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PROVINCIALITY, GLOBAL SHELF AREA,
AND SEDIMENT SURVIVORSHIP

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by

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ABSTRACT

MARINE BIOSPHERE DIVERSITY THROUGH TIME: PROVINCIALITY, GLOBAL SHELF AREA, AND SEDIMENT SURVIVORSHIP

By

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Provinciality, climatic gradations, shelf area variation, species packing, continental fragmentation, sediment survivorship, and stochastic variation are included in a comprehensive computer model that simulates an actual and a preserved species diversity pattern through 600 million years of time. Results show that the number of continents in the system is the dominant controlling factor. Actual species diversity varies greatly through time. Preserved diversities always increase dramatically from the beginning to the end of the simulations, are highly biased and mask actual variation in the older parts of these generated records. No global equilibrium number of actual species is apparent, but the average number of species per continent is approximately constant through time. No chronologic increase in the number of species per community occurs in the model, but a steady increase appears in the number of preserved species per community. In addition, the number of species per community is significantly correlated with global species diversity.

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CHAPTER I

INTRODUCTION

An ongoing paleontological controversy revolves around the pattern of marine species diversity through time. At present, two major models are employed to analyse recorded diversity observations. One model depicts the observed diversity pattern as essentially real (Valentine, Foin, and Peart, 1978); it holds that the diversity levels reach a peak in the present because of increased number of provinces (Valentine, 1970; 1972; 1973) and increased species packing (Bambach, 1977). A second model depicts the observed species diversity pattern as an artifact of the fossil record and not necessarily a real pattern; instead species diversity rose to essentially present levels in the Early Cambrian and remained approximately constant after reaching that level (Raup, 1972; 1976 a,b; Schopf, 1974; Simberloff, 1974; 1976, and May, 1974).

In order to construct a comprehensive and effective explanation of change in marine species diversity as many environmental and preservational factors as possible must be dealt with and incorporated into a model. As can be seen in the ecological and paleontological literature, numerous variables have been proposed as environmental (Connrell and Orias, 1964; Kormondy, 1969; Osman and Whitlach, 1978) or preservational (Lasker, 1978) factors that deterministically control observed diversity patterns. These factors include provinciality, climatic stability, number of climatic zones, species packing, number of continents, continental position, stability of the environment, resource abundance, niche size, province area, sea level fluctuations, differential preservation, and rock survivorship. In addition, the element of random chance should be included in the list to avoid the pitfall of erecting a deterministic explanation where none is justified and to search for statistical generalizations which could have predictive value in the fossil record (Raup, 1977; Raup, et al., 1973). Accordingly, all these factors (and probably more) acted upon the diversity patterns seen in the fossil record.

In this paper, I combine many of these environmental and preservational factors into a synthetic model that uses a computer simulation to examine possible species diversity patterns through time. This simulation combines deterministic and stochastic features to construct a complex earth system unlike previous studies which have not included both deterministic and stochastic features in their models. These previous studies also used only a few (one or two) factors for constructing their systems.

This model examines generated species diversity patterns (actual and preserved) to see if the number of species increases or remains constant through time, and to explain what factors cause the generated patterns. Previous works have generally limited their studies to the fossil record and have based their conclusions strictly on that record. These studies are limited by the biases in the same fossil record that they are attempting to explain.

An objective look at possible actual diversity patterns that are generated by a simulation and their biases in a preserved generated record is necessary because it can provide a valuable insight and an explanation that can help to interpret the complex fossil record. It is my hope that this simulation provides such an explanation of the observed fossil diversity pattern and sheds light on the debate of whether the number of species is increasing or remaining constant through time.

CHAPTER II

PREVIOUS WORK

Both Valentine (1970) and Raup (1972; 1976 a,b) agree that the observed diversity in the Phanerozoic fossil record started at low levels and generally increased through time to the present. Valentine (1968, 1972, and 1973), however, has suggested major deterministic causes for the changes in marine shelf diversity, emphasizing provinciality. The provinciality concepts hold that assemblages of endemic organisms are restricted by climatic and geomorphological boundaries (deep ocean basins and continents). Valentine (1970; 1972; 1973) has also suggested that the number of continents present at any time controls diversity for various reasons. As the number of unconnected continents increases (which can increase the number of provinces), the global circulation of sea water is changed, lowering the number of climatic zones present. The width of climatic zones increases and the latitudinal thermal gradient is lowered, thus causing a decrease in the global number of provinces. The number of continents present does not always have the same effect on province number. When long continental margins are parallel to the climatic boundaries, the number of provinces is low because climatic zones do not cut across the margins. When long continental margins are perpendicular to climatic boundaries, however, the number of provinces is high because climatic zones cut across long margins.

Other authors have also suggested causes for the variation in the pattern of observed species diversity. Shelf area availability is of major importance in diversity control according to Schopf (1974), Simberloff (1973; 1976) and Sepkoski (1976). According to these authors, as shelf area increases, diversity increases ($D=k\ A^x$, D is the diversity, A is the available area, x and k are empirical constants). Many ecologists have supported this view for much smaller areas (Preston, 1960; Mac Arthur, 1965; 1969). Schopf believes that shelf area availability is related to sea level transgressions and regressions. These sea level shifts are due to changes in the rate of sea floor spreading (Windley, 1977; Bond, 1978; Raup and Stanley, 1978). As the rate of spreading increases sea level rises and causes a transgression. As spreading slows down or stops, sea level falls, causing a regression and subsequent emergence of the continents. This correlation between sea floor spreading and degree of continental submergence is known as the Haug Effect (Raup and Stanley, 1978).

In addition to shelf area, Bambach (1977) offers no causes but suggests that the number of individual species within communities has increased through time, thus affecting the global diversity pattern. In analysis of a separate problem, Raup (1972; 1976; 1976) and Raup and Stanley (1978) contend that rock survivorship and fossil preservability play major roles in producing the observed diversity pattern. Sepkoski (1976) concurs, and relates observed diversity directly to rock volume and habitat area ($D=kA^xV^y$, D is the diversity, A is the available area, V is the rock volume, and x, y, and k are empirically derived constants).

The conclusions derived from the above considerations vary greatly, but consist of two general types. One view presents the earth's biota as an equilibrium system that has a constant marine diversity after an initial sigmoidal growth explosion (May, 1973; Raup, 1976; 1976; Raup and Stanley, 1978; and Sepkoski, 1976), and biases in the fossil record (Sheehan, 1977) distort the diversity pattern observed. When these biases are taken into account, the diversity resembles the steady state system of a population near its carrying capacity in a logistic growth equation (Mark and Flessa, 1978; Cowen and Stockton, 1978; Marshall and Hecht, 1978).

Valentine, Foin, and Peart (1978) present the earth's biota as an expanding biological system that has not yet reached its equilibrium point. According to this model, the earth is still in the growth phase of a pattern that has no specific end point and that probably does not result in an equilibrium system. Preserved diversity is, in their opinion, an accurate indicator of past absolute diversity.

Valentine, Foin, and Peart attempt to simulate species diversity patterns with a logical model that works on the provincial and temporal levels. This model uses only deterministic controls in its operation and relies greatly on the actual Phanerozoic diversity data. Since their model is totally deterministic, strict controls are incorporated into the model that define the exact time of species bursts. These controls build in the assumption that the time of origin for the beginning of the "unprecedented rise of provinciality" lay "near the middle of the Cenozoic". The limits for the provinciality factor "ranged within narrow limits before the Cenozoic" inevitably limiting the calculated diversity for early periods. Their model does not take into account Raup's (1976) analysis of the recorded diversity filtered against the preserved rock volume for each geological period. They also did not simulate the effect available shelf area would have on the model.

CHAPTER III

DISCUSSION

Valentine, et al. (1978) also depend on the tabulations of Bambach (1977) for their diversity simulation. In his study of species packing within a community, Bambach attempts to classify diversity patterns through time on the basis of 386 fossil associations, derived from a literature survey of fossil communities. Several factors exist that might bias the data on community size in the literature.

One factor Bambach (1977) does not consider is sediment availability. Generally, Cenozoic faunas are collected from extensive unit exposures and older faunas are collected from less extensive exposures. As time passes, older rocks constitute less of the average volume and area of exposed sedimentary rocks. This conclusion is supported by sediment recyclying data presented by Garrels and MacKenzie (1971) and Blatt and Jones (1975). The process of sediment cycling provides much more time to erode older rocks, greatly reducing their volumes and areas. Blatt and Jones (1975) present information on sediment exposures from the Precambrian to the Cenozoic. Their data show that very little (one percent) of the earth's land surface is sedimentary rock from the Paleozoic and that about one third of the exposed earth's surface is sedimentary rock from the Cenozoic. They conclude that older sedimentary rocks are important sources for new sedimentary rocks. They suggest that 80 percent of the grains in some new sediments are derived from older sediments. The reduced volume and area, therefore, caused by the recyclying make is harder to locate and document species richness patterns in older rocks, even at the community level.

Another factor that must be accounted for is the lithification of a sediment. As sediments get older, the effects of lithification generally increase. Young (primarily Cenozoic) sediments are predominantly unlithified and fossil extraction naturally produces greater species richness. Pre-Cenozoic rocks, especially limestones, are more lithified and fossil collection commonly produces only records of fossils exposed on bedding planes.

Other aspects of diagenesis must be taken into account. Pre-Cenozoic faunas have suffered most from these processes. Pre-Devonian faunas, for example, have probably lost much of their species richness because of dolomitization and solution replacement. Solution replacement and dolomitization preferentially affect aragonitic skeletons (Chave, 1964; Weyl, 1964) because of the high solubility and instability of this mineral. Bambach considers differential aragonitic preservation but does not agree that that it is important in potentially reducing species richness. Murray (1964) and Blatt, Middleton, and Murray, (1972) state that dolomitization does preserve original features but that it would be unrealistic to expect that a rock subject to dolomitization and solution replacement would emerge with an absolutely clear record of original features. Aragonitic fossils are most common in high diversity communities (Chave, 1964; Dodd and Schopf, 1972). If these skeletons are destroyed by extensive dolomitization and solution replacement, these high diversity communities would appear as low diversity communities in the fossil record (Chave, 1964). Other diagenetic processes also affect preservation. Dissolution and cementation erode away rock volume and destroy fossils and fossil fragments leaving ghosts (Bathurst, 1964; 1971). Likewise, the porosity of a sedimentary unit affects diagenesis. The more porous a unit is the more severe the diagenetic effects. Shalier sediments have lower porosity and generally show greater species richness through time with much more preservation of aragonite. Dissolution, cementation, and dolomitization are selective in their destruction. As a result, low porosities in shales leave high diversity communities relatively free of diagenetic effects and species richness intact. Aragonite is commonly preserved in shales as old as the Cretaceous. Bambach's data on Pre-Cretaceous offshore communities show no significant temporal variation in species richness. Bambach does state that two Middle Cambrian shales produced single fauna species richness typical of the Paleozoic but assumes these are atypical examples of species packing.

A fourth factor that will affect the observed data is chronological faunal differences. For example, during the Paleozoic, the shelf biota contained many more bryozoans and crinoids than afterwards. Because Paleozoic bryozoans are usually difficult to identify even to the genus level without the use of thin section techniques, most community analysts have lumped them into higher taxonomic levels (often no lower than phylum). As a result, where ten species of brachiopods occur in a community, researchers may report only "bryozoans" or a limited number of bryozoan genera. Similarly, highly fragmentary organisms, such as crinoids, are generally lumped into general categories. Unidentifiable diagenetically produced molds, casts, and "ghosts" are generally not tabulated in the reports of community diversity. Furthermore, it is very difficult to equate the number of trace fossil form taxa with the actual diversity of trace-producing organisms.

It is additionally possible that the data collected in the literature reflect inadequate geographic diversity variation. For example, the observed diversity of Late Ordovician corals and bryozoans varies significantly with geographic location (Anstey and Chase, 1974). If geographic sampling is restricted, diversity patterns are biased. As an illustration, in the Late Ordovician of the Cincinnati region, 220 species of bryozoans alone have been reported from the literature, but Bambach's data indicate a median of only 19 species _in toto_ for lower Paleozoic open marine communities. Also two low diversity Cincinnatian communities described by Lorenz (1973) each contain 48 species. The compilation of the Cincinnatian fauna provided by Dalvé (1948) indicates much higher community species packing than that of Bambach's survey.

Finally, Bambach's number of fossil assemblages for each time interval is quite small (only seven) and by chance alone could exhibit the variation observed.

CHAPTER IV

MODEL OVERVIEW

This model simulates a spherical planet with rectangular continents that have a probability of splitting randomly one time out of forty, move apart in a random direction with a velocity of 10 to 60 kilometers per million years (a realistic rate) with a speed dependent on the nearest neighbor distance, and collide while conserving a rectangular shape (for simplicity). The collided continents produce a single rectangular continent with the same total area as the two original continents and whose shape conserves that of its "parents". This continent is a "sutured" mass whose marine biotic diversity depends upon its characteristics alone rather than inheriting diversity from the parent continents. In the real world, it would take time to create a new biota for the "sutured" continent, which would be a blending of the two from the joined continents. For simplicity, the model assumes this process is complete in one iteration (one million years). Each continent has a marine shelf area (taken from actual shelf width data) from 500 to 1900 kilometers wide determined both randomly, to simulate topography of the continents, and by the nearest neighbor distance, to simulate transgressions and regressions related to variation in spreading rates.

The simulated globe has a climatic gradient divided into a number of latitudinal zones of equal width. The number of such zones varies, and depends upon the number of continents and degree of continental separation. Climatic zone limits, shorelines, and deep ocean basins define provincial boundaries. Each province contains a variable number of communities based upon spatial heterogeneity (simulated randomly), and a number of species that depend on the number of communities, the area of the province, and its location in the climatic gradient. The global marine shelf diversity is the sum of the diversities of all provinces for each iteration. A simple sediment survivorship model is applied to both the number of communities and the number of species so that an "actual" and a "preserved" record of global diversity can be obtained. In summary, the overall model is based on 22 basic assumptions (Table 1). A flow chart and complete program listing are provided in the Appendix.

Table 1. A list of the basic assumptions used in the model.

1. Constant sedimentary rates through time.
2. Constant exponential decrease in sediment survivorship.
3. Constant preservation at any time.
4. Linear acceleration/deceleration in rate of continental movement from 10 to 60 kilometers per million years.
5. Inelastic collisions between continents.
6. Conservation of rectangular shape for the continents.
7. Total continental area remains constant through time.
8. The upper limit to the number of climate zones is 15. The lower limit to the number of climate zones is 3.
9. The continents fragment, move apart, and recombine if they collide.
10. The continents split either parallel or perpendicular to latitude.
11. The continents after splitting move away from each other at 180°.
12. Continents only split into two parts.
13. Continents split on the average of once in forty times.
14. The location of splitting is randomly determined within and among continents.
15. Sea level is low when spreading rates are low.
16. Sea level is high when spreading rates are high.
17. Continental shelf width is constant during each iteration for any given continent.
18. Continents can be totally submerged.
19. All continents move at the same rate each iteration.
20. Climatic gradients control species diversity.
21. Habitat area controls species diversity.
22. The biota instantaneously populate a province to its capacity.

CHAPTER V

STOCHASTIC VARIABLES

This simulation is based upon seven stochastic variables and seven fundamental deterministic variables (Table 2). The random number generator used in the model calls a series of predetermined randomly arranged numbers. Each call to this random number generator obtains the same series of random numbers so that any run can be exactly reproduced. To change the temporal order of splitting, the random variable ISPLIT is compared against a number from one to forty; forty different unique runs can be generated by changing that number. Different runs can also be generated by reordering the calls to the random variable series.

The shoreline topography between two continents is not identical in the real world and one continent's topography does not generally affect the topography of another continent. Shoreline topographies of the continents appear to vary randomly. Since shelf width around a continent is partially an indicator of continental topography, this variable is generated in part randomly, and in part by global sea level (sea level is more important and thus weighted more heavily than topography in this simulation).

Winder (1977) summarizes recent splitting events. From his summary, splitting occurs independently of other variables. Since no variable (other than time) seems to control splitting, it is adequately

Table 2. List of fundamental* deterministic and stochastic variables.

Deterministic Variables	Stochastic Variables
Number of climate zones	Time of splitting
Species packing within provinces	Shoreline topography
Sediment Survivorship	Selection of splitting continent
Rate of plate movement (global sea level)	Direction of splitting
Number of provinces	Size of the split continent
Province boundaries	Direction of plate movement
Continental shapes	Community packing within provinces

*Some variables are omitted because of redundancy.

simulated by a stochastic model. Although not completely random in actuality, choice of the specific continent that splits is randomly simulated in this model for simplicity.

The orientation of splitting zones appears to be random in nature and is so simulated. As another simplification, the continents are randomly split either parallel to or perpendicular to the equator (the earth system has many directions of splitting). The new continents then move apart in a straight line, and are not able to change their direction of movement until either another splitting event occurs or two continents collide. The direction is determined randomly so that the direction of movement and the orientation of the split conserves rectangular continents and allows a random orientation of splitting. Location of splitting is a random event that determines the size of the split fragments. The split fragments must be at least 20 percent of the original area of the continent.

CHAPTER VI

MODEL SACRIFICES

According to Levins (1966), there are three types of information loss in modeling complex systems. The first "sacrifice" is of generality to realism and precision. The second "sacrifice" is of realism to generality and precision. The third "sacrifice" is of precision to realism and generality. All three sacrifices have been made in this simulation, which is a combination of recent models. It acts at the macroevolutionary level. It does not try to explain evolutionary mechanisms but assumes their operation. It attempts to assess the interaction and the relative importance of some of the major postulated controls on diversity variation through time.

The system as a whole is independent of the earth's physical history but simulates many of the earth's actual boundary conditions as closely as possible (as presently understood). A global system is set up as a scale model of the earth. Rates of continental movement, opportunity for splitting and continental and/or shelf area are estimated from the real earth.

The system is made to be as general as possible. When mathematical equations are used, they are generally simplified. The species area equation, the community area equation, the movement rate change equation, the survivorship equation, and the equations used to calculate the marginal province areas all assume simple general relationships. Square continents with smooth margins are used to simplify calculations. Their usage lowers the continental margin lengths making the system less real. Also, when continents split, they only split into two fragments with randomly fixed directions of movement. In the "real" world, a continent does not necessarily split into only two continents and can reverse its direction of movement.

Precision is usually lost to generality. In the climatic gradient, province effect, area effect, and the climatic-continental interaction, the system uses sound concepts but is not generally concerned with their precise fit to the real earth system. For example, it is noted that a climatic gradient exists from the poles to the equator but the exact gradient that the earth has and the paleogradient the earth had in the past is not used. A simplified mathematical relationship is used instead.

CHAPTER VII

THE SIMULATION

At the beginning of the Phanerozoic, all the present continental units were, according to some authors, bonded together into a single supercontinent (Valentine, 1973; Winder, 1977). This simulation starts out with that condition. One supercontinent (including shelf area) that is about one third the surface area of the earth is created. This continent is given an initial location (a theta and a phi coordinate) on a sphere the present size of the earth; this location is determined randomly. It is also randomly assigned a direction of potential movement. The shelf width, randomly determined in part and also based on global sea level, is a topographic variable that defines how much of the continent is submerged at any given time. The range of the possible shelf widths varies from 0.08 to 0.30 radians. The upper limit of the variance is dependent on the mean nearest neighbor distance which also controls continental separation rate. The supercontinent remains together until it is to split. For simplicity, the initial supercontinent is square in shape.

The initial splitting of the large plate is a relatively slow process. As the smaller plates move apart, the speed at which they move can vary. Winder (1977) documents times when the spreading rates increase or decrease as the plates separate. These changes in spreading velocity seem to be related to the distance between continents. When continents are clustered, spreading rates are low. As the continents move apart, spreading rates increase. As Winder (1977) documents, the present Atlantic's (a young and relatively small ocean) spreading rate is slow in comparison to the Pacific's (an old and relatively large ocean) spreading rate. For simplicity in this modeled simulation, the plates (continents) move apart at a uniform global spreading rate. That rate varies directly with the mean nearest neighbor distance of all the continental plates. Therefore, at any given time, all the continents move with the same speed but the speed differs with each iteration. When the nearest neighbor distance is at a minimum, the spreading rate is one centimeter per year. When the nearest neighbor distance is at a maximum, the global spreading rate is six centimeters per year.

$$\mathrm{VFACT} = (\mathrm{AVE} \times 15.96) + 0.84/6366.20 \tag{1}$$

AVE is the mean nearest neighbor distance in radians and VFACT is the spreading rate. The spreading rate generally increases or decreases linearly in the simulation. Non-linear increases or decreases in the spreading rate occur when continents split or collide changing the mean nearest neighbor distance in a step function.

In the real earth system, plates seem to separate on the average of once in forty to sixty million years (Winder, 1977). During each one million year period (simulated by one iteration), the continents have a finite chance of one out of forty of splitting or increasing in number. This chance is controlled by a call to a random variable generator. If splitting does not occur, execution of the main program continues. If splitting occurs, the program executes the SPLIT subroutine. The SPLIT subroutine randomly determines which continent splits, in which direction it splits (north-south or east-west only, for simplicity), and in what ratio the original continent splits into two smaller ones. The total area of the two new continents is the same as the total area of the old continent. Neither of the two new continents contain less than twenty percent of the area of the old continent. Each new continent is rectangular in shape with its long edge determined by the direction of the split.

When the continent, direction of split, and the areas have been determined, the SPLIT subroutine calculates the centers of the new continents, their theta and phi coordinates and lengths, the subsequent directions in which the continents move, and the width of the continents' shelf areas. The direction in which the continents move and their shelf area are determined randomly. The shelf area is also controlled by the global sea level which is determined by the mean nearest neighbor distance. After the number of provinces are determined on each continent, control returns to the main program.

During each iteration of the program, each continent moves a uniform distance along its path. The continental movement is performed in the MOCON subroutine. The amount of movement for all continents is a constant vector sum during each iteration determined by the VELCITY subroutine. The amount of movement ranges from 1 centimeter a year or 10 kilometers per iteration to 6 centimeters a year or 60 kilometers an iteration. The magnitude of this movement is determined by the mean distance between the continents. After each continent is moved (assuming there is more than a single continent), each continent is checked against the other continents to determine if during the next movement any two continents met the criteria for a collision. If no continents are to collide, control of the program returns from MOCON to the main routine. If two continents are to collide, a subroutine that sutures the two continents together is called. Two continents must be within a certain distance to collide. This distance allows for a slight overlap (-0.17 radians or -10 degrees) to insure that a collision is a "solid" collision instead of a grazing surface contact. This adjustment tends to lower the number of collisions or postpone them in time. This allows for more continents, thereby increasing the possibility for extremes in the number of continents. This program treats a collision as an inelastic, permanent, and irreversible event. The distances between the continents are determined by using similar triangles and trigonometric functions.

The COLLIDE subroutine which is only called by MOCON creates one new continent from the two originals ones. This new continent has the total land area of the two smaller continents. The continents are sutured along one axis in either the theta or phi direction depending upon the direction of impact. In the sutured direction, the length of the new axis is the sum of the lengths of the axes from the two continents. The other axis is calculated from this information and the area information. For simplicity, the new continent is a rectangle. The remainder of the subroutine centers the new continent in the center of the two collided masses, randomly sets a drift direction, randomly defines the shelf area within the 0.08 to 0.30 radian limit (500 to 1900 kilometers, estimated from measuring actual global shelf widths), and calculates the number of provinces present on the single continent (the province calculation is performed for technical reasons only). After all this is completed, the program returns to MOCON to finish the checks for additional collisions and when it finishes the checks returns to the main program.

After completing the MOCON subroutine, the number of climate zones is calculated. The number of climate zone depends on the number of continents and the mean nearest neighbor distance (Valentine, 1970; 1973) which control the global circulation patterns.

$$NUM = 1.2773 \times AVE - 0.012773 \tag{2}$$

$$IZONE = (15 - (2 \times (NC/2))) - NUM \quad . \tag{3}$$

IZONE is the integer truncated product, NC is the number of continents and NUM is a numerical factor (between 1 and 4) used as a correction for nearness. From this equation, the number of climate zones decrease with increased number of continents and increased scattering (Valentine, 1970; 1973). The number of climatic zones on the sphere is not allowed to fall below 3 (2 "polar" zones on either side of a "tropical" zone). The climatic zone width is found by dividing PI by the number of zones. All the climate zones have the same width.

$$ZOWID = PI/IZONE \tag{4}$$

The climatic boundaries are calculated from this information.

In the CLIMATE subroutine, the top edge and the bottom edge of the continents are reconstructed and compared against the climate zone boundaries. This routine calculates the number of climatic zones that cross each continent. From this information, it calculates the number of provinces that are associated with each continent and the shelf area of each province on each continent. The area calculation is of two forms depending upon whether the province is on the side of the continent or at the top or bottom of the continent. For the sides,

$$\text{AREA} = \text{ZOWID} \times C(L,10) \tag{5}$$

For the top and bottom,

$$\text{AREA} = (C(LL,10) \times (C(LL,5) - C(LL,10)) \times 2) + (C(LL,10) \times \text{ZOWID}) \tag{6}$$

ZOWID is the length of the climatic zone, C(LL,10) is the shelf width of the continent, and C(LL,5) is one half of the theta length of the continent.

The CLIMATE subroutine also calculates the value that is used in the species per province calculation using the species area equation from MacArthur (1965), Preston (1960), Simberloff (1974), and Sepkoski (1976).

$$S = k_s A^x \tag{7}$$

S is the species per area, A is the area of the province, x is an empirical constant (.263) taken from the literature (Sepkoski 1976; MacArthur 1965; and Preston 1960), and k_s is a constant that reflects the pole to equator climatic gradient (Valentine 1968a; 1970b; 1972; 1973). In this model, k is small at the pole and approaches unity as it goes to the equator. The minimum value k has is 0.125 when there is a single continent and the maximum number of climate zones

(Valentine, 1973). The maximum value always occurs at the equatorial or tropical climatic zone. The climatic gradient is mirrored above and below the equator. Care has been given to the special case in which a continent crosses a pole. If that occurs the number of provinces on that continent is reduced by two and the species and province areas are also corrected.

The total global shelf area is also calculated in CLIMATE. The total global shelf area is the sum of all the provincial areas.

$$TAG = \sum_{i=1}^{NC} TAC \tag{8}$$

TAG is the global shelf area, TAC is the individual continental shelf area which is the sum of the provincial areas, and NC is the number of continents.

Upon return to the main program, the total number of provinces for the globe is calculated by summing the number of provinces per continent.

$$PROV = \sum_{I=1}^{NC} C(I,8) \tag{9}$$

C(I,8) is the number of provinces on the I^{th} continent and PROV is the total global province number.

At this point, the number of communities per province is calculated. The number of communities per province depends on the spatial heterogeneity of that province. Spatial heterogeneity in a marine environment is in part a result of the rate of sedimentary influx and movement and type of substrates which define that environment. Blatt, Middleton, and Murray (1972) list a variety of sedimentary environments.

There seems to be no apparent deterministic order to the location of different bio-facies; therefore, these locations are considered to occur randomly for this simulation. As a result, the number of communities in a given province is controlled by a random variable and the area in the province (Simberloff, 1974). The same equation used to calculate the species area effect is used to calculate the number of communities per province (Simberloff, 1974).

$$C = k_c A^x \tag{10}$$

The term k_c is a random value representing heterogeneity that ranges from 1.0 to 1.1. The communities per province are summed to give a total number of communities for the globe.

The actual number of species per provinces depends on the number of communities in the province and the province's geographical location.

$$NS = k_c \times k_s A^x \tag{11}$$

This actual number of species is summed to yield the total number of species on the globe.

Sediment survivorship is applied to the total number of communities and species (Raup 1970; 1976b; 1978). The sediment survivorship factor used is a radioactive decay-type equation (one of several models according to Lasker, 1978) from the present to 600 million years before the present (Younker, 1976; Younker and Younker, 1977; Blatt and Jones, 1975). The sedimentary "half-life" is approximately 150 million years. This value is well within sedimentary recycling limits (perhaps even a little high) according to Younker and Younker (1977). The equation that is used is:

$$N_t = (N_o \times e^{-\lambda 150/t})^{-1} \times 0.01 \quad . \tag{12}$$

N_t is the decimal equivalent of the percent survival at time t, N_o is 0.16 (the population at time o), $-\lambda 150$ (a constant) is -4.62098120E-3, and t is the present number of iterations. At time 1 looking from time 600, 6.25 percent of the sediment survives (a little high according to Blatt and Jones, 1975). At time 600 (the present), 100 percent of the sediment survives and is observable.

Species number change with and without sediment survivorship analysis is calculated. This provides information on the variation in standing diversity from time t_{i-1} to time t_i.

Other variables that are determined include the mean shelf area per province, the mean number of species per community, and the mean preserved number of communities per province.

Correlation coefficients are calculated for 14 variables taken two at a time (6 correlation coefficients are presented in Table 3). The correlation coefficients test for a measure of linear association between two variables. Product-moment correlation coefficients are calculated in the COR subroutine (Sokal and Rohlf, 1969).

The VELCITY subroutine finds the nearest neighbor for each continent. This information is used to determine the mean nearest neighbor distance. The mean distance is used to calculate the global spreading velocity. It is also used to calculate the relative submergence of the continents (VSHELF).

Table 3. Correlation coefficients among six variables in six randomly varied simulations (runs 00, 01, 05, 15, 18, and 22, in that order; maximum number of continents is 8, 5, 7, 11, 7, and 8 respectively; values less than 0.12 are not significant at the 0.01 level).

	2.	3.	4.	5.	6.
1. Actual Number of Species	.88, .59, .96, .90, .94, .70	.88, .42 .80, .91, .79, .84	.90, .50, .92, .93, .95, .88	.26, .37, .60, .64, .59, .30	.78, .74, .70, .05, .93, .33
2. Preserved Number of Species	-- -- -- -- -- --	.85, .25, .68, .84, .68, .56	.69, .68, .67, .87, .97, .72	.03, .42, .62, .49, .66, .48	.79, .15, .74,-.12, .95, .14
3. Actual Number of Speices Per Community	-- -- -- -- -- --	-- -- -- -- -- --	.78, .51, .89, .95 .86, .78	-.13,-.49, .15, .39, .16,-.12	.54,-.01, .20,-.26, .59,-.13
4. Number of Continents	-- -- -- -- -- --	-- -- -- -- -- --	-- -- -- -- -- --	.46, .23, .50, .57, .61, .47	.53, .00, .43,-.27, .80, .08
5. Number of Provinces	-- -- -- -- -- --	-- -- -- -- -- --	-- -- -- -- -- --	-- -- -- -- -- --	.24, .34, .54, .43, .72, .38
6. Global Shelf Area	-- -- -- -- -- --	-- -- -- -- -- --	-- -- -- -- -- --	-- -- -- -- -- --	-- -- -- -- -- --

$$VFACT = (AVE \times 15.9631667 + 9.840336833)/6366.197723 \quad (1)$$

$$VSHELF = 0.0702517933 \times AVE + 0.000702517933 \quad (13)$$

AVE is the mean nearest neighbor distance.

CHAPTER VIII

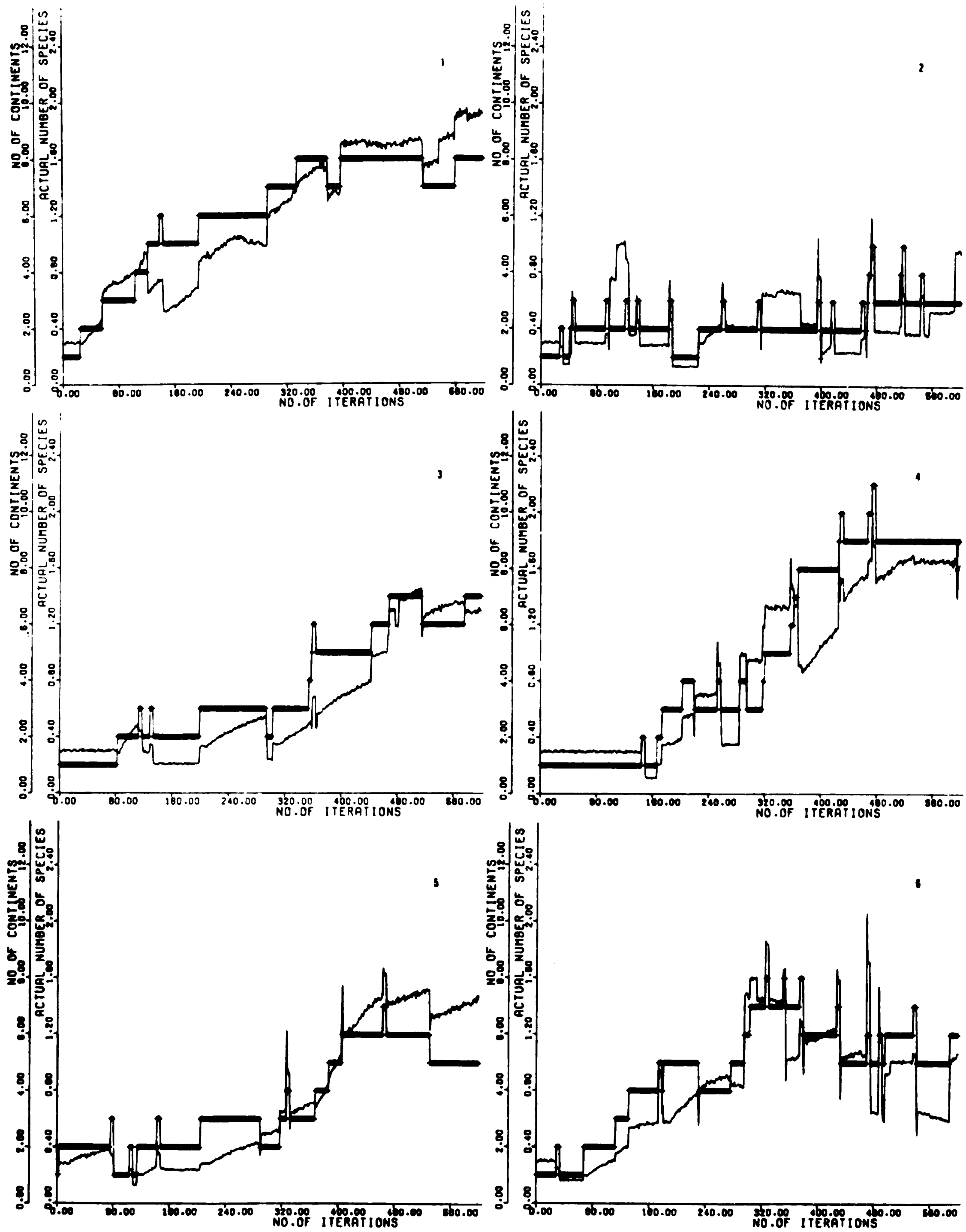
RESULTS

The fossil record shows a steady increase in the number or preserved species through time according to both Raup (1976) and Valentine (1978). Both authors agree on this observation, but do not concur in their explanations of what produces the observed pattern. Valentine, et al. (1978) feel that the observed information is real. Raup concludes that the observed information is biased.

This simulation presents an attempt at combining both Raup's and Valentine's ideas along with a consideration of Bambach's (1977) ideas on species packing within a community, and Schopf's (1974) and Sepkoski (1976) ideas on the species area relationship into a single working system. The system contains many deterministic controls and a number of stochastic variables (Table 2). Controls on the system were made as 'real' as possible while maintaining a reasonable degree of simplicity.

From the results of the correlation analysis (Table 3), several variables emerge as important controls of speciation in this modeled simulation. Since the number of provinces or shelf area was expected to be the main controlling factor, it was surprising to find that the most important control on global speciation was continental fragmentation. All the correlation coefficients are highly significant at the 0.01 level (Table 3). In Figure 1, continent number (continental fragmentation) is plotted against the actual species diversity. As

Figure 1. Plots of number of continents (heavy line) and actual global species diversity (light line) in six randomly varied simulations, numbered in the same order as in Table 3.


1
2
3
4
5
6
NO OF CONTINENTS
ACTUAL NUMBER OF SPECIES
NO.OF ITERATIONS

can be seen in the graphs (and from the correlation coefficients), when continental fragmentation rises, species diversity increases and when continental fragmentation declines, species diversity decreases. This relationship appears to be very general.

As Valentine (1973) and Valentine, Foin, and Peart (1978) suggest, province number also plays an important role (but less so than continental fragmentation) in the actual species diversification of the global system. A highly significant correlation coefficient at the 0.01 level is obtained when province number and actual species diversity are compared. The r-values for the 6 runs are, however, considerably lower than the r-values for the continental fragmentation and global species diversity comparison (Table 3). Figure 2 shows the province number plotted with the actual species diversity. From the graphs, a general trend of species diversity increase with province number increase is apparent. However, this relationship is not as strong as is the continental fragmentation and species number relationship.

A third important variable in the simulation is global shelf area, which produces result that corresponds to Schopf's (1974) and Sepkoski's (1976) ideas. Global shelf area for the most part (except when ISPLIT is equal to 15) is a highly significant factor at the 0.01 level when compared with actual species diversity (Table 3). This implies that as global shelf area increases, species diversity also increases (a relationship expected by the species area equation). This, however, is not always true since area is not the only variable that influences diversity (number of continents and their location in the climatic gradient and the number of communities are also important species control variables). Figure 3 shows the plots of global shelf area

Figure 2. Plots of number of provinces (heavy line) and actual global species diversity (light line) in six randomly varied simulations, numbered in the same order as in Table 3.

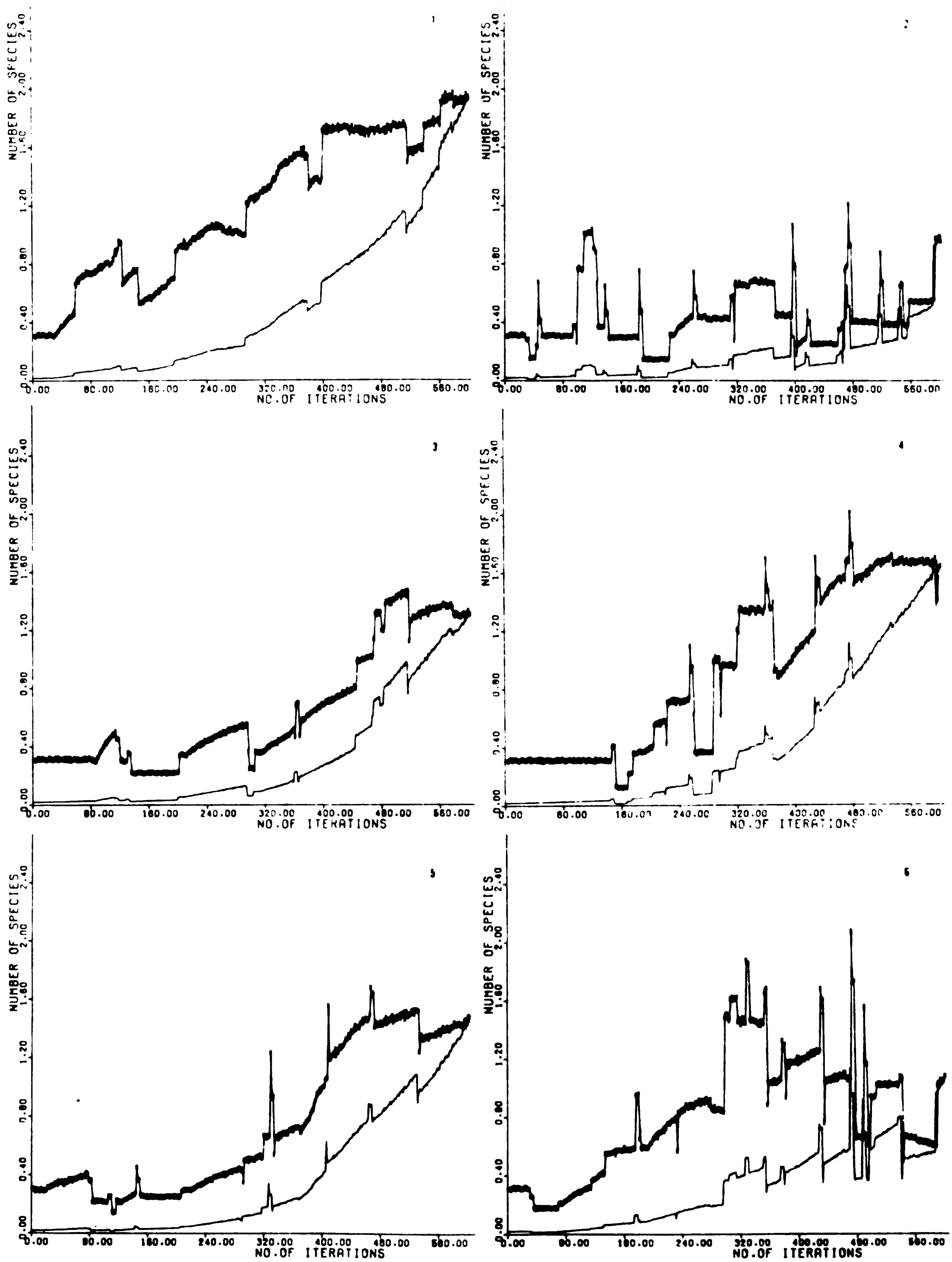
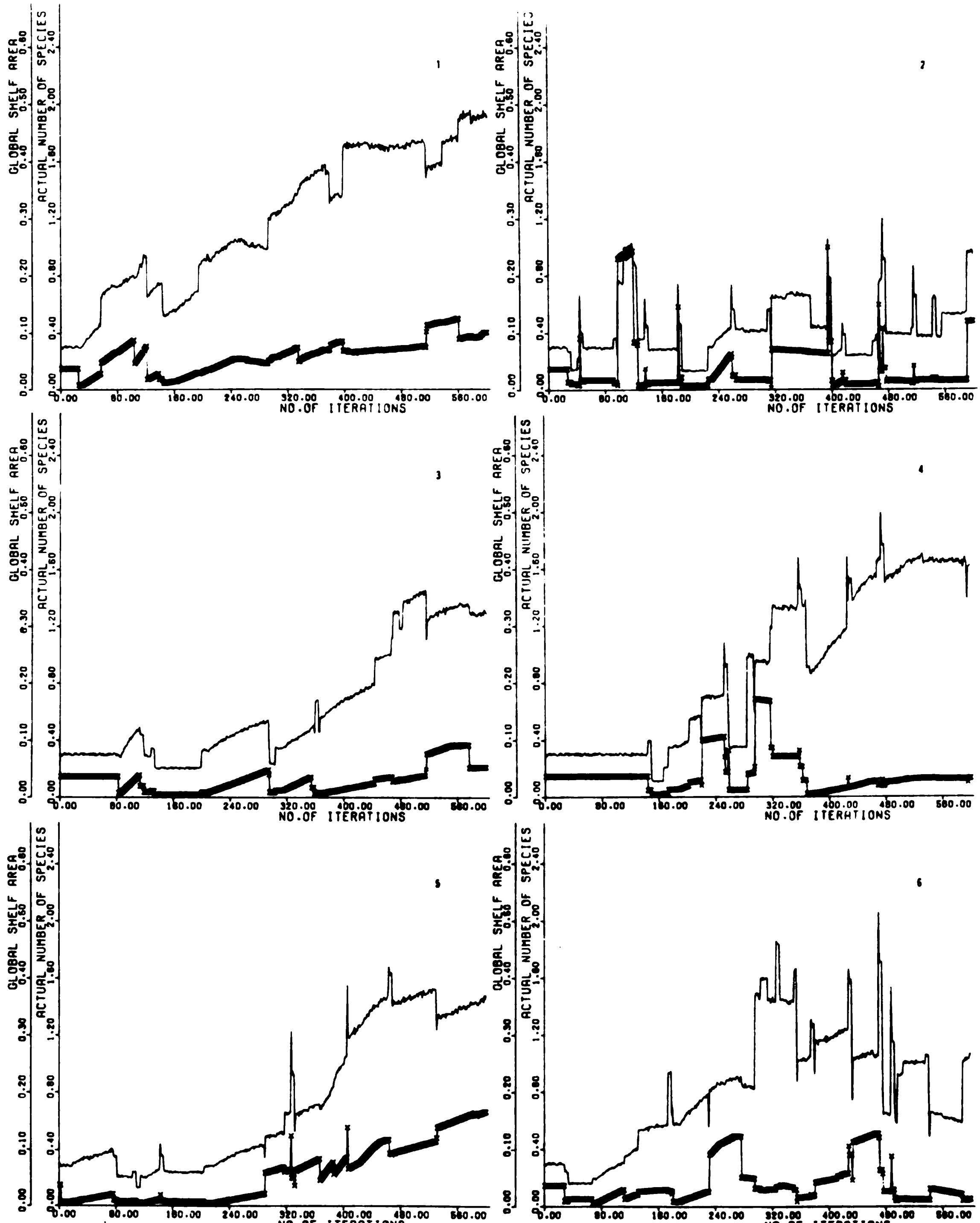

NUMBER OF SPECIES
NO.OF ITERATIONS
1
2
3
4
5
6

Figure 3. Plots of global shelf area (heavy line) and actual global species diversity (light line) in six randomly varied simulations, numbered in the same order as in Table 3.


GLOBAL SHELF AREA
ACTUAL NUMBER OF SPECIES
NO.OF ITERATIONS
1
2
3
4
5
6

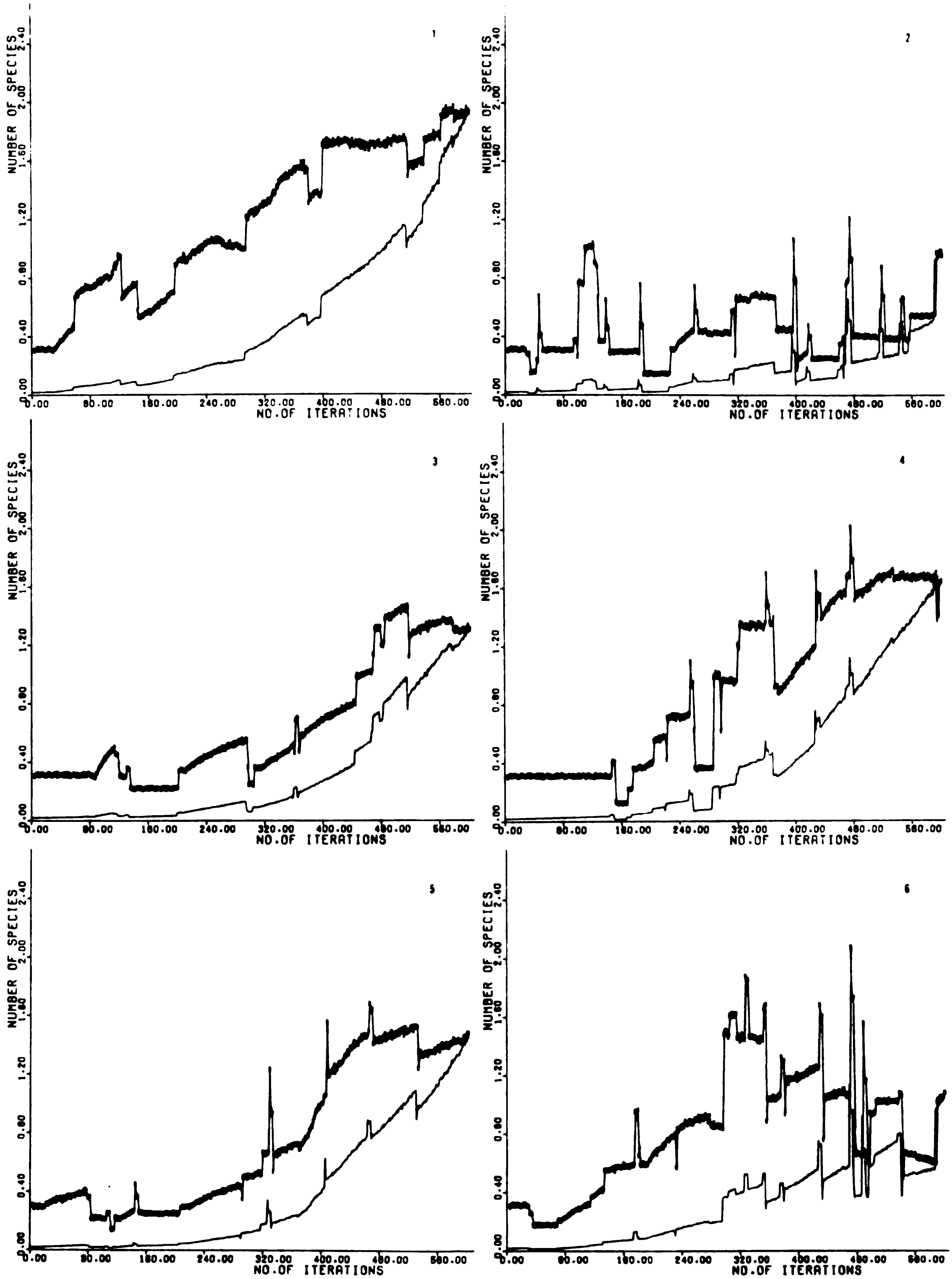
for various values of ISPLIT of global shelf area and actual species diversity data.

The results of the correlation analysis show that the total number of provinces is generally controlled by the number of continents (Table 3). However, this is not always the case. At times, province number is relatively low when the number of continents is relatively high. This relationship can be explained by continental orientation and size (Valentine, 1973). When many continents exist, climatic zone width is relatively large and chances are good that a 'small' continent (continental fragments are generally small when many continents exist) would not be located in two or more 'large' climatic zones or that a 'small' continent could be totally submerged thus lowering the number of provinces. When the long axis of a continent is parallel to climatic boundaries, the number of provinces is again lowered.

The number of provinces is negatively correlated with the number of climatic zones. This negative correlation does not at first appear correct (Valentine, 1973) but upon further consideration can be explained. The strongest variable in the system is the number of continents. According to Valentine (1973), the number and location of the continents affect the number of climatic zones present on the globe. When continents are large and close together, the number of climate zones is large because global circulation is restricted. When the continents are smaller and separated, global circulation is good and the number of climate zones is relatively small. As a result, as the number of continents increase (generally increasing the number of provinces), the number of climatic zones decrease causing the negative correlation of province number and climatic zone number.

The lowest level in the ecological hierarchy is the species network. The actual global number of species is the total of all the species in all the provinces at any specific time. This number also reflects community structure. A preserved number of species can be obtained by including sediment survivorship in the actual global species calculation. This information is presented in Figure 4. The actual species pattern varies greatly through time. The actual number of species can reach its highest peak early in the program or near the end of the program. After the peak is reached, the actual species diversity can decrease, remain the same, or vary greatly to the end of the program. The preserved species data show less pronounced fluctuations that correspond in time with the actual species fluctuations but not in magnitude. The preserved species diversity shows a marked increase in fluctuation magnitude through a 600 million year interval. The increase seen is a result of the sediment survivorship factor. Because of the factor, as the time nears the present, the magnitude of the fluctuations in the preserved record increases. (It is curious to note that the preserved species pattern is always very similar to the species diversity data seen in the real fossil record.) The number of species in the preserved pattern is extremely low in the beginning (at time 0) and reaches its peak near the present (at time 600). At time 600 (the present), the preserved record and the actual record of species diversity correspond exactly. The preserved species record near time 600, therefore, represents a closer picture of the real world diversity data then in earlier times because less information is lost to destructive forces (namely sediment survivorship). Different computer runs (with different ISPLIT values) give slightly different

Figure 4. Plots of preserved (light line) and actual global species diversity (heavy line) in six randomly varied simulations, numbered in the same order as in Table 3.

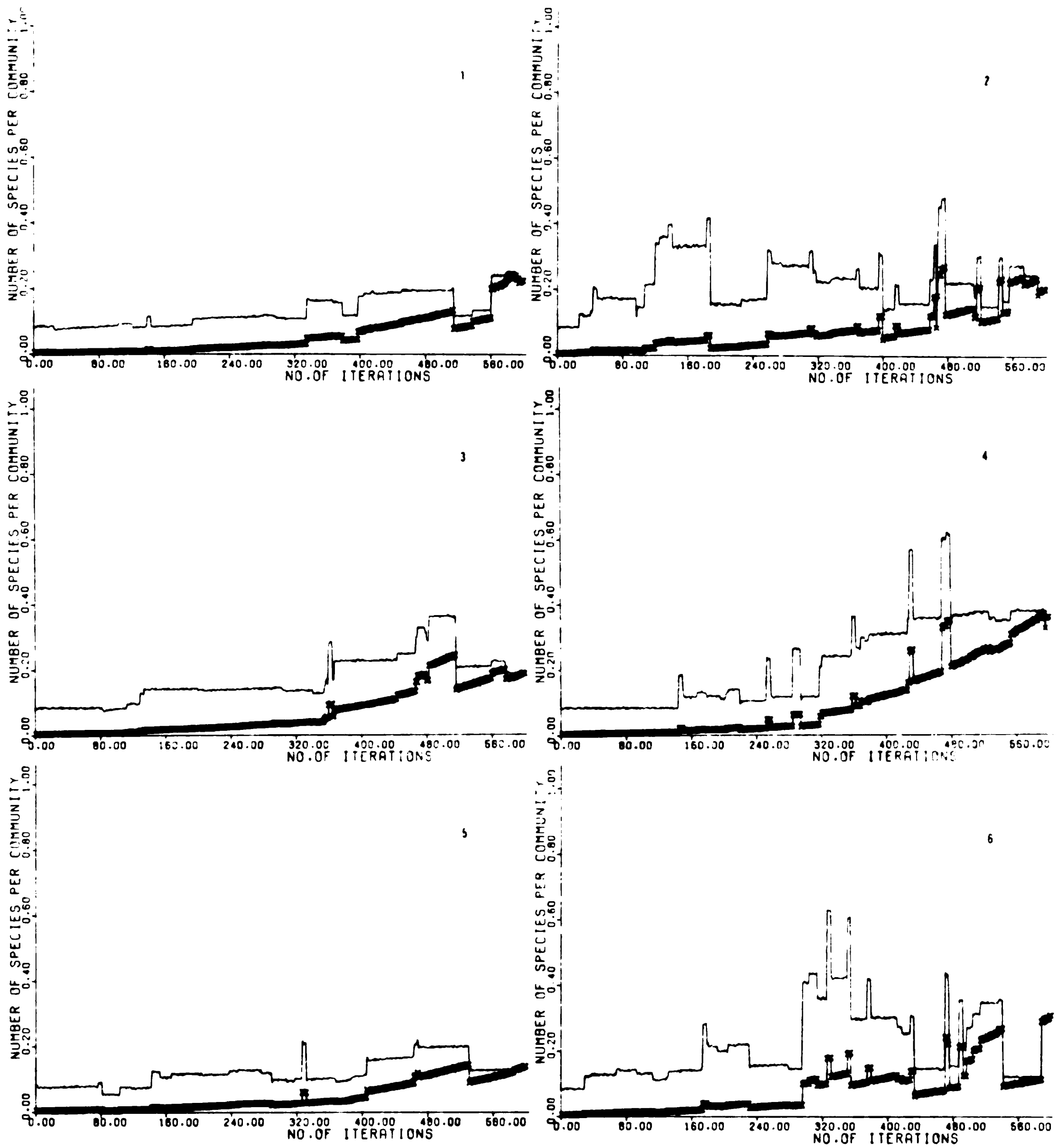

1
2
3
4
5
6
NUMBER OF SPECIES
0.00
0.40
0.80
1.20
1.60
2.00
2.40
NO.OF ITERATIONS
0.00
80.00
160.00
240.00
320.00
400.00
480.00
560.00

results because of the stochastic variables, but the overall patterns are quite similar.

Bambach's (1977) work addressed the concept of species packing within a community. To show species packing, in this model, the total number of species is divided by the total number of communities at time t. This produces the actual species packing information. This actual species per community information is used to calculate the preserved species packing information. Not surprisingly, it is similar to the actual and the preserved global species diversity data (Figure 5). Actual species packing is generally constant through time with major fluctuations occurring relatively randomly. Preserved species packing numbers increases constantly through time because of the sediment survivorship factor. Also, the species per community information is always highly correlated with both the actual and preserved species diversity numbers (Table 3). The correlation analysis (Table 3) reveals, however, that the number of species per community is not always correlated with the number of provinces and the global shelf area.

In a recent paper, Lasker (1978) presented different preservational models for sediments containing fossils. Lasker concluded that variations in the actual fossil record can be dampened by including a preservational model in the real data. The species and species packing information calculated in this simulation support that conclusion. Actual data fluctuates more than the preserved data. High early actual diversity and diversity fluctuations appear extremely low when sediment survivorship is taken into account.

Figure 5. Plots of preserved (heavy line) and actual number of species per community (light line) in six randomly varied simulations, numbered in the same order as in Table 3.

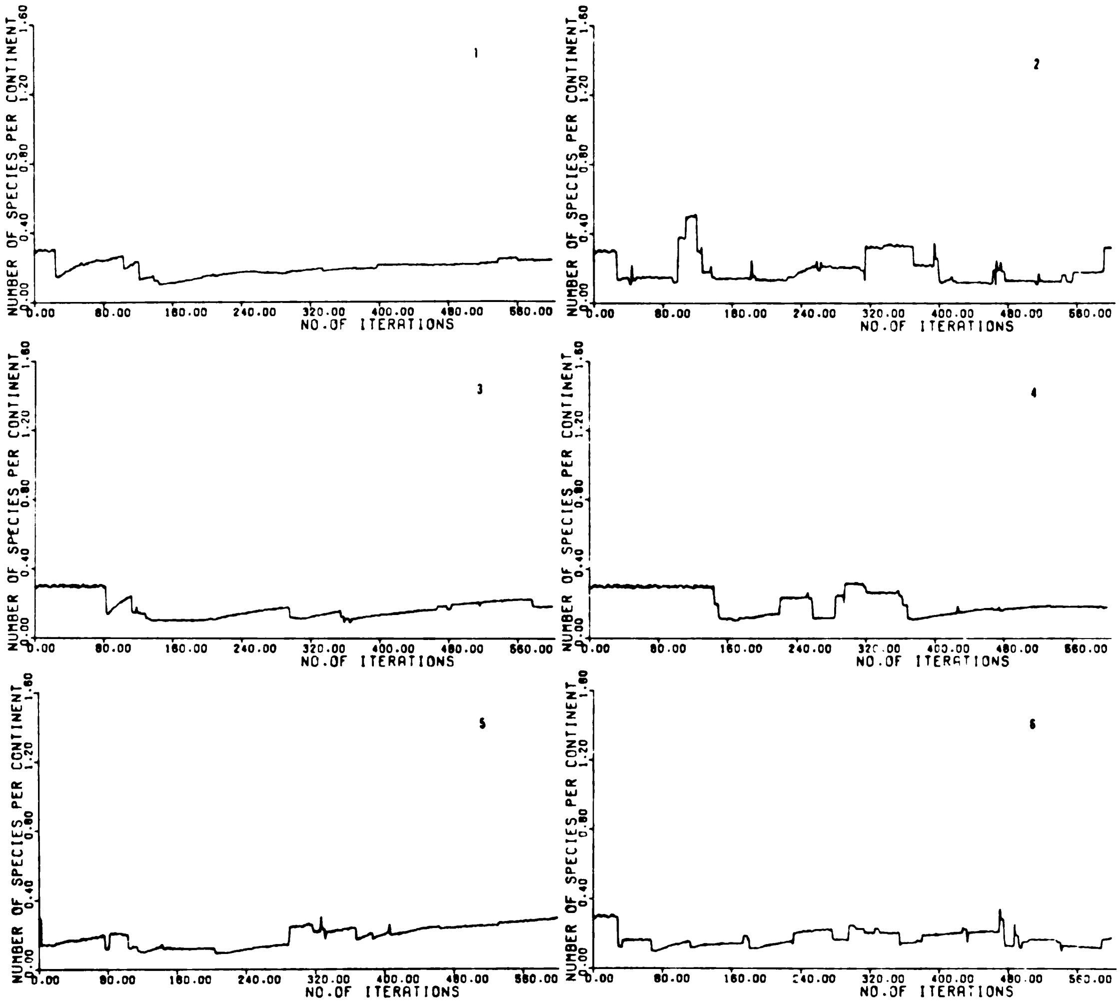


NUMBER OF SPECIES PER COMMUNITY
NO.OF ITERATIONS
1
2
3
4
5
6

The average number of species per continent is plotted in Figure 6. As can be seen in the graphs, actual species diversity per continent varies only slightly through time. May (1974) predicts that this would be the result if each continent has a limited number of species it can support. This value, according to May, could be almost constant through time and might represent the finite limit to the number of ecological niches on that continent. The actual number of species per continent is slightly more complex then the average actual species per continent value but this value provides a good first approximation of this capacity on the continents.

The effects of random variation seem to influence the general trends in the simulation results. The major result of the randomness is to shift the fluctuations in the real patterns in time. These temporal variations cause the differences in the absolute appearances of the graphs. One of the major findings is that the actual diversity reaches its peak much earlier than the preserved diversity. The actual diversity seems to fluctuate randomly through time but the preserved diversity (even mirroring these fluctuations) seems to steadily increase.

Figure 6. Mean number of species per continent in six randomly varied simulations, numbered in the same order as in Table 3.


NUMBER OF SPECIES PER CONTINENT
NO.OF ITERATIONS
1
2
3
4
5
6

CHAPTER IX

CONCLUSIONS

(1) In the majority of runs, the number of species varies through time, but does not consistently increase or decrease. In four out of six runs, there is a marked positive increase. In one run there is an early period of increase followed by a sharp decrease near the end of the time period. In one run there is continuous oscillation around a mean value. Based on the correlation analysis, the dominant control (within the context of the overall model) is the variation in the number of continents. The number of continents also controls the global number of biotic provinces and the total global shelf area. The effects of continental fragmentation and reassembly override the effects of global climatic variation and change in global sea level.

(2) Global biotic equilibrium cannot be achieved within the assumptions of the model because of the dominant effect of the variation in the number of continents. As long as the number of continents is allowed to vary the number of species will vary. In some runs, diversity oscillation is achieved that resembles equilibrium, but is only in fact a pseudoequilibrium caused by a stochastically induced stability in the number of continents. However, the number of species per continent area remains nearly constant through time in all the runs, and perturbations cause only temporary disequilibrium, following which

biotic equilibrium is restored in all cases. Therefore, this model supports the concept of dynamic biotic equilibrium at the continental level, suggesting that each continental shelf region holds a finite number of ecological niches that remain nearly stable after the continental saturation level has been reached. The global system, in contrast, is characterized by continuous increases and decreases in total diversity. Variation in the continental system resembles a K-strategy, whereas, global variations resemble an r-strategy.

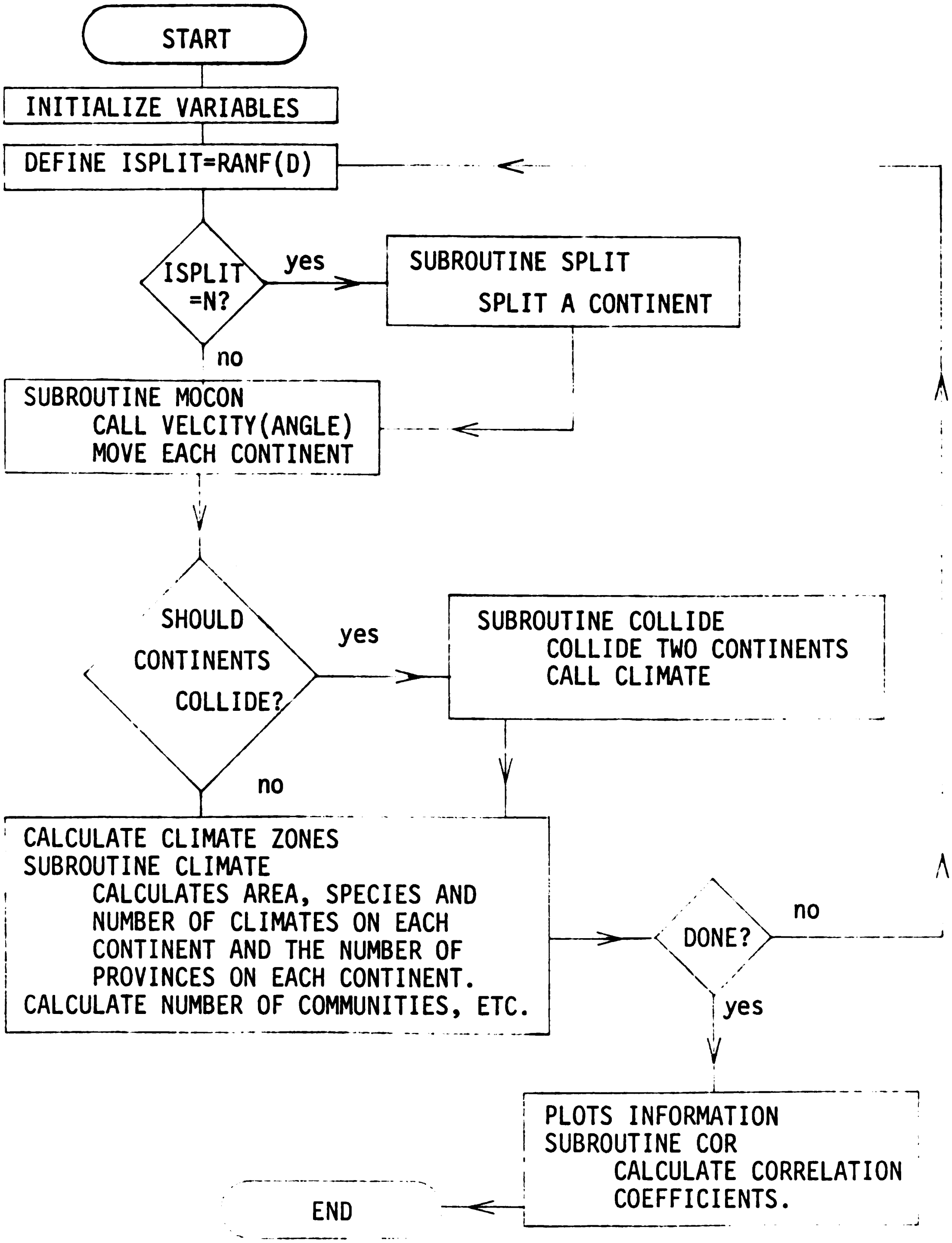
(3) A model of sediment survivorship based upon differential preservation through time produces two effects on the preserved record of biosphere diversity. Firstly, all runs exhibit an apparent increase in global diversity in the preserved record, whether such increases are present in the real record or not. Secondly, actual variations in the diversity are not preserved in the older parts of each simulated fossil record, but diversity fluctuations are more faithfully mirrored in the younger portions of each record. The effects of differential preservation, therefore, produce a record that appears to reflect nearly constant diversity through time if preserved diversity were normalized by rock volume. If this model is correct, then large diversity variations in the older part of the fossil record may not have been preserved.

(4) Although the actual number of species per community in this simulation does not consistently increase or decrease through time, it does appear to be a predictor of actual and preserved species diversities. This supports the concept that the number of species per community reflects the global species diversity and that this species packing

information can be used in constructing past diversity patterns. Even though the actual number of species per community displays no set pattern, the preserved number of species per community always increases. This increasing pattern is an artifact of preservational biases resulting from sediment survivorship factors. These factors (as well as diagenesis, lithification, and dolomitization) act to reduce observed diversity, thus lowering the early species packing index. These factors produce a pattern in the preserved number of species per community that is not an accurate reflection of the real pattern of the number of species per community.

APPENDIX

APPENDIX


START
INITIALIZE VARIABLES
DEFINE ISPLIT=RANF(D)
ISPLIT =N?
yes
SUBROUTINE SPLIT
SPLIT A CONTINENT
no
SUBROUTINE MOCON
CALL VELCITY(ANGLE)
MOVE EACH CONTINENT
SHOULD CONTINENTS COLLIDE?
yes
SUBROUTINE COLLIDE
COLLIDE TWO CONTINENTS
CALL CLIMATE
no
CALCULATE CLIMATE ZONES
SUBROUTINE CLIMATE
CALCULATES AREA, SPECIES AND NUMBER OF CLIMATES ON EACH CONTINENT AND THE NUMBER OF PROVINCES ON EACH CONTINENT.
CALCULATE NUMBER OF COMMUNITIES, ETC.
DONE?
no
yes
PLOTS INFORMATION
SUBROUTINE COR
CALCULATE CORRELATION COEFFICIENTS.
END

```
      PROGRAM DIVER(INPUT=64,OUTPUT=64,TAPE1=64)
C NC IS THE NUMBER OF CONTINENTS PRESENT IN THE SYSTEM.
C C(N,1) IS THE THETA COORDINATE OF CONTINENT N.
C C(N,2) IS THE PHI COORDINATE OF CONTINENT N.
C C(N,4) IS THE VELOCITY OF N IN THE PHI DIRECTION.
C C(N,5) IS 1/2 THE WIDTH OF N.
C C(N,6) IS 1/2 THE LENGTH OF N.
C C(N,7) IS A FLAG VARAIBLE.
C C(N,8) STORES THE NUMBER OF PROVINCES IN N.
C C(N,9) STORES THE NUMBER OF CLIMATES EFFECTING N.
C C(N,10) STORES THE SHELF WIDTH OF N.
C ANG REPRESENTS A RANDOM ANGLE OF MOVEMENT OF N.
C V1 IS THE NUMBER OF ITERATIONS, A REAL VALUE.
C V2 IS THE PRESERVED GLOBAL SPECIES DIVERSITY.
C V3 IS THE NUMBER OF CONTINENTS, A REAL VALUE.
C V4 IS THE PRESERVED GLOBAL NUMBER OF COMMUNITIES.
C V5 IS THE PRESERVED NUMBER OF COMMUNITIES PER PROVINCE.
C V6 IS IS THE ACTUAL NUMBER OF SPECIES PER COMMUNITY.
C V7 IS THE TOTAL GLOBAL SHELF AREA.
C V8 IS TNE MEAN AREA PER PROVINCE.
C V9 IS THE REAL NUMBER OF CLIMATE ZONES.
C VA1 IS THE GLOBAL NUMBER OF PROVINCES.
C VA2 IS THE VELOCITY FACTOR.
C VA6 IS ACTUAL GLOGAL SPECIES DIVERSITY.
C VA5 IS THE ACTUAL GLOBAL NUMBER OF COMMUNITIES.
C VA7 IS THE PRESERVED NUMBER OF SPECIES PER COMMUNITY.
C VA6 IS ALSO USED IN A DIFFERENT VERSION OF THE PROGRAM
C TO STORE THE AVERAGE NUMBER OF SPECIES PER CONTINENT.
C R STORES THE CORRELATION COEFFICIENTS.
C DS IS THE CHANGE IN SPECIES.
C DSS IS THE PRESERVED CHANGE IN NUMBER OF SPECIES.
C AVE IS THE VALUE OF THE MEAN NEAREST NEIGHBOR DISTANCE.
C ZOWID IS THE WIDTH OF THE CLIMATE ZONES.
C NC IS THE INTEGER NUMBER OF CONTINENTS.
C ZONE STORES THE LIMITS FOR EACH CLIMATE ZONE.
C IZONE IS THE INTEGER NUMBER OF CLIMATE ZONES.
C KOUNT, N, NN ARE COUNTER VARIABLES.
C SAREA IS THE SPECIES AREA PER PROVINCE (ACTUAL).
C NOFZ IS THE ACTUAL NUMBER OF CLIMATES THAT CROSS ONE CONTINENT.
C SAP IS A AREA PER PROVINCE PARAMETER.
C CAREA IS THE COMMUNITIES PER EACH AREA.
C VSHELF IS USED TO DETERMINE THE LIMITS FOR CONTINENTAL
C SHELF WIDTH.
       COMMON ZOWID,C(16,12),NC,N,AVE,NN,ZONE(40),IZONE,KOUNT,FX,FY,SAREA
     +(16,70),NOFZ(16),SAP(16,2),CAREA(16,40),VFACT,NIT,VSHELF,TAG,CPC(1
     +6),RANDY(16),SCON(16)
       DIMENSION V5(602),VA7(602),V6(602),V7(602),V8(602),V9(602),VA1(602
     +),VA2(602),DS(602),R(150),VA5(602),VA6(602),DSS(602)
       DIMENSION IBUF(257),V1(602),V2(602),V3(602),V4(602)
C SETTING THE INITIAL VALUES FOR THE VARIABLES.
```

```
      NC=1
      IG=1
      C(1,7)=0.
      AVE=.01
      IZONE=15
      TOPI=6.28318
      PRINT 4
4     FORMAT(* ENTER VALUE OF ISPLIT FOR SPLITTING. --*)
C THIS READS THE VALUE FOR THE ISPLIT CHECK.
      READ 7,NUMBER
7     FORMAT(I2)
      WRITE(1,9)NUMBER
9     FORMAT(* *I2* = SPLITTING NUMBER.*)
      KOUNT=0
      NIT=0
      PROV=0.
      D1=2.*TOPI
      C(1,5)=SQRT(D1)/3.
      C(1,6)=C(1,5)
      C(1,1)=(RANF(D)*TOPI)
      C(1,2)=(RANF(D)*TOPI/2.)
      ANG=(RANF(D)*TOPI)
      C(1,3)=COS(ANG)*TOPI*1.E-3
      C(1,4)=SIN(ANG)*TOPI*1.E-3
      C(1,8)=28.
      C(1,9)=15.
      VSHELF=(RANF(D)*3.13159+.01)*.07025179333+.00070251/933
      VFACT=((RANF(D)*15.953167*3.14159+.01)+9.84033683)/6366.2
      RANDY(NC)=RANF(D)+.08
      C(NC,10)=RANDY(NC)*VSHELF
101   ISPLIT=(RANF(D)*40.)
C THIS IS THE MAIN LOOP OF THE PROGRAM.
      IF(ISPLIT .EQ.NUMBER) CALL SPLIT
      CALL MOCON
      TS=0.
      TC=0.
C DETERMINING CLIMATE GRADIENTS AND ZONE WIDTHS.
      NUM=1.2773*AVE-.012773
      IZONE=(15-(2*(NC/2)))-NUM
      IF(IZONE.EQ.1)IZONE=3
      IF(IZONE.EQ.0)IZONE=3
      IF(IZONE.EQ.-1)IZONE=3
      IF(IZONE.EQ.-2)IZONE=3
      ZO=IZONE
      ZOWID=TOPI/2./ZO
      ZONE(1)=TOPI/2.-ZOWID
8     FORMAT(* *F12.5)
C SETTING THE CLIMATE ZONES BOUNDARIES.
      DO 60 K=2,IZONE
       KA=K-1
```

```
60      ZONE(K)=ZONE(KA)-ZOWID
        CALL CLIMATE
C CALCULATING THE TOTAL NUMBER OF PROVINCES.
        DO 61 K=1,NC
61      PROV=PROV+C(K,8)
C CALCULATING THE GLOGAL NUMBER OF COMMUNITIES AND
C THE GLOBAL NUMBER OF SPECIES.
        DO 111 KK=1,NC
        CPC(KK)=0.
        SCON(KK)=0.
        KT=C(KK,8)
        DO 1111 KM=1,KT
        D2=RANF(D)*.1+1
        IF(KM.EQ.1.OR.KM.EQ.KT)GO TO 112
        CAREA(KK,KM)=(SAP(KK,1)**.263)*D2
        GO TO 113
112     CAREA(KK,KM)=(SAP(KK,2)**.263)*D2
113        CPC(KK)=CPC(KK)+CAREA(KK,KM)
        SPCPP=SAREA(KK,KM)*D2
        SCON(KK)=SCON(KK)+SPCPP
1111     CONTINUE
        TC=TC+CPC(KK)
        TS=TS+SCON(KK)
111     CONTINUE
5       FORMAT(* IZONE= *I5*   NIT= *I5)
        NPROV=PROV
        NIT=NIT+1
C STORAGE OF THE VARIOUS VARIABLES FOR FUTURE
C REFERENCE IN THE PLOTTING PROGRAM AND THE CORRELATION
C COEFFICIENT SUBROUTINE.
        V1(NIT)=NIT
        TT=-4.620981203E-3*V1(NIT)
        TUM1=.01/(.16*EXP(TT))
        V2(NIT)=(TS*TUM1)
        V3(NIT)=NC
        V4(NIT)=(TC*TUM1)
        V5(NIT)=(TC*TUM1/PROV)
        V6(NIT)=(TS/TC)
        VA7(NIT)=((TS/TC)*TUM1)
        V7(NIT)=ALOG(TAG)
        V8(NIT)=(TAG/PROV)
        V9(NIT)=ZO
        VA1(NIT)=PROV
        VA2(NIT)=VFACT
        VA6(NIT)=(TS)
        VA5(NIT)=(TC)
        IF(NIT.EQ.1)GO TO 82
        NHI=NIT-1
        TS1=TS*TUM1
        DSS(NIT)=TS-(VA6(NHI))
```

```
      DS(NIT)=TS1-V2(NHI)
      GO TO 83
82    DS(NIT)=0.0
      DSS(NIT)=0.0
83    CONTINUE
C OUTPUTTING OF SOME INFORMATION.
 1    WRITE (1,78) NIT,NC,NPROV,TC,TS,VFACT
78    FORMAT(* NIT= *,I4,* NC= *,I3,* NPROV= *,I6,* TC= *,F10.5,* TS= *,
     +2F10.5)
      GO TO 3
C RESETTING VARIABLES TO 0.0.
 3    PROV=0.
      NPROV=0
      KOUNT=0
C CHECK TO SEE IF PROGRAM SHOULD STOP.
      IF(NIT.EQ.600) GO TO 2000
      GO TO 101
2000  CONTINUE
      GO TO 303
C THE PLOTTER ROUTINE.  THE SECTION OF CODE HAS THE
C ABILITY TO PLOT ALL THE VARIABLES ON A LARGE PLOT.
      X=0.0
      Y=1.0
      CALL PLOTS(IBUF,257,0)
      CALL FACTOR(.8)
      CALL PLIMIT(60)
      CALL PLOT(0.5,0.5,-3)
C THIS SECTION PLOTS ALL THE AXES.
      CALL SCALE(V5,10.0,600,1)
      CALL AXIS(0.0,0.0,30HNO OF COMMUNITIES PER PROVINCE,30,10.,90.,
     + V5(601),V5(602))
      CALL SYMBOL(X,Y,.14,23,90.,-1)
      CALL PLOT(.5,0.0,-3)
      CALL SCALE(V6,10.0,600,1)
      CALL AXIS(0.0,0.0,19HSPECIES/COMMUNITIES,19,10.0,90.,V6(601),
     + V6(602))
      CALL SYMBOL(X,Y,.14,24,90.,-1)
      CALL PLOT(.5,0.0,-3)
      CALL SCALE(VA7,10.0,600,1)
      CALL AXIS(0.0,0.0,37HSPECIES/COMMUNITIES WITH SURVIVORSHIP,
     + 37,10.,90.,VA7(601),VA7(602))
      CALL SYMBOL(X,Y,.14,13,90.,-1)
      CALL PLOT(.5,0.0,-3)
      CALL SCALE(V7,10.0,600,1)
      CALL AXIS(0.0,0.0,17HGLOBAL SHELF AREA,17,10.0,90.,V7(601),V7(602)
     +)
      CALL SYMBOL(X,Y,.14,9,90.,-1)
      CALL PLOT(.5,0.0,-3)
      CALL SCALE(V8,10.0,600,1)
      CALL AXIS(0.0,0.0,19HSHELF AREA/PROVINCE,19,10.0,90.,V8(601),
```

```
      +V8(602))
       CALL SYMBOL(X,Y,.14,5,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(VA2,10.0,600,1)
       CALL AXIS(0.,0.,5HVFACT,5,10.,90.,VA2(601),VA2(602))
       CALL SYMBOL(X,Y,.14,7,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(V9,10.0,600,1)
       CALL AXIS(0.0,0.0,19HNO OF CLIMATE ZONES,19,10.0,90.,V9(601),
      +V9(602))
       CALL SYMBOL(X,Y,.14,21,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(V3,10.0,600,1)
       CALL AXIS(0.0,0.0,16HNO OF CONTINENTS,16,10.,90.,V3(601),V3(602))
       CALL SYMBOL(X,Y,.14,3,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(VA1,10.0,600,1)
       CALL AXIS(0.0,0.0,15HNO OF PROVINCES,15,10.0,90.,VA1(601),VA1(602)
      +)
       CALL SYMBOL(X,Y,.14,4,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(V4,10.0,600,1)
       CALL AXIS(0.0,0.0,17HNO OF COMMUNITIES,17,10.,90.,V4(601),V4(602))
       CALL SYMBOL(X,Y,.14,1,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(DS,10.,600,1)
       CALL AXIS(0.0,0.0,17HCHANGE IN SPECIES,17,10.0,90.,DS(601),DS(602)
      +)
       CALL SYMBOL(X,Y,.14,8,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(DSS,10.,600,1)
       CALL AXIS(0.0,0.,34HCHANGE IN SPECIES W/O SURVIVORSHIP,34,
      + 10.,90.,DSS(601),DSS(602))
       CALL SYMBOL(X,Y,.14,10,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(VA6,10.,600,1)
       CALL AXIS(0.0,0.0,24HACTUAL NUMBER OF SPECIES,24,
      + 10.,90.,VA6(601),VA6(602))
       CALL SYMBOL(X,Y,.14,11,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(VA5,10.,600,1)
       CALL AXIS(0.0,0.0,28HCOMMUNITIES W/O SURVIVORSHIP,28,10.,
      + 90.,VA5(601),VA5(602))
       CALL SYMBOL(X,Y,.14,15,90.,-1)
       CALL PLOT(.5,0.0,-3)
       CALL SCALE(V1,10.0,600,1)
       CALL SCALE(V2,10.0,600,1)
       CALL AXIS(0.0,0.0,16HNO.OF ITERATIONS,-16,10.,0.0,V1(601),V1(602))
       CALL AXIS(0.0,0.0,13HNO OF SPECIES,13,10.,90.,V2(601),V2(602))
       CALL PLOT(0.0,0.0,3)
```

```
C THIS SECTION PLOTS THE ACTUAL DATA POINTS.
      CALL LINE(V1,V2,600,1,0,0)
      CALL LINE(V1,V3,600,1,1,3)
      CALL LINE(V1,VA6,600,1,1,11)
      CALL LINE(V1,DSS,600,1,1,10)
      CALL LINE(V1,VA5,600,1,1,15)
      CALL LINE(V1,V4,600,1,1,1)
      CALL LINE(V1,VA1,600,1,1,4)
      CALL LINE(V1,V5,600,1,1,23)
      CALL LINE(V1,V6,600,1,1,24)
      CALL LINE(V1,VA7,600,1,1,13)
      CALL LINE(V1,V7,600,1,1,9)
      CALL LINE(V1,V8,600,1,1,5)
      CALL LINE(V1,VA2,600,1,1,7)
      CALL LINE(V1,V9,600,1,1,21)
      CALL LINE(V1,DS,600,1,1,8)
      CALL PLOT(20,10,999)
303   CONTINUE
C THIS SECTION CALCULATES THE CORRELATION COEFFICIENTS.
      CALL COR(V2,V3,IG,R)
      CALL COR(V2,V4,IG,R)
      CALL COR(V2,V5,IG,R)
      CALL COR(V2,V6,IG,R)
      CALL COR(V2,V7,IG,R)
      CALL COR(V2,V8,IG,R)
      CALL COR(V2,V9,IG,R)
      CALL COR(V2,VA1,IG,R)
      CALL COR (V2,VA2,IG,R)
      CALL COR(V2,DS,IG,R)
      CALL COR(V2,VA5,IG,R)
      CALL COR(V2,VA6,IG,R)
      CALL COR(V2,VA7,IG,R)
      CALL COR(V3,V4,IG,R)
      CALL COR(V3,V5,IG,R)
      CALL COR(V3,V6,IG,R)
      CALL COR(V3,V7,IG,R)
      CALL COR(V3,V8,IG,R)
      CALL COR(V3,V9,IG,R)
      CALL COR(V3,VA1,IG,R)
      CALL COR(V3,VA2,IG,R)
      CALL COR(V3,DS,IG,R)
      CALL COR(V3,VA5,IG,R)
      CALL COR(V3,VA6,IG,R)
      CALL COR(V3,VA7,IG,R)
      CALL COR(V4,V5,IG,R)
      CALL COR(V4,V6,IG,R)
      CALL COR(V4,V7,IG,R)
      CALL COR(V4,V8,IG,R)
      CALL COR(V4,V9,IG,R)
      CALL COR(V4,VA1,IG,R)
```

```
      CALL COR(V4,VA2,IG,R)
      CALL COR(V4,DS,IG,R)
      CALL COR(V4,VA5,IG,R)
      CALL COR(V4,VA6,IG,R)
      CALL COR(V4,VA7,IG,R)
      CALL COR(V5,V6,IG,R)
      CALL COR(V5,V7,IG,R)
      CALL COR(V5,V8,IG,R)
      CALL COR(V5,V9,IG,R)
      CALL COR(V5,VA1,IG,R)
      CALL COR(V5,VA2,IG,R)
      CALL COR(V5,DS,IG,R)
      CALL COR(V5,VA5,IG,R)
      CALL COR(V5,VA6,IG,R)
      CALL COR(V5,VA7,IG,R)
      CALL COR(V6,V7,IG,R)
      CALL COR(V6,V8,IG,R)
      CALL COR(V6,V9,IG,R)
      CALL COR(V6,VA1,IG,R)
      CALL COR(V6,VA2,IG,R)
      CALL COR(V6,DS,IG,R)
      CALL COR(V6,VA5,IG,R)
      CALL COR(V6,VA6,IG,R)
      CALL COR(V6,VA7,IG,R)
      CALL COR(V7,V8,IG,R)
      CALL COR(V7,V9,IG,R)
      CALL COR(V7,VA1,IG,R)
      CALL COR(V7,VA2,IG,R)
      CALL COR(V7,DS,IG,R)
      CALL COR(V7,VA5,IG,R)
      CALL COR(V7,VA6,IG,R)
      CALL COR(V7,VA7,IG,R)
      CALL COR(V8,V9,IG,R)
      CALL COR(V8,VA1,IG,R)
      CALL COR(V8,VA2,IG,R)
      CALL COR(V8,DS,IG,R)
      CALL COR(V8,VA5,IG,R)
      CALL COR(V8,VA6,IG,R)
      CALL COR(V8,VA7,IG,R)
      CALL COR(V9,VA1,IG,R)
      CALL COR(V9,VA2,IG,R)
      CALL COR(V9,DS,IG,R)
      CALL COR(V9,VA5,IG,R)
      CALL COR(V9,VA6,IG,R)
      CALL COR(V9,VA7,IG,R)
      CALL COR(VA1,VA2,IG,R)
      CALL COR(VA1,DS,IG,R)
      CALL COR(VA1,VA5,IG,R)
      CALL COR(VA1,VA6,IG,R)
      CALL COR(VA1,VA7,IG,R)
```

```
      CALL COR(VA2,DS,IG,R)
      CALL COR(VA2,VA5,IG,R)
      CALL COR(VA2,VA6,IG,R)
      CALL COR(VA2,VA7,IG,R)
      CALL COR(DS,VA5,IG,R)
      CALL COR(DS,VA6,IG,R)
      CALL COR(DS,VA7,IG,R)
      CALL COR(VA5,VA6,IG,R)
      CALL COR(VA5,VA7,IG,R)
      CALL COR(VA6,VA7,IG,R)
      IG=IG-1
      DO 59 NH=1,IG
C PRINTS OUT THE CORRELATION COEFFICIENTS.
       IF(NIT.GT.400)      WRITE (1,53) NH,R(NH)
53    FORMAT(* NH=*,I2,* R= *,F10.5)
59    CONTINUE
      END
C
      SUBROUTINE MOCON
      COMMON ZOWID,C(16,12),NC,N,AVE,NN,ZONE(40),IZONE,KOUNT,FX,FY,SAREA
     +(16,70),NOFZ(16),SAP(16,2),CAREA(16,40),VFACT,NIT,VSHELF,TAG,CPC(1
     +6),RANDY(16),SCON(16)
C MOCON IS THE SUBROUTINE THAT WILL MOVE THE CONTINENTS
C AROUND THE GLOBE.
C THIS LOOP MOVES THE CONTINENTS.
      DO 1 I=1,NC
      IF(NC.NE.1)CALL VELCITY
      IF(NC.EQ.1)GO TO 101
      IF(RANDY(I).EQ.-1.0)GO TO 101
      C(I,10)=RANDY(I)*VSHELF
101   CONTINUE
      CK=ABS(C(I,3)*VFACT)
      IF(CK.GT.C(I,1).AND.C(I,3).LT.0.)GO TO 16
      C(I,1)=C(I,1)+C(I,3)*VFACT
15    CT=ABS(C(I,4)*VFACT)
      IF(CT.GT.C(I,2).AND.C(I,4).LT.0.) GO TO 17
      C(I,2)=C(I,2)+C(I,4)*VFACT
14    CONTINUE
C CHECKS FOR SPECIAL CONDITIONS.
      IF(C(I,2).LT.0..OR.C(I,2).GT.3.14159)C(I,4)=-C(I,4)
      IF(C(I,1).GT.6.28318)C(I,1)=AMOD(C(I,1),6.28318)
      IF(C(I,2).GT.3.14159)C(I,2)=3.14159-(C(I,2)-3.14159)
      IF(C(I,1).LT.0.)C(I,1)=6.28318+C(I,1)
      IF(C(I,2).LT.0.)C(I,2)=-C(I,2)
      GO TO 1
16    C(I,1)=-(CK-C(I,1))
      GO TO 15
17    C(I,2)=-(CT-C(I,2))
      GO TO 14
1     CONTINUE
```

```
33      IF(NC.EQ.1)GO TO 18
        KOUNT=0
C RECONSTRUCTION AND POSITIONING OF THE CONTINENTS.
        N1=NC-1
        DO 7 M1=1,N1
        N=M1
        N2=N+1
        DO 7 M2=N2,NC
        NN=M2
        IF(C(NN,7).NE.0.) GO TO 7
        IF(ABS(C(N,1)-C(NN,1)).GT.3.14159)GO TO 2
        CO1=C(N,1)
        CO2=C(NN,1)
        GO TO 3
2       CO1=AMOD(C(N,1)+3.14159,6.28318)
        CO2=AMOD(C(NN,1)+3.14159,6.28318)
3       IF(ABS(C(N,2)-C(NN,2)).GT.3.14159) GO TO 4
        CO3=C(N,2)
        CO4=C(NN,2)
        GO TO 5
4       CO4=3.14159-((C(NN,2)+1.570795)-3.14159)
        CO3=3.14159-((C(N,2)+1.570795)-3.14159)
5       Z1=ABS(C(N,4)-C(NN,4))*VFACT
        Z2=ABS(C(N,3)-C(NN,3))*VFACT
C DETERMINATION OF THE DISTANCES BETWEEN EACH PLATE.
C CHECKS TO DETERMINE IF ANY CONTINENTS COLLIDE.
        DETX=ABS(CO1-CO2)
        DETY=ABS(CO3-CO4)
        TANDY=DETY/DETX
        ANG2=ATAN(TANDY)
        T=-7.
        IF(SIN(ANG2).LT.ABS(10**T))GO TO 71
        IF(COS(ANG2).LT.ABS(10**T))GO TO 70
        HYP=DETY/SIN(ANG2)
        HYP1=C(N,5)/COS(ANG2)
        HYP2=C(NN,5)/COS(ANG2)
        FLAG=HYP-(HYP1+HYP2)
        FX=FLAG*COS(ANG2)
        FY=FLAG*SIN(ANG2)
        IF(FX.LT.-.17453.AND.FY.LT.-.17453)CALL COLLIDE
        GO TO 78
70      FY=DETY-(C(N,6)+C(NN,6))
        IF(FY.LT.-.17453)CALL COLLIDE
        GO TO 78
71      FX=DETX-(C(N,5)+C(NN,5))
        IF(FX.LT.-.17453)CALL COLLIDE
78      CONTINUE
        IF(KOUNT.EQ.-1)GO TO 33
7       CONTINUE
        IF(C(NN,7).NE.0.)C(NN,7)=C(NN,7)-1.
18      CONTINUE
        RETURN
        END
```

```
C
      SUBROUTINE COLLIDE
C THIS SUBPROGRAM IS CALL ON TO COLLIDE TWO CONTINENTS.
C THIS SUBPROGRAM CALCULATES THE NEW VALUES FOR THE
C  CONTINENTS THAT COLLIDE.
      COMMON ZOWID,C(16,12),NC,N,AVE,NN,ZONE(40),IZONE,KOUNT,FX,FY,SAREA
     +(16,70),NOFZ(16),SAP(16,2),CAREA(16,40),VFACT,NIT,VSHELF,TAG,CPC(1
     +6),RANDY(16),SCON(16)
      KOUNT=NC+1
C CALCULATION OF THE AREAS OF THE TWO CONTINENTS.
      A1=2.*C(N,5)*2.*C(N,6)
      A2=2.*C(NN,5)*2.*C(NN,6)
      AREA=A1+A2
C RESTRAINS TO LIMIT THE SIZE OF CONTINENTS TO LESS
C 5 RADIANS IN ONE DIRECTION.
      IF(C(N,6).GT.2.5.OR.C(NN,6).GT.2.5) GO TO 20
      IF(C(N,5).GT.2.5.OR.C(NN,5).GT.2.5)GO TO 22
      IF(FX.LE.FY)GO TO 22
      GO TO 20
C CONSTRUCTS A SHORT CONTINENT IN THE PHI DIRECTION.
20    C(KOUNT,5)=C(N,5)+C(NN,5)
      C(KOUNT,6)=AREA/(C(KOUNT,5)*4.)
      GO TO 28
C CONSTRUCTS A LONG CONTINENT IN THE PHI DIRECTION.
22    C(KOUNT,6)=C(N,6)+C(NN,6)
      C(KOUNT,5)=AREA/(C(KOUNT,6)*4.)
28    CONTINUE
C CENTERS THE CONTINENT IN THE MIDDLE OF THE TWO OLD ONES.
24    D2=C(NN,1)
      D1=C(N,1)
      Y=AMIN1(D1,D2)
      Z=AMAX1(D1,D2)
      IF(Z-Y.GT.3.1)Y=Y+6.28318
      P=(Y+Z)/2.
      C(KOUNT,1)=AMOD(P,6.28318)
      D3=C(N,2)
      D4=C(NN,2)
      Y=AMIN1(D3,D4)
      Z=AMAX1(D3,D4)
      IF(Z-Y.GT.2.1)Y=Y+3.14159
      P=(Y+Z)/2.
      C(KOUNT,2)=3.14159+(P-3.14159)
      CL1=C(N,9)
      CL2=C(NN,9)
      X=AMIN1(CL1,CL2)
      C(KOUNT,8)=(C(N,8)+C(NN,8))-(X*2.-2.)
C SETS NEW DRIFT DIRECTION.
      ANG=(RANF(D)*6.28318)
      C(KOUNT,3)=COS(ANG)
      C(KOUNT,4)=SIN(ANG)
```

```
C NOT GREATER THAN THE CONTINENTS WIDTH OR LENGTH.
      RANDY(KOUNT)=RANF(D)+.08
      C(KOUNT,10)=RANDY(KOUNT)*VSHELF
      IF(C(KOUNT,10).GE.C(KOUNT,6).OR.C(KOUNT,10).GE.C(KOUNT,5))GO TO 10
     +2
      GO TO 104
C CORRECTION FOR TO BIG A SHELF WIDTH IN THE PHI DIRECTION.
102   C1=C(KOUNT,5)
      C2=C(KOUNT,6)
      CC=(AMIN1(C1,C2))
      C(KOUNT,10)=CC
      RANDY(KOUNT)=-1.0
C AT THIS POINT  NC IS ONE MORE THAN THE NUMBER
C OF CONTINENTS.  THE NEW CONTINENT SHOULD BE ADDED AT NC.
C THIS SECTION DELETES THE TWO OLD CONTINENTS IN STORAGE
C AND STORES THE NEW CONTINENT AT NC.
104      DO 8 L=NN,NC
      NO=L+1
      RANDY(L)=RANDY(NO)
      DO 8 LL=1,12
      L8=L+1
8     C(L,LL)=C(L8,LL)
      NC=NC-1
      DO 9 L=N,NC
      NO=L+1
      RANDY(L)=RANDY(NO)
      DO 9 LL=1,12
      L1=L+1
9     C(L,LL)=C(L1,LL)
      KOUNT=-1
      NOT=NC+1
      DO 15 IJ=1,NOT
15    C(IJ,7)=0.
      CALL CLIMATE
      RETURN
      END
C
```

```
      SUBROUTINE SPLIT
C THIS SUBPROGRAM IS DESIGNED TO SPLIT A RANDOM CONTINENT
C  IN TO TWO COMPONENTS AND THEN SEND THEM ON THEIR
C  SEPARATE WAYS.
      COMMON ZOWID,C(16,12),NC,N,AVE,NN,ZONE(40),IZONE,KOUNT,FX,FY,SAREA
     +(16,70),NOFZ(16),SAP(16,2),CAREA(16,40),VFACT,NIT,VSHELF,TAG,CPC(1
     +6),RANDY(16),SCON(16)
      CON=NC
      NSC=(RANF(D)*CON)+1.
      SC=NSC
C DETERMINATION OF PERCENTAGE OF CONTINENT TO SPLIT FROM  PARENT.
      PAREA=(RANF(D)*13.+4.)*5.
      AREA=(C(NSC,5)*2.)*(C(NSC,6)*2.)*(PAREA/100.)
C DETERNIMATION OF SPLITTING DIRECTION.
      IDIRC=(RANF(D)*2.)
      A=(C(NSC,5)*2.)*(C(NSC,6)*2.)-AREA
      NC=NC+1
      C(NC,7)=5.
      RANDY(NC)=RANF(D)+.08
      C(NC,10)=RANDY(NC)*VSHELF
      RANDY(NSC)=RANF(D)+.08
      C(NSC,10)=RANDY(NSC)*VSHELF
C CONTROL TO MAKE SURE THE CONTINENTS STAY WITHIN
C A CERTAIN RANGE OF LENGHTS AND WIDTHS.
      IF(C(NSC,5).GT.2.0)IDIRC=1
      IF(C(NSC,6).GT.2.0)IDIRC=0
      IF(IDIRC.EQ.1) GO TO 40
      GO TO 45
C THE SPLIT IN THE THETA DIRECTION.
40    C(NC,6)=C(NSC,6)
      C(NC,5)=(AREA/C(NC,6))/4.
      C(NSC,5)=(A/C(NSC,6))/4.
      C(NC,1)=AMOD(C(NSC,1)+C(NC,5),6.28318)
      C(NC,2)=C(NSC,2)
      C(NSC,1)=C(NSC,1)-C(NSC,5)
      IF(C(NSC,1).LT.0.)C(NSC,1)=6.28318+C(NSC,1)
      ANG=((RANF(D)*3.14159))+(3.14159*.5)
      C(NSC,3)=COS(ANG)
      C(NSC,4)=SIN(ANG)
      ANG=AMOD(ANG+3.14159,6.28318)
      C(NC,3)=COS(ANG)
      C(NC,4)=SIN(ANG)
      GO TO 50
C THE SPLIT IN THE PHI DIRECTION.
45    C(NC,5)=C(NSC,5)
      C(NC,6)=(AREA/C(NC,5))/4.
      C(NSC,6)=(A/C(NSC,5))/4.
      C(NC,2)=3.14159-((C(NSC,2)+C(NC,6))-3.14159)
      C(NC,1)=C(NSC,1)
      C(NSC,2)=C(NSC,2)-C(NSC,6)
```

```
      IF(C(NSC,2).LT.0.)C(NSC,2)=3.14159+C(NSC,2)
46    C(NC,8)=1.
47    ANG=(RANF(D)*3.14159)
      C(NC,3)=COS(ANG)
      C(NC,4)=SIN(ANG)
      ANG=ANG+3.14159
      C(NSC,3)=COS(ANG)
      C(NSC,4)=SIN(ANG)
50    CONTINUE
C THIS TAKES CARE OF FACT THAT SHELF COULD BE GREATER
C THAN THE LENGTH OR WIDTH OF THE CONTINENT.
      IF(C(NSC,10).GT.C(NSC,5).OR.C(NSC,10).GT.C(NSC,6))GO TO 10
8      IF(C(NC,10).GT.C(NC,5).OR.C(NC,10).GT.C(NC,6))GO TO 11
      GO TO 12
10    C1=C(NSC,5)
      C2=C(NSC,6)
      CC=AMIN1(C1,C2)
      C(NSC,10)=CC
      RANDY(NSC)=-1.0
      GO TO 8
11    C1=C(NC,5)
      C2=C(NC,6)
      CC=AMIN1(C1,C2)
      C(NC,10)=CC
      RANDY(NC)=-1.0
12    CONTINUE
      RETURN
      END
C
```

```
      SUBROUTINE CLIMATE
C THIS SUBPROGRAM IS DESIGNED TO CALCULATE THE NUMBER OF
C  CLIMATE ZONES THAT CROSS EACH CONTINENT.
      COMMON ZOWID,C(16,12),NC,N,AVE,NN,ZONE(40),IZONE,KOUNT,FX,FY,SAREA
     +(16,70),NOFZ(16),SAP(16,2),CAREA(16,40),VFACT,NIT,VSHELF,TAG,CPC(1
     +6),RANDY(16),SCON
     +(16)
      DIMENSION TAC(16)
C TOP REPRESENTS THE TOP EDGE OF THE CONTINENT.
C BOTTOM IS THE LOWER EDGE OF THE CONTINENT.
      PI=3.14159
      FB=0.
      DO 91 LL=1,NC
      ICZ=1
      ICZI=ICZ
      TOP=C(LL,2)+C(LL,6)
       BOTTOM=C(LL,2)-C(LL,6)
8     CONTINUE
C THIS IS A CHECK TO DETERMINE IF THE TOP OF THE
C CONTINENT IS GREATER THAN  PI.
C IF TOP IS LARGER THAN   PI, A SPECIAL SET OF CALCULATIONS
C MUST BE PERFORMED TO CALCULATE THE NUMBER OF CLIMATE ZONES
C ON THAT CONTINENT.
      IF(TOP.GT.3.14159)GO TO 70
71    CONTINUE
C THIS IS A CHECK TO DETERMINE IF THE LOWER EDGE OF THE CONTINENT
C IS SMALLER THAN 0.0  IF SO, A SPECIAL SET OF
C CALCULATIONS MUST BE PERFORMED TO CALCULATE THE NUMBER
C OF CLIMATE ZONES ON THAT CONTINENT.
       IF(BOTTOM.LT.0.)GO TO 72
      GO TO 75
C IF THE TOP OF THE CONTINENT IS GREATER THAN PI
C THAN THIS LOOP IS PERFORMED TO CALCULATE THE NUMBER OF
C CLIMATE ZONES THAT HANG OVER THE TOP(POLE).
70    T=TOP-3.14159
      TOP2=3.14159-T
      TOP=3.14159
      ICZI=0
      DO 73 IK=1,IZONE
      IF(ZONE(IK).GT.TOP2)GO TO 173
      IF(ICZI.NE.ICZ)GO TO 174
      GO TO 73
C THIS ADDS TWO MORE PROVINCES TO THE RECORD FOR THAT CONTINENT.
173   ICZI=ICZ
      ICZ=ICZ+1
      J=IZONE-IK+1
      IF(IK.GT.J)J=IK
      JQ=IZONE/2+1
      Q1=JQ
      T=J
```

```
      Q=Q1/T
      NI=ICZ*2-1
      NJ=NI-1
      SAREA(LL,NI)=C(LL,10)*ZOWID**.263*Q
      SAREA(LL,NJ)=C(LL,10)*ZOWID**.263*Q
      IF(IK.EQ.1)GO TO 176
      GO TO 73
C THIS ADDS THE TERMINAL PROVINCE TO THE CONTINENT.
174   J=IZONE-IK+1
      IF(IK.GT.J)J=IK
      JQ=IZONE/2+1
      Q1=JQ
      T=J
      Q=Q1/T
      IF(IK.EQ.1)GO TO 175
      ICZI=ICZ
      SAREA(LL,1)=((C(LL,10)*2.*(C(LL,5)-C(LL,10)))+(2.*C(LL,10)*ZOWID/2
     +. ))**.263*Q
      GO TO 73
C THIS IS THE SPECIAL CASES WHERE THE TERMINAL PROVINCE IS
C IN THE POLAR CLIMATE ZONE.
175       SAREA(LL,1)=2.*C(LL,10)*ZOWID**.263*Q+((C(LL,10)*2.*(C(LL,5)-C(
     +LL,10)))+(2.*C(LL,10)*ZOWID/2.))**.263*Q
      ICZI=ICZ
      ICZI=ICZI-1
      GO TO 73
176   CONTINUE
C THIS DELETES 2 PROVINCES AND MAKES THE POLAR TWICE
C THE NORMAL SIZE OF THE PROVINCES ON THAT CONTINENT.
      IF(ZONE(1).LT.BOTTOM)GO TO 73
      SAREA(LL,NI)=2.*SAREA(LL,NI)
      SAREA(LL,NJ)=2.*SAREA(LL,NJ)
      GO TO 73
73    CONTINUE
      IF(ICZ.EQ.ICZI)ICZ=ICZ+1
      GO TO 71
72    BOTTOM2=0.-BOTTOM
      BOTTOM=0.
      FB=-1.
75    CONTINUE
C THIS LOOP CALCULATES THE NUMBER OF CLIMATE ZONES
C THAT CUT ACROSS EACH CONTINENT FROM THE TOP TO THE BOTTOM.
      DO 88 I=1,IZONE
      IF(ZONE(I).LT.TOP.AND.ZONE(I).GT.BOTTOM)GO TO 198
      IF(ICZI.NE.ICZ)GO TO 197
      IF(I.EQ.1)GO TO 188
      GO TO 88
C THIS CALCULATES THE PROVINCES AND CLIMATE FACTOR.
198   ICZI=ICZ
      ICZ=ICZ+1
```

```
      J=IZONE-I+1
      IF(I.GT.J)J=I
      JQ=IZONE/2+1
      Q1=JQ
      T=J
      Q=Q1/T
      IF(I.EQ.1.AND.TOP.EQ.3.14159)GO TO191
      IF(ICZ.EQ.2)GO TO 196
      NI=ICZI*2-1
      NJ=NI-1
      SAREA(LL,NI)=C(LL,10)*ZOWID**.263*Q
      SAREA(LL,NJ)=C(LL,10)*ZOWID**.263*Q
      GO TO 88
C LAST CLIMATE ZONE CONTINENTS IS IN.
197   J=IZONE-I+1
      IF(ICZI.EQ.0.AND.TOP.EQ.PI)GO TO 190
      IF(I.GT.J)J=I
      JQ=IZONE/2+1
      Q1=JQ
      T=J
      Q=Q1/T
      NJ=ICZI*2
      SAREA(LL,NJ)=((C(LL,10)*2.*(C(LL,5)-C(LL,10)))+2.*(C(LL,10)*ZOWID/
     +2.))**.263*Q
      ICZ=ICZI
      GO TO 88
C SPECIAL CASE--FIRST PROVINCE.
196   SAREA(LL,1)=((C(LL,10)*2.*(C(LL,5)-C(LL,10)))+(2.*C(LL,10)*ZOWID/2
     +.))**.263*Q
      GO TO 88
C SPECIAL CASE--FIRST ZONE MAYBE NOT FIRST PROVINCE.
188   IF(TOP.NE.3.14159)GO TO 88
      J=IZONE-I+1
      IF(I.GT.J)J=I
      JQ=IZONE/2+1
      Q1=JQ
      T=J
      Q=Q1/T
      NJ=ICZI*2-1
      SAREA(LL,NJ)=2.*SAREA(LL,NJ)+((C(LL,10)*2.*(C(LL,5)-C(LL,10)))+
     + (2.*(C(LL,10)*ZOWID/2.)))**.263*Q
      ICZ=ICZI
      GO TO 88
189   ICZ=ICZ-1
      ICZI=ICZI-1
      IF(ICZI.EQ.1)GO TO 187
      NI=ICZI*2-1
      NJ=NI-1
      SAREA(LL,NI)=SAREA(LL,NI)*2.
      SAREA(LL,NJ)=SAREA(LL,NJ)*2.
```

```
      GO TO 88
187   SAREA(LL,1)=2.*SAREA(LL,1)
      GO TO 88
190   C(LL,1)=C(LL,1)*2.
      GO TO 88
191   ICZ=ICZ-1
      ICZI=ICZI-1
      GO TO 88
88    CONTINUE
      IF(FB.EQ.-1.)GO TO 279
      GO TO 280
C THIS LOOP IS PERFORMED IF THE BOTTOM OF THE CONTINENT
C IS LESS THAN 0.0.
279   DO 74 III=1,IZONE
      II=IZONE-III
      IF(ZONE(II).LT.BOTTOM)GO TO 274
      IF(ICZ.NE.ICZI)GO TO 275
      ICZI=ICZ
      GO TO 74
274   ICZI=ICZ
      ICZ=ICZ+1
      JQ=IZONE/2+1
      Q1=JQ
      T=II
      Q=Q1/T
      IF(III.EQ.1)GO TO 276
      NI=ICZ*2-1
      NJ=NI-1
      SAREA(LL,NI)=C(LL,10)*ZOWID**.263*Q
      SAREA(LL,NJ)=C(LL,10)*ZOWID**.263*Q
      GO TO 74
276   ICZI=ICZI-1
      ICZ=ICZ-1
      NI=ICZ*2-1
      NJ=NI-1
      SAREA(LL,NI)=SAREA(LL,NI)*2.
      SAREA(LL,NJ)=SAREA(LL,NJ)*2.
      GO TO 74
275   JQ=IZONE/2+1
      Q1=JQ
      T=II
      Q=Q1/T
      NI=ICZ*2
      IF(III.EQ.1)GO TO 278
      SAREA(LL,NI)=((C(LL,10)*2.*(C(LL,5)-C(LL,10)))+(2.*(C(LL,10)*ZOWID
     +/2.)))**.263*Q
      ICZI=ICZ
      GO TO 74
278   SAREA(LL,NI)=2.*SAREA(LL,NI)+((C(LL,10)*2*(C(LL,5)-C(LL,10)))+
     + (2.*(C(LL,10)*ZOWID/2.)))**.263*Q
```

```
      ICZI=ICZ
      GO TO 74
74    CONTINUE
C THIS PART OF THE SUBPROGRAM STORES THE NUMBER OF CLIMATE
C PER CONTINENT IN THE PROPER VARIZBLE IN THE ARRAY.
280      C(LL,9)=ICZ
      NOFZ(LL)=ICZ
      IF(C(LL,9).EQ.0.)GO TO 89
      IF(C(LL,9).EQ.1.)GO TO 89
      C(LL,8)=2.*(C(LL,9)-1.)
      GO TO 90
89    C(LL,8)=1.
90    CONTINUE
C STORAGE OF THE SHELF AREA PER PROVINCE.
      SAP(LL,1)=C(LL,10)*ZOWID
      SAP(LL,2)=C(LL,10)*2.*(C(LL,5)-C(LL,10))
C CALCULATION OF THE SHELF AREA PER CONTINENT.
      T1=SAP(LL,1)*(C(LL,9)-2.0)
      IF(T1.LE.0.0)T1=0.0
      T2=SAP(LL,2)*2.
      TAC(LL)=T1+T2
      IF(C(LL,8).EQ.1)T2=SAP(LL,2)
      TAG=0.0
      FB=0.
      IF(C(LL,8).EQ.2.0)SAREA(LL,2)=SAREA(LL,1)
      IF(C(LL,8).EQ.1.AND.C(LL,9).EQ.1)SAREA(LL,1)=
     + ((C(LL,10)*2.*(C(LL,5)-C(LL,10)))+(2.*C(LL,10)*ZOWID/2.))**.263*Q
91    CONTINUE
C CALCULATION OF THE TOTAL GLOBAL SHELF AREA.
      DO 1 L=1,NC
1     TAG=TAG+TAC(L)
      RETURN
      END
C
```

```
      SUBROUTINE VELCITY
      COMMON ZOWID,C(16,12),NC,N,AVE,NN,ZONE(40),IZONE,KOUNT,FX,FY,SAREA
     + (16,70),NOFZ(16),SAP(16,2),CAREA(16,40),VFACT,NIT,VSHELF,TAG,CPC(
     + 16),RANDY(16),SCON(16)
      DIMENSION DNBOR(12)
      PIE=3.14159
C FIND NEAREST NEIGHBOR
      DO 1 L=1,NC
      CLOSE=10.
      DO 1 LL=1,NC
      IF(L.EQ.LL)GO TO 1
      CALL ANGLE (C(L,1),C(LL,1),0,TH)
      CALL ANGLE(C(L,2),C(LL,2),1,PH)
      TH=TH-C(L,5)-C(LL,5)
      PH=PH-C(L,6)-C(LL,6)
      IF(TH.LE.0.0)TH=0.
      IF(PH.LE.0.)PH=0.
      DIS=SQRT(TH**2.+PH**2.)
      IF(DIS.GE.CLOSE) GO TO 1
      CLOSE=DIS
      DNBOR(L)=DIS
1     CONTINUE
C FIND MEAN DISTANCE.
      SUM=0.
      DO 2 M=1,NC
      SUM=SUM+DNBOR(M)
2     CONTINUE
      A=NC
      AVE=SUM/A
      IF(AVE.LT..01)AVE=.01
      VFACT=(AVE*15.9631667+9.840336833)/6366.197723
      VSHELF=.0702517933*AVE+.000702517933
      RETURN
      END
C
      SUBROUTINE ANGLE(A,B,I,E)
C E=THE DIFFERENCE BETWEEN A AND B
C I=0 FOR THETA, I=1 FOR PHI
      PI=3.141592654
      C=AMAX1(A,B)
      D=AMIN1(A,B)
      E=C-D
      IF(I.EQ.0.AND.E.GT.PI) GO TO 1
      GO TO 2
1     E=D + PI-C
      IF(E.GT.PI)E=E - PI
      IF(E.LT.0.)E=E + PI
2     CONTINUE
      RETURN
      END
C
```

```
      SUBROUTINE COR(X,Y,IG,R)
      DIMENSION R(150),X(600),Y(600)
C CALCULATION OF THE PEARSON MOMENT CORRELATION COEFFICIENT.
      X1=0.0
      X4=0.0
      X5=00.0
      X2=0.0
      X3=0.0
      DO 1 I=1,600
      X1=X1+X(I)*Y(I)
      X2=X(I)+X2
      X3=Y(I)+X3
      X4=(X(I)**2.)+X4
      X5=(Y(I)**2.)+X5
1     CONTINUE
      SX1=ABS(X4-(X2**2./600.))
      SX2=ABS(X5-(X3**2./600.0))
      SP=X1-((X2*X3)/600.)
      R(IG)=SP/(SQRT(SX1*SX2))
      IG=IG+1
      RETURN
      END
```

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