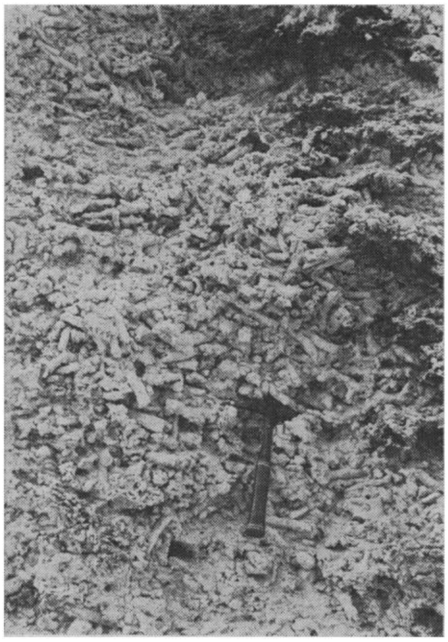

Fig. 2. An exposure within the *A. cervicornis* zone. Skeletons of *A. cervicornis* compose over one-half of this exposure; the remainder is infilling matrix. Hammer is 32 cm long.

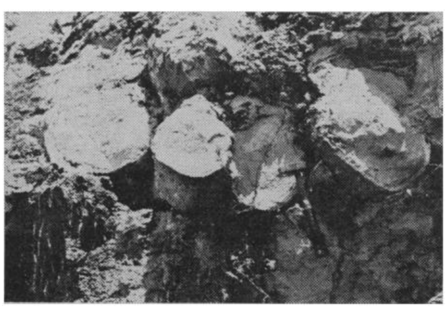

Fig. 3. Circular cross-sections of massive branches of *Acropora palmata* near the reef crest. Branches are oriented perpendicular to the trend of the reef tract. Hammer is 32 cm long.

general. Variations of a Recent West Indian fringing or barrier reef from this model might well be, in part, a function of its developmental history.

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8. Work supported in part by a grant from Gulf Oil Corporation to the Brown Department of Geological Sciences and in part by NSF grant No. GA306. I thank R. K. Matthews for assistance.

18 January 1967; 20 March 1967

Variation in Atmospheric Carbon-14 Activity Relative to a Sunspot-Auroral Solar Index

Abstract. *Radiocarbon activity was negatively correlated* (P < *.01) with a sunspot-auroral index during 25 designated solar activity periods from 129 B.C. to A.D. 1964. Change in carbon-14 activity during these periods was inverse to change in solar activity in 22 of 24 instances* (P < *.001). Contamination from carbon-14 formed during previous solar cycles may lessen the value of carbon-14 as a climate or solar index.*

A negative correlation between atmospheric radiocarbon activity and solar activity was suggested by Stuiver (*1*) on the basis of carbon-14 data of Willis *et al.* (*2*) which covered a 1300-year period. Subsequent analysis by Stuiver (*3*), Suess (*4*), and Bray (*5*) supported this suggestion. Bray found a significant negative correlation between C^{14} and solar activity over the period 200 B.C. to A.D. 1860, but the relationship was uncertain at the higher solar activity levels. Below I present a further analysis of this relationship, using a combined sunspot and auroral index of solar activity and an augmented set of radiocarbon activity data.

Sunspots and auroras are the only aspects of solar activity for which direct observations are available over a long-term historical interval. Since both these features indicate level of solar activity, a combination of sunspot and auroral data into a single solar activity index appeared feasible. The index was based on compilations by Schove of sunspot activity from 522 B.C. to A.D. 1947 (*6*) and of auroral activity from 500 B.C. to A.D. 1960 (*7*). Since some periods were represented by measurements of only one of these features, the relationship between the Schove sunspot and auroral indices was examined to allow representation by either feature if the other were missing. The mean auroral value was found to equal nearly half (.48) the mean sunspot activity value. An index was constructed, therefore, in which solar activity equalled (i) the sum of the auroral value and one-half the sunspot value, (ii) the sunspot value if auroral data were missing, (iii) twice the auroral value if sunspot data were missing. The result of this compilation gave indices of solar activity for every sunspot cycle from 527 B.C. to A.D. 1964 with the exception of the periods 378 to 355 B.C., 333 to 250 B.C., 239 to 220 B.C., and A.D. 203 to 283. These missing periods were tentatively assumed to represent low solar activity periods, since it is easier to discover historical records of high sunspot or auroral activity than of lower activity (*8*). As noted by Schove (*6*), historical observations of solar activity before A.D. 1600 are of less reliability, especially as to the exact year of observation.

A total of 361 C^{14} activity values from 12 laboratories were summarized from published data (*2, 4, 9–11*) by the criteria previously outlined (*5*). All C^{14} values were converted to the 5730-year half-life, thus allowing a more accurate representation of the older measurements and reducing their magnitude of variation relative to the more recent values. Such variation, due to the less correct half-life of 5568, partly accounted for the higher C^{14} values before around 100 B.C. summarized in Bray (*5*).

Examination of the sunspot-auroral index values from 527 B.C. to A.D. 1964 showed the same pattern of higher activity alternating with lower activity that was summarized for the period A.D. 1656 to 1964 (*12*). Intervals of three or more solar cycles with all or nearly all sunspot-auroral index values above 100 alternated with intervals in which all or nearly all index values were below 100. A division of the sunspot-aurora index data was made, therefore, into periods of alternating "high" (>100) and "low" (<100) values by the following criteria: (i) if a period was interrupted by one cycle of a different value, the period was continued; (ii) if the period was interrupted by two cycles of different value the period was continued if the next two cycles were within the period; (iii) if the period was interrupted by three successive cycles of different value, these cycles constituted the beginning of a new period. Application of these criteria over the interval 527 B.C. to A.D. 1964 resulted in the designation of 31 solar activity periods which varied in length from 28 to 189 years (Table 1). The mean solar index for the "low" periods varied from 60 to 89; that of the "high" periods, from 107 to 137.

Variation in C^{14} activity is shown

(Table 1) for the 31 outlined solar activity periods from 527 B.C. to A.D. 1964. From the 129 to 21 B.C. solar period, the first with adequate C^{14} data, there was a highly significant negative correlation of C^{14} activity with solar activity ($r = -0.51$, $P < .01$). This correlation occurred despite the pattern of generally positive C^{14} activity from 527 to 130 B.C., of negative activity from 129 B.C. to A.D. 1387, of positive activity from A.D. 1388 to 1834, and of negative activity from 1835 to the present. The presence of factors other than solar activity as a contributing influence on C^{14} activity is suggested by this pattern. It is possible, however, that this pattern may be the result of the cumulative influence of solar activity over a long-term period in that the 129 B.C. to A.D. 1387 period was on the whole of higher solar activity than the A.D. 1388 to 1834 period. There is, in spite of the variation in absolute magnitudes of C^{14} activity, a consistent pattern of alternating increase and decrease in C^{14} activity with alternately lower and higher solar activity periods. From the 129 to 21 B.C. period to the A.D. 1915–1965 period, the change in C^{14} activity was inverse to the change in solar activity in 22 of 24 instances (1 tie). This pattern of inverse change gave a chi-square of 20.3 ($P < .001$). Thus, both the observed C^{14} values and their trend of changing magnitude were inversely related to the outlined solar activity periods.

Radiocarbon activity relative to the sunspot-auroral index divided into 20 unit size classes is shown in Table 2. The same decrease in C^{14} activity with increasing solar activity is again demonstrated with the exception of the highest solar activity class. Only eight C^{14} values are available from this class. Four of these were from the period A.D. 1525 to 1586, an interval of very high solar activity which was both preceded and followed by long periods of notably low activity. If these four values are eliminated on the grounds of possible contamination from C^{14} found during the previous low activity sunspot period, the mean value of the remaining four measurements is -0.3.

The existence of possible contamination by C^{14} formed during a previous solar period of notably different activity is evident from examination of the C^{14} values during the A.D. 1359–1387 and 1525–1586 periods. Two main factors have apparently influenced this contamination: (i) the delay in equilibrium between atmospheric CO_2 and the bicarbonates dissolved in the ocean, which may be on the order of 10 to 30 years (*4*); (ii) the width of the cores taken from tree trunks for C^{14} analysis and the lack of exact horizontal orientation of the tree rings, which cause variation to ±75 years or more. Short periods of very high or very low solar activity will have a greater contamination of C^{14} formed during previous or subsequent periods of different solar activity than will longer periods of uniform solar activity. The elimination of shorter solar activity periods may correct these contamination difficulties.

The increasing evidence (*1, 3–5, 10, 12, 13*) for the control of both C^{14} activity and terrestrial temperature by solar activity suggests that any of these measurements may be used to predict the others. The usefulness of C^{14} activity as an index of past climate and solar activity is lessened, however, by the contamination factors noted above. By careful drilling or shaving of tree boles, the error based on the use of a large number of tree rings can be greatly decreased. Sample contamination from C^{14} which was formed during previous solar cycles of a different solar magnitude cannot be eliminated. The degree of such contamination is a function of the mean exchange time of C^{14} from the atmosphere to oceanic bicarbonates, which has been estimated by Suess (*4*) as 10 to 30 years. In summarizing the C^{14} activity data in Table 2, I observed a lag in time be-

Table 1. Indexes of sunspot-auroral activity, sunspot cycle length, and C^{14} activity at 31 designated solar periods of alternately lower and higher activity from 527 B.C. to A.D. 1964.

Period	Sunspot-auroral index*	Number of oriental sunspot and auroral observations per decade†	Sunspot cycle length (years)‡	Carbon-14 activity		
				No. of values	Mean ± S.D.	
(B.C.)						
527–456	113		10.2	4	+0.6	±0.6
455–399	< 100		11.2	2	+0.1	
398–334	< 121		10.7	1	+0.6	
333–255	(low)		11.4	2	−0.6	
254–187	126		11.4	4	−0.9	±1.0
186–130	81		11.4	1	+0.4	
129–21	111	0.2	10.8	8	−1.3	±1.2
20–169 A.D.	79	.1	11.2	21	−0.7	±0.9
(A.D.)						
170–202	107	.9	11.0	5	−1.7	±0.7
203–283	(low)	.0	11.6	5	−1.2	±1.1
284–316	114	1.2	11.3	6	−1.3	±0.2
317–348	76	0.6	10.3	2	−0.1	
349–380	126	1.0	10.0	2	−0.7	
381–426	86	0.4	12.2	4	−0.7	±0.5
427–591	107	.5	10.9	19	−1.0	±0.7
592–707	87	.0	11.4	18	−0.4	±1.1
708–880	108	.5	10.8	21	−1.1	±0.9
881–957	84	.7	11.1	11	−0.4	±1.3
958–1010	118	.4	10.6	7	−0.9	±1.0
1011–1083	84	.5	12.5	8	−0.1	±0.6
1084–1211	116	1.6	10.3	17	−1.2	±0.6
1212–1358	83	0.6	11.6	17	−0.4	±0.6
1359–1387	137	1.8	9.7	6	−0.3	±1.0
1388–1524	69	0.4	11.4	26	+1.0	±1.3
1525–1586	135	.3	10.3	10	+0.7	±0.5
1587–1723	68	.4	11.4	40	+1.1	±0.9
1724–1798	110	.5	10.0	16	+0.5	±0.9
1799–1834	60	.0	13.9	14	+0.8	±0.5
1835–1879	113	.0	10.2	42	−0.1	±0.5
1880–1914	74	.3	12.1	19	+0.1	±0.4
1915–1964	130	.6	10.2	3	−2.0	

* Calculated from Schove (*6, 7*). † From Kanda (*14*). ‡ Calculated from Schove (*6*) and Waldmeier (*15*).

Table 2. Radiocarbon activity relative to a sunspot-auroral index of solar activity.

Sunspot-auroral index	Carbon-14 activity	
	No. of values	Mean ± S.D.
21 to 40	7	+1.2 ± 1.0
41 to 60	38	+0.8 ± 1.0
61 to 80	78	+0.2 ± 1.2
81 to 100	85	−0.3 ± 1.0
101 to 120	80	−0.4 ± 1.0
121 to 140	53	−0.7 ± 1.2
141 +	8	+0.1 ± 0.6

tween a drastic change in solar activity and the subsequent change in C^{14} activity. Of the 30 instances between 527 B.C. and A.D. 1964 in which the sunspot-auroral index showed a large increase or decrease, 14 had sufficient C^{14} measurements to allow an approximate estimate of the lag period. Since C^{14} data were not available from every year, or even from every decade, this estimate represents a maximum value for the mean atmospheric C^{14} residence time. The length of the 14 observed lag periods varied from 2 to 39 years, with a mean of 15.1 years. This value falls within the estimated exchange period noted above and suggests that the use of C^{14} as a climatic or solar index should not be applied with an accuracy of less than around two decades.

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7 February 1967

Blake Outer Ridge: Development by Gravity Tectonics

Abstract. *A continuous seismic profile across the Blake Outer Ridge reveals clear evidence of a structural origin for the ridge. A ridge core separates distinctive regions of structure east and west of the crest and does not support a theory of depositional origin. The presence of horizon A continuously beneath the ridge rules out faulting or folding involving basement rocks. Gravity tectonics are suggested as the mechanism for formation of the ridge after the deposition of the sediments above horizon A.*

The Blake Outer Ridge is a low feature on the sea floor that forms the eastern boundary of the Blake-Bahama Basin which it separates from the Hatteras Abyssal Plain (Fig. 1; *1*). The ridge has two distinct portions: a relatively sharp, crested, southeastward-trending, northern portion that ends against the Blake Plateau; and a broad, rolling, southern portion that trends southwestward toward the Bahamas (*2*). The two portions are separated by a saddle near 28°30′N and may not be related to each other structurally or genetically, although this possibility seems unlikely.

The northern ridge rises 1000 m above the Blake-Bahama Basin and 1500 m above the abyssal plain to the east, with very gentle gradients (less than 0.5° to 2.5° along the eastern side of the crest). Comparison with other sea-floor topography emphasizes the gentleness of the gradients: normal continental-slope gradients average 5° to 6° (*3*), being as steep as 20°; 25° gradients are common on seamounts and volcanic islands (*4*). Very steep gradients exceeding 45° are known on the Blake Escarpment (*1*) and along the eastern edge of the Bahamian platform (*5*). Gradients of the same magnitude as those of the ridge occur only on the continental rise

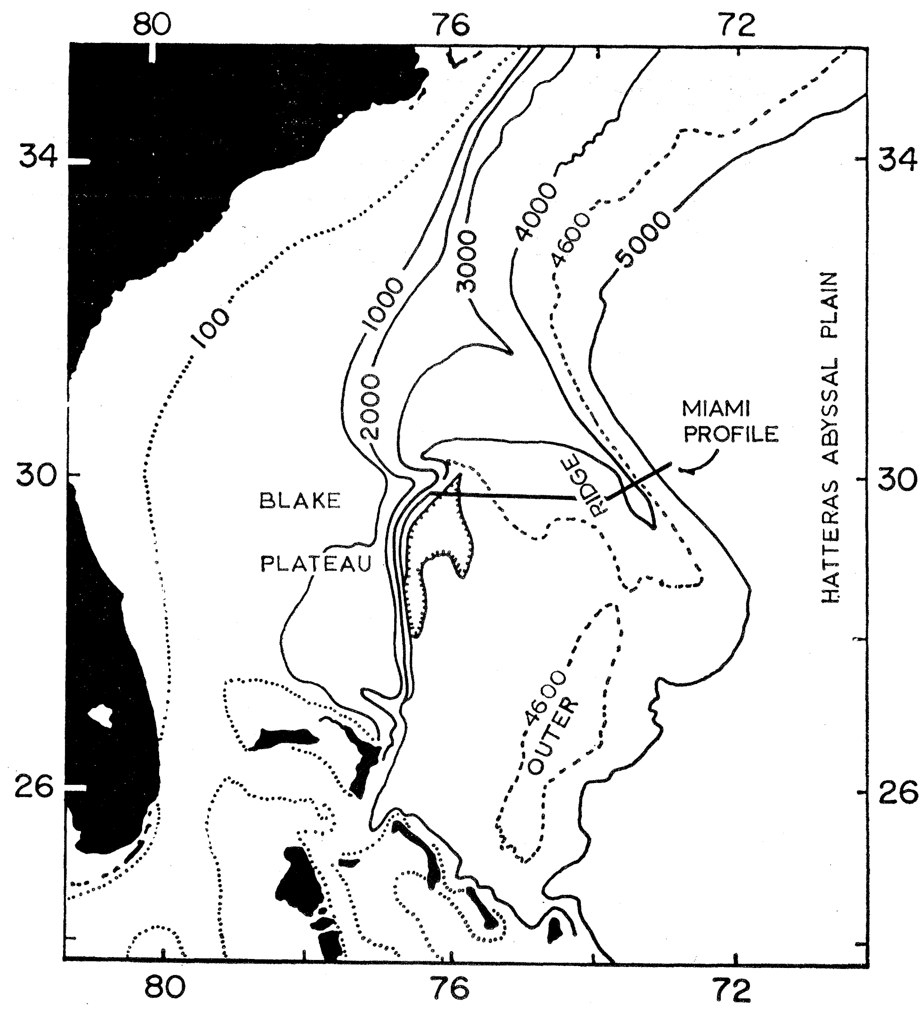

Fig. 1. Blake Plateau, Blake-Bahama Basin, and Blake Outer Ridge (after *2*), with track of profile 9a; contours in meters.