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ATMOSPHERE SEA-SALTS DESIGN CRITERIA AREAS

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ABSTRACT

Data on the amount and distribution of sea-salt fallout is presented so that designers of equipment and installations affected by salt corrosion can be made aware of the phenomenon and be apprised of the magnitude of the problem created by it.

By means of the data assembled, four preliminary design criteria areas have been distinguished: Area I — Oceanic Islands and Coastal Areas in which the sea-salt fallout from all processes is high — ranging in amounts from roughly 25 to 300 lb/acre/yr with extremes as high as 3,000 to 4,000 lb/acre/yr on well-exposed sites; Area II — Intermediate Humid Coastal and Inland Areas where saltfall is moderate to heavy and which varies from about 3 to about 25 lb/acre/yr; Area III — Subhumid and Humid Areas of Uniform Low Saltfall of somewhat stabilized levels of less than about 3 to 5 lb/acre/yr; and Area IV — Arid Areas of Variable Saltfall on which the saltfall is usually less than 3 to 5 lb/acre/yr but may locally rise to high amounts because the proximity of inland salt lakes and playas.

INTRODUCTION

Designers of military equipment have long been aware of the corrosiveness of salt particles when in contact with metals. Salt spray and salt water immersion tests have been much used. However, although the fact has been known since the middle of the last century, designers in general have not been aware that sea-salt, largely composed of sodium chloride, is deposited continuously even inland, either as a liquid in aqueous precipitation or as salt particles in dry fallout, by every importation of maritime air. This fact was vividly shown recently at an inland missile site where missile failures resulted from salt corrosion.

The primary source of sea-salt in the atmosphere is the oceans. Minor amounts of salts are contributed by weathering of rocks, by wind erosion of salt efflorescences in the topsoils of arid areas, and by industrial and human sources. Normal sea winds carry from 10 to 100 pounds of sea-salt per cubic mile of air and this may be increased to 0.5 ton on the windward shore during a storm[1]. About 1 billion tons of airborne oceanic mineral constituents are produced annually over oceanic areas. From air mass and wind data, about 10 per cent of this amount is estimated to be blown over the continents, precipitated, and eventually brought back to the sea in river waters. It has been estimated that it will take from 2 years in humid areas to many thousands of years in arid areas for this salt to return to its source[1]. The highest fallout is on the coast, and the amount decreases geometrically inland for roughly 50 to 1,000 miles, depending on the land mass and its geography and the size and character of the maritime air mass, until a point is reached where the amount is believed to be fairly constant[2,3,4,5].

Saltfall in the United States has been estimated to amount to 3.8lb/acre/yr and in some coastal areas may well be as high as 100 lb/acre/yr[1]. Extremes of chlorides in precipitation recorded in some areas of the world include the breakwater at Ft. Sherman, in the Canal Zone, where more than 4,400 lb/acre/yr have been reported[6]. Lagos, Nigeria has had a fall of 2,600 lb/acre/yr of sodium chloride[5]. Over 45 pounds of salt per acre were deposited in Perth, Western Australia, during a single 5-day storm in which 4.16 inches of rain fell[4]. Seasonally on the beach at Lagos, Nigeria in January 1954, 250 mg/m^2/day were deposited and during August over 2,000 mg/m^2/day were recorded[5]. At Ft. Sherman, Canal Zone, a daily average of 47.7 mg. of chloride was recorded in November 1964, and over 5,200 mg/m^2/day in March 1964[6]. The rate of precipitation of chloride during the passage of a typhoon (Kitty) in Japan ranged from about 0.003 to 0.08 mg/m^2/second with an average of about 0.02[7].

THE SEA-SALT CYCLE

A quick review of current thought pertaining to the sea-salt cycle is of interest. It should be mentioned that not all theories in this field are universally accepted, so this presentation may be subject to revision. Salt saturated droplets or particles in the air are formed from bubbles produced on the sea surface by breaking waves, by snowfall on the sea, by rainfall, or by warming of sea water in spring[8]. Bursting of a bubble jets a small positively charged droplet from the surface of the liquid into the air[9,10]. Such droplets are jetted upwards at a speed of from 10 to 80 mph and rise no higher than 6 to 8 inches[11]. The droplet usually evaporates at least in part, in a matter of seconds, leaving a salt crystal or droplet of concentrated brine to be picked up by the wind and carried away. The approximate critical relative humidity governing whether the salt, in equilibrium, will consist of droplets of solution or solid crystals is 76%. Only one of the four or five droplets ejected as the bubble bursts is expected to remain airborne. The great majority of bubbles are less than 200 microns in size. The larger the bubbles the greater the amount of salt[12].

Salt particle size varies from about 0.1 micron to 20 microns radius or even larger. Salt particles with radii from 0.1 to 0.8 micron are most numerous, but about 98% of the total mass of sea-spray particles in marine air are larger than 0.8 micron radius[2]. The sea-spray particles smaller than 0.1 micron radius are believed to be negligible in terms of either mass or number.

Major processes that contribute to the removal of sea-salt particles from the atmosphere are: washout by precipitation, fallout under force of gravity, combing by surface obstacles[13], and encrustation of the ground and surface objects by salt laden winds. Washout by precipitation, believed to be the most important process, is accomplished by removal of particles that act as nuclei during condensation, removal by agglomeration of cloud droplets, and removal by collection during fall of raindrops.

Dry fallout under force of gravity is important everywhere, but particularly close to the ocean source and to coastal areas where the larger salt particles fall out. The rate of descent of salt particles in the atmosphere has been computed to be 1 to 2 cm per second[1]. Two collecting bottles were exposed side by side at Boston, Massachusetts: one was open to precipitation only; the other open continuously. The open bottle collected 25 per cent more chloride as a result of dry fallout[2]. Dry fallout may prove to be very important in continental interiors such as that of the United States, where maritime air masses off the Pacific or tropical Atlantic encounter cold polar air and precipitate water and sea-salt during storms.

Impingement, or the combing of sea-salt particles by bushes and trees, is difficult to assess at this time because of lack of comparative data. Analyses show that rainwater collected under trees in Sweden has much higher concentrations of inorganic ions than that collected in the open[13]. This phenomenon is attributed to dry salt accumulated on the trees by impaction. It is probably safe to state that this may be an important process in forest and bush areas particularly near the ocean.

Encrustment, or the coating of the ground and surface objects with a salt layer during driving wind storms, is an impaction process of local importance. The conditions under which this coating is deposited is not known, but in Halifax, N.S. on 30 December 1956 and in Minorca in various years, it has been associated with rainless winds. In Mauritius the encrustation was associated with a hurricane[14]. Encrustment causes much damage. For days after the Halifax wind storm the salt layer interfered with the distribution of electricity because pole insulators became conductors every time a slight amount of moisture fell on them. Encrustment must be cleared off television antennae after an intense storm in island or coastal areas in order to receive a clear picture.

SEA-SALT FALLOUT OVER THE CONTINENTS

Although knowledge of the distribution of sea-salt over the continental land masses is rather incomplete, a number of noteworthy widespread systematic and local surveys have been made and these surveys have provided most of what is known about the distribution (Map I). No systematic surveys for South America or Asia are known. Many difficulties are involved in trying to estimate the total salt fallout from all processes from these data (which are usually restricted to one process of measurement only) and from isolated reports.

It is believed that in practically all cases the figures presented represent minimal figures unless actually so stated. Lacking day by day sampling and tie-in with daily weather conditions, certain generalizations regarding salt distribution for design criteria purposes have been made based upon the findings of these surveys. They are presented herewith and are supported where possible by data available from systematic corrosion surveys, which will be acknowledged by reference.

NORTH AMERICA

United States

The highest sea-salt fallout occurs along the sea coasts where the salt spray is continuously being generated and blown inland. Fallout decreases as the distance inland from the coast increases. About 300 to 1,000 miles inland, depending on the area, there appears to be a tendency toward constant fallout. The fallout level in winter is higher than in summer.

The figures used in the following description of fallout in the United States refer to the original figures obtained by Junge and Werby[15] as recomputed by Eriksson[1] and refer to the concentration of chlorides in precipitation. In order to estimate what the total saltfall of an area is, the figures should be increased by a factor of about 3 to include saltfall by impaction, dry fallout, and encrustment, particularly in the coastal and near-coastal areas[1]. Compared with the results obtained from the northwest European cooperative network and selected stations in other parts of the world, the figures for the coastal United States appear to be lower than one would expect. This can be attributed in part to the fact that the initial survey was limited to only 62 first order weather stations and that these were selected on the basis of location and hours of operation. Cities and industrial areas were avoided, as well as stations that did not operate on a 24-hour schedule. Also, in contrast with the European network, the collecting bottles were opened only during periods of precipitation.

The heaviest amount of sea-salt precipitated in the United States is at Tatoosh Island, Washington in the cyclonic storm area of the coastal Pacific Northwest, where amounts in excess of 32 lb/acre/yr have been recorded. Saltfall drops off rather rapidly to the east beyond Spokane where it is about 2 pounds and in the south beyond Eureka where it is about 7 pounds. Saltfall on the California coast varies from 3 to 5 lb/acre/yr and is highest in the Los Angeles area.

Along the Gulf of Mexico the saltfall in precipitation is 4 pounds along the Texas coast, 11 pounds along the Louisiana coast and 8 pounds on the Florida west coast. Along the Atlantic coast the greatest saltfall in precipitation is reported from Miami where about 15 lb/acre/yr is noted. Cape Hatteras, N. C. reports 10 lb/acre/yr.

From the coastal areas to about 300 miles inland, the concentration of salts in precipitation decreases until the amount becomes more or less constant over much of the continent at from 1 to 2 or less lb/acre/yr. Several exceptions to this statement should be noted: (1) the industrial areas of the east, where the concentration in precipitation appears to be slightly higher (5 pounds) than normally expected, even though industrial areas were avoided in selection of sites; (2) the Mississippi-Ohio Valley, where a monsoon-like inflow of maritime air from the Gulf of Mexico persists over much of the summer, carrying a relatively higher saltfall of 2 to 3 lb/acre/yr inland for over 1000 miles; and (3) the arid lands of the southwest, where various salts are picked up on the dry playas and salt lakes by strong gusty winds, which may cause severe local salt corrosion problems if the relative humidity is high enough.

Much of the interior of the United States from the eastern border of the Pacific states, including the inland valleys of those states, to a line extending from near Eagle Pass on the Rio Grande northeastward through eastern Oklahoma, central Missouri, and eastern Iowa to eastern Wisconsin, has a fairly uniform fallout of between ½ to 1 lb/acre/yr. The lowest amounts occur between Sheridan, Wyoming; Goodland, Kansas; Albuquerque, New Mexico; and Las Vegas, Nevada, where the amount drops below ½ lb/acre/yr.

The general pattern of distribution of sea-salt in precipitation presented here for the United States is confirmed, except in industrial areas, by a corrosion survey[16]. Uncoated pieces of 28 gauge, low-carbon, cold-rolled sheet steel were exposed in 523 cities in the United States. Survey results showed that those panels that were located in cities along the sea coasts and in industrial regions deteriorated in from 3 to 4 years but in inland cities of the Southwest corrosion took 15 or more years.

Canada

Data on sea-salt fallout in Canada is provided by several researchers[17,18]. One group found that a point 135 feet from the ocean at the entrance to Halifax Harbor, N.S., the saltfall amounted to 98 lbs per acre which is equivalent to 1,176 lb/acre/yr while about 11 miles inland at the Technical College at Halifax, the fallout estimated from samples taken at specific intervals during the years amounted to only 48 to 144 lb/acre/year.

An analysis of rust samples from outdoor corrosion exposure sites established by the National Research Council across Canada indicates the chloride content of the rust samples in Saskatoon, Saskatchewan and Norman Wells, N.W.T., is much higher than inland stations to the east and west of these towns. The figures are shown in Table I.

Halifax City, N. S.	796*
Halifax-York Redoubt	216
Montreal, Quebec	230
Ottawa, Ontario	161
Saskatoon, Saskatchewan	359
Norman Wells, N. W. T.	568
Trail, B. C.	146
Rocky Point, Vancouver Island	307

* Chloride in parts per million.

TABLE I

At present there appears to be no solution to this enigma. It might be pointed out that a similar situation appears to exist in the dry areas of the Soviet Union where highly saline dust particles may contribute to the high fallout.

South and Central America And the Caribbean Sea

The only data available for South America reports chloride concentration in precipitation at British Guiana as equivalent to 193 lb/acre/yr[19]. Central America data includes monthly reports from the U.S. Army Tropical Testing Center at Ft. Sherman, Canal Zone, where amounts as high as 4,600 lb/acre/yr are recorded on the beach breakwater[6].

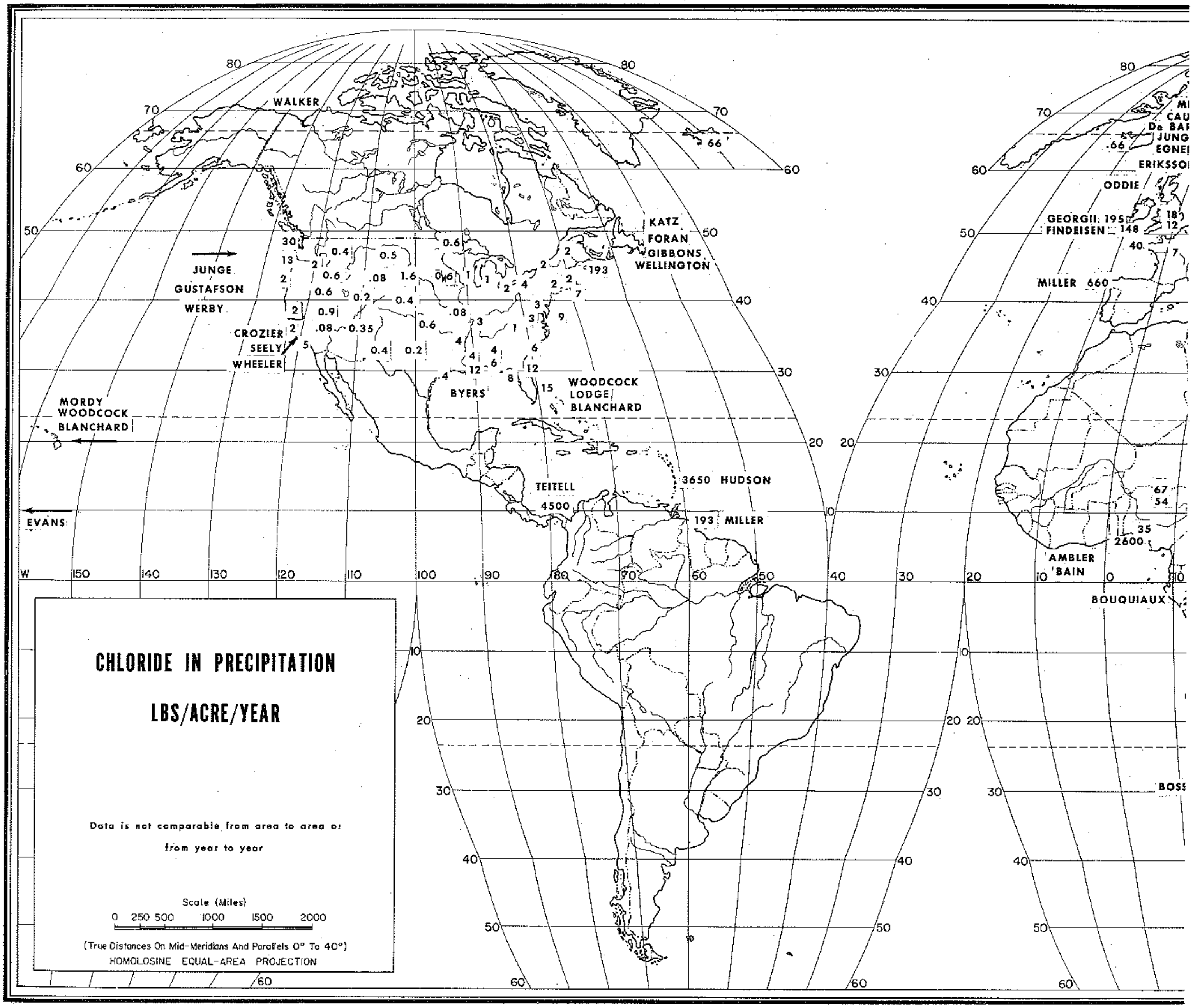
One report on chlorides in precipitation in Barbados, B.W.I. indicated that 211 lb/acre/yr were received in precipitation[19]. However, another report showed that a station network operating from mid-June to mid-August yielded a maximum of 20 and a minimum of 10 pounds per acre every day[21].

From the above limited data and from a knowledge of climatic conditions certain generalizations can be made concerning distribution of chlorides in this area. Very high saltfall can be expected on coasts exposed to the northeast and southeast trade winds because this is a region of relatively low humidity which is conducive to the production of large salt crystals, which make up the main mass of atmospheric salt in the source areas. Most of the Caribbean Islands, including the drier trade wind islands, can be expected to have a high saltfall because of the trades and fall hurricane winds. Much fallout can also be expected along the Mexican coast east of the Sierra Madre Oriental, from east winds from the Caribbean Sea in summer and in southern Chile and Argentina including the South Atlantic islands within the zone of prevailing westerlies. The major part of the continent extending from Colombia, Venezuela, and the Guianas southward through Brazil, Paraguay, and northern Argentina can be expected to have moderate amounts of saltfall (from 5 to 25 lb/acre/yr). On the arid areas of Patagonia east of the Andes the saltfall can be expected to fall below 1 lb/acre/yr. In the arid area in northwest Argentina the saltfall may be as high as 3 lb/acre/yr from the deflected Southeast trade winds that seasonally bring maritime air to northwest Argentina. The desert region on the west coast of South America can be expected to have a moderate to high saltfall along the coast because of the fog and the winter drizzle that accompanies it created by contact of tropical maritime air with the cold water in the Humboldt current and the on-shore anabatic winds. The saltfall inland above the fog zone on the west face of the Andes is presumably low.

Europe

The most comprehensive data on chlorides in precipitation is provided by the Western Europe cooperative network. Data in this section primarily are based upon reports of this network.

In Europe, the salt fall is heaviest on the immediate ocean coast and lessens with increasing distance from the ocean. The gradient is steepest along the mountain-backed Norwegian coast and least in the industrial areas of France, Belgium, Germany, Switzerland, and Czechoslovakia. The chlorides in precipitation along the sea coast vary from about 200 lb/acre/yr at Valencia in southwestern Eire, to 130 at Lands End, southwest England,



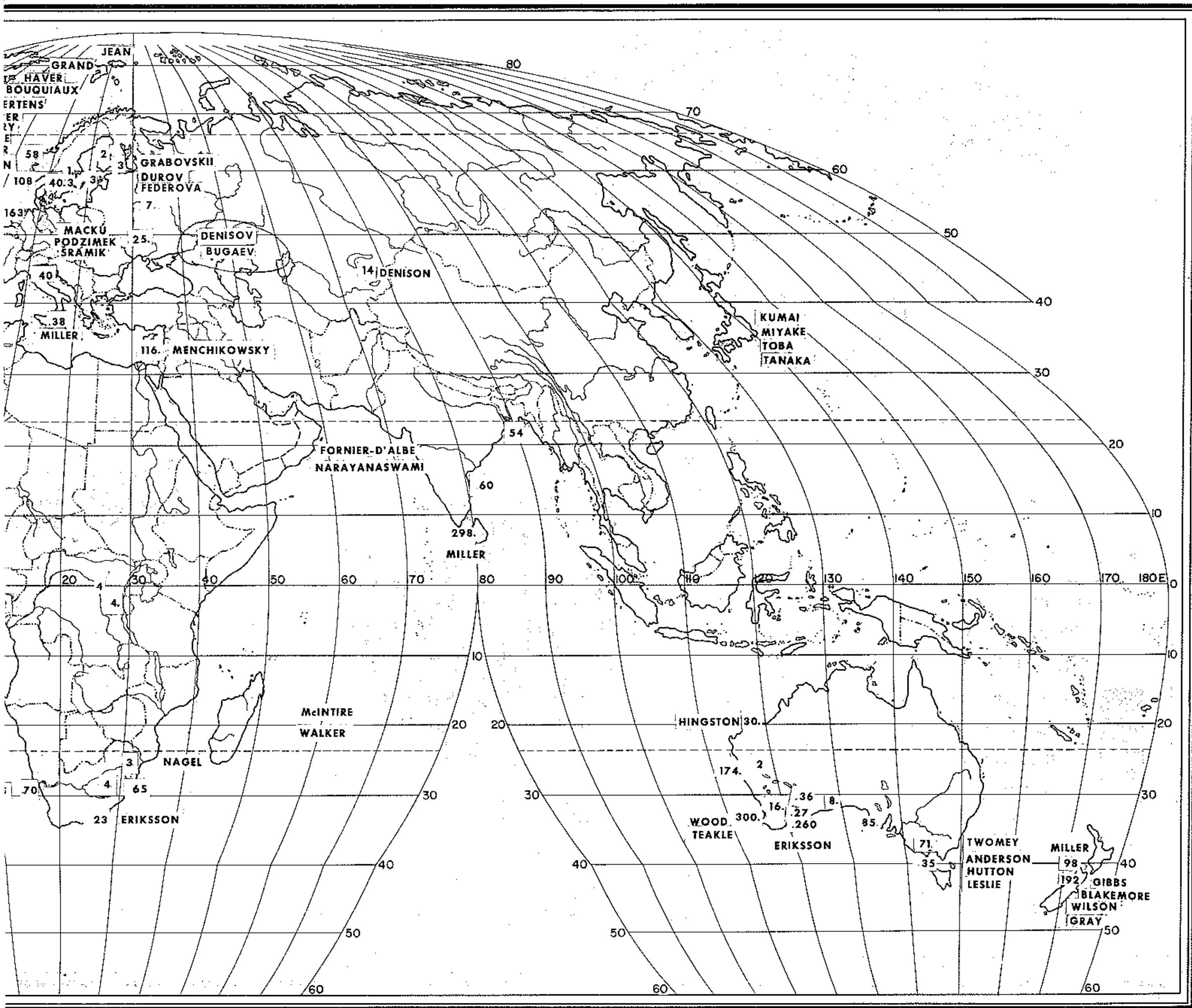
MAP I — Chloride in precipitation. Names indicate source of data used in preparing the text and maps.

40 on the Brittany Peninsula, 160 on the Netherlands Coast, 40 on the coast of Denmark and the Kattegat coast of Sweden (Vinga), 100 at Lista on the southwestern tip of Norway, about 60 on the west coast of Norway and about 270 in the Shetland Islands. Another source reported 660 lb/acre/yr on the Galician coast of northwest Spain[19].

The decrease inland is quite pronounced in England where chlorides in precipitation decline from 130 lb/acre/yr on the west coast to 10 to 20 lb/acre/yr on the eastern side of the island and also on the Scandinavian peninsula where chlorides decrease from 100 in Norway and 40 elsewhere on the west side of the peninsula to 1 to 3 lb/acre/yr in eastern Sweden. Central Finland shows a slight increase which may be attributed to the Gulf of Bothnia even though the salt content of that water body is low. Saltfall over Germany, Czechoslovakia, Netherlands, Belgium, Luxembourg and France does not show the rapid drop expected from coastal areas to inland areas.

Higher amounts than expected have also been reported in precipitation south of Moscow where 7 lb/acre/yr have been reported[21] and near Kharkov where amounts as high as 24 pounds were reported[22]. The latter high amount is ascribed to the proximity of the Black Sea and frequent cyclonic southerly winds along the coast in winter, even though the winds are predominantly from the northeast both in summer and winter. The higher saltfall than expected in the USSR is attributed in part to the cyclonic storms that enter the USSR through the Baltic-North Sea gap[3].

The sea-salt totals in precipitation over southern continental Europe generally are believed to be much less than in central and northern Europe[3]. On the other hand, fallout on the Galican coast of northwest Spain is shown to



be among the highest in Europe — 660 lb/acre/yr* at Guardia[19]. The same source states saltfall data for Perugia at 40 pounds and for Scandicci at 55 pounds in Italy. Although background details of this report are not available, it would appear that some areas of southern Europe have very high rates as would be expected because of the variable relief. For example, on this island of Minorca, northerly winds from off the sea prevail for two-thirds of the year, and at times blow with such force as to carry salt spray across the island, covering the ground with an encrustation of salt. Similar conditions may prevail on other islands and coasts in the Mediterranean, particularly in the Gulf of Genoa, the Adriatic east coast, and the Greek Islands.

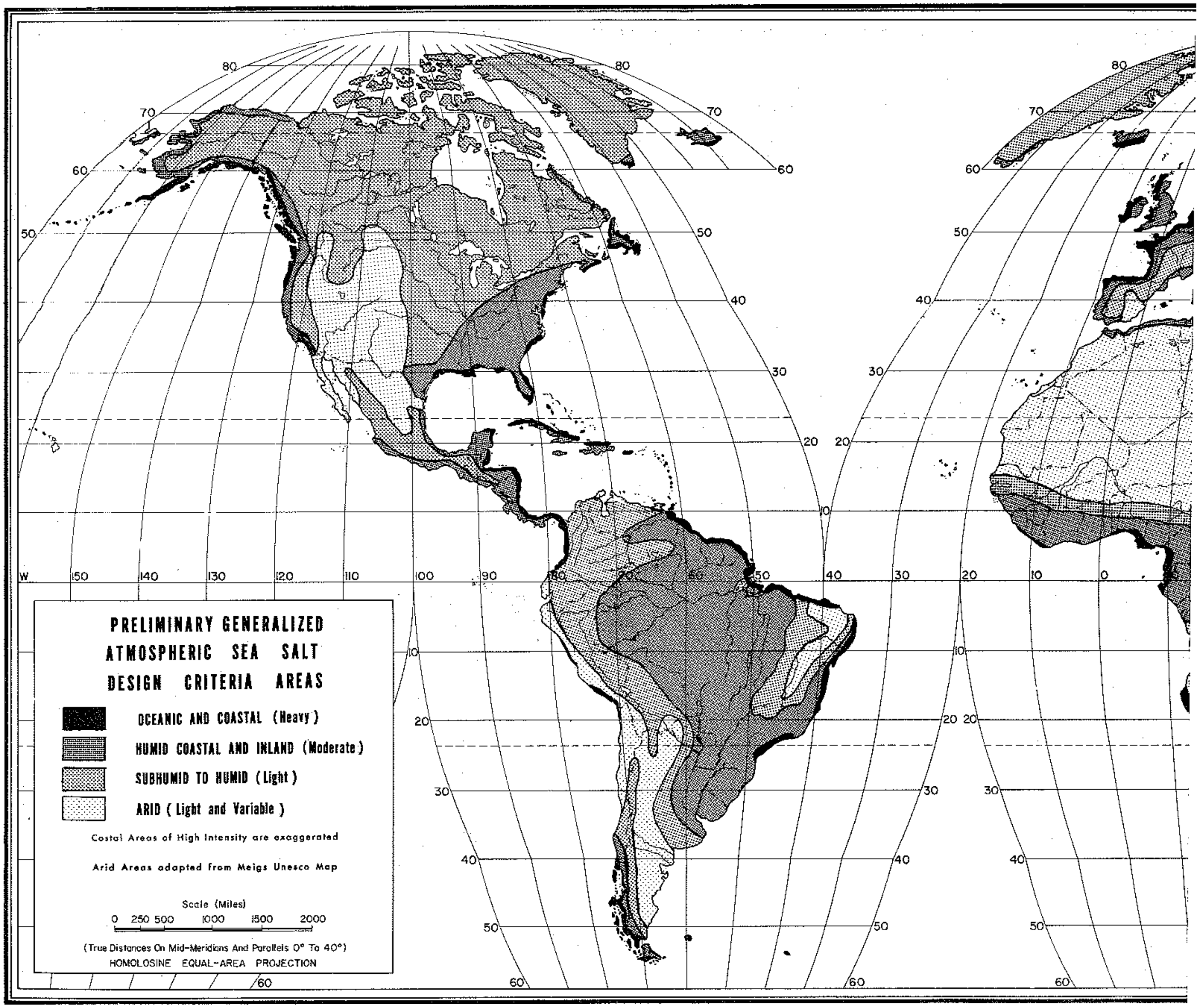
* Eriksson[21] cites B. Merino's original figure as comparable to 447 kg/ha/yr or 398/lb/Acre/yr.

Asia

In view of the scanty data available from Asia, the distribution of chlorides in the atmosphere has to be inferred from what relationships have been developed between environmental conditions and the distribution of sea-salt particles on other continents.

In Asia, only scattered reports are available from Israel, Ceylon, India and Kirghiz SSR, and the data are quite unrelated from a time sequence viewpoint. About 115 lb/acre/yr are reported received on coastal Israel at Tel-Aviv[23]. One report states Ceylon received 298 lb/acre/yr, and India at Madras received 60 pounds and Calcutta 54[19]. About 130 pounds of chloride per acre were contained in the 43 inches of rain that fell on Bombay during the 1939 monsoon[24]. A citation by Eriksson reported that 14 lb/acre/yr were received at Frunze, capital of the Kirghiz SSR[1].

Going beyond available data, it is expected that the highest rates in Asia will be found on coasts exposed to the southwest monsoon, and areas which



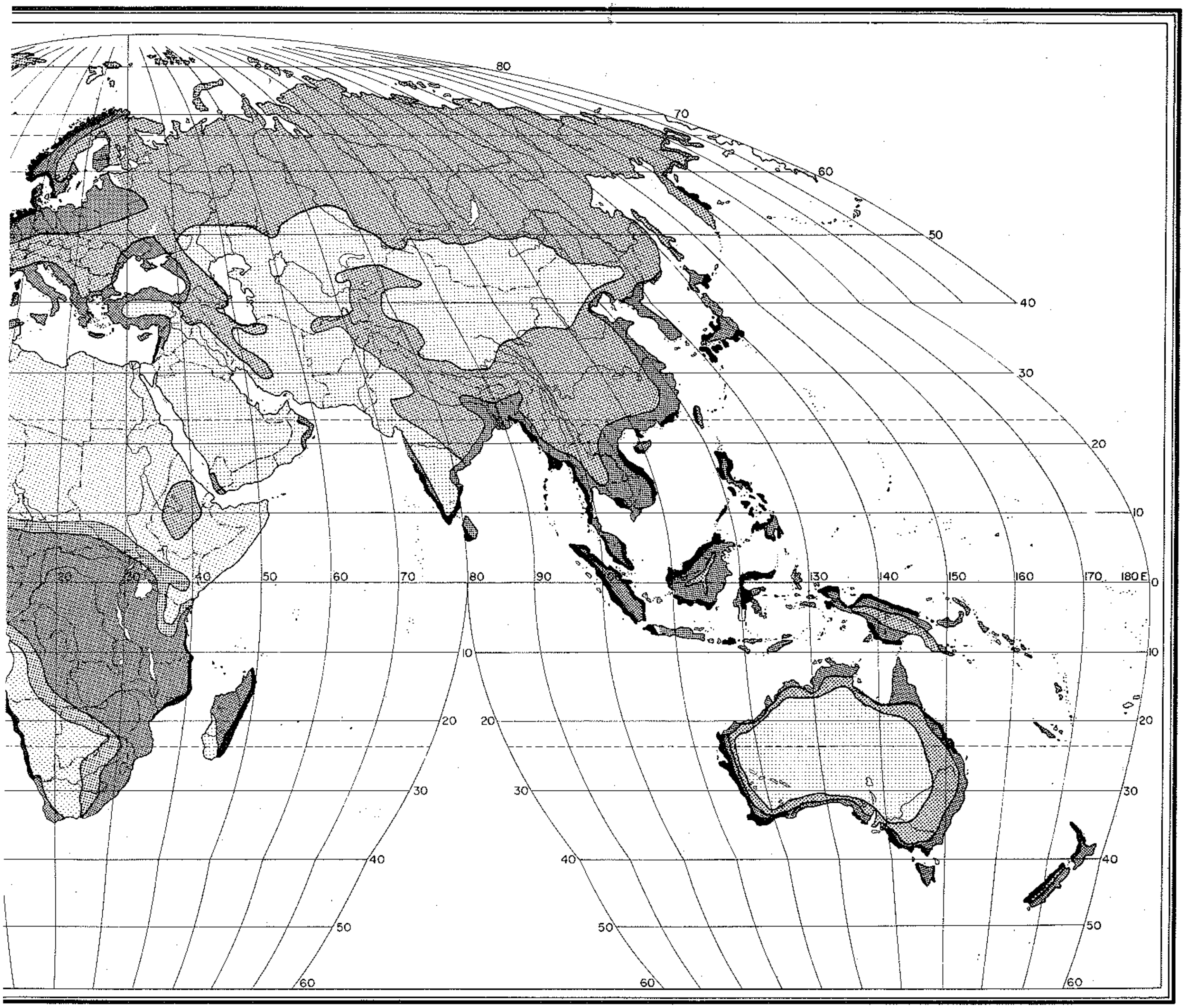
MAP II

can be expected to have a high saltfall, include Ceylon the East and West Ghats of India, the lower Ganges valley, the Burma and Malayan coasts, Sumatra, Java and the other islands of Indonesia, the Siamese and Viet Nam coasts, Borneo and New Guinea, southeast China coast and Hainan and Formosa, Japan, Korea, northeast China, eastern Siberia and Kamchatka.

With the exception of the Black, Aegean and Mediterranean Sea coasts of Turkey and the coasts of Syria, Beyrouth and Israel and the Caspian Sea Coast of Iran and the USSR, the Near East probably receives very little saltfall. Central Turkey, Syria, northern Arabia, and northwest Iraq, may receive as much as 1 lb/acre/yr, but the eastern part of the Near East and extending into Iran, Afghanistan, and Baluchistan probably receive no more than 0.5 lb/acre/yr. Southern Arabia can be expected to receive more because of the influence of tropical maritime air from India, and Gulf of Guinea air from the south Atlantic. This influence is probably greatest in the mountains of Yemen and Oman with reduced amounts along the Hadhramaut coast.

In the vast arid region of central Asia centered on the below-sea-level Turfan depression, saltfall derived directly from the sea is probably as low as any region in the world. Maritime air blowing toward the summer low pressure area may bring small amounts into the fringe areas of the southeastern Gobi but it is not expected that saltfall will anywhere exceed from .25 to .5 lb/acre/yr. Salts derived from blowing dust, however, for which this region has been known since early historic times, may amount to a considerable quantity over the years and should be considered in designs of equipment expected to be used in these areas.

Saltfall in the Arctic and subarctic areas in Asia can be expected to be



low — probably less than 3 lb/acre/yr owing to the low salinity of Arctic waters, the low air temperature, low evaporation rate and high humidity during the summer months when saltfall is possible.

Africa

Data on chloride concentration in precipitation are available for only a few stations on the continent of Africa. They include: Lagos, Nigeria (2,600 lb/acre/yr); Congo Republic (from 2 to 4 pounds); Bloemfontein (4 to 5 pounds); Durban (65 pounds); and Grahamstown (23 pounds).

One report of work with corrosion of metals in the tropics showed that where there is no industrial pollution, the governing factor is airborne salt and while in very saline atmospheres steel may corrode as much as $8 g/dm^2/$ month, in very humid areas free of high salinity, the rate may be less than $0.1 g/dm^2/month$[5]. Also noted was that corrosion of ferrous metals and zinc is proportional to the rate of deposit of salt on a damp textile surface. In Nigeria airborne salinity as measured by any method seems to reach a minimum about 50 miles inland from the sea but then increases to about 500 miles in the semi-desert where the salinity (when determined by the dew-flask method) is of the same order as at the ocean shore. This increase is attributed to fine particles that probably come from the northwest or west and traveled over 2,000 miles without being precipitated[5]. There is also the possibility that these particles originate in the Sahara desert.

This same air mass, deflected toward the southern hemisphere low pressure area during its summer, may account for the strange condition in the Congo where the two stations farthest from the sea near Stanleyville and the northern end of Lake Tanganyika have double the saltfall of Leopoldville, the station nearest to the sea. Inland stations in South Africa obtain their salt-

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ABOUT THE AUTHOR

fall at the same season from maritime air inblowing from the Indian Ocean. It seems that the chlorides in precipitation over much of interior humid Africa are fairly uniform at 2 to 4 lb/acre/yr[1].

In most arid areas the saltfall detected by universal methods is much less than 1 lb/acre/yr. Fog along the southwest Africa coast created at the contact of warm air and the cold water in the Benguela current is responsible for a saltfall of 70 lb/acre/yr on the coast and about half that amount 30 miles inland[1]. Passing cyclonic storms bring a moderate amount of chloride to the South Africa coast during July. The east and northeast coasts can be expected to receive moderate to heavy amounts of salt fallout during the northeast monsoon season when some of the coasts are exposed to the prevailing winds. It is expected that the North Africa Mediterranean coast may receive moderate amounts of salt during the winter months, when onshore winds seem to be dominant in some areas. Inasmuch as the winds along the northwest Africa coast are parallel to the coast much of the year the saltfall there can be expected to be low. There may be come salt fog on the islands and on land areas adjacent to the cool Canaries current.

Australia

Analysis of rainwater in coastal areas of western Australia shows that the mean salt content ranges from 15 to 50 ppm and inland it is 4 to 20 ppm[4]. This amounts to from 100 to 600 lb/acre/yr in coastal areas and from 10 to 60 lb/acre/yr inland. The Mundaring Reservoir received 80 lb/acre/yr and the researcher concluded that this salt is wholly derived from the ocean and is brought to the catchment area by the wind and precipitated with the rain[25].

Over a period of 25 years there was an increase of salinity in railway reservoirs (which created locomotive boiler problems) following the clearing of vegetation in the surrounding country. It was observed that the first water entering reservoirs after the dry summer period was much more saline than the normal winter supplies. This was attributed to salt being deposited on the surface of the soil during the summer[26]

In southeastern Australia 85 lb/acre/yr was deposited in precipitation on the York Peninsula west of Adelaide and 35 lb/acre/yr on the coast near Melbourne[27]. On the north flank of the Great Divide range north of Melbourne the rate had declined inland to only 7 lb/acre/yr. The mountain range is an effective barrier to the westerlies that bring rain to the area in winter.

There are no data available for other parts of the continent. The northern part receives its moisture during summer when moist northeast winds enter the continent and continue as far as the center covering the central and northeastern parts of the continent. At that time, the north-central part probably receives a moderately heavy saltfall along the northern coast with an inland decrease to about 3 to 4 lb/acre/yr. The southeast trades can be expected to bring a rather heavy to moderate saltfall along the eastern coast east of the Great Divide range.

PRELIMINARY SEA-SALT DESIGN CRITERIA AREAS

Designers frequently request information where no known data exists. Under the circumstances, an estimate can only be given reflecting a comparison of environmental conditions of analogous areas of the world where the salt fallout is known. Based upon the data provided in the preceding section, and estimates inferred from environmental conditions over the continents, a preliminary map has been prepared showing world-wide sea-salt design criteria areas (Map II). Four areas are outlined: I—oceanic islands and coastal areas; II—intermediate coastal and humid inland areas; III—subhumid and humid interior areas of uniform low saltfall; and IV—inland and coastal arid areas of variable saltfall. The demarcated areas are general and, as stated above, represent the best estimate that the writer has been able to make for use by designers. Quantitative values have been assigned to each of these areas for mapping purposes. The values assigned are approximate only and may not be realistic for any station near the boundaries, where considerable overlap exists, or in arid areas where salty dust is a major factor. It should also be pointed out that the salt content of the atmosphere, like the weather, changes from day to day or year to year within known extremes. Sea coasts are always vulnerable to exceptional wind storms and as a result the amount of salt precipitated during one violent storm could exceed the total amount received the preceding year. However, despite these and other limitations, it is believed that the map will be useful to designers. The following paragraphs describe each of the areas shown on the map.

Area I: Oceanic Islands and Coastal Areas — Heavy Fallout

Saltfall from all processes varies from a minimum of 25 lb/acre/yr to more than 300. Specific well-exposed areas may receive as much as 3,000 to 4,000 lb/acre/yr. Individual 2-or 3-day storms may deposit as much as 30 pounds per acre per storm. Daily saltfall during maximum periods may be as high as 20 pounds per acre per day. Gale winds have been known to encrust the surface of the land and all exposed trees, buildings and other objects with a salt cover and to scorch trees and sugar cane and other crops severely for several miles inland. Considerable variation in salt fallout can be expected from year to year but the amount of saltfall is always high in this area. Knowing certain weather conditions, saltfall probably could be predicted with reasonable accuracy in many areas.

Coastal areas of low-lying relief, and gaps in hills and mountain ranges that permit entrance of maritime air containing sea-salt particles into the interior of continents, have a lower coastal fallout but a higher inland fallout. The same is also true of embayments and inland arms of the sea that penetrate the land masses. Cuspate forelands, peninsulas, tombolos, exposed coral reefs, rocks awash, offshore sandbars and islands in areas of moderate or more intense winds can be expected to have a high sea-salt fallout. Coastal areas that come under domination of cyclonic storms, trade winds, seasonal monsoon rains, hurricanes and tornadoes, and low pressure areas in general along with areas subject to sea fogs can be said to have high sea-salt fallout.

Area II: Intermediate Coastal and Humid Inland Areas — Moderate Fallout

Saltfall from all processes varies from a minimum of about 3 lb/acre/yr to about 25. A belt of decreasing amounts of saltfall extending from and including parts of the coast where offshore winds or winds that parallel the coast are dominant, to a point from 50 to 1,000 miles inland (depending on the continent) where saltfall variability is reduced to a minimum and the amount is more or less stabilized.

This area includes the industrial areas of northwest Europe, eastern United States, and southeastern Australia that are believed to contribute chlorides to the atmosphere in such amounts that there is a rise of several pounds per acre above that of the air in adjacent regions.

In areas thus classified, corrosion rates of ferrous metals and zinc fall off very rapidly from the coastal area to a point inland where there is little or no visible corrosion within a year. The area includes those humid parts of continents that are affected by large scale air turbulence, brought about as the maritime air passes from the relatively smooth sea surface to the uneven land surface. Relief varies from low-lying coasts with plain-like areas in the hinterland, in which the sea-salt fallout rates fall off gradually inland, to cliffed coasts backed by mountain ranges which cause considerable uplift and orographic precipitation. Such coasts may be moderately saline, but salinity drops off very rapidly inland.

Area III: Subhumid and Humid Area of Uniform Low Salt-Fall — Light Fallout

Saltfall from all processes in such regions is less than about 3 to 5 lb/acre/yr from atmospheric sea-salt fallout as recorded by standard measurements. The areas are located primarily in the interior of continents but approaches the coasts on the margins of arid areas. The outer boundary is determined by the area where horizontal and vertical distribution of sea-salt particles is relatively uniform in the troposphere and saltfall therefore becomes more or less uniform. The inner boundary is marked by the surface soils which have a noticeable salt content which became airborne during windy periods and increases the total saltfall to the area (see Area IV).

Area IV: Arid Areas of Variable Saltfall — Light to Moderate Fallout

Sea-salt fallout is normally less than about 3 to 5 lb/acre/yr but total saltfall may locally be abnormally high due to salt laden winds from off the lakes of very high salinity (some as high as 300 parts per thousand), or, to wind-blown topsoil efflorescences from intermittent playa lake surfaces. The area includes not only the areas of inland drainage but also includes areas of external drainage where rainfall is not sufficient to remove the surface salts.

Winds may blow the sodium chloride and other salts not only onto installations and equipment but may also blow salt particles into or be injected into parts of operating machinery or vehicles where the relative humidity is high enough to cause internal corrosion. Another unique feature is the amount of external abrasion resulting from driving sand, dust and salt particles which assist the corrosion processes by removal of protective surfaces and surface coatings. Characteristics of this area are the seasonally continuous high temperatures or large daily ranges in temperature, low or negligible precipitation and consequently little salt fallout from this process. Evaporation is high and this contributes to the salinity of water bodies.

The area encompasses the low latitude hot-dry deserts which have resulted from the subtropical high pressure and trade wind belts. Such belts occupy the central and western sides of continents from 15° to 35° north and south of the equator. On the western side of the continents, where cold currents with local fog prevails, the area is from 5° to 10° closer to the equator. Also included in this area are the cold deserts that extend from 30° to 50° north latitude and occupy the interior enclosed basins of continents.

REFERENCES

1. Eriksson, E. (1959-1960). The yearly circulation of chloride and sulfur in nature; meteorological, geochemical and pedological implications. *Tellus 11*, 4: pp. 375-403 and *Tellus 12*, 1: pp. 63-109.
2. Junge, C. E., and P. E. Gustafson (1957). On the distribution of sea-salt over the United States and removal by precipitation. *Tellus 9*, 2, pp. 164-174.
3. DeBary, E. and C. Junge (1963). Distribution of sulfur and chlorine over Europe. *Tellus 15*, November, pp. 371-381.
4. Teakle, L. J. H. (1937). The salt (sodium chloride) content of rainwater. *J. Agric. West Australia 14*, pp. 115-123.
5. Ambler, H. R., and A. A. J. Bain (1955). Corrosion of metals in the tropics *J. Appl. Chem. 5*, September, pp. 437-467.
6. Teitell, Leonard (1965). Salt content of atmosphere at tropical exposure sites in the Panama, Canal Zone. U. S. Army Trop. Test Center Monthly Reports since September 1963.
7. Miyake, Y. and Suguira, Y. (1954). Chemical studies of rainwater accompanied by a typhoon. *Geophys. Mag. Tokyo 26*, pp. 29-34.
8. Blanchard, Duncan C., and A. H. Woodcock (1957). Bubble formation and modification in the sea and its meteorological signifcance. *Tellus 9*, May, pp. 145-158.
9. Kientzler, C. F., A. B. Arons, D. C. Blanchard, and A. H. Woodcock (1954). Photographic investigation of the projection of droplets by bubbles bursting at a water surface. *Tellus 6*, pp. 1-7.
10. Blanchard, Duncan C. (1958). Electrically charged drops from bubbles in sea water and their meteorological significance. *J. Meteor. 15*, August, p. 383.
11. Woodcock, A. H. (1957). Salt and Rain, *Sci. Am.*, October, pp. 42-47.
12. Blanchard, Duncan C., and A. H. Woodcock (1957). Bubble formation and modification in the sea and its meteorological significance. *Tellus 9*, May, pp. 145-158.
13. Eriksson, E. (1955). Air borne salts and the chemical composition of river waters. *Tellus 7*, pp. 243-250.
14. McIntire, W. G., and Harley J. Walker (1964). Hurricane effects on the coast of Mauritius. Paper presented at the Annual Meeting of the Association of American Geographers, Syracuse, N. Y., March 1964.
15. Junge, C. E., and R. T. Werby (1958). The concentration of chloride, sodium, potassium, calcium and sulphate in rainwater over the United States. *J. Meteor.* 15 pp. 417-425.
16. Rust-Oleum Corporation (1958). Rust Index of the United States — 1 Map. Published by the Corporation, Evanston, Ill. pp. 8.
17. Katz, Morris (1952). *Proc. 2nd Nat. Air Pollution Symposium*, Pasadena, California, pp. 95-105.
18. Foran, M. R., E. V. Gibbons, and J. R. Wellington (1958). Measurement of atmospheric sulfur dioxde and chlorides. *Chemistry in Canada 10*, 5, May, pp. 33-41, also *Res. Paper No. 61*, Div. Building Res. NRC, Canada, August.
19. Miller, N. H. J. (1906). The amounts of nitrogen as ammonia and nitric acid, and of chlorine in the rainwater collected at Rothamsted. *J. Agric. Sc. 1*: pp. 280-303.
20. Hudson, J. C. (1963). Some meteorological observations in Barbados. *Bull. No. 33*, December, pp. 12. Ministry Agric., Lands and Fisheries. Barbados Gov. Printing Office.
21. Eriksson, E. (1952). Composition of atmospheric precipitation II. Sulfur, chloride, iodine compounds. Bibliography. *Tellus 4*, pp. 280-303.
22. Denisov, P. V. and A. L. Bugaev (1955). The chemical composition of atmospheric precipitation of the northeastern part of the Ukraine. Paper presented before CCCP Akad. Nauk.
23. Menchikovsky, F. (1925). Composition of rain falling at Tel-Aviv. Agric. Exp. Sta. Tel-Aviv, *Bull. 2*, pp. 25-36. (In Hebrew).
24. Narayanaswami, R. (1939). Measurements of the chloride, nitrate and nitrite present in the water of monsoon rains of Bombay. *Proc. Indian Acad. Sci. 9A*, pp. 518-525.
25. Weller, W. K. (1926). Note on the salinity in the Mundaring Weir. *Australian Assoc. Adv. Sci. 18*, pp. 633-674.
26. Wood, W. E. (1924). Increase of salt in soil and streams following the destruction of native vegetation. *J. Roy. Soc. West Australia 10, No. 7*, pp. 35-47.
27. Anderson, V. G. (1945). Some effects of atmospheric evaporation and transpiration on the composition of natural waters in Australia. *J. Proc. Austr. Chem. Inst. 12*, pp. 41-68, 83-98.
28. Meigs, P. (1960). Distribution of arid homoclimates. Unesco map No. 392 and 393 Rev. 1 Rep. United Nations, Paris.