and belong to the transgressive stage.

Coralline algae and hermatypic corals can be used as sea-level indicators, but only with care, because certain species can live in depths greater than 20 m. Several samples of unrecrystallized algal rock were obtained from an algal ridge system that lies off the coast of North Carolina and Florida (*7, 8*). Dates for these algae range from 11,000 to 19,000 years.

Beachrock, which forms in the intertidal zone, can be recognized by its fragmented shallow-water components and by its bedded nature. Submerged beachrock appears to be rather common on the shelf off the southeastern United States. We dated two samples of beachrock dredged off the coast of North Carolina (*8*).

In addition to dates for these samples, Table 1 includes eight samples of shallow-water mollusks and salt-marsh peat. The new dates, plus those reported (*9, 10*) are plotted in Fig. 1. The values lie within an envelope that widens with age, perhaps reflecting both greater contamination with greater age, and the effects of regional uplift or subsidence. For example, many samples south of Cape Hatteras are shallower for given times than are samples farther north; thus the southern area may have participated in the uplift now evident for the continental shelf off Texas.

Several significant trends are indicated. The last interglacial high stand of sea level was near the present level about 30,000 to 35,000 years ago. Sea level then fell slowly until about 21,000 years ago. Between 21,000 and 16,000 ago it fell rapidly, reaching a maximum depth of about −130 m. By 14,000 the Holocene transgression had begun, and sea level rose rapidly until about 7000 years ago, after which the rise was more gradual. This date for the transgression coincides with the sharp increase of surface temperature about 15,000 years ago, indicated in Caribbean deep-sea cores (*11*). We find no evidence that transgression began 19,000 years ago. This date, the usual one given for transgression (*12*), is based on the time of glacial retreat in North America, and it may not coincide with the worldwide retreat of glaciers. Neither do we find any indication of a sharp climatic change at 11,000 years ago (*13*).

Emery and Garrison (*10*) noted the difference in ancient sea-level curves for the shelves off the Atlantic and Texas coasts. They suggested either a subsidence of the Atlantic shelf or an uplift of part of the Gulf of Mexico. Lacking sufficient data, they were unable to identify the eustatic curve. On the basis of deviations from a "eustatic" curve, Newman and March (*14*) concluded that the Atlantic shelf had downwarped as much as 80 m. However, their eustatic curve was based only on a few freshwater peats, which are poor sea-level indicators.

Thirty-eight radiocarbon ages greater than 8000 years have been reported from 11 areas throughout the world. These areas include Campeche Bank, Mexico (*15*), the southeastern Caribbean Sea (*16*), Australia (*17*), western Mexico and Panama (*17, 18*), western Florida (*19*), the East China Sea (*20*), and others (*10*). Dates from the elevated Hawaiian terraces were omitted because of their probably very great (Sangamon) age (*21*). Nearly all the dates cluster near the Atlantic shelf sea-level curve, whereas only five of them coincide with data for the Texas shelf (*12*) (Fig. 2). Three values from the southeastern Caribbean Sea are significantly below the curve of the Atlantic shelf, but these are for coralline algae and corals which may have lived in deep water. The fact that so many of the world dates coincide with those for the Atlantic shelf of the United States suggests that the latter defines a eustatic curve. It further suggests that the Texas shelf probably has undergone uplift during the Holocene.

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Manganese Nodules in Lake Michigan

Abstract. *Manganese nodules containing up to 22 percent manganese oxide were found in Green Bay and the western and northern parts of Lake Michigan. The chemical composition of these nodules resembles that of shallow-water lacustrine and marine nodules. The manganese content of interstitial water is in some places enriched as much as 4000 times over that of lake water.*

Manganese nodules were discovered at several localities in Lake Michigan: in the western and northern portions of the basin and Green Bay (Fig. 1). Before the first nodule was discovered (June 1967), the only known manganese deposits in the Great Lakes occurred as crusts on a buoy in Lake Erie and in the sediment of Lake Superior (*1*). Nodules from stations 1, 2, and 4 are brown, spherical concretions with an internal structure of alternating brown and black layers. Those from the other stations, except station 12, consist of black ferromanganese aggre-

Table 1. Chemical composition of Lake Michigan manganese nodules.

Station	Depth (m)	Av. diameter (mm)	Oxides (%)				Carbon (%)		Nitrogen (total)	Mn/Fe
			CaO	MgO	Fe_2O_3	MnO	Organic	Inorganic		
1	18	5.0	6.45	0(?)	73.3	5.41	0.68	0.58	0.06	0.15
2	23	7.0	6.79	3.22	42.2	22.2	0.12	0.87	0.14	1.16
3	14	1.0	3.39	0.68	41.2	2.96	0(?)	0.34	0.03	0.16
4	32	0.7	8.40	0(?)	47.5	8.98	2.27	0.37	0.32	0.42
5	23	1.0	14.8	0(?)	41.7	19.5	0.54	0.62	0.28	1.03
6	25	2.0	8.94	0(?)	46.7	14.4	1.46	0.49	0.18	0.68
7	36	2.0	8.94	0(?)	60.8	11.4	0.99	0.55	0.14	0.41
8*	90	1.0	2.74	2.29	1.75	0.31	0.25	0.63	0.06	0.38
9	35	0.5			36.6	11.2				0.68
10	30	0.5	2.52	0.25	1.34	0.89	0(?)	0.52	0.06	1.47
11	47	1.0	5.03	1.05	6.79	6.61	0.78	0.39	0.22	2.13
12	10	30.0	2.95	2.13	15.7	2.78	0.71	0.31	0.21	0.37
13	36	0.5	3.60	0.32	5.47	2.80	0(?)	0.47	0.05	0.74

* See (8).

gates surrounding a nucleus, and have no obvious concretionary structure. Nodules found in several dredge hauls at station 12 are discoidal and consist of sand- and silt-sized material cemented by ferromanganese compounds. The concentration of nodules in all samples varies from scarce to abundant; samples from Green Bay contain the greatest abundance. Most of the nodules occurred on the sediment surface. Those that occurred below the surface were found to a depth of 0.5 m.

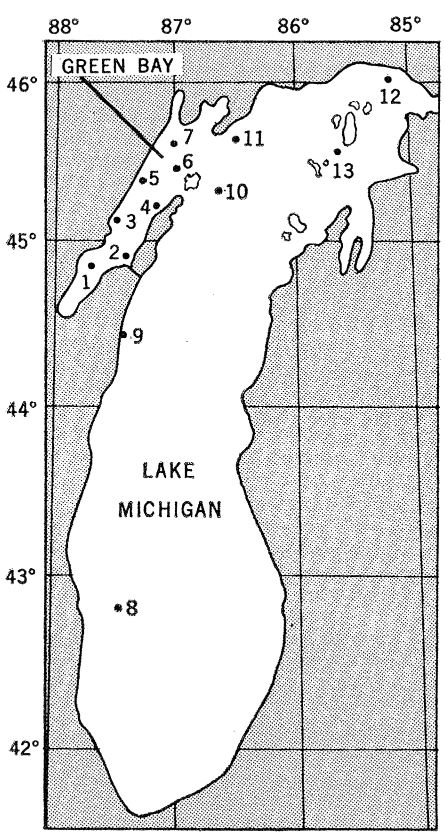

Fig. 1. Location of manganese nodules in Lake Michigan. Numbers refer to stations discussed in text and analyses presented in Table 1.

Standard volumetric and colorimetric techniques (*2*) were used to determine the chemical composition of the nodules. Manganese was extracted from powdered samples with a mixture of concentrated nitric acid and 3 percent hydrogen peroxide. The extraction was carried out in a boiling water bath. Peroxide was added several times during extraction (1 hour) to insure complete oxidation of organic matter (*3*).

The chemical composition of Lake Michigan nodules (Table 1) is similar to that of shallow marine and lacustrine material (*4*). The ratio of manganese to iron of the Lake Michigan material averages 0.75, close to the average ratio of shallow-water marine nodules (*4*). The high inorganic carbon, calcium, and magnesium contents of Lake Michigan nodules may reflect the calcareous nature of glacial till and bedrock in the Lake Michigan Basin (*5*). The chemical composition of the nodules, as of most shallow-water nodules, is somewhat variable at any particular locality.

Manganese occurs as coatings and crusts on sand grains, pebbles, cobbles, and as part of the bulk sedimentary material in Lake Michigan. The upper 10 cm of several sediment cores is enriched in manganese as compared to the lower parts. The manganese content of interstitial water extracted from these cores shows a pronounced increase with depth. This inverse relation between sedimentary and interstitial manganese is illustrated by 12 of 30 cores, whereas five cores show a direct relation, and 13 cores show no relation. Manganese in interstitial water from Green Bay sediments (< 0.5 to 8.6 parts per million) and from northern Lake Michigan sediment (< 0.5 to 4.7 parts per million) is enriched over lake water (< 1 to 25 parts per billion) as much as 2500 and 4000 times, respectively.

Manganese nodules are more abundant in Green Bay and northern Lake Michigan than in other parts of the lake basin. The middle and northern portions of Green Bay are extensively covered by nodules ranging in diameter from 0.5 to 12 mm. The manganese content of rivers (50 to 180 parts per billion) entering Green Bay (*6*) may be derived from extensive iron ore deposits to the north and west (*7*). These concentrations exceed those in lake water by several orders of magnitude. Green Bay nodules apparently receive nourishment from overlying water masses and from interstitial water. Similarly, nodules from northern and western Lake Michigan may receive substantial nourishment from manganese-enriched water flowing out of Green Bay.

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