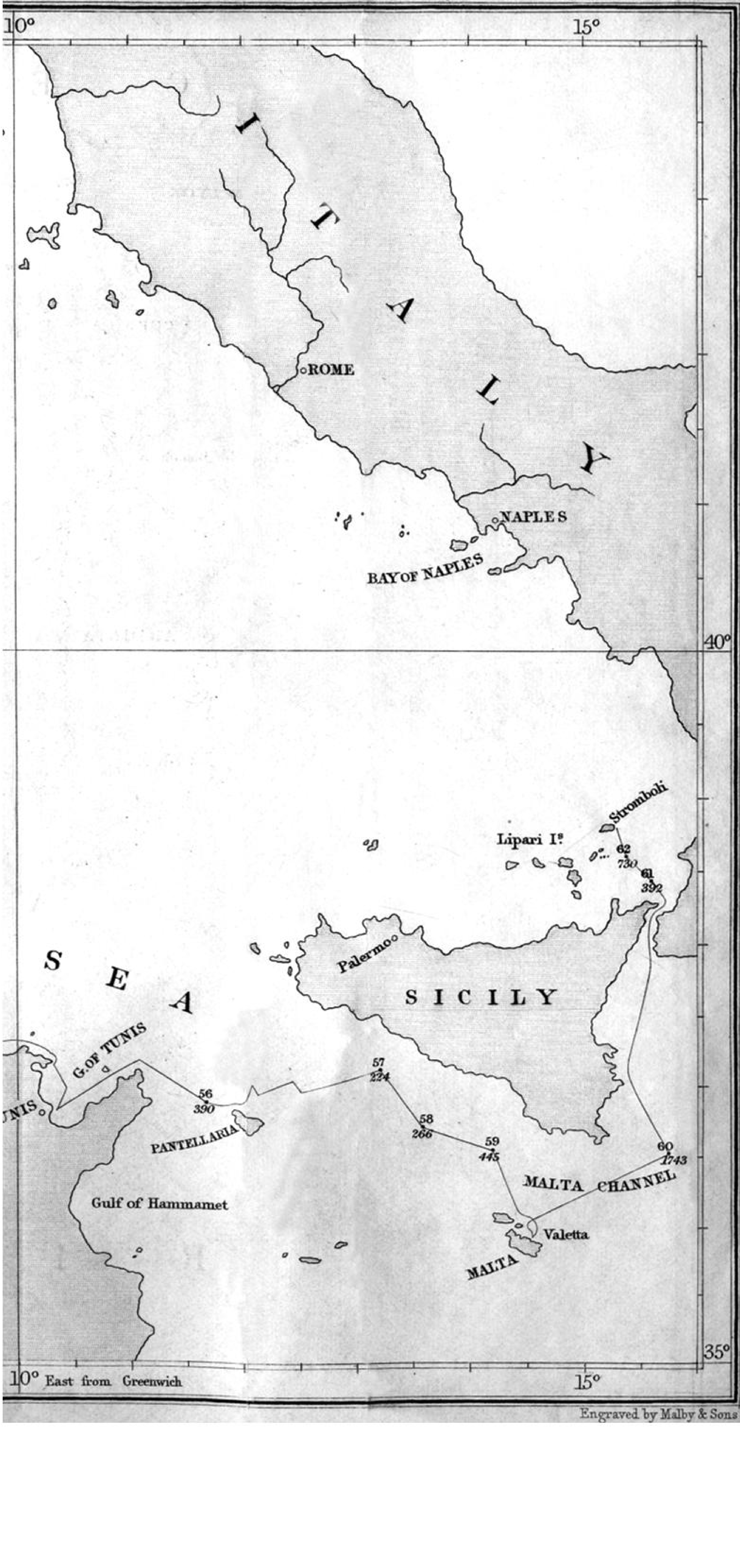
Chart I.



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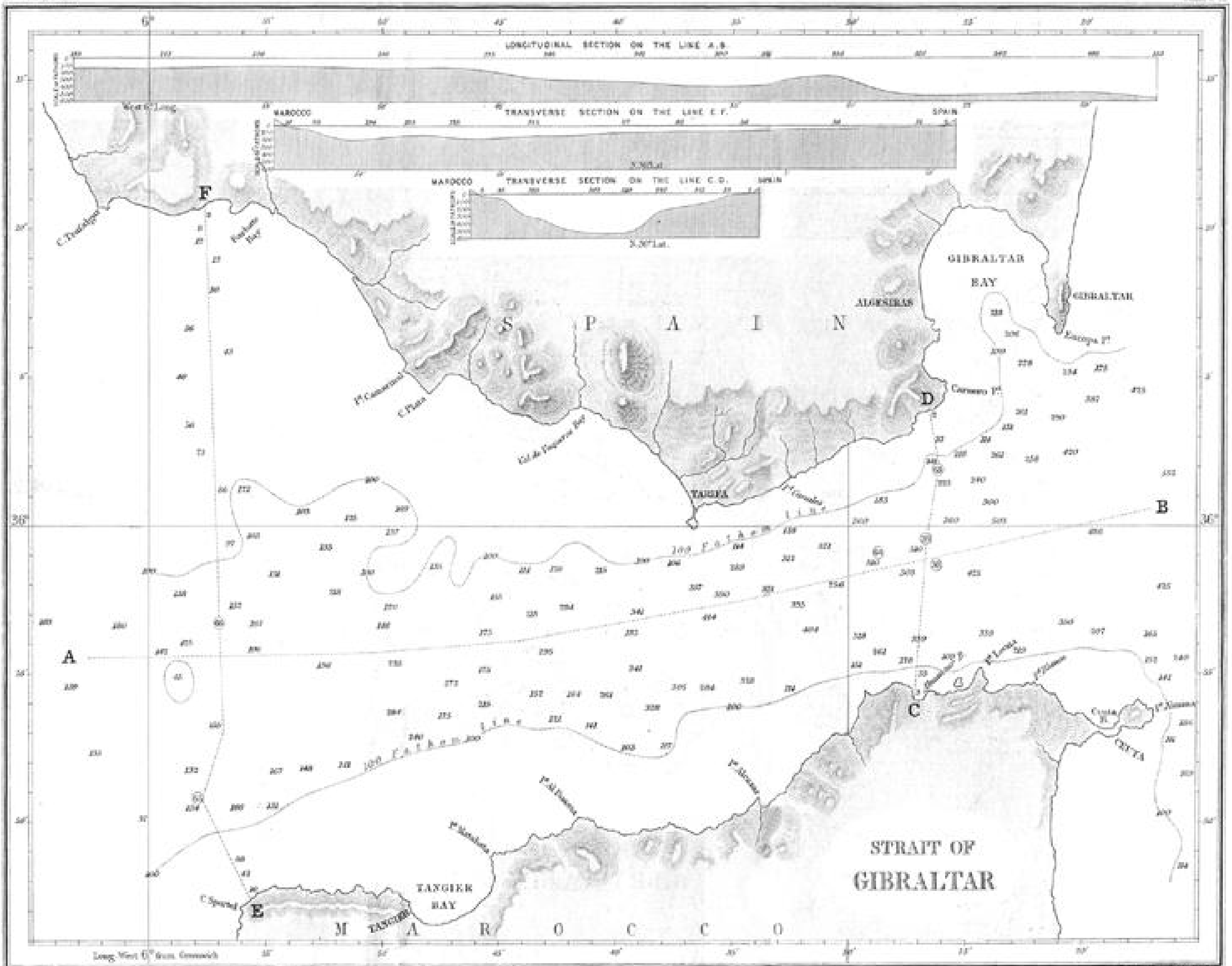

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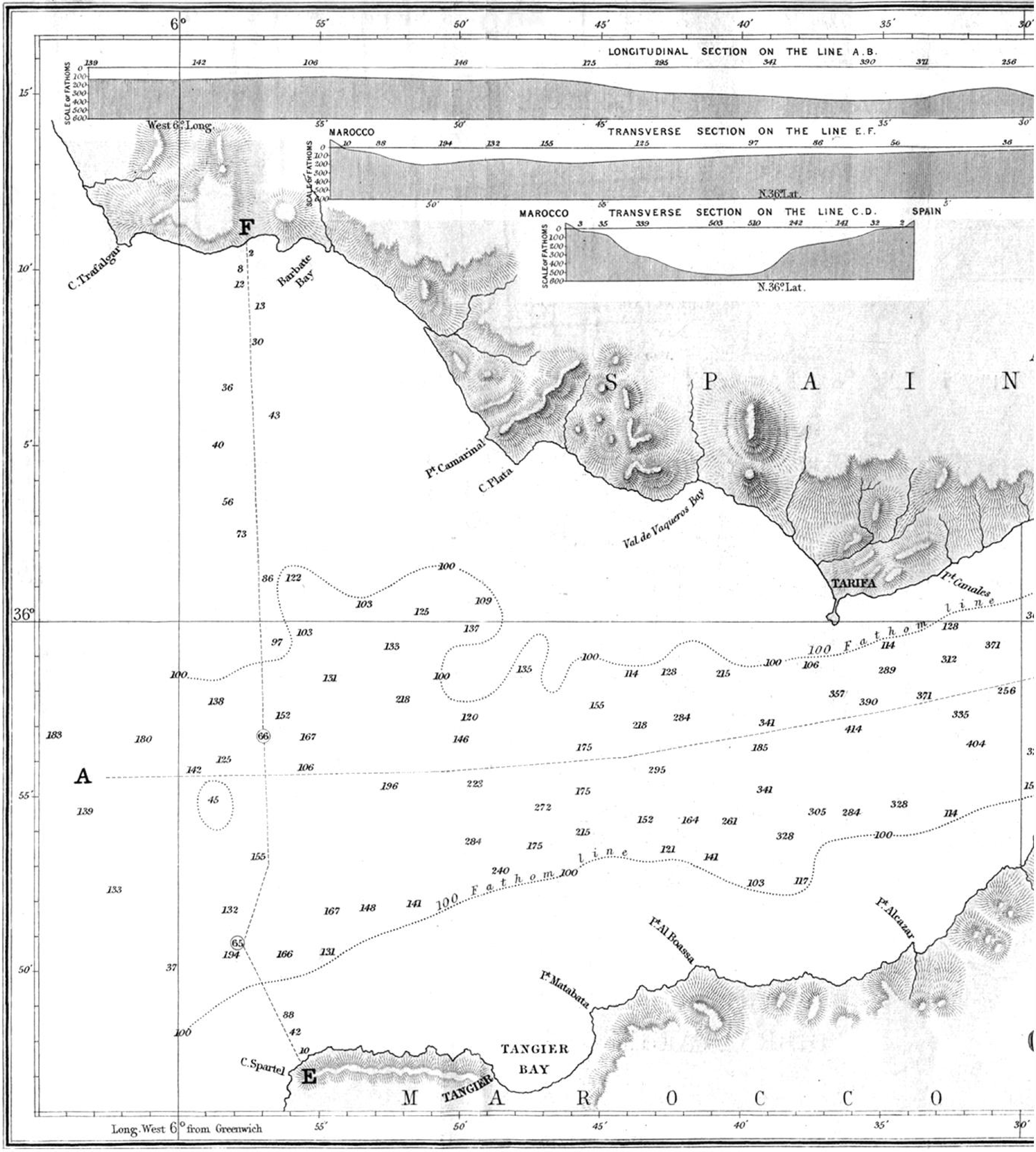
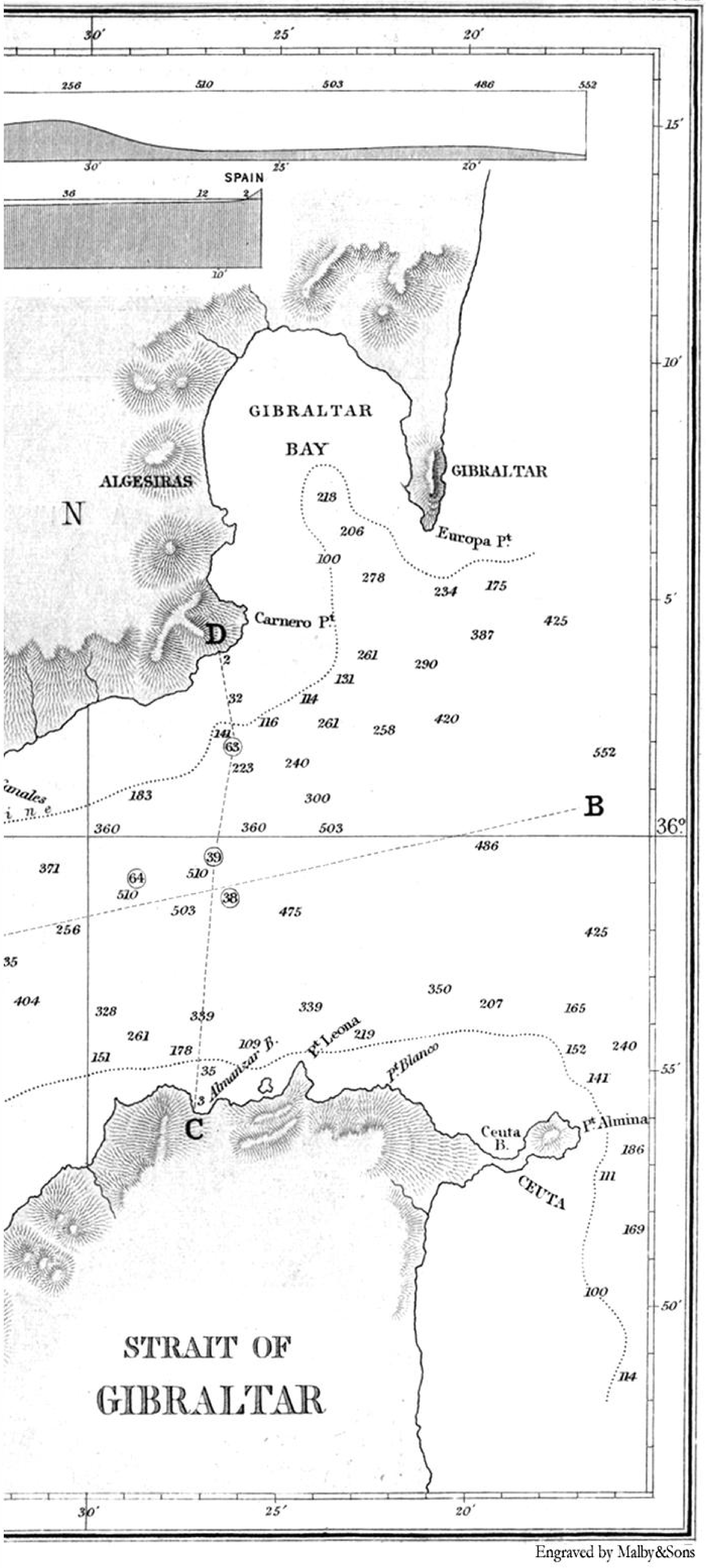


Chart II



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