REGIONS OF INTERIOR-BASIN DRAINAGE

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[With separate map, Pl. II, facing p. 414]

THE extent and hydrography of the land areas in the world served by interior basin drainage are of interest to all students of earth science. The physiographic relations of a third of the lands would be changed if precipitation everywhere found its way to the oceans, as is the normal condition in most inhabited regions. In the physical economy of the globe one may consider as two separate domains the regions of interior and the regions of oceanic drainage. It is convenient to describe each of these two great regions by a single word: we may term through-flowing, or ocean, drainage "exoreism" (ex-o-rē-ism, from the Greek ἐξ, out, and ῥεῖν, to flow), interior basin drainage "endoreism" (en-do-rē-ism, from ἐν, in, and ῥεῖν).[1] In this paper we shall attempt to define the extent of the endoreic, or interior-basin, domain and explain its causes. The deserts are *par excellence* the domain of interior-basin drainage, or endoreism. But they present a particular case where run-off is nil and for which the term "areism" is proposed (a-rē-ism, from α, privitive, and ῥεῖν).

Early Work on the Problem

Richthofen[2] distinguished between the peripheral and the central regions of Asia, the latter marked by an arid climate and interior-basin drainage. The first and, up to the present, the only attempt to represent cartographically the extent and disposition of interior-basin drainages is in Berghaus' Physikalischer Atlas, Plate No. 16, 1891, which has been reproduced in divers other works. John Murray, in a paper read before the Royal Society of Edinburgh on Jan. 17, 1887, gave the first estimate of the inland drainage area.[3] He placed it at about a fifth of the land surface, or 11,486,350 square miles, a figure only a little less than that of the arid regions (12,200,000 square miles), or regions of annual rainfall under 10 inches. His calculation was made on an equal-area projection on which were superlaid the

[1] Emmanuel de Martonne: Aréisme et Indice d'aridité, *Comptes Rendus de l'Acad. des Sci.* [*de Paris*], Vol. 182, 1926, pp. 1395–1398.

[2] Ferdinand von Richthofen: China: Ergebnisse eigener Reisen und darauf gegründeter Studien, (5 vols., Berlin, 1877–1912), Vol. 1, p. 7.

[3] John Murray: On the Total Annual Rainfall on the Land of the Globe, and the Relation of Rainfall to the Annual Discharge of Rivers, *Scottish Geogr. Mag.*, Vol. 3, 1887, pp. 65–77.

boundaries of the interior-drainage basins according to Berghaus. In his admirable monograph on Lake Bonneville[4] G. K. Gilbert, also following Berghaus, gives values for the continents thus: Australia, 52 per cent; Africa, 31; Eurasia, 28; South America, 7.2; North America, 3.2.

Penck's "Morphologie,"[5] so rich in numerical estimates, gives figures for the "Binnengebiete" as 22.1 for the continents as a whole, or 29,900,000 square kilometers, of which Europe has 1.6; Asia 12.6; Africa 9.6; Australia 4; North America 0.9; South America 1.2. All these have been calculated on the basis of the Berghaus map: there appear to have been no attempts to improve on this generalization. Penck and Murray note the zonal disposition of the interior drainage and its connection with climate. Neither concerns himself with the Caspian Sea. G. K. Gilbert alone seems to have envisaged the complexity of the problem. Since the publication of Berghaus' map our knowledge of the earth's surface has progressed enough to permit of more precise representation of the endoreic domain and of delimitation of the areic domain—a distinction that has not been attempted before.

Method of Work

From the standpoint of hydrologic records it is unfortunate that regions of interior-basin drainage are in general but little inhabited. The great modern states lie in regions of normal or through-flowing drainage. The United States is the chief exception: the extent of the interior-drainage basins of the West is exactly known. We are also fortunate in having figures for the basins of the old Russian Empire from the Baltic to the Pacific.[6] With such data in hand, however, the question is not always solved. It often happens that in the higher parts of a basin there is flow, permanent or temporary, which does not attain base level. The hydrographers who measure the area of each basin are not concerned with this distinction, for us essential. The inverse case is also known. A river abundantly fed from its sources may in its lower course traverse a desert, which should be included in the endoreic or perhaps the areic domain. The Nile is an alien feature of the Libyan Desert; it does not receive a drop of water therefrom but, on the contrary, loses a great part of its volume. The same is the case with the Sir Darya and Amu Darya in Russian Turkestan. Our predecessors have not taken account of these facts. The entire Nile basin is included in oceanic drainage on Berghaus' map and in the calculations of Murray, Gilbert, and Penck. Whence arises a serious

[4] G. K. Gilbert: Lake Bonneville, *U. S. Geol. Survey Monograph No. 1*, 1890.

[5] Albrecht Penck: Morphologie der Erdoberfläche (2 vols., Stuttgart, 1894), Vol. 1, p. 189.

[6] Jules de Schokalsky and A. de Tillo: Superficie de la Russie d'Asie, avec les bassins des océans, des mers, des rivières et des lacs, St. Petersburg, 1905, French text, 1907. See also Jules de Schokalsky: La comparaison des mesures de superficie, de l'Asie Russe et de ses bassins, *Atti X Congr. Internaz. di Geogr., Roma*, 1913, Rome, 1915, pp. 642–651.

error in the results as a whole. Thus even where the surfaces of the hydrographic basins have been exactly delimited and measured we have been obliged to repeat a part of the work; but in most cases the results had to be built up basin by basin through original studies.

The accompanying map of the endoreic and areic regions has been the object of a series of studies prosecuted during some ten years by the students at the Institut de Géographie of the Sorbonne under the direction of M. de Martonne. Maps of the continents or parts thereof have been drawn up on scales ranging from 1 : 1,000,000 to 1 : 6,000,000. Use has been made of all cartographic documents in the collections of the Institut, which numbers about 35,000 sheets, in particular of the sheets of the millionth map of the world and of all the maps covering considerable territory on this scale. The work, however, might not have been accomplished even yet if, after five years of interruption (1914–1919), there had not been available the devoted collaboration of L. Aufrère, who has had charge of the editing of the world map on the scale of 1 : 20,000,000. This work has included complete and detailed revision, all doubtful points being referred to the original documents.[7]

The difficulties arise in part from the unequal value of the source material, in part from the indefiniteness inherent in the limits themselves. The boundary between the endoreic and the exoreic regions can be drawn without hesitation, granted the accuracy of the maps used; it is different, however, with areism. Only on maps of scale not less than 1 : 100,000 with the detail and precision of regular surveys can the boundary of areism be recognized; and it is a zone rather than a line, a zone fluctuating from year to year with variations in climate.

In principle we include in the areic regions all areas that do not originate rivers that reach the sea either directly or through flow into some other stream. A river crossing the region without rising therein does not change the areic character, as was pointed out above. Regions of intermittent streams are not included in the areic domain provided the streams flow at some time in every year, if only for a few days. The maps do not always enable us to decide this point: yet on scales larger than the millionth, if well executed, they give certain unmistakable indications if degradation of the hydrographic network is in progress. A stream channel that is not utilized will not keep continuity of gradient; it broadens in section, a succession of hollows appears, obstacles such as a barrier of dunes choke the valley. Such characters are easily observed in the lower courses of great wadis of

[7] In consequence of this revision the figures differ somewhat from the earlier calculations given in: Emmanuel de Martonne and L. Aufrère: Extension du drainage océanique, *Comptes Rendus de l'Acad. des Sci.* [*de Paris*], Vol. 180, 1925, pp. 939–942, and Emmanuel de Martonne: Extension des régions priveés d'écoulement vers l'océan, *Compte Rendu Congr. Internatl. de Géogr.*, Cairo, 1925, Vol. 3, pp. 25–50. The diagrams of percentage of areism and endoreism also have been based on a new method which better permits comparison with the index of aridity: zonal values have been transformed to linear values.

the Sahara descending from the Atlas or the Ahaggar[8]. Among extreme forms of degradation may be noted the torrential character of stream flow in the desert observed on the mountain borders, as in the Arabian desert east of the Nile and in the Tassili of the western Sahara. The torrent beds are well enough defined, but often they remain without water for several years. An occasional heavy rain launches a flood known as *sêil*,[9] similar to the *lave* of the alpine torrents, which carries all before it but lasts only a short time and generally does not reach the end of the valley. Such a régime is revealed on a good map by the absence of the regular network of stream channels. The effects of heavy downpours are shown in sheet flood erosion as described by McGee[10] and in excessively broadened river beds passing to the form of the wadi. The piedmont waste descending towards the center of the basin is furrowed by dry discontinuous channels. Such inundation may extend over immense distances at the foot of the mountains enclosing interior basins. Good examples may be seen on certain sheets of the West of the United States and southern Algeria.

Even in a rapid survey one cannot fail to notice areas thickly sprinkled with unconnected lakes. It is an imperfect form of areism, which we may term "humid" areism, frequently seen in plains where a rainy season occurs too short to permit organization of drainage. Such may be noted in Senegal and the Sudan, where one speaks of "winter lakes," in Turkestan, on the edge of the Karroo, etc. The number and extent of these bodies of water vary from one season to another; so that the reconnaissance maps give very different pictures of the country according to the time when they have been made.

It is obvious that the work on our map has necessitated a rational interpretation of cartographic documents of very unequal value. To supplement the maps use has been made of meteorological data, of scientific results of explorations, and of travel narratives.

The influence of the nature of the ground has also to be considered. Limestones and permeable sands, sandstones, even recent basalts, loess in sufficient thickness may produce artificial effects as in the karst of Dalmatia. Permeability of soil really deserves a special study in both arid and semiarid regions. Central Yucatan, where rainfall reaches 800 millimeters, would probably enjoy a temporary run-off, though probably not a regular run-off, if the subsoil were not a limestone.

The Calculation

Measurement of the surface areas has been made according to the method that gives the highest degree of accuracy within the scope of

[8] E. F. Gautier: The Ahaggar: Heart of the Sahara, *Geogr. Rev.*, Vol. 16, 1926, pp. 378–394.

[9] W. F. Hume: Geology of Egypt, Vol. 1, Survey of Egypt, Cairo, 1925, p. 85.
F. Foureau: Ma mission de 1893–1894 chez les Touareg Azdjer, Paris, 1894.

[10] W J McGee: Sheetflood Erosion, *Bull. Geol. Soc. of Amer.*, Vol. 8, 1897, pp. 87–112.

the problem. Our original on the scale of 1:20,000,000 has been carried out on a base map by Eckert, which has a complete network of meridians and parallels by degree units. We counted for each continent the number of whole units (trapeziums) and estimated the value of the fractions in each latitudinal zone in the endoreic and areic domains. The total obtained was multiplied by the area of a trapezium by degrees given by tables for the spheroid. Adding the values by zones gave figures by continents, hemispheres, and for the globe as a whole.

This method, formerly employed by Schokalsky for measuring the basins of the Russian Empire, appears to us well designed for all areal measurements on the continents and especially for such as concern the whole of the globe. It avoids the corrections which must be applied to planimetric methods or measurements by weight. It is applicable, furthermore, to maps on other than the equal-area projection; for the only surfaces directly measured are very small, fragments of a degree trapezium, and here it is a matter of the proportion and not a direct measure. The method has the additional advantage of giving figures by zones of latitude permitting the examination of several interrelations of phenomena, particularly of climate.

Results of the Study As a Whole

According to our map the entire surface having interior-basin drainage covers nearly 42,000,000 square kilometers, to be precise 41,838,000, rather more than a quarter (27 per cent) of the total land surface of the globe, a third (33 per cent) if the polar lands are excluded, as we shall exclude them from the following discussion. These figures surpass previous estimates. The difference is not due simply to a greater precision in execution but to a more exact definition of the interior-drainage basins.

Of the 41,838,000 square kilometers without drainage to the sea (endoreic domain) 27,991,000 only appear to be entirely without run-off; in other words the areic domain accounts for 17 per cent of the total land surface, 23 per cent if the polar regions be omitted.

We may now stop to consider the importance of these results. It is significant that on 23 per cent of the continents evaporation exceeds precipitation and that on 11 per cent of the remainder the rains are insufficient to assure flow to the ocean under the present conditions of relief; so that on 33 per cent of the surface the meteoric waters, abstracted for the most part from the surface of the sea, do not return there. It must be concluded that extension or reduction of endoreism would have as consequence a lowering or a raising of the level of the sea and thus cause important changes in the shore lines. Precipitation is not abundant in regions of interior drainage; the index of run-off, zero in the areic domain, rarely exceeds an average of 10 centimeters in the endoreic domain. Nevertheless with a surface of 14,000,000 square kilometers there would still be a volume of 1400 cubic kilometers escaping to the oceans each year—a value corresponding to a lowering of sea level of 0.47 meters a century. There is a unity in the earth's hydrography which justifies, in a measure, the expression hydrosphere.

From the point of view of continental morphology the endoreic and areic domains exhibit abnormality. The law of the common base level is not applicable to a third of the lands. The proportion would be still greater if exception were made of those parts of America and Eurasia where the ground is frozen to a depth; perhaps it would attain 40 per cent. As the endoreic domain is unable to export its waste, the interior basins tend to fill up with progressive raising of the base level offset in some instances, of course, by exportation of desert dust to extradesert regions.[11] This has a bearing on sea level, difficult, however, of numerical expression. All available estimates of denudation are based on observation in the exoreic regions. L. W. Collet[12] gives 57 millimeters as the mean lowering of surface per century for the northern slopes of the Swiss Alps. Reducing this to one-third, a total of 3 cubic kilometers of material a century is kept back from marine sedimentation by the fact of interior-basin drainage. The raising of sea level that would result from complete removal of waste to the sea is small in comparison with that which would be produced by the return to the sea of the endoreic waters (3/100), yet it is not negligible. Finally, if isostatic equilibrium is not an idle expression, the displacement of material of erosion must affect it; and one cannot doubt that it would be sensible to a change in the extension of endoreism. The surface area of terrigenous sediments is estimated at 73,000,000 square kilometers; the 3 cubic kilometers of sediments remaining in the interior basins would, on this surface, be equivalent in a century to a layer 17 meters thick, disregarding the effect of settlement. In weight, and accepting Collet's figure of 1.5 for mean density of sediments, it would represent a load of 4.5 milliard tons, or 26 tons per square meter.

Variation According to Latitude

The method that permits us to calculate the total area of the endoreic and areic domains gives us a means of showing the variations of their latitudinal extent calculating the proportion for each degree

[11] Siegfried Passarge: Die Kalahari: Versuch einer physisch-geographischen Darstellung der Sandfelder des südafrikanischen Beckens, Berlin, 1904.

W. M. Davis: The Geographical Cycle in an Arid Climate, *Journ. of Geol.*, Vol. 13, 1905, pp. 381–407.

Erich Kaiser: Die Diamentwüste Südwest-Afrikas, 2 vols., Berlin, 1926.

[12] L. W. Collet: Les lacs: Leur mode de formation, leurs eaux, leur destin, Paris, 1925.

zone. Table I gives these numerical values graphically shown in Figure 1. The irregularities of the curve need not prevent us from arriving at some general conclusions. Disregarding anomalies such as rise from the varying and dissimilar distribution of land and water in northern and southern hemispheres, the general trend of the curve is clear enough: oceanic drainage, or exoreism, dominates in the high latitudes and in the equatorial zone; its minimum extension in both hemispheres is about the tropic but is better displayed in the northern hemisphere. The continental hemisphere also is that in which endoreism is most extended, having about three-quarters of the domain (32,000,000 square kilometers).

The curve of percentage of areism is close to the zero line on 25 degrees in low latitudes, it returns there from the 55th parallel in the northern hemisphere and the 50th in the southern hemisphere. Its ups and downs in the southern latitudes between the 40th and 50th parallels are as erratic as those of the endoreic curve and need not claim our attention here.

The explanation of the variations of percentage in the endoreic and areic regions according to latitude must be sought for in the climatic factor. We have already noted the vital importance of precipitation and temperature. The zonal means of these phenomena have been deduced from meteorological maps and may be compared with the percentages of endoreism and areism by calculating in round numbers the percentage for corresponding parallels.[13] It appears that the curve of endoreism follows that of temperature in the temperate zone, that of rainfall in the warm zone. This is as would be expected; in middle and high latitudes the variations of temperature are much greater than that of the rains, whereas in low latitudes the temperature variations are small. The extent of interior drainage appears to be reduced to a minimum when mean annual precipitation exceeds 1200 millimeters, whatever the temperature, and when the mean temperature falls to 0° C., however deficient the precipitation. Yet it should be noted that the relations are not the same in the two hemispheres. Furthermore, the minimum towards the equator does not correspond with a rainfall maximum: it lies at about the 10th parallel in the southern hemisphere.

The Index of Aridity

If the action of temperature is preponderant in the high latitudes and that of precipitation in the low latitudes these two influences act everywhere, and it appears desirable to find some means of expressing their combined function. After several attempts we believe a satisfactory combination has been found, and we call it the "index of

[13] Martonne, Traité de Géographie physique, 4th edit., Vol. 2, 1926, p. 940.

TABLE I—EXTENT OF ENDOREIC AND AREIC REGIONS BY LATITUDINAL ZONES

(*Expressed by area in 1000 square kilometers and as percentage of total land area*)

Latitude	Northern Hemisphere				Southern Hemisphere			
	Endoreic		Areic		Endoreic		Areic	
	Area	Per Cent	Area	Per Cent	Area	Per Cent	Area	Per Cent
0	74	7	61	6	43	4	28	3
1	120	13	74	8	55	5	30	3
2	135	15	74	8	49	5	18	2
3	135	15	61	7	59	5	10	1
4	107	11	61	6	66	6	6	1
5	98	10	49	5	49	5	12	1
6	159	16	61	6	29	3	10	1
7	195	18	55	5	45	4	8	1
8	218	19	36	3	33	3	9	1
9	250	23	54	5	15	2	14	2
10	261	25	78	8	8	1	8	1
11	289	31	91	10	4	0.5	4	0.5
12	370	38	147	15	18	2	11	1
13	437	42	326	31	41	5	13	1
14	612	56	447	41	68	7	19	2
15	653	59	511	46	111	11	23	2
16	707	64	640	55	124	12	31	3
17	776	63	712	58	241	24	91	9
18	821	62	771	58	382	38	170	17
19	843	64	770	59	453	47	266	27
20	859	65	803	61	522	51	375	37
21	858	61	803	61	567	55	333	32
22	863	59	801	55	530	51	268	26
23	836	57	768	52	551	55	311	31
24	822	57	788	54	539	56	370	39
25	859	56	799	52	501	56	354	40
26	847	54	764	49	507	58	328	37
27	931	58	828	52	504	58	323	37
28	924	57	769	48	488	58	406	48
29	954	58	743	45	494	61	398	50
30	1040	61	751	44	483	63	386	50
31	920	57	642	40	379	54	279	40
32	813	52	422	27	265	44	183	30
33	654	44	329	23	212	40	161	31
34	606	40	292	19	158	44	96	27
35	593	39	188	12	127	44	80	27
36	592	39	188	12	119	44	55	20
37	686	46	309	21	89	33	30	11
38	740	50	393	27	48	23	19	9
39	690	46	461	30	57	42	29	11
40	729	47	538	34	56	44	28	22
41	729	48	452	30	46	34	18	13
42	700	46	468	31	50	39	36	28
43	743	47	547	35	45	41	43	39
44	720	46	572	36	44	42	33	32
45	709	44	582	36	35	37	11	12
46	736	45	553	34	25	34	20	27
47	636	37	413	24	34	48	30	42
48	505	29	257	15	36	52	28	40
49	400	24	179	11	28	44	24	38
50	298	18	134	8	16	35	12	26
51	245	15	85	5	3	6	3	6
52	259	16	83	5	1	3	1	3
53	304	19	103	6				
54	317	22	115	8				
55	293	21	98	7				
56	202	15	12	1				
57	185	14	10	1				
58	165	13	4	0.3				
59	112	9	3	0.2				
60	43	3						
61	9	1						

aridity," Ar = P: (T + 10), T representing the mean annual temperature in degrees centigrade and P the annual precipitation.[14] The establishment of an arbitrary zero at − 10° C. is based on two considerations: endoreism is unknown in regions having an annual mean temperature lower than this; in most of these regions the ground remains frozen at a depth the year round, giving rise to abnormal conditions of circulation.

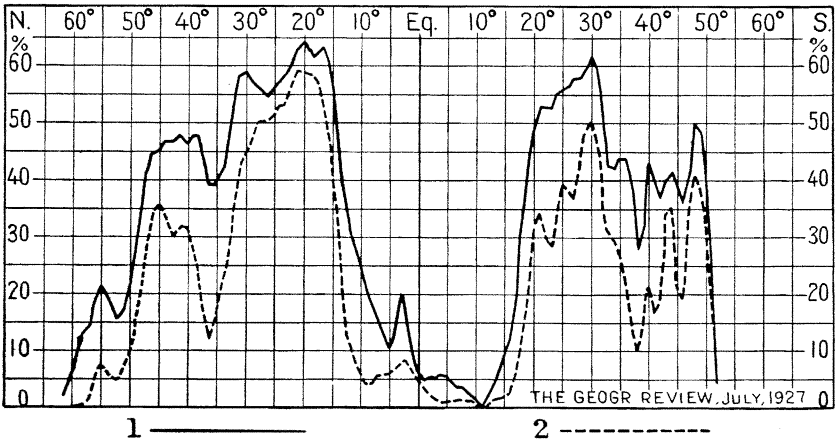

FIG. 1—Areas of the endoreic and areic domains in relation to the total area of the lands by degree zones of latitude. The endoreic domain is shown by a solid line, 1; the areic domain by a dashed line, 2. Compare Table I.

We still have to set forth a correction of T calculated by the meteorologists, for we apply it to continents alone. T in our formula represents a zonal mean newly calculated for this purpose after Hann's isotherms.[15]

A glance at Figure 2 shows us that the curve of the index of aridity follows faithfully that of endoreism and areism. It has the same points of inflexion, save the equatorial minimum, and values comparable in the two hemispheres (excepting the high latitudes of the southern hemisphere). The arid zone is farther from the equator in the southern hemisphere and is more reduced. It is at about the 30th parallel in the southern hemisphere that the maximum of endoreism as well as of areism is found, whereas in the northern hemisphere it lies at about the 20th parallel; and these latitudes correspond to minimum values of the index of aridity. As a whole we can say that exoreism is at a maximum for values of Ar above 35 and at a minimum for values below 20; the limit of areism corresponds about to 10.

[14] Emmanuel de Martonne: Aréisme et indice d'aridité, *Comptes Rendus de l'Acad. des Sci.*, [*de Paris*], Vol. 182, 1926, June 7, pp. 1395–1398.

[15] Julius von Hann: Atlas der Meteorologie, forming Part III of Berghaus' Physikalischer Atlas, Gotha, 1887.

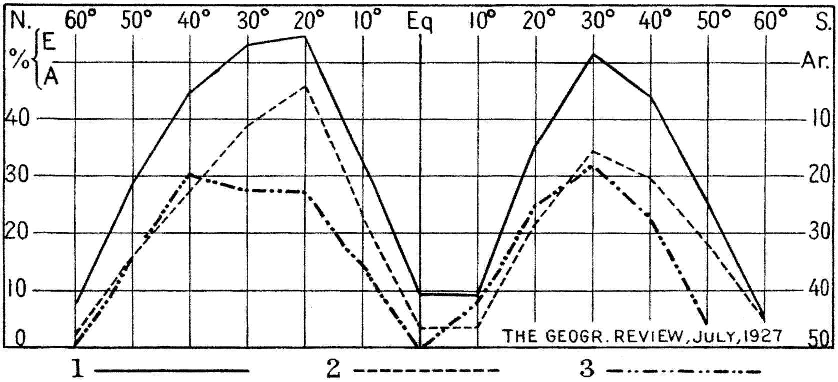

FIG. 2—Extent of the endoreic and areic domains compared with the index of aridity by 10-degree latitude means. Endoreism is shown by solid line, 1; areism by a dashed line, 2, with scale of percentages on the left: the index of aridity is shown by dot-and-dash line, 3, scale on right.

The value of the index of aridity can be checked by calculations for a certain number of points in critical areas: in such case it is understood that the mean temperatures are not reduced to sea level. In the areic regions we invariably find indices below 10, reaching scarcely 1 or 2 in the most typical deserts. Thus in the Sahara 6 at Laghwat, 2 at El Golea, 5 at Tozeur; in Russian Turkestan 3 at Khiva, 5 at Merv; in the center of Australia 4 at Strangways Springs; in the deserts of the west of the United States 2 at Yuma; in those of South America 2 at Lima and 1 at Copiapó. Between the limits of areism and endo-

TABLE II—PERCENTAGE OF ENDOREISM (E) AND AREISM (A) COMPARED WITH INDEX OF ARIDITY (AR)

(By 10-degree means)

Latitude	World as a Whole			Eastern Old World			Western Old World			New World		
	E	A	Ar	E	A	Ar	E	A	Ar	E	A	Ar
60 N.	8	2	50	7	5	55	20	0	35	1	0	75
50 "	28	16	34	45	32	25	30	6	40	7	2.5	47
40 "	44	27	20	65	40	15	41	25	21	17	7.5	30
30 "	53	39	17	35	19	25	80	65	5.6	26	18	27
20 "	54	46	17	8	5	36	86	75	7.6	18	13	28
10 "	33	23	35	0	0	48	49	34	31	2.5	1	41
0	9	3	51	0	0	67	18	6	39	0	0	58
10 S.	9	4	42	12	4	53	16	6	36	4.5	2.5	45
20 "	35	22	25	53	31	15	28	17	20	21	13	38
30 "	51	34	18	72	52	12	23	17	17	39	21	32
40 "	44	30	27	30	26	47	(5)	(4)		49	28	21
50 "	25	18	46							32	22	43

reism the indices vary between 10 and 20; for example in Asia, Samarkand 14, Semipalatinsk 15, Peshawar 10; in North America, Salt Lake City 17, Winnemucca 11; in South America, Salta 17.

These examples bring us to an attempt to show the value of the index of aridity on a map for the continents as a whole. About 200 stations conveniently chosen permit the drawing of curves for indices of 5, 10, 20, 30, and 40 (Fig. 4). Comparison with the map of interior-basin drainage shows in general a remarkable correspondence between the limits of areism and the 5 Ar line which appears to enclose the true deserts. The curve of 20 is less faithful to the limit of endoreism which is often determined by relief, notably in Asia. But beyond the index of 30 drainage is everywhere organized to the ocean with the exception of the Volga, whose waters flow to the greatest inland sea, the Caspian.

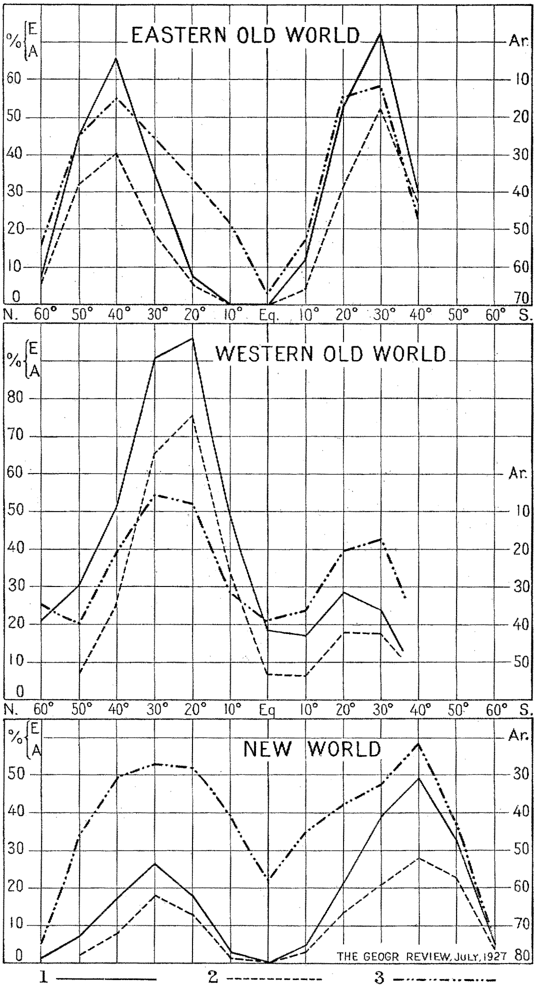

FIG. 3—Extent of the endoreic and areic domains compared with the index of aridity for the three continental spindles. Endoreism is shown by solid line, 1; areism by dashed line, 2, with scale on left: the index of aridity is shown by dot-and-dash line, 3, with scale on right. Compare Table II.

It appears, then, that we have in the index of aridity a climatic function of great value for explaining conditions of drainage. Its geographical significance is still broader. Such a combination of temperature and rainfall explains the character of the vegetative cover much more adequately than rainfall alone. It seems that indices below 5 characterize the true deserts from the botanical as

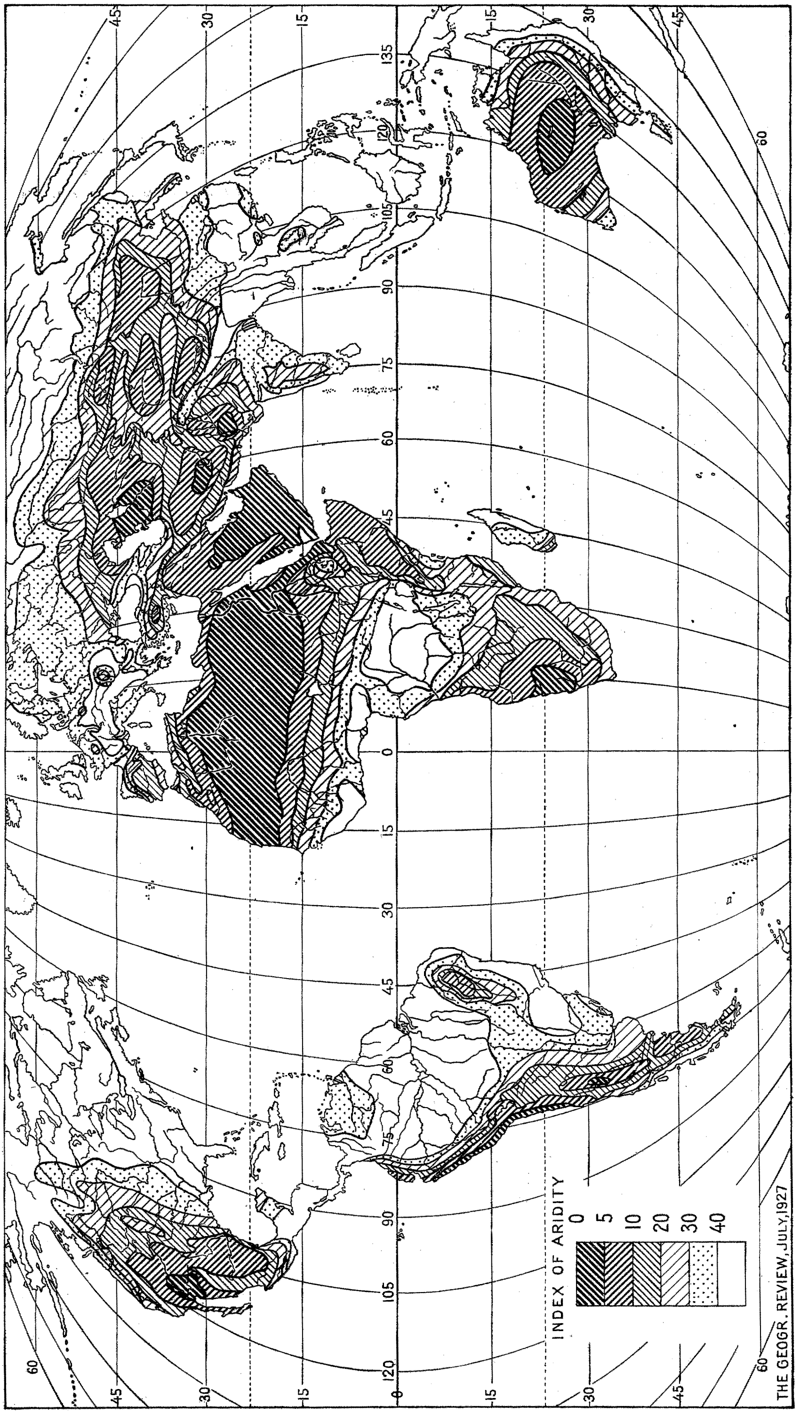

FIG. 4—World map of the index of aridity. Scale approximately 1 : 160,000,000.

well as the hydrographical point of view; indices about 10 correspond with the dry steppes; those of 20, more or less, to the prairies; above 30 forest vegetation tends to predominate and gains complete control of the soil where the index exceeds 40 provided that the temperatures are not too low. The relation with agricultural possibilities may also be noted. No cultivation is possible without irrigation where the index of aridity is below 10; between 10 and 20 is the domain of dry farming. Applications of the index of aridity have been developed elsewhere.[16] It has the advantage[17] of requiring only two sets of meteorological data whose values are known for almost the entire globe.

FIGURES FOR THE CONTINENTS[18]

We shall now consider the distribution of interior-basin drainage according to the major divisions of the land surface of the world. We may first group the continental masses into three spindles: (1) the New World, the Old World divided into (2) Western and (3) Eastern sections by the Urals, the Caspian Sea and Persian Gulf, and the 50th meridian (Table II and Fig. 3).

The New World is the best drained; outside of the tip of South America no zone has more than 40 per cent interior drainage. Accordance with climatic conditions as synthesized by the index of aridity is marked. The Western and Eastern spindles of the Old World present contrasts. The former exhibits in the northern hemisphere the highest proportions of endoreism and areism in the neighborhood of the tropics and the lowest about the 40th parallel, whereas the Eastern spindle shows the greatest extension of oceanic drainage in the low latitudes. In this spindle the great extent of areism outside the tropics in the southern hemisphere (in Australia) is noteworthy. Clearly it is the Western spindle of the Old World that is responsible for the asymmetry of the curve of endoreism for the world as a whole, this spindle being the only one where the equatorial minimum lies at 10° S. This peculiarity is not reflected in the index of aridity, but we may inquire as to whether we are sufficiently well informed on the climate of equatorial Africa.

North America is the best-drained continent, the endoreic and areic domain being there reduced to 10 per cent, 2,136,000 square kilometers. This is not surprising, considering the high values of the index of aridity for all latitudes. Climate, then, is the chief cause here.

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[16] Emmanuel de Martonne: Une nouvelle fonction climatologique: l'Indice d'Aridité, extract from *La Météorologie*, October, 1926.

[17] Compare D. Szymkievicz: Études climatologiques, *Acta Soc. Botan. Poloniae*, Warsaw, 1923, 1925. Compare also Dr. Paul Hirth's recent attempt at combining temperature and rainfall, "Die Isonotiden," in *Petermanns Mitt.*, Vol. 72, 1926, pp. 145–149, discussed (with maps) by Mark Jefferson in the April number of the *Geogr. Rev.*, pp. 335–338.

[18] Lack of space prevents inclusion here of a section by L. Aufrère, discussing individually the more important basins of interior drainage. In a special reprinting of the paper this section is included as an appendix and may be obtained on request.—EDIT. NOTE.

But it should be noted that nearly half the continent lies north of the 45th parallel, that is in a zone where endoreism is almost unknown. The endoreic domain is scarcely more extended than that of the areic and is strictly limited to the west. This is not only because of the orographic structure, which is as unfavorable to run-off to the Pacific as it is favorable to the Atlantic: the climate is as dry in the one as it is humid in the other. The map shows the index of aridity dividing the United States into two halves, the one to the east where Ar is everywhere above 30 and even exceeds 40 between the Mississippi and the Atlantic, the other below 30 and even below 20 over the entire extent of the dry Rockies and the Great Basin.

It is perhaps surprising that South America is not so well drained as North America, in spite of the enormous rainfall of the great Amazon basin—so admirably organized, it would seem, for regular run-off. The per cent of endoreism (14) is raised by the aridity of the continent south of 30° S.

South America, however, is better drained than Europe, where one expects a better organization of the run-off. If the endoreic domain occupies 24 per cent of Europe (2,205,000 square kilometers) areism is almost unknown. In reality the anomaly is due to the northward extension of the Volga basin, tributary to the Caspian. The greatest part of this basin has indices of aridity comparable to those of France (Samara, 27; Kazan, 30), but the slope leads the waters into an interior basin too broad and deep for overflow and enclosed by areic plains (Astrakhan, 7).

Asia, Africa, and Australia are continents where drainage is less perfect. A high proportion of their areas is in latitudes about the tropic; and their structures are massive, without coastal articulations as in western Europe, without great open plains like the Amazon and Mississippi basins. Interior depressions due to faulting or warping are numerous and everywhere create systems of slopes converging towards closed basins that could drain towards the ocean only if the climate were very humid.

Australia has the record for endoreism, 64 per cent, and for areism, 43 per cent. It is the only continent traversed centrally by the tropic. Its relief is nowhere sufficiently important to favor precipitation save on the eastern coast; but if the Australian Alps favor the littoral over which they look it is to the detriment of the plains stretching westward.

Nearly half of Africa drains towards the ocean: the endoreic domain amounts only to 52 per cent, the areic to 40 per cent. The reason is that a large part of that continent lies in the equatorial zone. The Congo basin is apparently a closed basin that has overflowed. The case is the same with the Zambezi and the Niger. Among the tectonic depressions of eastern Africa those lying in sufficiently rainy regions have maintained their outlets; the others are isolated, their centers being occupied by lakes, some of them saline.

Asia is the most interesting continent hydrographically. The percentage of interior-basin drainage is lower than that of Africa, although it includes 14,847,000 square kilometers, or 35 per cent of the total endoreic domain. All monsoonal Asia has oceanic drainage with indices of aridity above 40. The great plains of Siberia for the

TABLE III—AREA AND PERCENTAGE OF ENDOREIC AND AREIC REGIONS BY MAJOR DIVISIONS

(Areas in 1000 square kilometers)

Region	Endoreic		Areic	
	Area	Per Cent	Area	Per Cent
Europe	2,205	24	452	5
Asia	14,847	35	9,935	24
Africa	15,223	52	11,771	40
Australia	4,920	64	3,309	43
North America	2,136	10	1,070	5
South America	2,507	14	1,454	8
Northern Hemisphere	32,386	34	22,139	23
Southern Hemisphere	9,452	28	5,852	17
World	41,838	33	27,991	23

most part have regular drainage, having indices of over 35 and 40. The principal area of endoreism is found in latitudes where elevation is very great. The reason is to be sought in the numerous tectonic depressions whose size demands a humid climate for the maintenance of through drainage, whereas the climate is dry because the mountains cut off the rainy winds. Observations are lacking for the calculation of indices of aridity in the greater part of these regions; we only know that it falls below 10 in Russian Turkestan (Merv, 5; Kasalinsk, 6; Irgis to the north of the Aral, 11).

Some Exceptions to Latitudinal Zoning

Having examined the most striking feature of distribution of interior-basin drainage we may now inquire into some of its numerous irregularities. Along the equator oceanic drainage is the rule, as interior drainage is along the tropic. Yet there are exceptions. The most important is in eastern Africa. From Eritrea to Nyasa stretches a belt where endoreism and even areism prevail. Meteorological data are lacking, but the vegetation bespeaks true aridity. In northeastern Brazil is an arid region more limited, it is true, but similar in situation to that of the steppes and deserts to the east of Lake Victoria. The extension of aridity to the tip of the Somali country and the seaboard is not matched anywhere, and a really satisfactory explanation has not yet been offered.

The western borders of the continents do not escape aridity in the equatorial zone. South America offers the most striking example with the coast desert of Peru. That the cold Humboldt Current is a contributary cause has been confirmed by the recent incidence of the rains of 1925 and the weakening of the current.[19] South Africa offers an analogous case in the aridity that extends from the mouth of the Orange River almost to the Congo and is associated with the cold Benguela Current.

It is along the tropic that the greatest stretches of endoreism and areism are found: but these zones, which correspond to indices of aridity below 10 or even 5, are not continuous. The monsoonal domain of southeastern Asia has an index of aridity above 40. The Antilles, southeastern North America, and other tropical and subtropical eastern seaboards are also humid.

Beyond the 30th and 40th parallels humidity becomes the rule on the western coasts and endoreism is thrown back into the interior. The southern extremity of South America is divided into a narrow, very wet littoral section on the west and an arid section covering all Patagonia on the east. In North America the prairies show patches of endoreism up to the 55th parallel. In Eurasia areism exists at least to 56° or 57° in the west Siberian plains. The polar limit of areism is systematically advanced under the continental climate in these flat alluvial plains. That of endoreism is advanced still further by exceptional conditions of relief: the waters of the Volga are abundant enough to reach the ocean did not the slope lead them to the greatest closed basin created by deformation on the earth's surface and lying, furthermore, on the borders of a great areic region. With this exception the index of aridity explains the systematic irregularities in the zonal distribution of interior basin drainage. These may be summarized thus: aridity limited to the borders of the equatorial masses of the continents, especially to the western littoral in the southern hemisphere; general aridity along the tropics with the exception of the eastern slopes; westward extension of aridity in the subtropical zone; aridity confined to the continental interiors towards the poleward limit of areism. Departures in detail are to be ascribed to the direct influence of relief or of geological structure on stream run-off.

Considerations of conditions as they are today will not explain everything. Relief is affected by crustal movements still in progress in places, and everywhere erosive forces are at work. Nor is climate

[19] R. C. Murphy: Oceanic and Climatic Phenomena Along the West Coast of South America During 1925, *Geogr. Rev.*, Vol. 16, 1926, pp. 26–54.

constant. Hence hydrographic adaptation to conditions as we see them is not perfect. Headward erosion of the systems draining to the ocean threatens the independence of the interior basins, particularly in the endoreic regions where local base level is being raised by sedimentation if not by lake formation. In Africa the basins of the Nile, the Niger, and the Zambezi exhibit the conquest of exoreism over endoreism. Lake Chad is threatened by the Niger. In the rainy season the Benue, a tributary of the Niger, is already tapping the waters of the Logone, tributary of the Shari.

The case of the Nile is curious, for its lower course is through an areic region. The basins of the equatorial region overflow and yield water in abundance, so that erosion of the rock barriers forming the cataracts continues. Probably it was during the humid phases corresponding to the Quaternary glaciations that captures of the interior basins of the upper Niger and the upper Zambezi took place. The Niger was then reinforced by the entire network of fossil wadis of Tafassasset. Erosion of the Victoria Falls is still in full swing on the Zambezi. The Niger has only rapids, no falls, in its course.

As regards evolution of the present drainage in northern Africa French geographers and geologists have rightly protested against Grund's hypothesis of the extension of interior drainage.[20] All indications point to headwater erosion in the basins of the high Algerian-Moroccan plateaus by Atlantic and Mediterranean rivers. But it is probable that the most appreciable gains were made during the humid periods of the Quaternary.

In Asia many conquests of oceanic drainage over endoreism also date from the Quaternary. The Ob captured the Black Irtish and the Zaisan Nor, the Amur and the Liao Ho invaded Manchuria, the Hwang Ho and the Brahmaputra penetrated, the one the Ordos, the other Tibet. Nor has postglacial aridity compromised the situation, thanks to these powerful watercourses. It is certain that communication by the Uzboi existed between the Aral and Caspian Seas during the Quaternary when the level of the former sea was higher: it is even probable that there was an outlet from the Caspian to the Sea of Azov by the Manytsch. The Volga is threatened with capture by the Don: so far it has escaped, owing to the sinking of the water surface of the Caspian, 30 meters below sea level, a lowering which in turn is due to the enormous evaporation under a desertic climate.

These are a few examples of the fluctuating fortunes in the strife between oceanic and interior drainage since the Quaternary. It may be asked if annexation to the exoreic domain always constitutes an advantage. It may be considered so if it occurs in a region anciently endoreic where return to normal conditions leads to the exportation of waste, to the establishment of a regular drainage network, and perhaps

[20] E. F. Gautier: Sahara algérien (Missions au Sahara, Vol. 1), Paris, 1908.

to an amelioration of climate, access of winds from the oceans being facilitated. It is not certain that there is climatic or even physiographic advantage in the case of an areic region. The retention of waters as a lake in an arid region, as Chad, Lob Nor, the Aral Sea, is favorable to life; evaporation renders the air less dry, infiltration creates ground-water resources. The Kalahari appears to have lost by the conquests of the Zambezi and the Orange. It is a fact that the life of Bornu depends on the Chad, and Colonel Tilho[21] considers that a great danger threatens these territories in the imminent capture of the Shari by the Benue.

The development of interior-basin drainage, like other geographical facts, cannot be explained by present conditions alone. Important changes have occurred in the recent past, are in operation now, or are being prepared for in the future. They are of interest to us for the light they throw on the relations of the physical phenomena to which the face of the earth is due. They may have economic consequences to which no one can remain indifferent.

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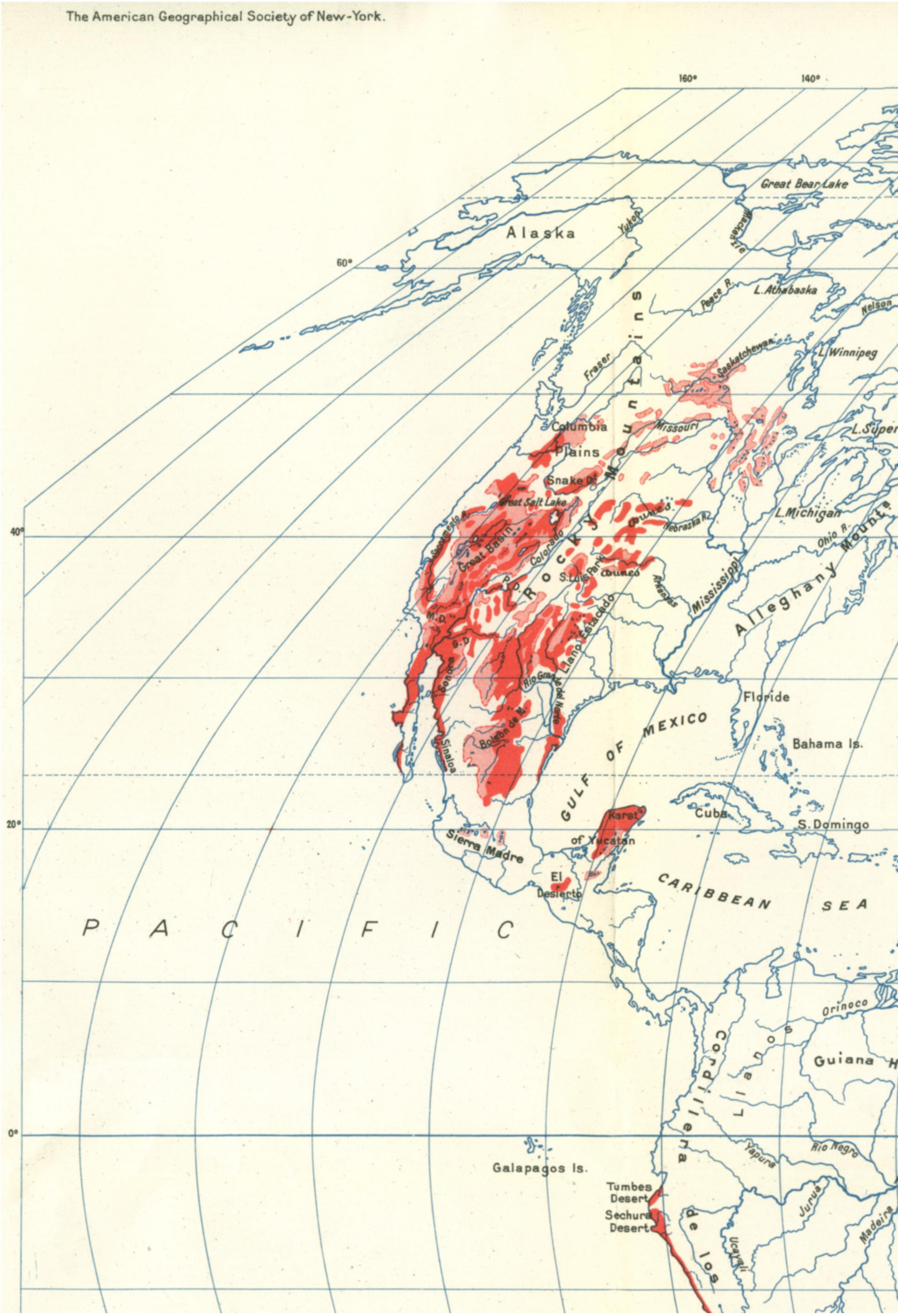
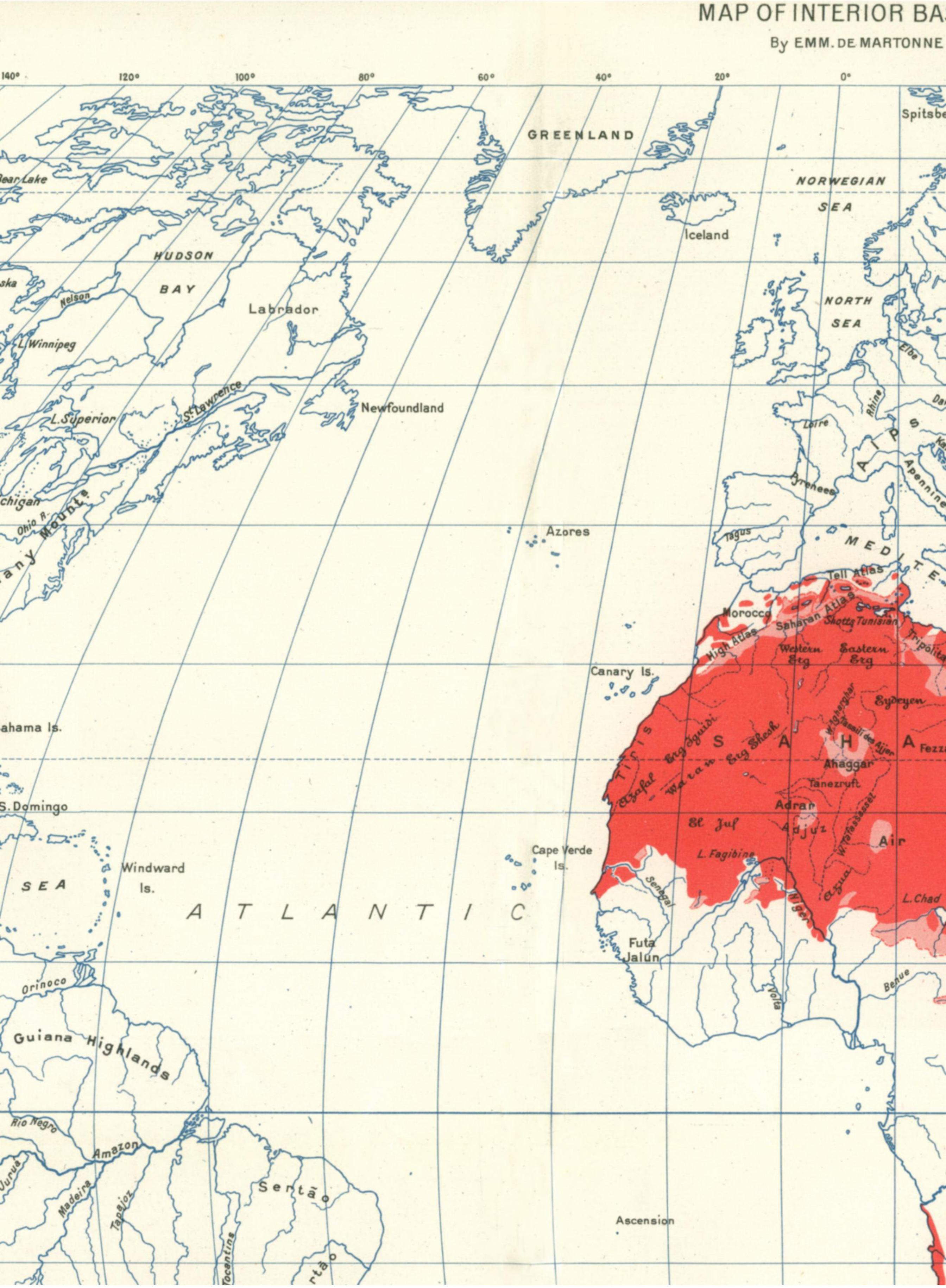
[21] Jean Tilho: Sur l'ordre de grandeur des variations de profondeur et d'étendue du Lac Tchad, *Comptes Rendus de l'Acad. des Sci.* [*de Paris*], Vol. 180, 1925, pp. 1233–1236.

Idem: Les variations du Lac Tchad, *Bull. Assn. de Géographes Français*, No. 9, May, 1926.

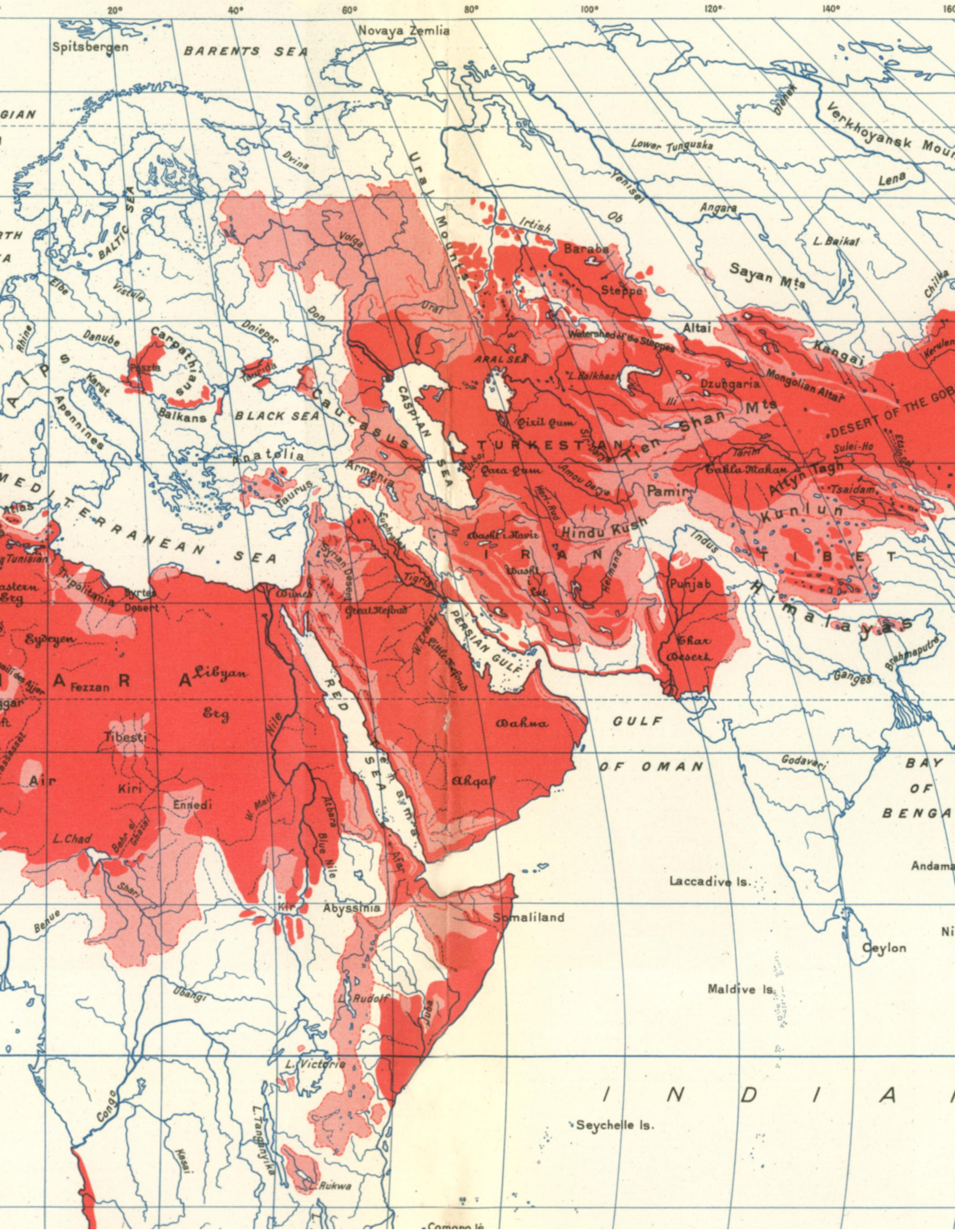


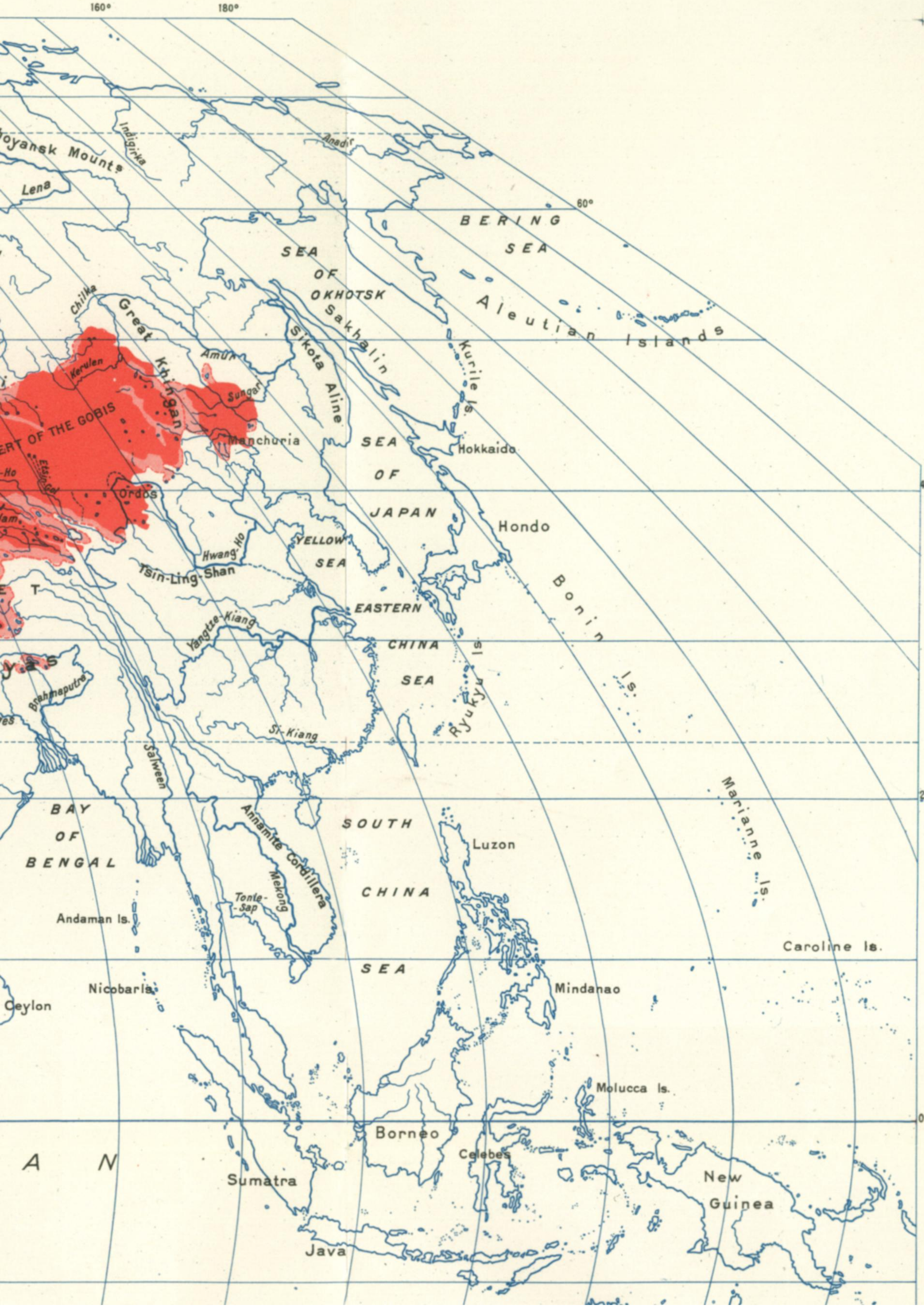
The American Geographical Society of New-York.
160°
140°
60°
40°
20°
0°
Alaska
Yukon
Great Bear Lake
Peace R.
L. Athabaska
Nelson
Fraser
Saskatchewan
L. Winnipeg
Rocky Mountains
Columbia
Plains
Missouri
Snake R.
Great Salt Lake
Great Basin
Colorado
Nebraska R.
L. Michigan
L. Super
Ohio R.
S. Luis Park
Arkansas
Mississippi
Alleghany Mounts
M. D.
G. D.
Llano Estacado
Sonora
Rio Grande del Norte
Florida
Sinaloa
Bolson de M.
GULF OF MEXICO
Bahama Is.
Karst
of Yucatan
Cuba
S. Domingo
Sierra Madre
El
Desierto
CARIBBEAN SEA
PACIFIC
Orinoco
Cordillera de los
Llanos
Guiana
Rio Negro
Yapura
Galapagos Is.
Tumbes
Desert
Sechura
Desert
Jurua
Ucayali
Madeira

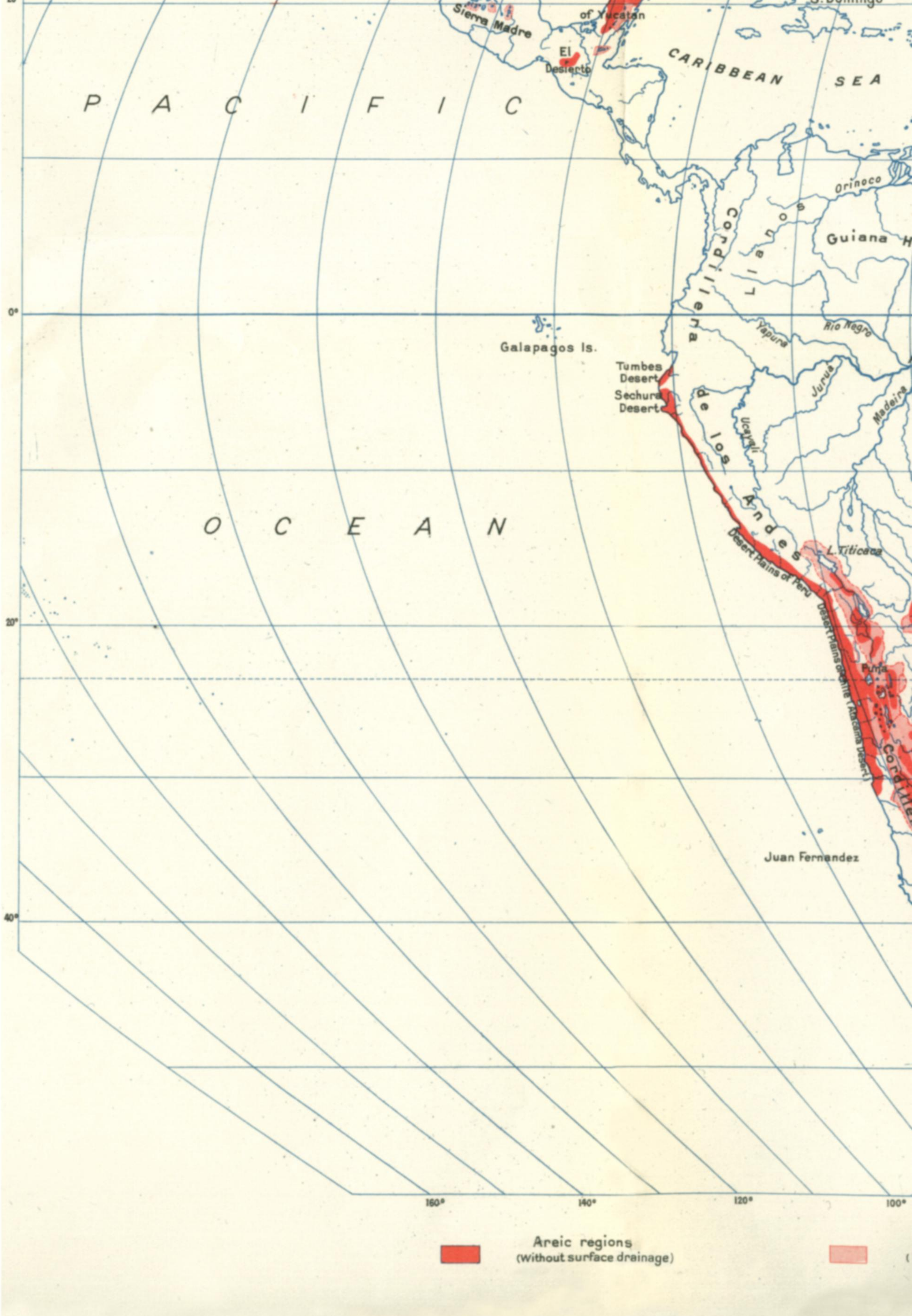

MAP OF INTERIOR BA
By EMM. DE MARTONNE
140°
120°
100°
80°
60°
40°
20°
0°
GREENLAND
Spitsbe
Bear Lake
HUDSON
BAY
Nelson
L. Winnipeg
Labrador
Iceland
NORWEGIAN
SEA
NORTH
SEA
Elbe
Rhine
Loire
Newfoundland
St. Lawrence
L. Superior
Ohio R.
Pyrenees
Alps
Apennine
Tagus
Azores
MEDITE
Tell Atlas
Morocco
Saharan Atlas
Shotts Tunisian
High Atlas
Western Erg
Eastern Erg
Tripolita
Canary Is.
Erg Iguidi
SAHARA
Fezza
Ahaggar
Tanezruft
Adrar
El Juf
Adjuz
Air
L. Fagibine
Senegal
Niger
L. Chad
Cape Verde Is.
Windward Is.
S. Domingo
SEA
ATLANTIC
Futa Jalun
Volta
Benue
Orinoco
Guiana Highlands
Rio Negro
Amazon
Jurua
Madeira
Tapajoz
Tocantins
Sertão
Ascension

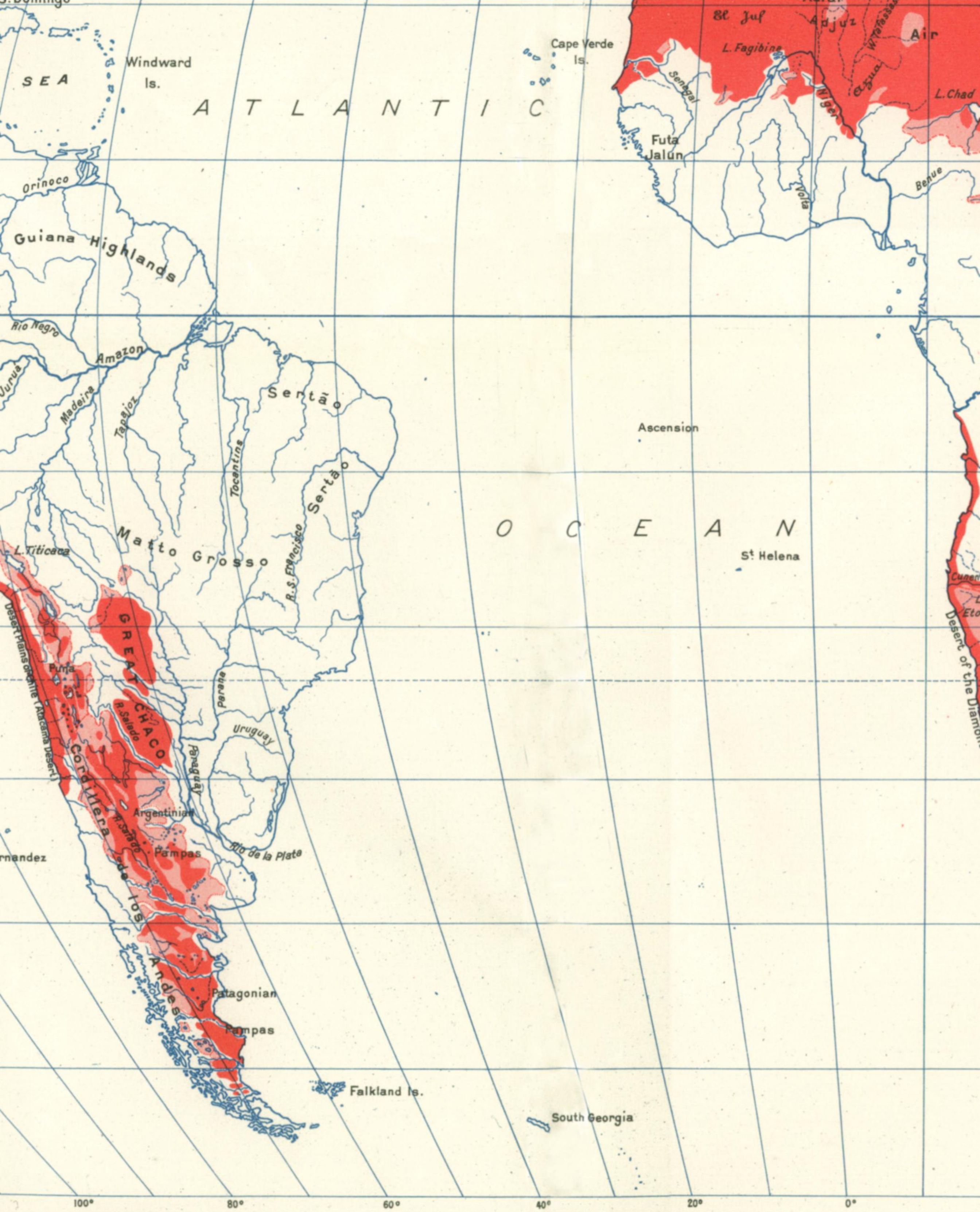
RIOR BASIN DRAINAGE

E MARTONNE and L. AUFRÈRE




160°
180°
60°
40°
20°
0°
Indigirka
Anadir
Lena
BERING SEA
SEA OF OKHOTSK
Aleutian Islands
Sakhalin
Chilka
Great Khingan
Kerulen
Amur
Sungari
Sikota Aline
Kurile Is.
DESERT OF THE GOBIS
Manchuria
SEA OF JAPAN
Hokkaido
Ordos
Hondo
YELLOW SEA
Hwang Ho
Tsin-Ling-Shan
Bonin Is.
EASTERN CHINA SEA
Yangtze-Kiang
Ryukyu Is.
Brahmaputra
Si-Kiang
Salween
Marianne Is.
BAY OF BENGAL
SOUTH CHINA SEA
Luzon
Annamite Cordillera
Mekong
Tonle-Sap
Andaman Is.
Caroline Is.
Nicobar Is.
Mindanao
Ceylon
Molucca Is.
Borneo
Celebes
New Guinea
Sumatra
Java


Sierra Madre
of Yucatan
El Desierto
CARIBBEAN SEA
P A C I F I C
O C E A N
Orinoco
Guiana
Llanos
Cordillera de los Andes
Yapura
Rio Negro
Galapagos Is.
Tumbes Desert
Sechura Desert
Jurua
Ucayali
Madeira
L. Titicaca
Desert Plains of Peru
Desert Plains of Chile (Atacama Desert)
Puna
Juan Fernandez
0°
20°
40°
160°
140°
120°
100°
Areic regions
(Without surface drainage)

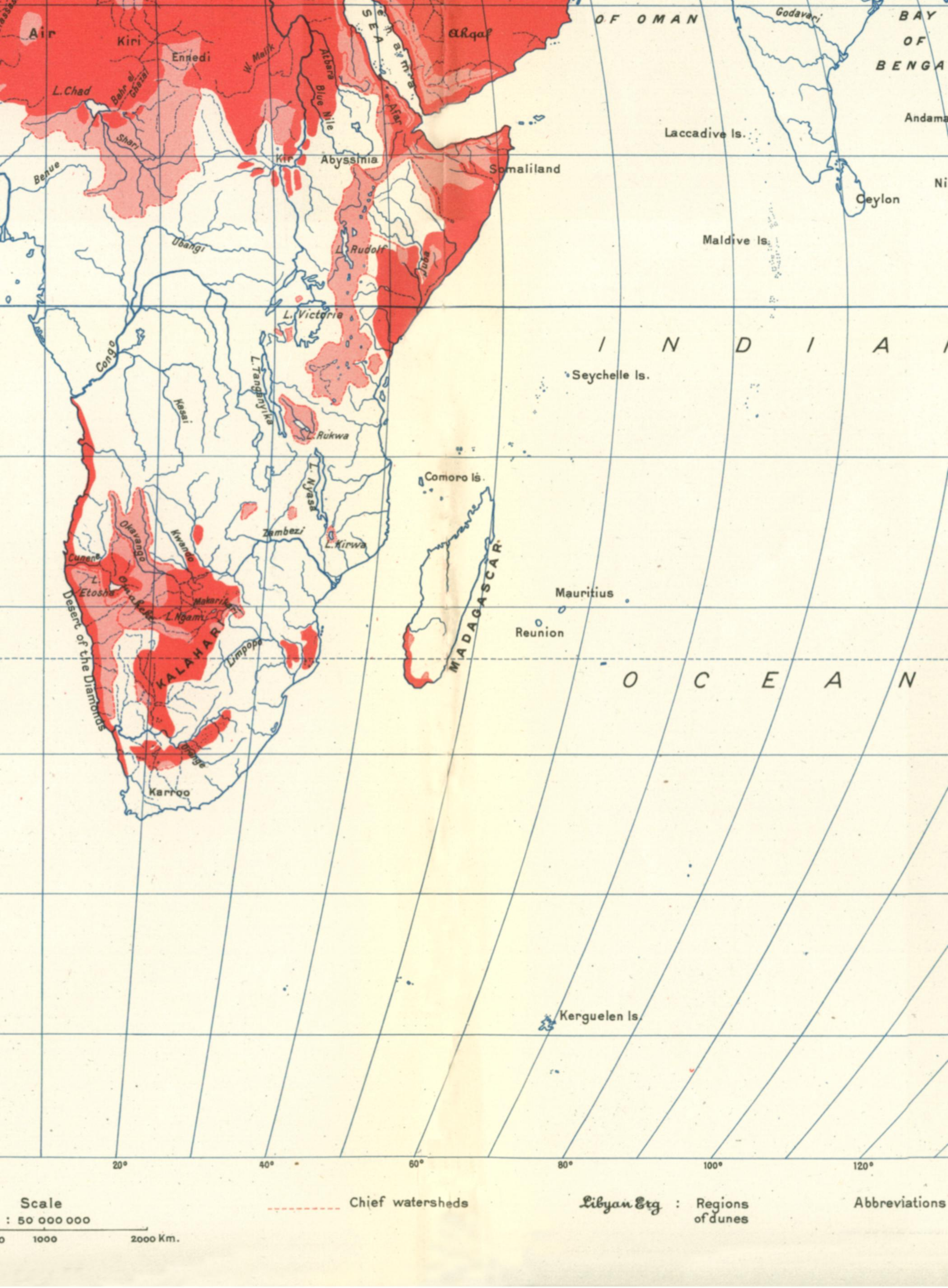


Endoreic regions (Interior basin drainage)

Endoreic regions (throng-flowing drainage)

Scale 1 : 50 000 000

0 500 1000



Air
Kiri
Ennedi
L. Chad
Bahr el Ghazal
W. Malik
Atbara
Blue Nile
Shari
Benue
Kir
Abyssinia
Afar
SEA
Ahqaf
OF OMAN
Somaliland
Godavari
BAY OF BENGA
Laccadive Is.
Andama
Ceylon
Maldive Is.
Ubangi
L. Rudolf
Juba
L. Victoria
Congo
L. Tanganyika
Kasai
I N D I A
Seychelle Is.
L. Rukwa
L. Nyasa
Comoro Is.
Zambezi
L. Kirwa
Kwando
Okavango
Cunene
L. Etosha
Makarikari
L. Ngami
MADAGASCAR
Mauritius
Reunion
KALAHARI
Limpopo
Desert of the Diamonds
O C E A N
Orange
Karroo
Kerguelen Is.
20°
40°
60°
80°
100°
120°
Scale
: 50 000 000
1000
2000 Km.
Chief watersheds
Libyan Erg : Regions of dunes
Abbreviations

Abbreviations ._ M.D.= Mohave Desert. G.D.= Gila Desert. P.D.= Painted Desert.
Bolson de M.= Bolson de Mapimi.