fifths. But it seems to me that this rule can hardly be very accurate, and that it would be desirable to find the mean velocity by the use of a current metre, working in different parts of the section. However, this element once determined, it is of course only necessary to multiply the area of the section in feet, by the mean velocity in feet for a given time, to ascertain the number of cubic feet which flow past in that time.

3rd. The proportion of sediment held in suspension is ascertained by collecting a certain measure of water (a quart bottle answers the purpose very well), and then decanting and filtering it. If the filter be carefully dried and weighed, before and after the experiment, the difference gives the weight of mud from which the per centage of grains to ounces of water can be obtained. We shall now have sufficient data to determine how much solid matter passes down the river in a given time at any flood.

4th. Besides these observations, the rainfall at different points of the watershed of the river should be carefully registered. Thus some correlation between the two could probably be ascertained, so that from year to year an average rate of the wear and tear of the surface of the land might be obtained.

Many subjects of interest will naturally suggest themselves as we proceed with these experiments, such as the variation of the sediment after a long drought, and after a continued fall of rain.

Of the above data, the most unsatisfactory are those relating to the mean velocity of the stream at different heights. Perhaps some of your readers may be able to furnish suggestions upon the best mode of ascertaining this.

Besides the mud actually held in suspension, it would be very desirable to determine the rate at which the mud, sand, and gravel which compose the bed of the river are propelled. Some suggestions on the means of doing so would be very acceptable.

Stokesay, Craven Arms, Salop,
February 5th, 1869.

V.—On the Influence of the Gulf-stream.

By James Croll, of the Geological Survey of Scotland.

THE modern method of determining the amount of heat effects in absolute measure is no doubt destined to cast new light on all questions connected with climate, as it has done and is still doing in every department of physics where energy under the form of heat is the phenomenon under consideration.

Owing to the complicated nature of the phenomena with which the meteorologist has generally to deal, the application of this method will very often be found practically impossible. The method, however, is particularly suitable to all questions regarding the direct thermal effects of currents, whatever the nature of those currents may happen to be.

If the question, for example, is asked—"Is the heat conveyed by the Gulf-stream sufficient to affect to any great extent the climate of Northern Europe and the Arctic regions?" the answer can be given in the most positive manner by determining the absolute quantity of energy in the form of heat conveyed by the stream.

The fact of the climate of our island being greatly modified by the heat derived from the Gulf-stream has lately been called in question by Mr. A. G. Findlay and some others.

Mr. Findlay takes the breadth of the stream, as it issues from the Gulf of Mexico, at 45 miles, and its depth at 900 or 1200 feet, and maintains that a stream of this size, leaving the Gulf with a velocity of only a few miles an hour, would not be able to force itself across the Atlantic and onwards to the Polar Regions against the Arctic current and other impediments in its way; and even supposing it were able to do this, still its volume, he asserts, is too small and its temperature too low to produce the thermal effects attributed to it. It is certainly, no doubt, true that if the Arctic current was an *opposing* current as well as a contrary one, and if the Gulf-stream had to push its way to the Polar Regions by means of some impulse received before leaving the Gulf, it is not at all likely that it would ever reach to even the latitude of New York, far less to the shores of Great Britain. But neither the Gulf-stream nor any other ocean current moves in this manner. It is, however, not with this phase of the objection that I am at present concerned, but with the other and more important one, viz. that a current 45 miles broad and 900 or 1200 feet deep is too small to convey the amount of heat necessary to produce the warming effects usually attributed to the Gulf-stream.

There are perhaps few, if any, who have not actually subjected the matter to calculation, but would be inclined to agree with Mr. Findlay, that a stream so comparatively small, leaving the Gulf of Mexico at a temperature of not over 70° or 80°, and losing heat during a journey of several months across the Atlantic, could not possibly be able to maintain the winter temperature of the whole of Northern Europe 20° or more above the normal. They would naturally conclude that the only way of meeting Mr. Findlay's objection would be by denying that the stream is so small as he asserts it to be.

Although I am inclined to believe that Mr. Findlay has underestimated the volume of the Gulf-stream, still I can see no necessity for insisting on this in order to be able completely to meet his objection; for, taking his estimate of its size, it can be proved that his conclusion is incorrect, as the following, it is hoped, will show.

In the following calculations the breadth of the stream is taken at 50 miles, and its depth at 1000 feet, and its velocity at four miles an hour. This is almost exactly Mr. Findlay's estimate. The temperature of the water on leaving the Gulf is taken as low as 65°.

"The enormous effect that ocean-currents have in equalising the temperature of our globe by diminishing the difference between the temperature of the equator and the poles, has never been duly estimated. This will be seen if we merely consider for a moment the effect produced by one current alone, viz., the Gulf-stream. The total quantity of water conveyed by this stream is probably equal to that of a stream 50 miles broad and 1000 feet deep, flowing at the rate of four miles an hour. And the mean temperature of the entire mass of moving waters is not under 65° at the moment of leaving the Gulf."[1] I think we are warranted to conclude that the Gulf-stream, before it returns from its northern journey, is on an average cooled down to at least 40°, consequently it loses 25° of heat. Each cubic foot of water, therefore, in this case carries from the tropics for distribution upwards of 1500 units of heats, or 1,158,000 foot-pounds. According to the above estimate of the size and velocity of the stream 5,575,680,000,000 cubic feet of water are conveyed from the Gulf per hour, or 133,816,320,000,000 cubic feet daily.[2] Consequently the total quantity of heat transferred from the equatorial regions per day by the stream amounts to 154,959,300,000,000,000,000 foot-pounds. From observations made by Sir John Herschel and by M. Pouillet on the direct heat of the sun, it is found that were no heat absorbed by the atmosphere, about 83 foot-pounds per second would fall upon a square foot of surface placed at right angles to the sun's rays.[3] Mr. Meech estimates that the quantity of heat cut off by the atmosphere is equal to about 22 per cent. of the total amount received from the sun. M. Pouillet estimates the loss at 24 per cent. Taking the former estimate, 64·74 foot-pounds per second will therefore be the quantity of heat falling on a square foot of the earth's surface when the sun is in the zenith. And were the sun to remain stationary in the zenith for twelve hours, 2,796,768 foot-pounds would fall upon the surface.

It can be shown that the total amount of heat received upon a unit-surface on the equator during the twelve hours from sunrise till sunset at the time of the equinoxes is to the total amount which would be received upon that surface, were the sun to remain in the zenith during those twelve hours, as the diameter of a circle to half its circumference, or as 1 to 1·5708. It follows, therefore, that a square foot of surface on the equator receives from the sun at the time of the equinoxes 1,780,474 foot-pounds daily, and a square mile 49,636,750,000,000 foot-pounds daily. But this amounts to only $\frac{1}{3,121,870}$ part of the quantity of heat daily conveyed from the tropics by the Gulf-stream. In other words, the Gulf-stream conveys as much heat as is received from the sun by 3,121,870 square miles of surface at the equator. The amount thus conveyed is equal to all the heat which falls within 63 miles on each side of the equator. According to calculations made by Mr. Meech,[4] the annual quantity

[1] Phil. Mag. for February 1867, p. 127.

[2] Captain Maury considers the Gulf-stream equal to a stream 32 miles broad and 1200 feet deep, flowing at the rate of five knots (38,415 feet) an hour (Physical Geography of the Sea, § 24). This gives 6,166,700,000,000 cubic feet per hour as the quantity of water conveyed by this stream. Sir John's Herschel's estimate is still greater. He considers it equal to a stream 30 miles broad and 2200 feet deep, flowing at the rate of four miles an hour (Physical Geography, § 54). This makes the quantity 7,359,900,000,000 cubic feet per hour. Sir John estimates the temperature at 86° F.

[3] Trans. of Royal Soc. of Edin., Vol. xxi., p. 57. Phil. Mag. S. 4, Vol. ix. p. 36.

[4] Smithsonian Contributions to Knowledge, Vol. IX.

of heat received by a unit surface on the frigid zone, taking the mean of the whole zone, is $\frac{5 \cdot 45}{12}$ of that received at the equator. Consequently the quantity of heat conveyed by the Gulf-stream in one year is equal to the heat which falls on an average on 6,873,800 square miles of the arctic regions. The frigid zone or arctic regions contain 8,130,000 square miles. There is actually, therefore, nearly as much heat transferred from the tropical regions by the Gulf-stream as is received from the sun by the entire arctic regions; the quantity conveyed by the stream to that received from the sun by those regions being as 15 to 18.

But we have been assuming in our calculations that the percentage of heat absorbed by the atmosphere is no greater in polar regions than it is at the equator, which is not the case. If we make due allowance for the extra amount absorbed in polar regions in consequence of the obliqueness of the sun's rays, the total quantity of heat conveyed by the Gulf-stream will probably nearly equal the amount received from the sun by the entire arctic regions.

If we compare the quantity of heat conveyed by the Gulf-stream with that conveyed by means of aërial currents, the result is equally startling. The density of air to that of water is as 1 to 770, and its specific heat to that of water is as 1 to 4·2. Consequently the same amount of heat that would raise 1 cubic foot of water 1° would raise 770 cubic feet of air 4°·2, or 3234 cubic feet 1°. The quantity of heat conveyed by the Gulf-stream is therefore equal to that which would be conveyed by a current of air 3234 times the volume of the Gulf-stream, and at the same temperature and moving with the same velocity. Taking, as before, the width of the stream at 50 miles, and its depth at 1000 feet, and its velocity at 4 miles an hour, it follows that in order to convey an equal amount of heat from the tropics by means of an aërial current, it would be necessary to have a current about 1¼ mile deep and at the temperature of 65° blowing at the rate of four miles an hour from every part of the equator over the northern hemisphere towards the pole. If its velocity were equal to that of a good sailing-breeze, which Sir John Herschel states to be about twenty-one miles an hour, the current would require to be above 1200 feet deep. A greater quantity of heat is probably conveyed by the Gulf-stream alone from the tropical to the temperate and arctic regions than by all the aërial currents which flow from the equator.

We are apt, on the other hand, to over-estimate the amount of heat conveyed from tropical regions to us by means of aërial currents. The only currents which flow from the equatorial regions are the upper currents or anti-trades, as they are called. But it is not possible that much heat can be conveyed to us directly by them. The upper currents of the trade-winds, even at the equator, are nowhere below the snow-line. They must, therefore, lie in a region actually below the freezing-point. In fact, if those currents were warm, they would elevate the snow-line above themselves. The heated air rising off the hot burning ground at the equator, after ascending for a few miles, becomes exposed to the intense cold of the upper regions of the atmosphere. It then very soon loses all its heat, and returns from the equator much colder than it came. It is impossible that we can receive any heat directly from the equatorial regions by means of aërial currents. It is perfectly true that the south-west wind, to which we owe so much of our warmth in this country, is a continuation of the anti-trade. But the heat which this wind brings to us is not derived from the equatorial regions. This will appear evident, if we but reflect that, before the upper current descends to the snow-line after leaving the equator, it must traverse a space of at least 2000 miles; and to perform this long journey several days will be required. During all this time the air is in a region below the freezing-point; and it is perfectly obvious that by the time it begins to descend it must have acquired the temperature of the region in which it has been travelling.

If such be the case, it is evident that a wind whose temperature is below 32° could never warm a country such as ours, whose temperature does not fall below 38° or 39°. The heat of our south-west winds is derived, not from the equator but from the warm water of the Atlantic—in fact, from the Gulf-stream. The upper current derives its heat after it descends to the earth. There is one way, however, whereby heat is indirectly conveyed from the equator by that current; that is, in the form of aqueous vapour. In the formation of one pound of water from aqueous vapour, as Professor Tyndall strikingly remarks, a quantity of heat is given out sufficient to melt five pounds of cast iron.[1] It must, however, be borne in mind that the greater part of the moisture of the south-west and west winds is derived from the ocean in temperate regions. The upper current receives the greater part of its moisture after it descends to the earth. The greater part of the moisture received at the equator is condensed and falls as rain in those regions.

These, as well as many other considerations which might be stated, lead to the conclusion that, in order to raise the mean temperature of the whole earth, water should be placed along the equator—and not land, as is generally believed. For if land is placed at the equator, we prevent the possibility of conveying the sun's heat from the equatorial regions by means of ocean-currents. The transference of heat could only then be effected by means of the upper currents of the trades; for the heat conveyed by *conduction* along the solid crust, if any, can have no sensible effect on climate. But these currents, as we have just seen, are ill adapted for conveying heat.

The surface of the ground at the equator becomes intensely heated by the sun's rays. This causes it to radiate off its heat more rapidly into space than a surface of water heated under the same conditions. Again, the air in contact with the hot ground becomes also more rapidly heated than in contact with water; and consequently the ascending current of air carries off a greater amount of heat. But if the heat thus carried away were transferred by means of the upper currents to high latitudes and there employed to warm the

[1] Heat as a Mode of Motion, article 240.

earth, then the heat thus conveyed might to a considerable extent compensate for the absence of ocean-currents, and land at the equator might in this case be nearly as well adapted as water for raising the temperature of the whole earth. But such is not the case; for the heat carried up by the ascending current at the equator is not employed in warming the earth, but is thrown off into cold stellar space above. This ascending current, instead of being employed in warming the globe, is in reality one of the most effectual means that the earth has of getting quit of the heat received from the sun, and of thus retaining itself at a much lower temperature than it would otherwise be. It is in the equatorial regions that the earth loses as well as gains the greater part of its heat. So of all places it is here that we ought to place the substance best adapted for preventing the dissipation of the earth's heat into space if we wish to raise the general temperature of the earth. Water, of all substances in nature, seems to possess this quality to the greatest extent; and, besides, it is a fluid, and therefore adapted by means of currents to carry the heat which it receives from the sun to every corner of the globe."[1]

VI.—Notes on Continental Geology and Palæontology.

By Thomas Davidson, F.R.S., F.G.S.

(Part I.)

RECENT considerations of health having induced me to spend from five to six months on the continent, I beg to submit to the readers of the Geological Magazine the result of my notes made during my journey, which may perhaps prove not entirely uninteresting.

I. *On the Cretaceous System.*—All the foreign geologists with whom I have had occasion to converse in France, Switzerland, and Italy, concur in the opinion that no country has been better studied than Great Britain, and that the Museum of the Geological Survey and its published Maps are unsurpassed by any works of a similar kind hitherto produced.[2]

Our geologists have done their work well, and justly deserve the favourable judgment so liberally bestowed upon them by their continental colleagues; but we must not therefore suppose that our geological work is perfected and that we have no more to learn—for example—that our classification of British strata is either complete or entirely satisfactory. It is absolutely necessary we should know and compare the labours of continental observers with our own and see whether their discoveries or hints might not lead us to

[1] Trans. of Glasgow Geol. Soc. vol. ii. part iii. p. 185; Phil. Mag. Feb. and June, 1867.

[2] See "De la Science en France" by Jules Marcou, 1869. This work, to which I would call the attention of British geologists, is being published in numbers, and treats of the Imperial School of Mines, the Geological Map of France, the Academy and Institute of France, and of the Museum of Natural History in Paris, and may be obtained from C. Reinwald, Bookseller, 15, Rue des Saint Pères, Paris; or through Messrs. Trübner & Co.