Hydrography of the Andes: Discussion

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Source: *The Geographical Journal*, Vol. 25, No. 1 (Jan., 1905), pp. 70-74

Published by: [The Royal Geographical Society \(with the Institute of British Geographers\)](#)

Stable URL: <http://www.jstor.org/stable/1775984>

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Tertiary times.* These rivers continued, with the help of the rainfall brought by the western winds, to keep open their channels while the earth-foldings occurred which formed the present Cordillera.

The accumulations during periods of depression of marine deposits derived from the denudation of the mountain slopes or the eruption of volcanoes has sometimes shifted the watershed in the intervening epochs of elevation westward to the gorges,† but with the help of the rains from the north-west the Pacific streams at once commenced to cut their way back to the eastward through the unconsolidated material that filled the old channels; and in many places the process is still going on.

The history of the rivers of the region has been complicated by subsequent earth-movements that have raised new subsidiary elevations to the east of the main axis and depressed the intervening valleys, and, during the last submergence, by arctic conditions, that clothed the mountain slopes that remained above the sea-level with enormous glaciers, which penetrated at their base far down below the surface of the ocean, and, when the land was raised and the climate became milder, left the deep lake-basins that fringe the eastern margin of the Cordillera.

In the extreme south there are fiords, such as Otway water and the western part of the Straits of Magellan, which are ancient river valleys still submerged in the sea. These too were, I believe, carved out by ancient streams that flowed into the Pacific before the Andes rose across their paths.

It is not only in the Andes that we find evidence of similar relations between the winds and rivers; there are many other parts of the world where considerations such as those I have suggested will throw light on the present hydrography and assist us in reading the history of the past. The long period during which the meteorological conditions in the Andean region have remained comparatively unchanged, and the north and south extension of the mountains, render it a peculiarly favourable area for recognizing the effects of the prevalent winds in different latitudes on the river system.‡

Sir THOMAS HOLDICH: Whilst I agree with the general deductions which Dr. Evans has drawn from the conformation of the Andes, viz. that the watershed appears to shift gradually away from the direction in which the wind blows, I think that there are certain very important exceptions to the rule, particularly in the southern part of the Andes. I am not acquainted with the northern section, but as regards the Patagonian Andes, I have had the opportunity of looking pretty closely into their structure, and I found that the watershed there zigzags backwards and forwards, not by any means always along the eastern foot of the hills, but sometimes approaching so closely to the Pacific shore that it had to be condemned as a possible

* These rivers appear to have followed the still older transverse and longitudinal valleys of the ancient axis of elevation which stretched from north-west to south-east. See Dr. Hans Steffen, "The Patagonian Cordillera and its Main Rivers between 41° and 48° South Latitude," *Geographical Journal*, vol. 16, p. 38.

† The great river valleys of the pampas have been excavated in the course of successive elevations, at times when the watershed retained its western position. They probably followed, in the first place, the line of the valleys of the ancient westward-flowing rivers covered by deep accumulations of sediment, but still represented by depressions.

‡ The inset map illustrating the rainfall of the Andes can only be regarded as diagrammatic, as materials for an accurate representation of the rainfall are wanting throughout the greater part of the area.

boundary, because it gave insufficient hold on the Pacific coast to Chile. The principal exception is at a point not marked on the map exhibited. Lakes Viedma and Argentina both have an Atlantic outlet; and the watershed of the continent, the main divide, is situated so far to the west of them as almost to overlook the sea. As the two lakes occupy considerable space, this is a big exception to the rule; but still I think, on the whole, that rule holds good. Dr. Evans mentioned something about Lake Buenos Aires. Lake Buenos Aires is a very remarkable hydrographical feature, and I am not quite sure that I know of any other like it elsewhere. A very curious feature occurs with regard to the source. Lake Buenos Aires draws most of its waters from northern glaciers by means of a bigish river called the Fenix. For about 30 miles that river holds its own as an important stream, until it divides into two channels, one flowing to the lake, and through the lake to the Pacific, and the other to the Atlantic. What are we to call such a feature as that? The river itself becomes the actual water-divide of the country, so far as I can see, rather upsetting the usual theories of a *divortium aquarum*. There was another point about Dr. Evans's address with which I hardly agree. He says, "In Patagonia the gorges through the Andes are not the work of the streams which now occupy them, and which date only from the last and still incomplete emergence of the southern portion of the continent from the sea. They were excavated by older and longer rivers that, before the Andes were raised, flowed from a region of ancient rocks in Eastern Patagonia, now almost completely hidden under the detritus laid down in periods of submergence in Secondary and Tertiary times. These rivers continued, with the help of the rainfall brought by the western winds, to keep open their channels while the earth-foldings occurred which formed the present Cordillera." I have often discussed that question with the well-known Argentine scientist, Dr. Moreno, and Dr. Moreno was of opinion that there was no evidence of antecedent drainage. That is to say, the lines the rivers have taken have not existed from all times, but their extraordinarily irregular course has been determined by the lines of weakest resistance, probably due to volcanic action. Nor can I agree that the general conformation of the Andes has remained the same for so very long. It is certain that very great changes in altitude have taken place in different parts of the Andes lately. Some parts are still rising, some falling. There is no general elevation; there is no general depression. In one place you will find forests submerged under the sea, and not far away you will find modern shells on the cliff edge hundreds of feet above your head. I might also remark that with these constant changes in the elevation that have taken place, the lake region of South America has changed its outlet constantly, sometimes on the one side and sometimes on the other. I think Dr. Evans is right in saying that the majority of the lakes have now a westward outlet into the Pacific; but a great many still have outlets to the Atlantic, and in almost every case in which we observed the present conformation of those lakes, we found distinct evidence of a former exit to the Atlantic.

Mr. R. D. OLDHAM desired to express his admiration of Dr. Evans's very interesting paper. In it the good old idea of antecedent drainage had been accepted wholeheartedly—an idea which was both popular and venerable, and consequently to be treated with respect. It had been fully established in certain cases, such as the channels of the Himalayan rivers through the sub-Himalayan ranges, and of the Lune valley in England, but he was unaware of any instance where it had been proved that a river had been able to cut down its channel and maintain its course across anything which could be described as a mountain range, while in all the established cases the source of the river was in a higher range than that across which its course had been maintained. The case of the Indus and Brahmaputra

had been referred to, and though he stood committed to the notion that the course of these rivers across the Himalayas was older than those mountains, yet, since the date of the publications in which this view had been accepted, he had seen cause to modify his opinion, and was more and more inclined to accept the alternative explanation of capture, an explanation which certainly seemed the most probable one in the case of the Sutlej. On the western frontier of India many of the gorges which were ordinarily explained by the theory of antecedent drainage seemed to him more probably cases of capture. He did not think that Dr. Evans had made sufficient allowance for the rapidity with which erosion and cutting back of valleys might take place in rising mountains. He had found that the Scind valley, which drains into Kashmir from the north, had extended its valley by 20 miles, and at one place the old valley-level stood over 2000 feet above the present; the whole of this lengthening, as well as the 2000 feet of erosion through hard limestone, having taken place since the last, and least considerable, extension of the glaciers—that is to say, since a date which is certainly not older than the close of the Glacial period. In view of these considerations, he was inclined to think that the close relation between the direction of the prevailing winds and the position of the watershed, which Dr. Evans had described, indicated that the present hydrography of the Andes is more largely dependent on capture than on antecedent drainage.

Dr. HERBERTSON: We have listened to a most interesting paper, and I think that Dr. Evans's suggestion that rainfall has considerable control over the position of a watershed ought certainly to be applied to other regions than the Andes. As to his theory of the origin of South American rainfall, I should like to enter one or two protests, more particularly about the rainfall in central Chile, which I do not think can be explained by the heating of Argentina. It is a winter rainfall, not a summer one, and is brought by the ordinary westerly storm winds of the southern hemisphere in their most northerly position. I also think that the south-east trade wind is not accountable for most of the rainfall in the Amazon valley, much of which can be explained as due to locally uprising air or monsoonal brought in by a more northerly wind. But those points have nothing to do with the main thesis which has been discussed this afternoon. The chief objection to Dr. Evans's antecedent drainage explanation has been raised both by Sir Thomas Holdich and Mr. Oldham. In the case of the Southern Andes, the drainage from Lake Buenos Aires is very remarkable. The tributaries of the main streams, as Sir Thomas Holdich said, nearly all run the wrong way. You have tributaries running in the opposite way to the main stream. This happens with most of these west-flowing South Andean rivers, and is an indication of a change of the direction of flow in the main valley. There is another point of some importance. I was especially delighted to hear Mr. Oldham renounce the antecedent theory for the Ganges, because I have ventured within the last year or two to express the opinion that it could not explain all the gorges in the Himalayas. If you make a valley-curve, you find, in the case of the Himalayas, and also in the case of the Andes, that you have a curve which becomes almost flat; then as the river passes through the mountains turns very steep, and then is relatively flat again. Now, if the river had cut its way through rising land, the nick in the curve at the end of the upper flatter part where there had been a temporary base would take place along the axis of most rapid elevation. In the Andes that nick seems to occur on the eastern side of the mountain system, and that is what one would expect if the waters of the rivers on the dry side of the mountain had been tapped by the more vigorous rivers on the wet western side. I should also like to ask Dr. Evans if he has any definite evidence of rivers which now flow to the west of the Southern Andes

through old gorges, if the old deposits have been observed in them, and if there are valleys with old deposits which are not occupied by any river flowing to the west at the present time.

Sir CLEMENTS MARKHAM: I should like to make a few observations. In the first place, I wish to point out to Dr. Evans that north of the Cerro Pasco knot the great rivers work to the north just as the Atrato and Magdalena work to the north to the Caribbean sea. In the same way, the rivers Huallaga and Marañon work to the north, to what may be called the Amazonian sea. I should like to call attention to one very remarkable feature in the Andes, namely, what is called the Callejon du Huaylas, in which a river close to the Marañon has a course for many miles due north, and then turns the other way into the Pacific. If you look at that map you will see what an extraordinary feature that is. All those rivers—Huallaga, Marañon, Huaylas—appear to be working northward, and not to the eastward. I would also refer to the period when the Andes are supposed to have risen to their present great height, which you place, I think, in the secondary period.

Dr. EVANS: They have risen recently as well.

Sir CLEMENTS MARKHAM: I should imagine the rise to be very much more recent. If, as we find in the coast deserts, there are fossil animals in enormous quantities which require dense forests to live in, like the gigantic anteater, there cannot possibly have been lofty mountains entirely stopping the rainfall from coming down on the coast. The Andes must have been much lower, rising gradually. It is also evident that at that period, when those creatures existed, there must have been abundant vegetation where there is now a sandy desert. I have always felt very strongly that it was impossible that those enormous ruins could have existed on the coast of Lake Titicaca, if it was at its present height when they were built. The land must have been lower, sufficiently low to allow grain to ripen, for the builders represented a dense population.

Dr. EVANS: In reply to our President's question as to the age of the Andes, I can only say that I do not regard the range as of very great antiquity, as the term would be understood in geology, and agree with him that considerable elevation has taken place in comparatively recent times; but it is probable that throughout Tertiary and even later Secondary times the mountains, though not, it may be, as lofty as at present, were sufficiently high to diminish materially the rainfall to the leeward.

At an earlier period, instead of a continuous mountain chain with a general north-and-south direction, there appear to have been several disconnected elevations with a north-west to south-east strike. The north-eastward flow of the Peruvian rivers referred to by the President probably dated from a time when there was a gap between the Peruvian Andes and the mountains in the south of Colombia.

If the general relation of the winds, rainfall, and watershed for which I have been contending is established, the main purpose of my paper is accomplished, though the question of the manner in which that relation has been brought about remains to be considered. I cannot agree with Mr. Oldham in the importance which he attributes to the operation of cutting back. Except where limestones, comparatively unconsolidated materials, or rocks that have been softened by laterization are concerned, the rate at which a river cuts back at its source is, I believe, so slow that it cannot affect the hydrography and orography of a mountain region to any considerable extent, even in the vast periods with which geology deals.

In my opinion, it is by the antecedent character of the river system that we must explain the main features of the hydrography, not only of the Andes, but of the Himalayas and many other great mountain regions. This is a much more

reasonable hypothesis, for it supposes the great mountain gorges to be the work of the waters of considerable streams and the stones they carry along their beds, which are far more efficient excavating agents than the surface flow that forms a river source. In this position I have the powerful support of Prof. Bonney, who is unfortunately unable to be present, but has addressed me a letter on the subject (see below).

The facts adduced by Sir Thomas Holdich are full of interest, but are not, I think, inconsistent with the views I have advocated.

The seemingly erratic course of the transandine rivers of Patagonia points strongly to an antecedent system of drainage, following, like the Thames, alternately dip-and-strike courses roughly at right angles to one another; but in this case the dip and strike are not those of the elevation of the present Andes, but of earlier earth-movements oblique to them.

Mr. Herbertson has referred to the fact that the rainfall in Central Chili occurs mainly in the winter months, and suggests that this is inconsistent with the view that the summer heat of the Argentine plains causes an indraught from the west. The winter rain is due to the increase of the north-west winds in the winter, which is not a local phenomenon, but occurs throughout the south temperate zone. But the wind charts of the south Pacific show that, relatively, the north-west winds are more prevalent in summer and less prevalent in winter off the coast of Chili than at other points in the same latitudes.

With regard to the direction of the rain-bearing winds of the Amazonian plains, I can testify from my own experience that in the portion which falls within the limits of Bolivia by far the greater part of the rain comes from the south-east. In the north of Brazil a different state of things no doubt prevails.

Mr. Herbertson also referred to the valley curve or profile of the western-flowing rivers of Patagonia, and refers to the fact that the steepest part is to the east of the principal range. This is, however, due to the fact that the land is now far below the level at which it stood when the gorges through the mountains were excavated, and the original valley bottoms are now either submerged below the sea or covered with *debris* brought down by the rivers.

In conclusion, I may mention that I believe that the present eastern drainage of peninsular India south of lat. 21° N. dates from a period when the normal north-east trade winds blew over it throughout the year, and all the rainfall came from that quarter. The present south-west monsoon is the result of the great extent of land to the northward, much of which was still covered by the sea as late as Eocene times.

Rev. Canon BONNEY wrote as follows to Dr. Evans: That when a river cuts through a range the latter is the younger, is a statement to which it would be very difficult to find an exception. I have long been convinced of this, and have stated it in print, in the case of the Alps and Himalayas; also that South America, south of about lat. 41° S., is a partially submerged land like Norway. The relation between the river courses and the meteorology strikes me as important, particularly as bearing on the antiquity of the existing conditions. But, I suppose, allowing for expansion and contraction of the trade-wind belts (and, of course, others relating to them) and for important local interferences owing to geographical changes, the general arrangement of aerial currents on the globe must have been constant from the first.