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CLASSIFICATION OF THE COASTAL ENVIRONMENTS OF THE WORLD. PART II. AFRICA

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CLASSIFICATION OF THE COASTAL ENVIRONMENTS OF THE WORLD

PART II
AFRICA

Bruce Hayden
Mary Vincent
Donald Resio
Carlton Biscoe, Jr.
Robert Dolan

Department of Environmental Sciences
University of Virginia

FEBRUARY 1973

OFFICE OF NAVAL RESEARCH
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13 ABSTRACT

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Coastal vegetation was analyzed and distributions were compared with the physical components of the system. Close agreement was found between the biotic and physical environments, which served to verify the methodology employed. (U)

The existence of both north-south and east-west hemispheric symmetry at all levels accounts for the high degree of internal coupling among the processes operative within the coastal zone. The similarities and differences between the coastal environments of Africa and those found in the earlier study of the Americas are discussed and causal factors explored. (U)

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INTRODUCTION

In 1972, the authors of this study published Classification of the Coastal Environments of the World, Part I: The Americas (hereafter referred to as The Americas) which presented a concept of how coastal environments might be classified on a basis of processes rather than on attributes. The investigation of the Americas hypothesized and indicated the presence of ". . . natural complexes of coastal environments that are duplicated around the world when process forcing functions are similar."

This report applies the classification rationale and methodology for the Americas to the coastal regions of Africa. The objective of the African case study is twofold: [1] to test the feasibility and ease of applying the previously developed classification to a major portion of the world's coasts where data availabilities differ from the Americas; and [2] to further test the hypothesis concerning the occurrence of natural complexes by examining an area where classification types are likely to differ from those found in the Americas. In addition, the study helps to further the hypothesis discussed in The Americas by providing a process-oriented classification of coastal environments for Africa.

The environment along any coast presents a complexity of integrated processes, yet it may be stratified into three primary components: atmospheric, marine, and terrestrial. Despite the many interrelationships, each component is characterized by a particular set of processes and so may be viewed as a separate subsystem. Along the coast, the atmospheric and marine subsystems are responsible for the transfer of energy and mass to which the terrestrial materials respond. Variation and interaction within the three components result in different products as evidenced by the different types of shore environments.

A single coastal environment, termed an elemental unit, is defined as being homogeneous in its atmospheric and marine fluid subsystem and in its terrestrial interface with these fluids. Homogeneity for each of the subsystems is established through independent classification; the atmospheric analysis is based on air masses, the marine on water masses, and the terrestrial on landforms. Individual coastal environments may be recognized after the integration of the classifications has been completed.

The three subsystems when considered together exhibit a process-response hierarchy on which the rationale of the three-part classificatory scheme is based. The atmospheric and marine processes are mesoscale, with the features of their mean annual motions operating on the order of approximately 500 miles; while the terrestrial features are recognized at a resolution of 20 to 50 miles.

The features chosen to be analyzed within each subsystem are the same in Africa as those in the Americas. On the mesoscale, the coastal climatic types, or regimes, are differentiated by seasonality, air mass type, track, and direction of surface flow; while the oceanic types, or subregimes, are differentiated by surface water temperatures and currents. On a smaller scale, individual interface units are identified on the basis of shoreline form and material character.

The integration of the process analysis (the regimes and subregimes) and of the materials response (the interface units) allows the identification of homogeneous segments of the coastal environment, or elemental units. Although elemental units are distinctly separated, repetition may occur in another area if that particular combination of atmospheric, marine, and interface classificatory types repeats.

Discussions of the climatic regime, the marine subregime, and the terrestrial interface classifications are presented. In order to avoid interruptions of the discussions, the data sources for each classification are listed in the Appendix. Sources used in conjunction with methodology, concepts, or historical discussion appear in the list of references.

CLIMATIC REGIMES OF AFRICA

In the atmospheric system, cyclical changes may be observed in the semipermanent planetary scale circulation features such as the circumpolar lows and waves in the midlatitude westerlies. These variations, which are both spatial and temporal, give rise to air mass seasonality, characteristic weather patterns, and the repetition of natural climatic complexes throughout the world. The regimes of this classification refer to these coastal climatic complexes and are identified through air mass analysis.

The use of air masses as a basis allows the climatic classification to deal with tangibles which: [1] possess secondary characteristics of temperature, water content, and stability; [2] undergo predictable modifications when in transit; and [3] are bounded by atmospheric fronts. These are advantages over climatic classifications which rely on arbitrarily selected rainfall and temperature boundaries. Vegetation boundaries may be used as a validation of regime boundaries since they are not considered in the classificatory criteria.

The climatic regimes, or climatic complexes, are delineated through the analysis of mean monthly atmospheric motions. Utilizing data from the <u>Sailing Directions</u>, the analysis begins with the calculations and streamline contouring of resultant surface wind fields (Bryson, 1966). The convergence of streamlines indicates a frontal boundary between air masses, while their median positions indicate the climatic regime boundaries. It should be noted that whereas the regime boundaries are represented by a line (Figs. 1 and 2), the boundaries are actually zones of climatic transition.

Data from the <u>Sailing Directions</u> proved inadequate for the African analysis; consequently a set of independently compiled monthly resultant wind maps were used.[1] Secondary data sources, including satellite cloud photography (which indicate frontal locations) and IGY humidity measurements (which reflect air mass characteristics) were also consulted. A comparison of regime boundaries with the coastal vegetation analysis and histograms of mean monthly precipitation helped to verify the regimes.

Names are given to the regimes according to the four essential attributes by which these climatic complexes are differentiated. The attributes and the possible subdivisions of each are given in Table 1. Of the twelve climatic regimes found in the coastal regions of Africa, four are duplicated in the Americas (Table 2 and Figs. 1 and 2). The characteristics of the twelve regimes are briefly given in Table 3.

The differences between the coastal climates, or regime types, of Africa and those of the Americas are a function of the relative continental orientations with respect to latitude, oceans, and orography. A summary of these differences is presented in Table 4.

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[1] These maps were prepared by Dr. Carl Aspliden of the University of Virginia Department of Environmental Sciences. He has done considerable research on African climate and its relationship to locust migrations, although his maps of monthly resultant winds over Africa have not yet been published.

Contrasts in planetary scale circulation are also a factor in the differences of coastal climates between the Americas and Africa and should be noted. Much of the difference is attributed to the Asian monsoonal flow. During the Southern Hemisphere summer, the climate of eastern Africa is influenced by the strong flow of cT air from the Northeast monsoon; while during the Northern Hemisphere summer, the area comes under the influence of a strong southerly flow of mE air from the Southwest monsoon (Fig. 3). Counterparts of this flow are not found in the Americas; instead, the eastern coasts are influenced by mT or mE air throughout the year. A further contrast in circulation involves the Atlantic subtropical anticyclone. Although it provides a source of moist air for the east coasts of the Americas, the west coast of Africa experiences dry, subsiding air with little capacity for precipitation.

TABLE 1

Attributes for Climatic Regime Differentiation
(With abbreviations indicated)

SEASONALITY	
Dominant	(Dom)
Subdominant	(Sub)
AIR MASS TYPE BY SOURCE REGION	
Arctic	(A)
Maritime Polar	(mP)
Continental Polar	(cP)
Continental Tropical	(cT)
Maritime Tropical	(mT)
Maritime Equatorial	(mE)
Continental Mixed	(cM)
SURFACE OVER WHICH AIR MASS TRACKS	
Marine	(m)
Continental	(c)
CONFLUENCE OF AIRSTREAMS IN THE COASTAL ZONE	
Divergent	(D)
Convergent	(C)

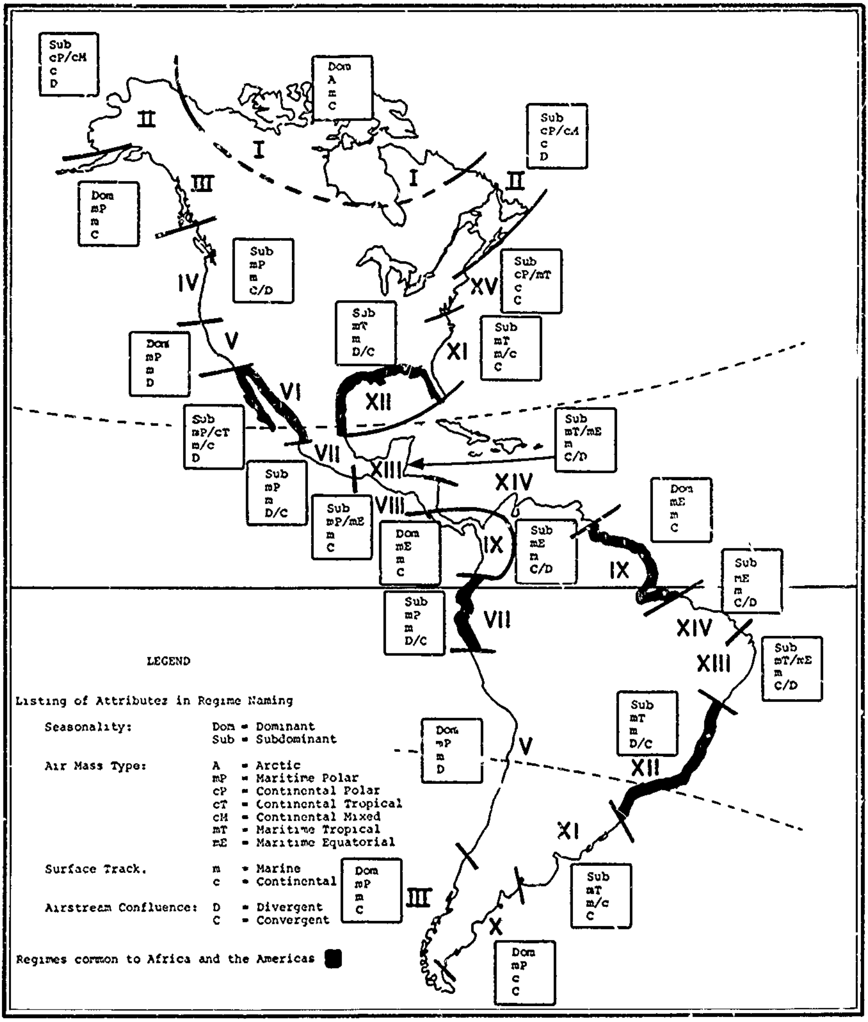

Figure 1. Coastal Climatic Regimes of the Americas.

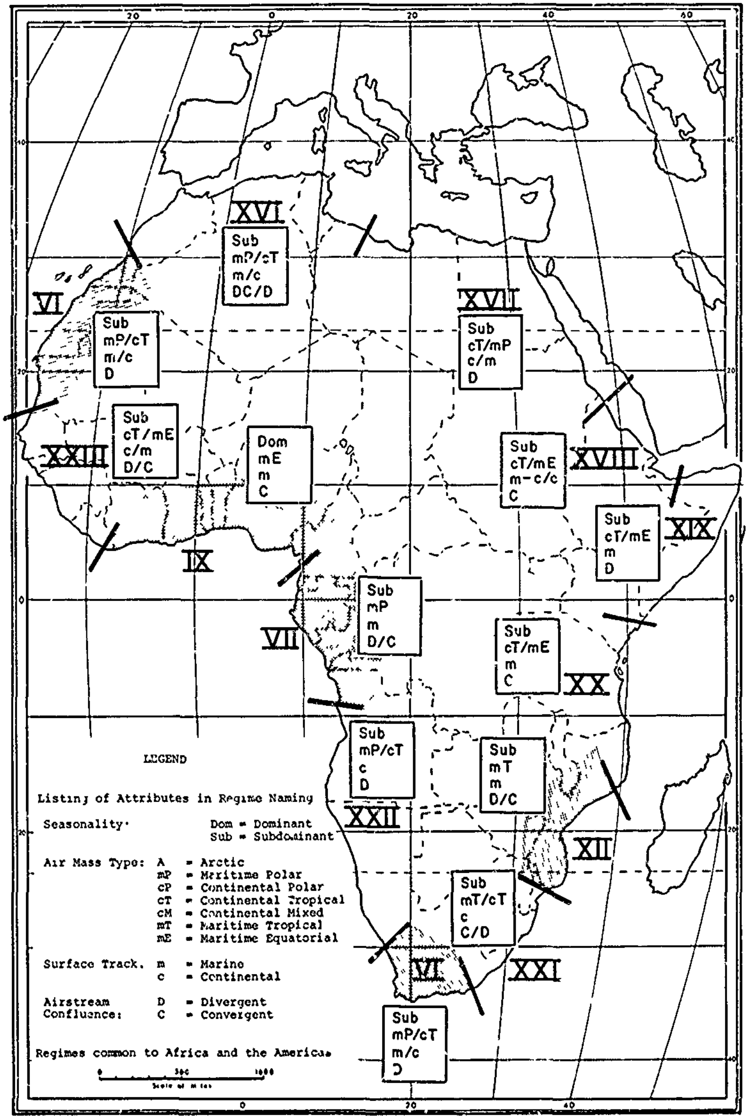

Figure 2. Coastal Climatic Regimes of Africa.

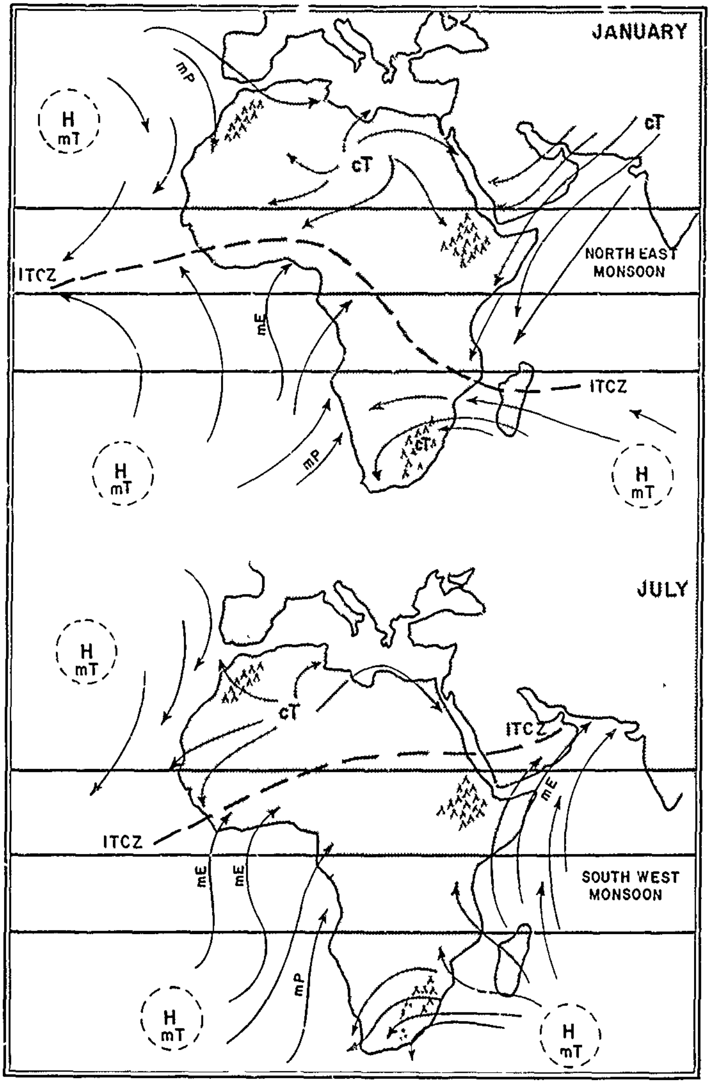

Figure 3. Resultant Surface Wind Streamlines for the Coasts of Africa.

TABLE 2

Climatic Regimes of The Americas and Africa

REGIME	SEASONALITY	AIR MASS TYPE	SURFACE TRACK	AIRSTREAM CONFLUENCE	REGIME LOCATION*	CASES
I	Dominant	A	m	C	NA	1
II	Subdominant	cP/cM	c	D	NA	2
III	Dominant	mP	m	C	NA, SA	2
IV	Subdominant	mP	m	C/D	NA	1
V	Dominant	mP	m	D	NA, SA	2
VI	Subdominant	mP/cT	m/c	D	Africa, CA	3
VII	Subdominant	mP	m	D/C	Africa, CA, SA	3
VIII	Subdominant	mP/mE	m	C	CA	1
IX	Dominant	mE	m	C	Africa, CA, SA	3
X	Dominant	mP	c	C	SA	1
XI	Subdominant	mT	m/c	C	NA, SA	2
XII	Subdominant	mT	m	D/C	Africa, NA, SA	3
XIII	Subdominant	mT/mE	m	C/D	CA, SA	2
XIV	Subdominant	mE	m	C/D	CA, SA	2
XV	Subdominant	cP/mT	c	C	NA	1
XVI	Subdominant	mP/cT	m/c	DC/D	Africa	1
XVII	Subdominant	cT/mP	c/m	D	Africa	1
XVIII	Subdominant	cT/mE	m-c/c	C	Africa	1
XIX	Subdominant	cT/mE	m	D	Africa	1
XX	Subdominant	cT/mE	m	C	Africa	1
XXI	Subdominant	mT/cT	c	C/D	Africa	1
XXII	Subdominant	mP/cT	c	D	Africa	1
XXIII	Subdominant	cT/mE	c/m	D/C	Africa	1

*NA, SA, CA--North, South, and Central America.

TABLE 3

Characteristics of the Climatic Regimes of Africa

*Regime VI:	SUBDOMINANT - MARITIME POLAR/CONTINENTAL TROPICAL - MARINE/CONTINENTAL - DIVERGENT Dominated winter and spring by warm, dry, subsiding mP from the Atlantic. Dominated summer and fall by cT, resulting in warmer temperatures and lower precipitation.
*Regime VII:	SUBDOMINANT - MARITIME POLAR - MARINE - DIVERGENT/CONVERGENT Dominated year round by moisture-laden mE from South Atlantic. Precipitation maximum occurs with southward shift of ITCZ during Southern Hemisphere summer. Convergence characterizes winter maximum rainfall period; divergence occurs during Northern Hemisphere summer with northward shift of ITCZ.
*Regime IX:	DOMINANT - MARITIME EQUATORIAL - MARINE - CONVERGENT Dominated throughout year by ITCZ; mE from South Atlantic subtropical anticyclone converges with cT from Saharan source region. Precipitation high throughout year.
*Regime XII:	SUBDOMINANT - MARITIME TROPICAL - MARINE - DIVERGENT/CONVERGENT Dominated year round by mT of southeast trades from Indian Ocean. Precipitation abundant; summer maximum. Convergence occurs spring and fall; divergence, winter and summer.
Regime XVI:	SUBDOMINANT - MARITIME POLAR/CONTINENTAL TROPICAL - MARINE/CONTINENTAL - DIVERGENT CONVERGENT/DIVERGENT Dominated November through June by Atlantic mP air modified by passage over Iberian Peninsula. Dominated July through October by extremely hot, dry cT from Saharan source region. Precipitation moderate year round, reaching maximum during convergence period November through February.
Regime XVII:	SUBDOMINANT - CONTINENTAL TROPICAL/MARITIME POLAR - CONTINENTAL/MARINE - DIVERGENT Dominated most of year by hot, dry cT (the "Harmattan") from Saharan source region. Dominated one month in spring and one month in fall by mP. Like Regime XVI, precipitation maximum occurs in late fall to early winter, but significantly drier than XVI due to long periods of cT dominance.
Regime XVIII:	SUBDOMINANT - CONTINENTAL TROPICAL/MARITIME EQUATORIAL - MARINE CONTINENTAL/CONTINENTAL - CONVERGENT Dominated during Northern Hemisphere summer by continentally modified mE air. Dominated in winter by cT from Asian land

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*These regimes have analogues in the Americas.

mass (Northeast monsoon) and by cT from Saharan region during transitional seasons. Strong convergence year round; regime delineates east coast location of ITCZ. In contrast to ITCZ regimes of the Americas and on west coast of Africa, precipitation slight year round.

Regime XIX: SUBDOMINANT - CONTINENTAL TROPICAL/MARINE EQUATORIAL - MARINE - DIVERGENT

and

Regime XX: SUBDOMINANT - CONTINENTAL TROPICAL/MARITIME EQUATORIAL - MARINE - CONVERGENT

Strong influence by monsoonal flow in Indian Ocean in both regimes; regimes differentiated by change in air stream confluence occurring just south of the equator. Dominated during Northern Hemisphere winter by cT crossing the Indian Ocean from Asia. Dominated during summer by northward flowing mE from subtropical anticyclone, Precipitation much greater in regime of convergence (XX), than in regime of divergence (XIX).

Regime XXI: SUBDOMINANT - MARITIME TROPICAL/CONTINENTAL TROPICAL - CONTINENTAL - CONVERGENT/DIVERGENT

Dominated during winter by cT developed from former mT over South African highlands. During remainder of year southeast trades from Indian Ocean converge over coast and follow a continental track. Minimum precipitation during winter associated with dry cT air.

Regime XXII: SUBDOMINANT - MARITIME POLAR/CONTINENTAL TROPICAL - CONTINENTAL - DIVERGENT

Dominated all year by cT developed from former mT off the Indian Ocean during passage over the South African highlands. Moist air from South Atlantic occasionally will reach coast, but prevented from becoming major source of precipitation by the Benguela Current (Hare, 1965).

Similar arid zones recognized by others on the west coasts of California and South America (Putnam, et al., 1960) are differentiated in this analysis: arid regimes in the Americas experience winter precipitation maximum; precipitation maximum occurs in summer in Africa.

Regime XXIII: SUBDOMINANT - CONTINENTAL TROPICAL/MARITIME EQUATORIAL - CONTINENTAL/MARINE - DIVERGENT/CONVERGENT

Dominated during Northern Hemisphere summer by the ITCZ; summer climatic conditions similar to Regime VII. Dominated during winter by cT from Saharan source region with southward displacement of ITCZ.

TABLE 4

Comparative Summary of Factors Involved in Climatic Differences Between the Americas and Africa

FACTOR	AMERICAS	AFRICA	MEANING IN TERMS OF CLASSIFICATION
Latitudinal Position	Extends from northern polar regions to about 55° South.	Extends no farther poleward than 37° South; most of land mass lies in tropics.	Regimes I, II, XV occur in polar latitudes of North America, but are absent in Africa. Large African tropical mass contributes to development of Regimes XVI, XVII, XVIII, XIX, which are not found in South America.
Consequences	Large cP source region exists in North America.	No corresponding cP source region.	
	No corresponding cT source region.	Extensive source region of cT exists.	
Oceanic Basins	Nearly uninterrupted ocean basins extend from pole to pole along both coasts.	Off northeast coast, Asian land mass prevents poleward extent of Indian Ocean	mT and mP influence in South America contributes to development of Regimes XI and X. Continental rather than maritime air in Africa helps to explain the delineation of Regimes XVI, XVII, XVIII, XIX, which are not found in S. America.
Consequences	Year round influence of mT-mP along east coast from Atlantic by subtropical anticyclones.	No corresponding influence; absence of mT air mass source in N. Hemisphere contributes to aridity of east Mediterranean and Red Sea Coasts.	
	No corresponding cT source region.	Asian land mass provides source region of cT air.	
	No corresponding monsoonal development.	Seasonal anticycloric monsoonal flow develops over Asia, partly due to latitudinal position.	
Mountain Chains	Rocky Mountain-Andes Cordillera form a western spine.	No corresponding cordillera.	Orographically influenced Regimes XI and X present in South America, but not in Africa; Regime XXI in Africa.
Consequences	Large portion of east coast of southern S. America lies in Andes "rain shadow"; air masses off the Pacific are much drier when reaching the east coast due to orographic and continental influences.	No corresponding orographic influences on scale of that in South America.	

COASTAL VEGETATION TYPES OF AFRICA: VALIDATION OF THE CLIMATE CLASSIFICATION

Evidence for the close integration between the physical and biological environmental processes is given by the strong response of biotic distributions to physical parameters. Plants, being responsive to abiotic factors, are better environmental indicators than are animals which are dependent on both abiotic and biotic controls. Vegetation studies have long been used as a means of establishing environmental relationships, particularly the covariance of vegetation and climate. Early climate classifications effectively used vegetation data in determining climatic boundaries. Of greater significance to this research are the works of Borchert (1950) and Bryson (1966) both of which demonstrated the covariance of vegetation and air mass dominance.

In the previous investigation of coastal environments in the Americas (Dolan, et al., 1972), a close relationship between vegetation types and air-mass-derived climatic boundaries was found. Similarly, the objective of the classification of coastal vegetation types in Africa is to validate the climatic regimes.

The vegetation classification is based on plant features which are indicators of the main climate parameters (Table 5). The first criterion, vegetative life form, is related to the macroscale climates, particularly their latitudinal zonation. Leaf phenology, considered as the presence or absence of the deciduous characteristic, reflects seasonal aridity or extreme temperatures. The final criterion, relative leaf size, relates to the moisture stress of the environment during the yearly growing season.

The resulting distribution of vegetation types in coastal Africa is given in Figure 4. Although a greater number of uniform vegetation regions than climatic regions are found, a close relationship between climate and vegetation is evident.

A comparison of vegetation types of South America with those found in Africa yields interesting climatic considerations, particularly with regard to the arid coastal regions which dominate Africa. Nannophyllous deciduous angiosperm deserts along the west coasts of both continents lie adjacent to the common climatic causative factor, subtropical anticyclones. In contrast the extensive arid portions of north and east Africa are the products of the continental tropical air mass source regions; counterparts to these deserts are not found in South America where corresponding areas are dominated by maritime air. It is then apparent that uniform vegetation responses result regardless of varying atmospheric dynamics which may produce aridity. An additional example of regions dissimilar as to climatic regime but supportive of the same vegetation type is the arid coast of southwest Africa with maximum rainfall during the high-sun season. However, the climatic counterparts in North Africa and along the west coasts of North and South America experience rainfall maxima during the low-sun period.

The east coast of Africa differs significantly from the east coasts of North and South America. As a result of the monsoonal flow of the Indian Ocean atmosphere, the east coast exhibits desert conditions not found on corresponding coasts in the Western Hemisphere In addition, the microphyllous deciduous angiosperm savanna, which characterizes southern Africa, reflects a unique east coast climate since this vegetation type is not encountered in the Americas. Similarly, the humid tropical vegetation which is characteristic of eastern South America is missing in Africa as a result of the weak intertropical convergence zone along the eastern coast.

Compared to the distribution of climate types of other classifications, for example Köppen (1931), it may seem questionable that eight new regimes are established in Africa, and only four regimes are repeated from the Americas. However, the vegetation classification, by underlining vegetational differences, supports the reality of the new climatic types.

TABLE 5

Coastal Vegetation Classification Scheme

VEGETATION LIFE FORM

- Tundra
- Forest
- Savanna
- Grassland
- Shrub and Brushland
- Desert

FOLIAGE PHENOLOGY

- Coniferous
- Deciduous Angiosperm
- Evergreen Angiosperm

FOLIAGE DIMENSION*

- Macrophyllous
- Microphyllous
- Nannophyllous

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*Macrophyllous--large leaves; microphyllous--small leaves; nannophyllous--tiny leaves or leafless.

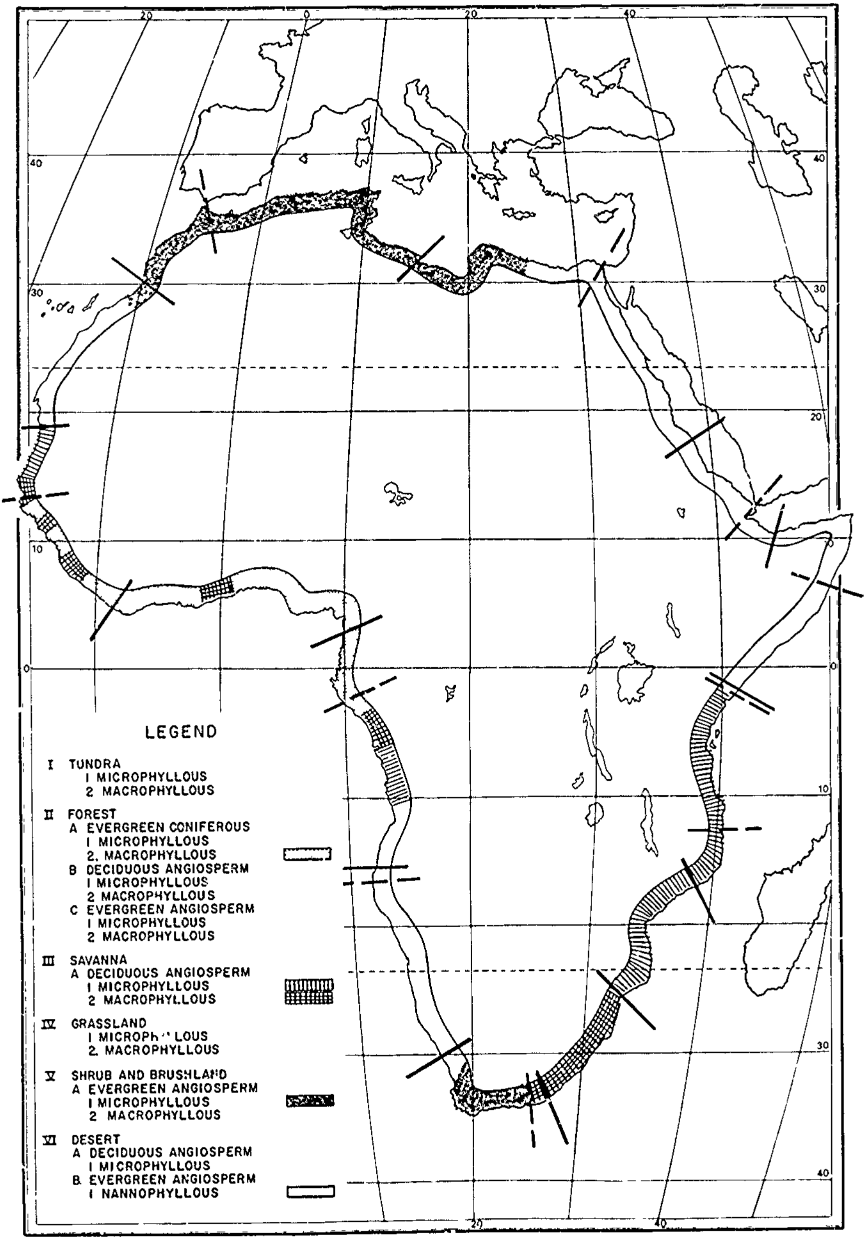

Figure 4. Coastal Terrestrial Vegetation of Africa.

MARINE SUBREGIMES OF AFRICA

Just as climatic regimes are delineated by air mass analysis, the oceanic subregimes are distinguished through the study of water masses in this second part of the classification. Like air masses, water masses possess a set of measurable characteristics which substantiate their use as a basis of classification. Since synoptic data sets are not available, water masses are identified by their two characteristic properties, salinity and temperature.

Water masses are vertically stratified by depth. However, since depths in coastal regions are commonly less than 300 meters and since all water masses originate at the surface where air-sea transfers of energy and mass occur, only the active surface masses (0-200 m) are examined in this classification.

Water masses, and thus the subregimes, are dependent on global distributions of solar radiation and large oceanic current systems. In that the atmospheric variables, including cloud cover and winds, influence the development of water masses, and since air masses derive properties such as absolute humidity and temperature from the ocean surface, it is apparent that the distributions of air masses and water masses are interrelated.

In the classification of coastal water masses, possible complication by several factors must be considered: temperature distributions may be affected by upwelling and currents, and salinities may be modified by sea ice, continental runoff, and currents. For the classification of the subregimes in Africa, two additional factors have to be taken into account: the monsoon-dominated circulation of east Africa and the presence of large, semienclosed seas.

The subregimes, or oceanic water masses, are identified through the analysis of seasonal surface water temperatures and seasonal current fields.[2] Use of presummarized data allows resolution no less than approximately 100 miles for mapping and graphical analysis. However, since the scales of the subregimes (average of 1500 mi) and the seasonal variation in boundary position (average of 250 mi) both exceed the resolution, presummarized data are adequate.

In most cases, the subregime boundaries are indicated by the mean yearly positions of current difluence or confluence. An exception to this occurs along the east coast of Africa where monsoon winds dominate current strength and direction. Here, establishment of the mean annual current position cannot accurately reflect the flow regimes since a complete seasonal reversal in currents takes place. In order to help substantiate the existence and placement of these east coast boundaries, corroborative evidence from an investigation by Gallagher (1966) was reviewed (Fig. 5).

Subregime boundaries are also indicated where water bodies are physically constricted as at the Suez Canal, Strait of Gibralter, and the mouth

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[2] For the Americas, these temperatures were determined by an average taken within 300 miles of the shore (Dolan, et al., 1972). For Africa, however, a more accurate estimate of the actual temperature is given by the intersection of isotherms with the coast.

of the Gulf of Aden. The limited interaction through these narrow passages verifies the disjunction of these water masses.

The nine subregimes found in the coastal waters of Africa are shown in Figure 6; their characteristics are summarized in Table 6. The analysis indicates broad similarities between Africa (Fig. 6) and South America (Fig. 7). Three subregime types as well as their approximate latitudinal boundaries are duplicated on the west coasts of both southern continents; similarly, a fourth type appears on their eastern coasts. Contrasts in water masses between South America and Africa relate to differences of latitudinal position, monsoonal circulation, and water body confinement. Thus, while Africa lacks the subregimes present in the more polar latitudes of South America, new types are found due to the monsoon influence on the northeast coasts and to enclosed areas like the Gulf of Aden.

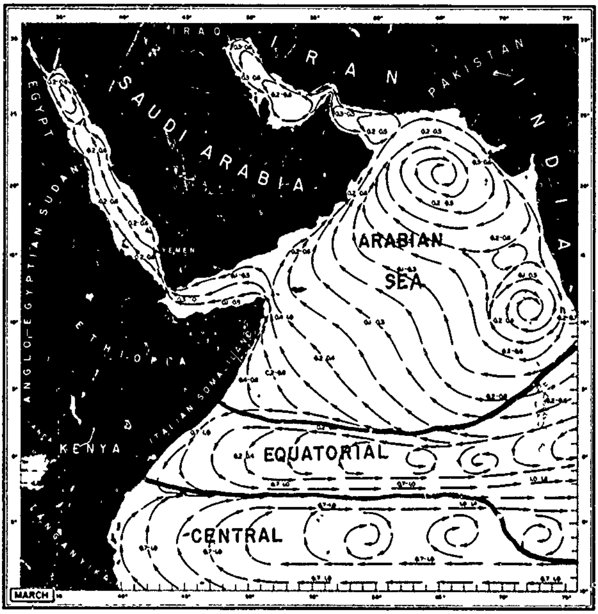

Figure 5. Water Mass Types of Eastern Africa.

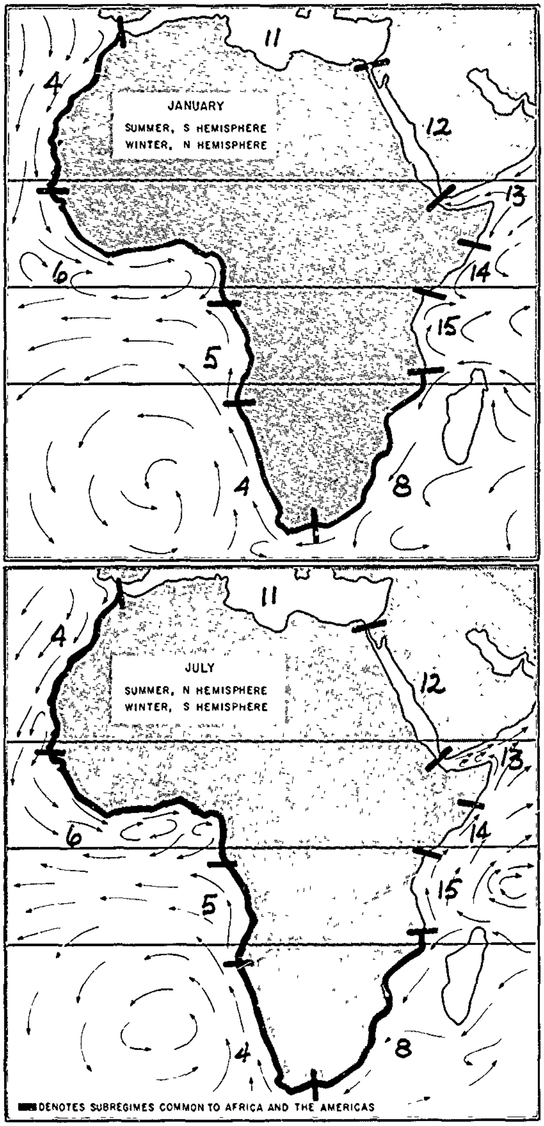

Figure 6. Marine Subregimes of Africa.

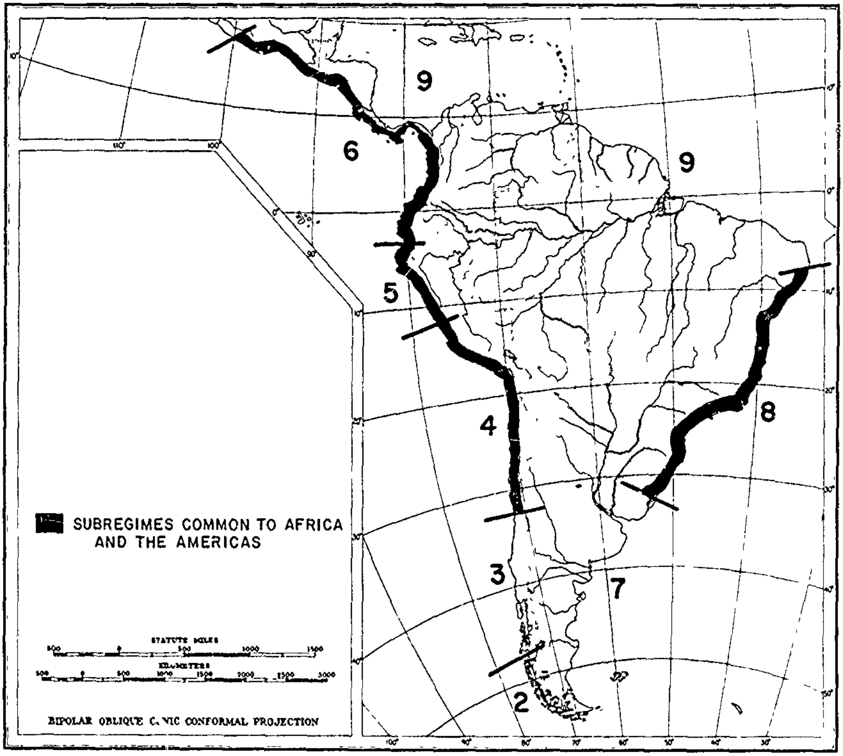

Figure 7. Marine Subregimes of South America.

TABLE 6

Sea Surface Characteristics of the Subregimes of Africa

AREA	MONTH	MEAN T(°F)	MEAN SALINITY (0/00)	MEAN DENSITY
4(SW)	February	66°	35.00	1.02535
	August	58°	35.25	1.02635
5	February	77°	34.75	1.02300
	August	68°	35.25	1.02475
6	February	82°	34.00	1.02200
	August	77°	34.25	1.02250
4(NW)	February	64°	36.50	1.02660
	August	73°	36.25	1.02540
11	February	60°	37.75	1.02775
	August	77°	37.50	1.02550
12	February	76°	39.00	1.02600
	August	87°	39.50	1.02500
13	February	78°	36.00	1.02380
	August	79°	36.25	1.02400
14	February	78°	35.75	1.02325
	August	76°	35.00	1.02375
15	February	82°	35.25	1.02275
	August	76°	35.00	1.02350
8	February	75°	35.25	1.02375
	August	68°	35.50	1.02500

CLASSIFICATION OF WAVE ENERGY INCIDENT ON AFRICAN COASTS

As an important element within the coastal environment, ocean waves control many coastal processes associated with relief, configuration, and shoreline conditions. Nevertheless, waves do not constitute a separate level within the three-part classification structure of coastal environments. First, their dependency on the atmospheric elements incorporated in the regime analysis is strong; and secondly, their organization into areas of similarity analogous to air or water masses is still hypothetical.[3]

Although waves are generated by the atmospheric systems, problems are involved in the establishment of boundaries between wave classes. Along straight coasts waves are not bounded by the atmospheric systems, instead they disperse until dissipated or incident upon some coast. As a result, the boundaries between classes of incident wave energy cannot be sharply defined. Along coasts exhibiting abrupt changes in shoreline direction secondary breaks in wave energy, independent of the atmospheric systems, may be produced.

The parameters and coverage of available data determine the procedure used in compiling wave classes. Since the only available coastal data is for wave heights at ten selected harbors along southwest Africa (from the Sailing Directions), it is necessary to use presummarized deep-water visual wave observations. Also, since wave heights estimated in deep water include waves traveling in all directions, it is impossible to estimate incident wave energy directly from these wave heights.

Despite data problems, it is possible to obtain seasonal estimates of wave energy for Africa (Fig. 8) from directional spectra, if it is assumed that energy is distributed around its mean wave direction by a cosine power law (Longuet-Higgins, 1962). Shoreward wave energy can then be estimated through application of directional multipliers to deep water wave data (from Ocean Wave Statistics). While the cosine power law may not be accurate for waves outlying the area of wind generation, the deviation may not be too large, since most of the observations do not record swell.

In order to compare the wave classes determined for Africa with those previously classified in South America, statistics for the percent of total wave heights greater than five feet are derived.[4] Data sources used for both continents have maps constructed from identical criteria: for South America, South American Marine Energy (Russell, 1969); and for Africa, Frequency of Occurrence of Ocean Surface Waves in Various Height Categories for Coastal Areas (U.S. Dept. of the Army, 1962).

A presentation of waves incident along the coasts of Africa and the Americas is given in Figures 9 and 10. In addition, a conceptualization

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[3] A major difficulty involved in the classification of wave climate regions is the lack of coastal wave data on a worldwide scale. Nevertheless, two attempts have been made (Davies, 1964; Russell, 1969).

[4] The five coastal classes selected to denote similarity on the basis of yearly total energy durations are: VERY HIGH (>50%>5 ft.), HIGH (>40%> 5 ft.), MODERATE (>30%>5 ft.), LOW (>20%>5 ft.), and VERY LOW (<20%>5 ft.).

of sources of maximum wave energy is given (Fig. 11) as well as a summary of African coastal wave energy by regime (Table 7). As with the analysis of water masses, wave energies for Africa and South America are analogous; patterns in wave energy along the west coast indicate higher wave energy toward the polar latitudes and grading into lower wave energy at the equator. Significant differences in wave energy classes between the two continents are attributed to latitudinal position, geographical arrangement, and monsoonal flow. A summary of these differences is presented in Table 8.

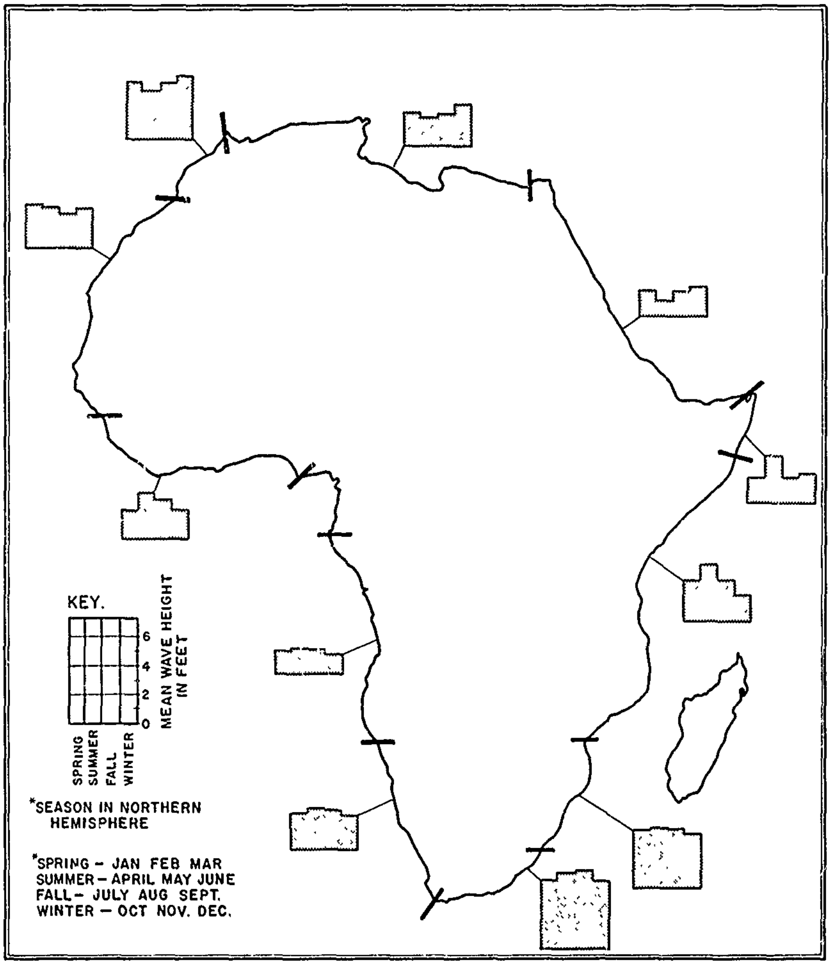

Figure 8. Estimates of Mean Wave Energy Along the African Coasts.

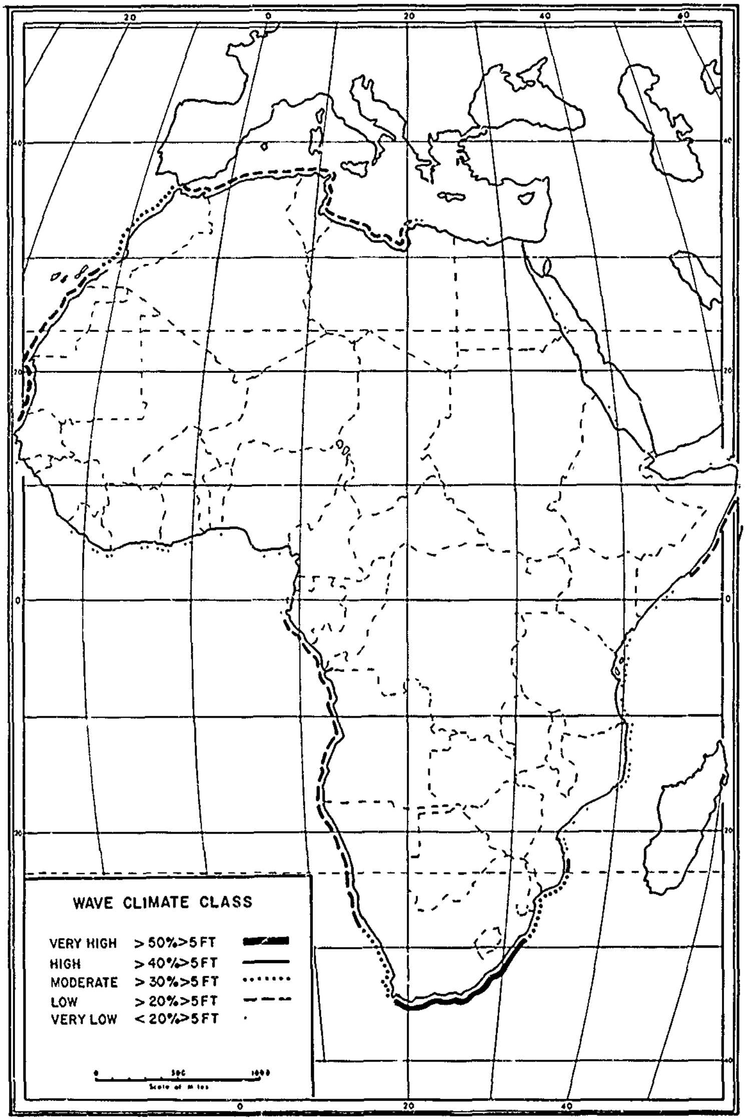

Figure 9. Estimation of Yearly Mean Wave Energy by Class for Africa.

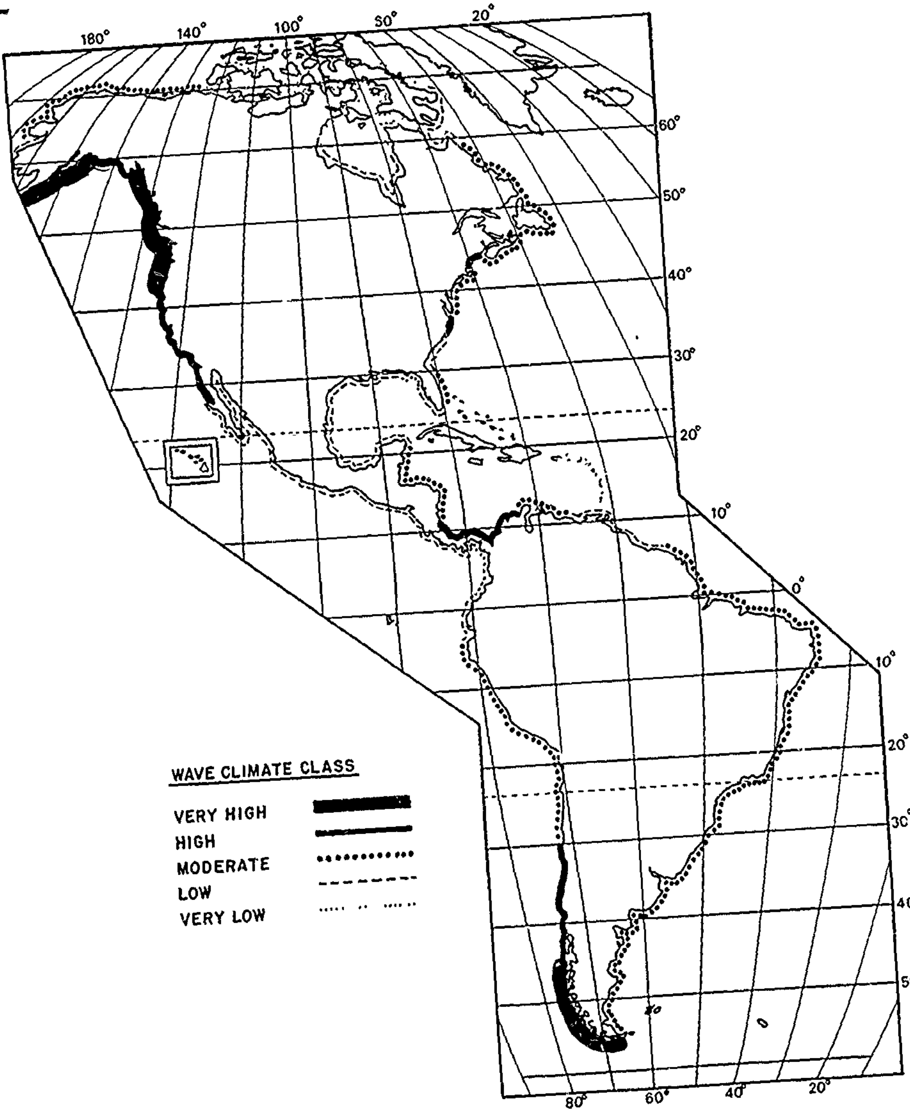

Figure 10. Estimation of Yearly Mean Wave Energy by Class for the Americas.

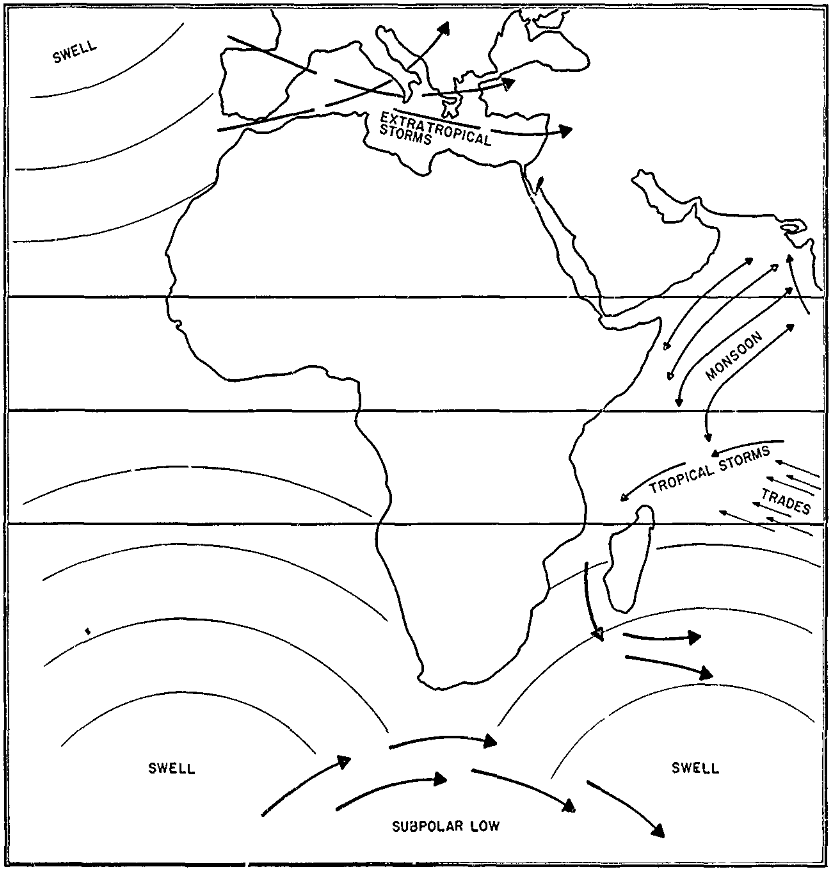

Figure 11. Conceptualization of Sources of Maximum Waves.

TABLE 7

Seasonality of Coastal Wave Energy by Regime for Africa

REGIME	MEAN	SEASON OF MAXIMUM & MINIMUM				SOURCE MAXIMUM WAVE ENERGY
		W	Sp	S	F	
XVI	M/L	+		-		Ex
XVII	L/VL			-		Ex
XVIII	VL	+		-		M
XIX	L/VL			+		M
XX	VL	+		-		Tr
XII	M/L/VL	+	+			Tr
XXI	H/M	+	+			SP
VI	H/M/L	+	+			SP, sw
XXII	M/L	+	+			SP, sw
VII	L/VL	+	+			Sw
IX	VL	+	+			T, sw
XXIII	L/VL	-		+		Sw

KEY:

W = winter (low sun)
Sp = spring
S = summer (high sun)
F = fall
(+) = maximum
(-) = minimum

Ex = extratropical cyclones
SP = subpolar cyclones
M = monsoon circulation
Sw = swell
Tr = tropical cyclones
T = trade winds

TABLE 8

Comparative Summary of Factors Involved in Wave Energy Differences Between South America and Africa

FACTOR	SOUTH AMERICA	AFRICA
Latitudinal Position	Extends to approx. 55°S.	Extends no farther than 37°S.
Consequences:	Coastal segment in polar latitudes records at least 50% of waves greater than 5 ft. ("very high" wave class).	Class of "very high" waves absent.
Geographical Arrangement	Ocean basins, uninterrupted by significant islands or confined seas, extend along both coasts.	1) Madagascar extends for nearly 15° latitudinally along the coast. 2) Three shoreline water bodies confined: Mediterranean, Red Sea, and Gulf of Aden.
Consequences:		Wave energy from open ocean blocked from coast.
Monsoonal Flow	No monsoonal development.	Northeast section influenced by the seasonal anticyclonic-cyclonic monsoonal flow over Asia.
Consequences:	Coasts comparable to African area record at least 30% of waves greater than 5 ft. ("moderate" wave class).	Monsoon circulation keeps easterly trades from dominating equatorial regions with results that less than 20% of waves greater than 5 ft. ("very low" wave class).

In this three-part classification of coastal environments, the final level is concerned with the shoreline itself. The coastal interface, or the boundary between land and sea, exists as the physical expression of the interaction of land materials with the atmospheric and oceanic systems. The interface classification attempts to view the shoreline types as a response related to the ongoing processes within the first two levels of the classification: the atmospheric regimes and the marine subregimes.

Ideally, a classification based on ongoing processes at the interface would be most useful; however, process data at the scale and coverage required are not available. The best data available, from topographic map coverage and to some extent from the Sailing Directions, provide considerable information for extraction of descriptive and quantitative parameters.

Originally, it was thought that standard terminology for coastal forms would suffice for the classificatory elements. However, after the application of standard interface types in the Americas, it was realized that terms such as sand beach, barrier island, cliffed coast and mudflat are not necessarily mutually exclusive nor are standard definitions truly definitive.

The classification of interfaces along the coasts of Africa is solidly based on three descriptive attributes of shoreline material: gross form, chemical composition, and size character (Table 9). Three attributes reflect and are responsive to the ongoing processes; in addition they relate better to the first two levels of the classification and better represent the type of shore than does standard terminology for coastal form.[5]

Of the 24 classes of interfaces possible through random combination of the three attributes, many are nonexistent, such as: a "barrier interface of organic silts" or a "riverine interface of organic rock." In actuality, 15 types of interfaces are derived (Table 10) including two types best described as "pocket beach" and "sand beach with rock headlands," which exhibit both sand and rock material sizes in a specific configuration. Twelve of the 15 interface types are found in Africa (Table 11).

In determining the interface types, topographic maps at 1:250,000 provide the basic information, while nautical charts, the Sailing Directions, topographic maps at 1:1,000,000 and primary literature are used as supplementary and corroborative sources. Decisions as to interface types are first mapped at 1:5,000,000. When mapped, the interface units present information as to the type of shoreline expected. At 1:5,000,000 quantitative measurements can be made, while at 1:10,000,000 distributional patterns are readily recognized.

With regard to the data, availability and consistency are the primary problems. Although topographic coverage is far more complete for Africa than for Central and South America, the maps of Africa do not provide the

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[5] The history of coastal classification has seen two major approaches in schematization: genetic and descriptive, with most being genetic. Recently, it has been recognized that while genetic classifications may be desirable, they can only fail due to data problems, controversy, and misinterpretation (Bird, 1969; Vogel, 1966).

level of precision and detail as those for the United States and Canada.[6] Further, the shoreline descriptions given in the Sailing Directions for the African coastlines are either confined to harbors, or are more generalized and cover longer shore reaches than do comparable descriptions for the Americas. The most probable reason for data problems in Africa is that the comparative underdevelopment and underpopulation of coastal areas provide minimal interest for economic and cultural activities; the type of information which would be useful to this classification has not yet been compiled because there has been little demand for it.

Figure 12 presents the distribution of interface types in Africa, and the percentage of occurrence of each type in Africa and the Americas is given in Table 11. Several general observations may be made. As expected, the majority of the African shores are mainland in form, inorganic in chemical nature, and composed of sand-gravel-sized material. Like the Americas, the riverine interfaces of Africa are located along the more stable coasts, particularly the Ivory, Gold, and southeastern coasts. Whereas the stable coasts exhibit silts and sands, the active areas along the Mediterranean, Red Sea, and the Horn, are characterized by larger materials: rocks and sands, including rock headlands. Furthermore, no cobble-shingle coasts of mappable size are found in either Africa or the Americas. Since it does not extend into the polar latitudes, Africa lacks the glaciated fiorded coasts prevalent in the higher latitudes of both North and South America.

It is interesting to note that organically composed interfaces are equally common in Africa and South America, which reflects the relative similarity in continental orientation, shape, position, and tropical influence. The high percentage of materials classed as sands and gravels is associated with the dominance of arid coastal areas.

In considering the relationship between interface type and marine processes, it is noted that the 'living organic' coastlines are associated with 'very low' wave energies (Fig. 9), while the extensive stretches of sand-gravel and mixed materials (A2b/A2d and A2d/A2b) occur in 'moderate' and 'low' wave climate regions.

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[6] Approximately 85% of the African coastline is available on 1:250,000 topographic sheets as compared to about 5% of the coasts of South America and Central America.

TABLE 9

Organization of the Coastal Interface Classification

GROSS FORM: Relative configuration of the mainland material with respect to the open ocean.

[A]	Mainland Interface:	Direct interface between mainland and open ocean.
[B]	Barrier Interface :	No direct interface between mainland and open ocean, a linear mass parallels mainland.
[C]	Riverine Interface:	Direct interface between mainland and open ocean, interrupted by fluvial discharge and associated landforms.

CHEMICAL COMPOSITION:* Relative chemistry of the interface material.

[1] Living Organic

[2] Inorganic

SIZE CHARACTER: Relative particle size of the interface material. The diameters are modified after C.K. Wentworth.

[a]	Silts & Clays	Less than 1/16 mm
[b]	Sands & Gravels	Between 1/16 mm and 4 mm
[c]	Shingles & Cobbles	Between 4 mm and 256 mm
[d]	Rocks	Greater than 256 mm

*While a wide range of stratifications based on interface material chemistry are conceivable, the simple subdivision of living organic versus inorganic is the most meaningful in terms of response to ongoing processes. Further subdivision within the classes of organic and inorganic is not necessary and is limited by available data.

TABLE 10

Structure and Elements of the Coastal Interface Classification

GROSS FORM		CHEMICAL CHARACTER		SIZE CHARACTER		DESCRIPTIVE EXAMPLE*	
[A]	Mainland Interface	[1]	Living Organic	[a]	Silts & Clays	[A1a]	Swamp
				[b]	Sands & Gravels		
				[c]	Shingles & Cobbles		
				[d]	Rocks	[A1d]	Fringing Reef
		[2]	Inorganic	[a]	Silts & Clays	[A2a]	Mudflats
				[b]	Sands & Gravels	[A2b]	Sand Coast
				[c]	Shingles & Cobbles	[A2c]	Shingle Beach
				[d]	Rocks	[A2d]	Rock Coast
					Rock/Sand	[A2d/A2b]	Pocket Beach
					Sand/Rock	[A2b/A2d]	Sand Beach/ Rock Headland
[B]	Barrier Interface	[1]	Living Organic	[a]	Silts & Clays		
				[b]	Sands & Gravels		
				[c]	Shingles & Cobbles		
				[d]	Rocks	[B1d]	Barrier Reef
		[2]	Inorganic	[a]	Silts & Clays		
				[b]	Sands & Gravels	[B2b]	Barrier Island
				[c]	Shingles & Cobbles		
				[d]	Rocks		
[C]	Riverine Interface	[1]	Living Organic	[a]	Silts & Clays	[C1a]	Swamp Delta
				[b]	Sands & Gravels		
				[c]	Shingles & Cobbles		
				[d]	Rocks		
		[2]	Inorganic	[a]	Silts & Clays	[C2a]	Mudflat Delta
				[b]	Sands & Gravels	[C2b]	Sand Delta
				[c]	Shingles & Cobbles	[C2c]	Cobble Delta
				[d]	Rocks	[C2d]	Fiord

*This is not intended to be an exhaustive inventory of examples.

TABLE 11

Occurrence of Interface Types in Africa and the Americas*

INTERFACE CLASS	DESCRIPTIVE EXAMPLE	NORTH AMERICA # UNITS	NORTH AMERICA MILES	NORTH AMERICA PERCENT	SOUTH AMERICA # UNITS	SOUTH AMERICA MILES	SOUTH AMERICA PERCENT	AFRICA # UNITS	AFRICA MILES	AFRICA PERCENT
A1a	Swamp	10	684	1	18	3757	19	16	635	3
A1d	Fringing Reef	Included in B1d			Included in B1d			9	334	2
A2a	Mudflat	93	11409	22	5	376	2	13	607	3
A2b	Sand Coast	83	5624	11	56	4655	24	113	7191	38
A2c	Shingle Coast	Does not occur			Does not occur			Does not occur		
A2d	Rock Coast	107	8335	17	19	2468	12	25	1150	6
A2d/A2b	Pocket Beach	42	3203	6	25	2497	13	39	2049	11
A2b/A2d	Sand Beach/Rock Hdld	12	711	1	7	272	1	51	2166	13
B1d	Barrier Reef	14	714	1	5	612	3	22	1926	10
B2d	Barrier Island	33	4126	8	2	283	1	6	970	5
**C1a	Swamp Delta							12	1192	6
C2a	Mudflat Delta	61	5557	11	18	2804	14	3	142	1
C2b	Sand Delta							7	373	1
C2c	Cobble Delta	Does not occur			Does not occur			Does not occur		
C2d	Fiord	39	10999	21	5	2025	10	Does not occur		
	TOTAL	494	51862	99	160	19729	99	316	18735	99

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See the following pages
for greater detail.
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CLASSIFICATORY ELEMENT	PERCENT OF TOTAL COASTLINE NORTH AMERICA	PERCENT OF TOTAL COASTLINE SOUTH AMERICA	PERCENT OF TOTAL COASTLINE AFRICA
Gross Form:			
[A] Mainland Interface	80	82	76
[B] Barrier Interface	9	3	15
[C] Riverine Interface	11	14	8
	100%	99%	99%
Chemical Composition:			
[1] Living Organic	2	22	21
[2] Inorganic	97	77	78
	99%	99%	99%
Size Character:			
[a] Silts and Clays	23	21	13
[b] Sands and Gravels	19	25	44
[c] Shingles and Cobbles	0	0	0
[d] Rocks	39	25	18
[b&d] Sand/Rock Configuration	7	14	24
*Indifferentiable	11	14	0
	99%	99%	99%

*In that the interface classification used in the Americas underwent extensive revision, resulting in a different scheme and terminology for use in Africa, direct correspondence between the two areas is impossible without remapping the Americas.

**In North and South America, classes C1a, C2a, and C2b could not be differentiated on the basis of the previous classification scheme; therefore, the data represents total occurrence of these three types.

TABLE 11

Occurrence of Interface Types in Africa and the Americas*

INTERFACE CLASS	DESCRIPTIVE EXAMPLE	NORTH AMERICA # UNITS	MILES	PERCENT	SOUTH AMERICA # UNITS	MILES	PERCENT	AFRICA # UNITS	MILES	PERCENT
A1a	Swamp	10	684	1	18	3757	19	16	635	3
A1d	Fringing Reef	Included in B1d			Included in B1d			9	334	2
A2a	Mudflat	93	11409	22	5	376	2	13	607	3
A2b	Sand Coast	83	5624	11	56	4655	24	113	7191	38
A2c	Shingle Coast	Does not occur			Does not occur			Does not occur		
A2d	Rock Coast	107	8835	17	19	2468	12	25	1150	6
A2d/A2b	Pocket Beach	42	3203	6	25	2497	13	39	2049	11
A2b/A2d	Sand Beach/Rock Hdld	12	711	1	7	272	1	51	2166	13
B1d	Barrier Reef	14	714	1	5	612	3	22	1926	10
B2d	Barrier Island	33	4126	8	2	283	1	6	970	5
**C1a	Swamp Delta							12	1192	6
C2a	Mudflat Delta	61	5557	11	18	2804	14	3	142	1
C2b	Sand Delta							7	373	1
C2c	Cobble Delta	Does not occur			Does not occur			Does not occur		
C2d	Fiord	39	10999	21	5	2025	10	Does not occur		
	TOTAL	494	51862	99	160	19729	99	316	18735	99

CLASSIFICATORY ELEMENT	PERCENT OF TOTAL COASTLINE NORTH AMERICA	SOUTH AMERICA	AFRICA
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[A] Mainland Interface	80	82	76
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	99%	99%	99%
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C2b	Sand Delta							7	373	1
C2c	Cobble Delta	Does not occur			Does not occur			Does not occur		
C2d	Fiord	39	10999	21	5	2025	10	Does not occur		
	TOTAL	494	51862	99	160	19729	99	316	18735	99

CLASSIFICATORY ELEMENT		PERCENT OF TOTAL COASTLINE NORTH AMERICA	SOUTH AMERICA	AFRICA
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		100%	99%	99%
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Size Character:				
[a]	Silts and Clays	23	21	13
[b]	Sands and Gravels	19	25	44
[c]	Shingles and Cobbles	0	0	0
[d]	Rocks	39	25	18
[b&d]	Sand/Rock Configuration	7	14	24
	*Indifferentiable	11	14	0
		99%	99%	99%

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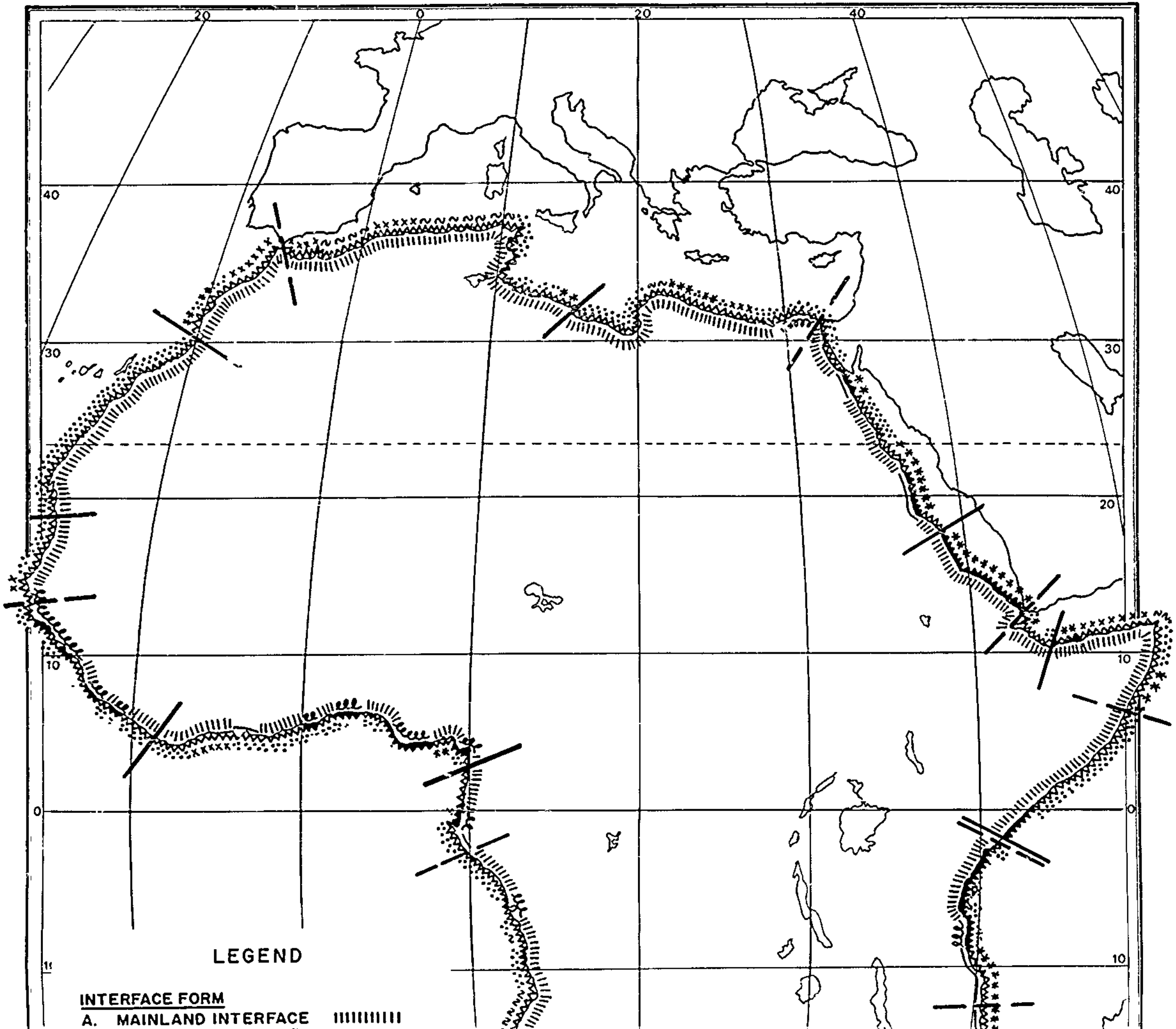
*In that the interface classification used in the Americas underwent extensive revision, resulting in a different scheme and terminology for use in Africa, direct correspondence between the two areas is impossible without remapping the Americas.

**In North and South America, classes C1a, C2a, and C2b could not be differentiated on the basis of the previous classification scheme; therefore, the data represents total occurrence of these three types.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LEGEND
INTERFACE FORM
A. MAINLAND INTERFACE IIIIIIIIII

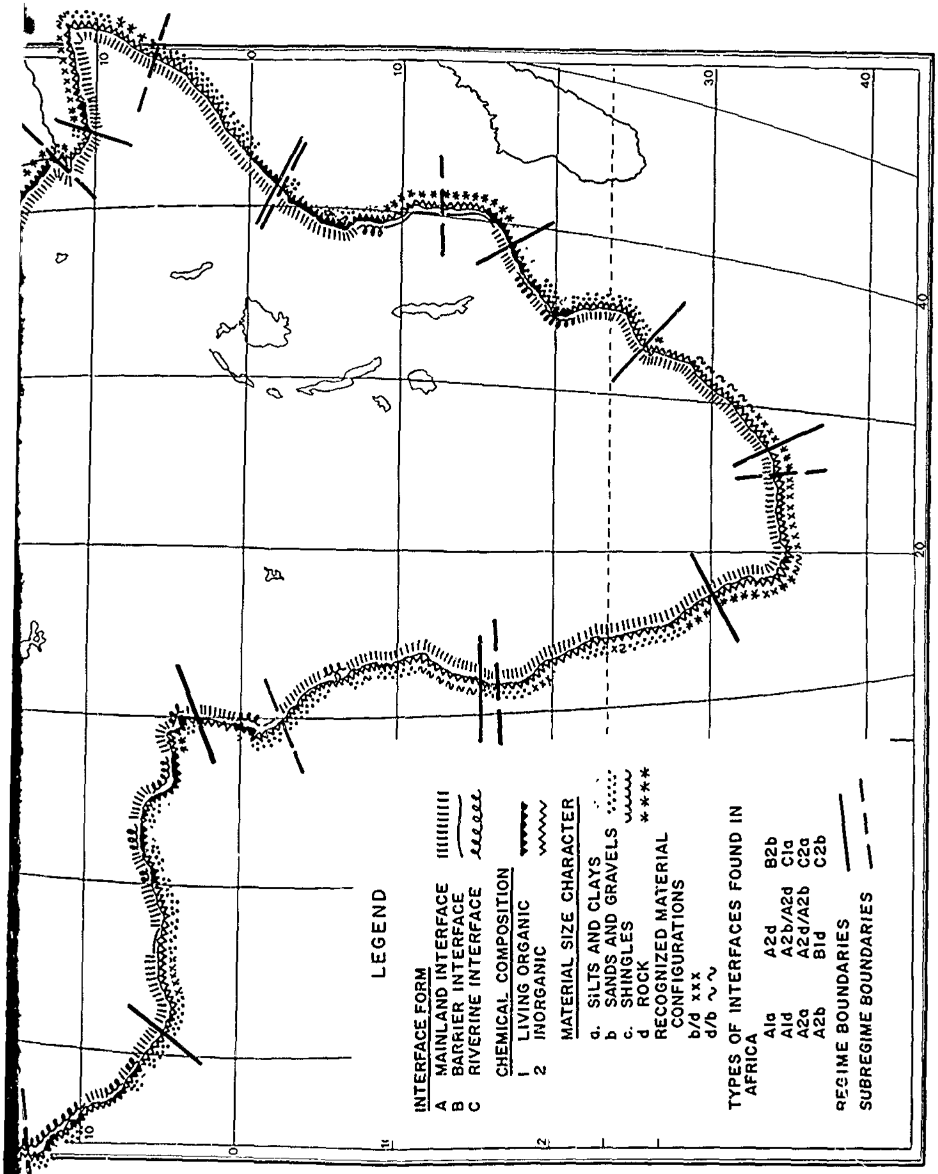

Figure 12. Interface Types and Elemental Units of Africa.

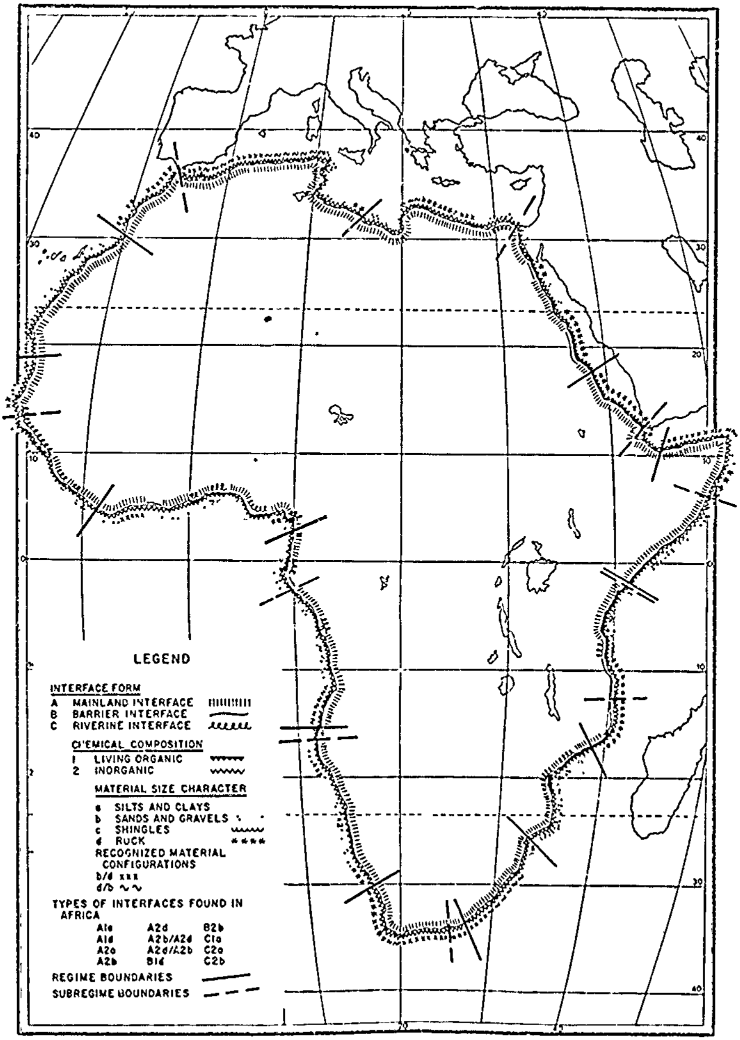

Figure 12. Interface Types and Elemental Units of Africa.

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for greater detail.
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ELEMENTAL UNITS OF AFRICA: THE INTEGRATION OF THE CLASSIFICATIONS

The concept of the elemental unit has been discussed in the introduction. The distribution of elemental units in Africa is given in Figure 12 when the superimposition of Regime and Subregime boundaries on the Interface Units is considered. Thus, the classifications of atmospheric, marine and interface types are integrated; each individual resulting segment or coastal environment defines a specific set of characteristics distinct from adjacent segments, but which may repeat at other locations further along the coast as well as throughout the world.

As expected, the number of coastal environmental types common to both Africa and the Americas is low; four Regime types recur in Africa (Figs. 1 and 2), with the result that only portions of the west and southeast coasts potentially hold elemental unit types repeating from the Americas. This low level of duplication is attributed to: [1] continental configuration within latitudinal position which gives Africa a large tropical land mass; [2] the presence of a large land mass to the north which contributes to continental and monsoonal influences; and [3] the absence of a cordillera analogous to that in the Americas.

SUMMARY

This research was undertaken to provide an evaluation of the classification scheme presented earlier in The Americas.[7] The study of the African coasts sought to: [1] determine the time required to apply the procedures established in The Americas to a new area; [2] determine the feasibility of obtaining comparable data sets; and [3] test the hypothesis stated in The Americas that coastal environmental types are identifiable and recurrent.

Since a team of four researchers completed the data analysis and the classification of African coast types in one month, the classification procedures are easily employed in a new area. Data acquisition presented the major difficulty, requiring four months to locate and obtain data sets comparable to those used in the Americas. In cases where corresponding data were nonexistent, alternate procedures were developed based on available data. Where corresponding data were incomplete, supplementary data sources were used.

Finally, while the number of coastal environmental types common to the Americas and to Africa is small, the basic attributes of the natural processes in Africa have been found to be similar to those in the Americas and to differ only in organization, the coastal environments identified in this report constitute support for the hypothesis that there are ". . . natural complexes of coastal environments that are duplicated around the world when process forcing functions are similar."

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[7] Since publication of The Americas, a revised interface classification was implemented and used in this research.

APPENDIX

Coastal Classification and Data Sources

CLASSIFICATION AND ANALYSIS OF THE ATMOSPHERIC REGIMES

In the classification of climate, the work by Bailey (Putnam, et al., 1960) represents the single direct attempt to delineate coastal climates. Although the systems of Köppen (1931) and Thornthwaite (1931, 1948) are popularly used in extrapolating coastal zone conditions, these classifications are continentally oriented. Based on the seasonality of thermal and hydrologic characteristics, the schemes of Bailey, Köppen, and Thornthwaite neglect the obscure but important relationships between the seasonality characteristics and coastal upwelling, fog and winds. The feasibility of utilizing the techniques of air mass climatology (streamline analysis and Rossby diagrams) to identify natural climatic complexes has recently been demonstrated (Borchert, 1950; Bryson, 1966; Mitchell, 1969; and Oliver, 1970) and is a significant contribution toward the dynamic classification of coastal climates.

Delineation of the atmospheric regimes according to an air-mass-based classification is dependent upon the compilation and streamlining of resultant winds. A data base comparable to that for the Americas is not available for Africa. While the Southern Hemisphere is more deficient in climatic data than the Northern, Africa is even more deficient than South America. Wind data for oceanic stations is usually available; but for the small number of land-based stations, it is incomplete. Monthly maps of zonal and meridional wind components prepared by the Naval Weather Service Command (NAVAIR) have not yet been published. In addition to the monthly resultant wind maps by Dr. Carl Aspliden, supplementary data to determine front locations and air mass characteristics are used.

Aspliden, C. 1972. Mean monthly resultant wind maps of Africa (2000 ft. level). Unpublished collection.

Peixoto, J.P. and G.O.P. Obasi. 1965. Humidity conditions over Africa during the IGY. Cambridge: M.I.T. Press.

U.S. Dept. of Commerce. Catalog of meteorological satellite data, ESSA 3,5,7, Television Cloud Photography. Apr. 1 - Dec. 31, 1967; Apr. 1 - Jun. 30, 1968; Oct. 1 - Dec. 31, 1968; Jan. 1 - Mar. 31, 1969. Silver Springs, Md.: Environmental Sciences Services Administration.

U.S. Dept. of the Navy. Various dates. Sailing directions (HOP 50, 51, 52, 55, 60, 61). Washington, D.C.: U.S. Naval Oceanographic Office.

CLASSIFICATION AND ANALYSIS OF THE COASTAL VEGETATION ZONES

Two major approaches have been taken in the classification of terrestrial vegetation. One is concerned with the description of life form, such as deciduous forest, as exemplified by Polunin (1960) and the U.S. Air Force

(1960). The other, which is more complex, delineates communities by the dominant species (Sauer, 1950; Axelrod, 1960; Shelford, 1963; Good, 1964; Eyre, 1968). As noted with the climate classifications, vegetation classifications are continentally oriented; Axelrod is the only one to present a classification concerned with littoral vegetation. A major difficulty in coastal vegetation zonation is data reliability; coastal vegetation mapping is at best a compilation of extrapolations from existing classifications since the detailed distributions of vegetation types, particularly littoral, have not been established.

Data sources used in the African analysis are presented below. Eyre is a particularly valuable source which provides completeness and detail.

Axelrod, D. 1960. Coastal vegetation of the world. In *Natural coastal environments of the world*, W.C. Putnam, et al., pp. 43-58. Los Angeles: University of California.

Eyre, S.R. 1968. *Vegetation and soils: a world picture*. Chicago: Aldine Publishing Co.

CLASSIFICATION AND ANALYSIS OF THE MARINE SUBREGIMES

Several coastal classifications exist which include various aspects of the marine system (Price, 1954; McGill, 1958; Tanner, 1958; Davies, 1964; and Inman and Nordstrom, 1971). A classification of surface oceanic water masses based on temperature and salinity has been developed by Sverdrup, et al., (1942) while a similar classification of the Pacific water masses has been compiled by Muromtsev (1958). However, both Sverdrup and Muromtsev are concerned with the open ocean; no classification has been designed to systematize water masses of coastal areas. Odum (1969) has structured a descriptive classification of coastal ecological systems utilizing temperature, salinity, turbidity, and nutrient concentration.

Sources having presummarized data used in the African analysis:

Mazeika, P.A. 1968. Mean monthly sea surface temperatures and zonal anomalies of the tropical Atlantic. In *Serial atlas of the marine environment, folio 16*, ed. W. Webster. New York: American Geographical Society.

U.S. Dept. of the Navy. 1944. *World atlas of sea surface temperatures*, HOP 225, 2nd ed. Washington, D.C.: U.S. Naval Oceanographic Office.

1960. *Summary of oceanographic conditions in the Indian Ocean*, SP-53.

1966. *Ocean currents in the Arabian Sea and Northwest Indian Ocean*, SP-92.

1967. *Currents along the east coast of Africa*, IR 67-93.

1967. *Major currents in the North and South Atlantic Ocean between 64°N and 60°S*, TR 193.

1967. *Monthly charts of mean, minimum, and maximum sea surface temperatures of the Indian Ocean*, SP-99.

U.S. Dept. of the Navy. 1967. *Oceanographic atlas of the North Atlantic Ocean: Section II, Physical properties*, HOP 700-II. Washington, D.C.: U.S. Naval Oceanographic Office.

CLASSIFICATION AND ANALYSIS OF INCIDENT WAVE ENERGY

As a result of the general lack of coastal wave data, only two classifications have been given toward the regionalization of wave climates (Davies, 1964; Russell, 1969). To circumvent the data problem, research in wave climatonomy and wave climatology is undertaken in the determination of coastal wave climates. Although three approaches are possible in wave climatonomy, all are designed for the open ocean:

[1] Estimation of mean wave energies from mean winds
[2] Summarization of daily hindcasts
[3] Utilization of wind and fetch data to construct empirical fits of log-normal and other distributions.

The wave climatology techniques used in the African analysis involve the use of wave directions within 90° of a normal shore to estimate the relative deep water energies traveling shoreward. The data sources are:

Hogben, N. and F. E. Lumb. 1967. *Ocean wave statistics. A statistical survey of wave characteristics estimated visually from voluntary observing ships sailing along the shipping routes of the world.* London: Her Majesty's Stationery Office, National Physical Laboratory.

U.S. Dept. of the Army. 1962. *Frequency of occurrence of ocean surface waves in various height categories for coastal areas.* Research Report 1719-RR. Fort Belvoir: U.S. Army Research and Development Laboratories.

U.S. Dept. of the Navy. Various dates. *Sailing directions* (HOP 50, 51, 52, 55, 60, 61). Washington, D.C.: U.S. Naval Oceanographic Office.

1948. *Atlas of sea and swell charts, South Atlantic Ocean,* HOP 799B.

1965. *Atlas of sea and swell charts, Indian Ocean*, HOP 799G.

1970. *Oceanographic atlas of the North Atlantic Ocean: Section IV, Sea and swell*, HOP 700-IV.

CLASSIFICATION AND ANALYSIS OF COASTAL INTERFACES

Of the many coastal landform classifications developed since the early nineteenth century, two completed on a worldwide scale have made significant contributions (McGill, 1958; Valentin, 1952). Both of these however, are strongly genetic in approach and thereby inherent to problems in data and meaning. The most outstanding descriptive classification is perhaps that of Alexander (1962) which is easy to apply and satisfactorily describes and classifies shorelines; but the detail of mapping involved prohibits its use on a worldwide scale.

Topographic maps are the primary data source; secondary sources include *Sailing Directions*, nautical charts, and the literature.

TOPOGRAPHIC MAPS: For decisions concerning interface type, topographic sheets are preferred; however, for some areas of Africa 1:1,000,000 is the largest scale available. 1:250,000 coverage is more extensive for Africa than for the Americas but not nearly as precise or detailed as for the United States and Canada where it is complete. On many of the African sheets, no indication of shoreline material and composition is given. With inconsistency in scale and information level, equivalent decisions are not possible.

U.S. Dept. of the Army. Various dates. Topographic maps of Africa, 1:250,000 Series 1501. Washington, D.C.: U.S. Army Topographic Command.

Various dates. Topographic maps of the world, 1:1,000,000, Series 1301.

U.S. Dept. of Commerce. Various dates. World aeronautical and operational navigation charts, 1:1,000,000, Series for Africa. Washington, D.C.: National Ocean Survey.

SAILING DIRECTIONS AND NAUTICAL CHARTS: In order to verify some classification decisions for areas poorly depicted on topographic maps, the *Sailing Directions* and nautical charts were used extensively in the African analysis. By comparison, such supplemental data is of relatively little importance in the United States and Canada, but essential for Central and South America. Scales of nautical charts vary, but like the Americas, most of Africa (particularly the Atlantic and Mediterranean Coasts) is available at scales between 1:200,000 and 1:400,000. This supplemental data source helps to provide information on shoreline character where other sources are weak.

U.S. Dept. of the Navy. Various dates. *Sailing directions* (HOP 50, 51, 52, 55, 60, 61). Washington, D.C.: U.S. Naval Oceanographic Office.

Various dates. Hydrographic charts of Africa.

PRIMARY LITERATURE: Use of primary literature of Africa is mainly to determine locations of living organic composition and reefs. A preliminary search indicated that the volume of literature of interest to the classification is small; furthermore, much is outdated and already incorporated into other data sources.

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Gerasimov, I.P., ed. 1964. *Fiziko-Geographicheskiy atlas mira* (Physical geographic atlas of the world). Moscow: USSR and the Main Administration of Geology and Cartography, State Geological Committee.

Keay, R.W.J. 1959. Vegetation map of Africa south of the Tropic of Cancer, 1:10,000,000. New York: Oxford University Press.

Valentin, H. 1952. Die kusten der erde (Coasts of the world). In *Petermanns Geogr. Mitt. Erganzungsheft*, 246.

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