has periods corresponding to the typical climate cycles (the diurnal cycle due to day-to-night temperature variation, a 3- to 7-day cycle due to the passage of mesoscale front systems, and finally the seasonal cycle).

The actual load distribution depends on social and climatic factors, such as the length of day, the amounts of electricity used for space heating and cooling, and the working hours in industry and commerce. I will give the WEG power fluctuations relative to an approximate load function representing Danish conditions (*8*). Here the hourly variation ranges from 0.57 (2 to 4 a.m.) to 1.23 (10 a.m.) times the average, with a second peak occurring at 6 p.m. The monthly variation ranges from 0.8 (July) to 1.2 (January) times the average. This is somewhat different from the U.S. situation, where a second maximum occurs during summer in most states.

At the Risø site the WEG output exhibits a monthly maximum in March, a minimum in July, an hourly maximum just after noon, and a broad minimum at night (10 p.m. to 6 a.m.). The fluctuations relative to the approximate load function are 137 watt/m^2 (without storage), 131 (3 hours' storage), 121 (10 hours), 109 (24 hours), 95 (60 hours), 83 (120 hours), and 73 (200 hours). In other words, the expected output from a WEG plant with or without storage is practically as well correlated with the actual load (in Denmark) as it is with a constant load.

The power-minus-load duration curves are quite similar to the corresponding ones in Fig. 1, except that the flat part of the curves including storage is now at $E = 0$ (power output equal to actual load). This part extends to a few percent more of the time than do the flat parts of the curves in Fig. 1, reflecting the gross similarity between the power output and Danish load variations. Since the fluctuations are the same as when compared to constant load, or even a bit higher, this can be interpreted by saying that the power output exceeds the actual load more often than it exceeds the yearly average, but the surplus or deficit in some periods of time may reach larger values when actual load is considered.

The prospects of developing economically viable short-term storage systems for use in conjunction with WEG's have been considered elsewhere (*9*), as have the requirements for long-term storage, which will allow an arbitrarily large coverage with wind energy (*10*).

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Calcium Carbonate Production, Coral Reef Growth, and Sea Level Change

Abstract. *Shallow, seaward portions of modern coral reefs produce about 4 kilograms of calcium carbonate per square meter per year, and protected areas produce about 0.8 kilogram per square meter per year. The difference is probably largely a function of water motion. The more rapid rate, equivalent to a maximum vertical accretion of 3 to 5 millimeters per year, places an upper limit on the potential of modern coral reef communities to create a significant vertical structure on a rising sea.*

The rate at which a coral reef community produces sedimentary materials has long been a subject of speculation and estimation. Indeed, it has been recognized that coral reefs are unique in their ability to precipitate materials from seawater at a sufficient rate to keep pace with a rising sea, and to consolidate those materials into a regionally extensive three-dimensional structure. We consider here primarily the rate of production of $CaCO_3$ sediment by coral reefs in relation to the potential of coral reef growth to keep pace with a rising sea.

Most estimates of the $CaCO_3$ production rates of reefs have been based upon either biological or stratigraphic evidence. The standing crop of reef organisms multiplied by the growth rate of these organisms provides a biological measure of the $CaCO_3$ production rate. Alternatively, the vertical accumulation of materials (for example, in a drill core) together with isotopic (for example, ^{14}C) ages yields a stratigraphic record of the net accumulation rate. Chave *et al.* (*1*) summarized much of the pre-1971 literature on coral reef $CaCO_3$ production as estimated by one or other of these approaches.

A third method is based on the mass balance of $CaCO_3$ precipitated from seawater. The reduction in the total alkalinity of the water (normalized with salinity to account for conservative changes in alkalinity associated with evaporation, rainfall, groundwater input, and other factors) multiplied by an estimate of the flushing rate of water through the reef system can be converted to an estimate of $CaCO_3$ precipitation rate (*2–7*). Observed alkalinity changes range from near analytical detection limits (that is, < 0.005 meq/liter) to 100 or more times these limits. Production rates reported here involve approximately 100 to over 1000 individual analyses from each site.

This method avoids the tedium and inaccuracies inherent in any cumulation of the contributions by individual biological components. Moreover, the alkalinity estimate of $CaCO_3$ production is not sensitive to the potential stratigraphic biases of physical dispersion or concentration of detrital sedimentary materials. Finally, where applicable, the alkalinity method provides real-time data on the $CaCO_3$ production rate at the site of production.

Inspection of recent published and unpublished data on the alkalinity reduction of seawater has revealed some striking consistencies which have important implications with respect to potential coral reef growth as a function of sea level change, major calcifying biota, physiography (and consequently physical environment), and latitude. We present these data and our interpretations, not as new concepts, but rather as the restatement of old concepts in the light of these modern data.

The $CaCO_3$ production rates obtained from numerous measurements in each of six shallow, well-flushed seaward reef flat environments are consistently near 4

Table 1. Coralreef $CaCO_3$ production rates, as estimated by the alkalinity reduction technique.

Location	Latitude	Environment	Approximate depth (m)	$CaCO_3$ production (kg m^{-2} $year^{-1}$)	Reference
		Shallow seaward reef flat environments			
One Tree Reef	23°S	High coral cover,	1 to 2	4.5	(*3*)
		algal pavement	1 to 3	4	(*3*)
Enewetak Atoll	11°N	Coral-algal cover,	1 to 2	4	(*5*)
		algal turf-pavement	1	4	(*5*)
Lizard Island	14°S	Agal pavement,	1	3.8	(*4*)
		coral-algal cover	1	3.6	(*4*)
Mean ± standard deviation				4.0 ± 0.3	
		Top of coral pinnacle (assumed equivalent to reef slope)			
Lizard Island	14°S	High coral cover	1.5	3.7	(*4*)
		Protected environments			
One Tree Reef	23°S	Lagoon	5*	0.3–1.5	(*3*)
Lizard Island	14°S	Lagoon	5	1	(*4*)
Fanning Atoll	4°N	Lagoon	5	1	(*6*)
Canton Atoll	3°S	Lagoon	6	0.5	(*7*)
Bahama Banks	25°N	Bank	5	0.5	(*2*)
Mean ± standard deviation				0.8 ± 0.4	

*Lagoon depths, and in all likelihood lagoon production rates, are bimodally distributed between shallow reef features and deeper lagoon floors.

kg m^{-2} $year^{-1}$ (Table 1). Production rates from many samples in five atoll lagoons or otherwise protected environments average 0.8 kg m^{-2} $year^{-1}$ (Table 1). The reef slope remains a major environment unsampled by the alkalinity reduction technique—because of obvious problems associated with isolating water there, sampling that water, and estimating its residence time within the environment. Data from the top of a submerged coral-covered pinnacle (3.7 kg m^{-2} $year^{-1}$) provide insight into likely rates of reef slope production, within the range spanned by the reef flat production rates. These chemically derived $CaCO_3$ production rates are within the range of biological estimates (*1*), although a few extreme biological estimates exceed the alkalinity values by severalfold.

Three major taxa ordinarily account for most $CaCO_3$ in reef sedimentary materials: corals, coralline red algae, and calcareous green algae (*8*). Available growth rate data on these taxa generally show relatively constant growth rates, or slight decreases in growth rates, with increasing water depth (*9*). The data of Table 1 suggest that $CaCO_3$ production is not sensitive to coral versus coralline algal dominance of the community. In waveswept environments, most hard bottom areas are covered by one or the other of these two high-calcification components. We therefore conclude that our shallow-water production rate estimates do not dramatically (or probably at all) underestimate reef slope production. The sediment quality (the biotic and mineralogic composition and the framework-producing potential) surely can vary considerably as a function of water depth or other independent variables. We anticipate that any variation in the $CaCO_3$ production rate as a function of water depth deeper than the reef flats is likely to be a general decrease, although the net accumulation rate might show a maximum at moderate depths on the reef slope. In fact, present-day net vertical accumulation on the reef flat must be near zero despite the rapid rate of $CaCO_3$ production there, if the present rate of sea level change is small relative to the vertical accretion potential offered by that production (*10*).

The three locations from which data on ocean reef flat production rates come span a latitudinal range of 34° (23°S to 11°N); the protected environments span 48° of latitude (23°S to 25°N) (Table 1). Neither data set shows evidence of significant latitudinal gradients in community $CaCO_3$ production. There may be decreases at higher latitudes, although limited data (*11*) suggest that the extremes of (noncoral reef) $CaCO_3$ production as far north as 34°N may be similar to the reef production rates. There are obvious latitudinal shifts in the composition of the calcareous sedimentary material produced (*12*).

The most dramatic variation in $CaCO_3$ production rates within the reef environments summarized in Table 1 is the fivefold variation from rapid production in seaward environments to slow production in protected environments. We interpret this variation to be largely a function of variable water motion, recognized at least since the time of Semper (*13*) to be an important influence on reef growth. Although many roles for the effects of water motion have been postulated (*14*), the mechanisms by which water motion enhances calcification remain unknown.

It thus appears that coral reefs, and perhaps by extension some other $CaCO_3$-dominated nearshore marine environments, show two dominant modal rates of $CaCO_3$ production: about 4 and 0.8 kg m^{-2} $year^{-1}$. The higher rate appears to represent the present-day upper limit on community-wide production rates, whereas the latter rate may more nearly represent a common regional rate for reef systems. If we assume that carbonate sediments commonly have a porosity of 50 to 70 percent (*15*), then the extreme potential for upward reef growth is about 3 to 5 mm $year^{-1}$; the regional figure would be about 0.6 to 1 mm $year^{-1}$. Additional, higher modal rates of $CaCO_3$ production in shoal water may eventually be recognized in reef systems; we do not presently see significant clues for such modes.

Limited geological data on the maximum rates of vertical reef accumulation are available (*16–18*). Individual pairs of age dates have suggested deposition rates as high as 15 mm $year^{-1}$ (*16*), far above the maximum production rate we have observed. However, mean deposition rates in vertical sections, which appear to be more valid geological reflections of the total community potential for long-term upward growth, generally fall below 5 mm $year^{-1}$ (*17, 18*). This geological evidence is consistent with our findings.

It therefore appears from biological, geological, and chemical evidence that coral reef communities as presently comprised would be unable to persist as three-dimensional structures if sea level were rising more rapidly than about 3 to 5 mm $year^{-1}$ [generally consistent with conclusions drawn by Purdy (*17*)]. A growing reef could survive short periods of more rapid sea level rise, because the optimum range of water depths for reef growth is probably 10 m or more. If a rapid rise of the sea continues, this optimum depth range for reef growth will be exceeded and reef accumulation will terminate. Components of the reef community may survive but be incapable of producing stratigraphic reef structures, as apparently evidenced by present-day submerged reef communities in the Caribbean Sea (*19*).

Clearly the formation of stratigraphic reef structures hangs in a delicate balance. A substantial vertical thickness of in situ reef material can ordinarily accumulate only on a rising sea. Modern reefs can keep up with a rising sea only if the sea level rise is no more than a few millimeters per year. Rapid oscillations of sea level occurred during much of the Quaternary (*20*), and these rapid oscillations probably occasioned interruptions in the stratigraphic records of extant reefs. Evidence for the interruption or termination of reef growth can indeed be found in drill holes (*21*) and seismic reflection profiles (*22*), although it is not certain that these interrupted records are entirely responses to rapidly rising sea level.

The same principle of reef growth limitation by a rising sea, and perhaps much the same absolute upper limit on reef growth rates, must have applied during much of geological time. Reef structures thus not only indicate rather precise paleobathymetric limits during the formation of these features but can also define a narrow range for long-term rates of sea level change.

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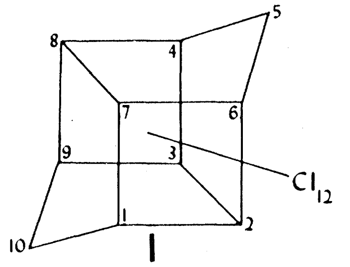
Mirex in the Environment: Its Degradation to Kepone and Related Compounds

Abstract. *The chlorocarbon mirex undergoes slow, successive loss of chlorine in the field to a series of related compounds that had lost one or more chlorine atoms. Soil samples were recovered 12 years after treatment at 1 part per million (ppm), and ant bait was recovered 5 years after an aircraft crash. As much as 50 percent of the original mirex was recovered at levels of about 0.5 and 640 ppm, respectively. Kepone was present at levels of 0.02 ppm in soil and 10 ppm in the bait or up to 10 percent of the recovered mirex, as determined by combined techniques of chromatography and mass spectrometry. This constitutes the first observation of the degradation of mirex in nature, and demonstrates a pathway for its eventual disappearance from the environment.*

We have recently detected degradation products of mirex (**1**) in samples from two locations in the field where unusually large amounts of mirex were deposited and left exposed to the elements for 12 and 5 years. The presence of Kepone (**2**) and several other dechlorinated derivatives of mirex was confirmed in extracts. Recent concern over environmental contamination involving Kepone prompts this report.

Mirex, which is the chlorocarbon insecticide dodecachloropentacyclo[5.3.0.$0^{2,6}$.$0^{3,9}$.$0^{4,8}$]decane (**1**), is the most effective bait toxicant known for use against imported fire ants, *Solenopsis invicta* and *Solenopsis richteri*. The bait is prepared by dissolving mirex in soybean oil which is then adsorbed onto corncob grits. A single application of this formulation, when applied by aircraft at the rate of 1.7 g/acre (4.2 g/ha) of actual mirex, provided 97 to 99 percent suppression of *S. invicta* (*1*). Mirex has been reported to be highly resistant to metabolic attack by soil microorganisms (*2*) and higher organisms including rats (*3*) and cattle (*4*), but was dechlorinated slowly to a monohydro derivative (**3**) by anaerobic microbes (*5*). Mirex, exposed to sunlight as a deposit on a silica gel thin-layer plate, was slowly converted to several products including two monohydro derivatives (**3 and 4**) of mirex, Kepone (**2**) and a monohydro derivative of Kepone (*6*). Mirex was shown to undergo photolytic dechlorination in solution (*6*) and on egg solids (*7*) with ultraviolet light to mono and dihydro derivatives **3** to **6**; Kepone was shown to undergo analogous loss of chlorine to a monohydro derivative (*6*).



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In 1962, mirex on attapulgite clay was applied as a residual treatment for fire ant control to experimental plots near Gulfport, Mississippi, at a dosage of 1 pound of mirex per acre (1120 g/ha) (*8*). Soil cores and samples of loose sandy soil were gathered from three plots in 1974 and held in sealed metal cans until extraction. Individual plugs or mixed soil samples (170 g) were stirred with hexane at room temperature for 24 hours. Also, 25-g samples were extracted with acetone in a Soxhlet extractor for four complete cycles in less than 2 hours. The samples were concentrated to 5 ml on a rotary evaporator, diluted with 250 ml of hexane, and again concentrated to 10 ml by evaporation. Portions of the soil samples were diluted for gas chromatographic (GC) analysis; the remainder was concentrated for gas chromatographic–mass spectral (GCMS) analysis.

In 1969, a plane carrying Mirex Granu-