three exponential slopes are reasonably well approximated by a cycloid. In Table 2 we use the hillslope data from the crest to the boundary between shallow, mainly sedentary soils and deeper soils on transported materials (*9*). These deep soils are associated with the long exponential lower slopes. No such deep soils occurred on the Wyangapinni, Umbiram Creek, and Majuba hillslopes. The Mount Russell hillslope is the only case where the exponential is better than the cycloid in Table 2, but only six points were available for curve fitting.

Taking these considerations into account, the cycloid curve appears to be a good model for hillslopes where wash processes are operating. Its "least time" shape may be the one to which erosional slopes and slopes of transportation trend, regardless of scale. Its finite limits and tangency to the vertical and horizontal axes correspond well with vertical cliffs and horizontal drainage lines. Its use may thus solve the problem raised by Ruhe and Walker (*4*) concerning the fit of mathematical curves on steep upper slopes.

If we assume that a hillslope tends to a state of minimum erosion in the long term and that the erosion rate is not a function of elevation, then the hillslope profile of minimum erosion corresponds to the curve of least time, the cycloid. Here contact between the wash water and the ground surface is minimized, a property recognized intuitively by King (*7*). The calculus of variations for ideal particle mechanics as given in Courant (*10*) indicates that once the cycloid is established, the erosion rate of the hillslope becomes equal at all elevations and the cycloid is maintained as erosion proceeds. Real hillslopes are subjected to frictional forces including drag and turbulence, and it would be interesting to pursue this line of analysis further.

Although the data presented here refer to southeastern Queensland, inspection has shown that some hillslopes on sandstones, shales, and granites in the southwestern United States have concave profiles of cycloidal form. Their fit is being checked. It has also been observed that Mount Mayon, an almost perfectly symmetrical volcanic cone in the Philippines, has cycloidal profiles.

On the other hand, the exponential curve seems to be a good model for hillslopes where depositional processes are operating. It obviously applies to colluvial slopes and has been observed on ash volcanoes in New Zealand.

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17 May 1977; revised 15 August 1977

Salt-Marsh Plant Geratology

Abstract. *Measurement of individual culms of several salt-marsh plants demonstrates seasonal community change in terms of height increments and live and dead leaves. Tissue production and its ultimate transition from live to dead components and culm mortality all suggest a continuum of geratologic processes contributing to the estuarine ecosystem.*

The importance of coastal United States wetlands is becoming increasingly evident as we learn more about their contribution to estuarine and offshore ecosystems (*1, 2*). Primary productivity is widely used as an indicator to evaluate these wetlands; thus it is imperative that accurate estimates be made. The culm height has been suggested as the controlling parameter in determining culm biomass for many salt-marsh halophytes (*3*), yet the turnover of leaves from a culm, and culm mortality during the growing season, may contribute significantly to estimates of primary productivity (*4*). Through measurements of height increments and number of leaves, we have quantified the seasonal and spatial contribution of individual culms to overall biomass and structure of several salt-marsh plant communities.

Table 1. Calculation of tissue production, development, and death. Abbreviations: E, culm elongation; ΔH, change in height (in centimeters) of a culm during any interval; P, leaf production; ΔL, change in number of live leaves for a culm over any interval; ΔD, change in number of dead leaves for a culm over any interval; Net, $\Delta L + \Delta D$ over any interval; S, leaf senescence; and A, leaf abscission.

Value		Condition
	Culm elongation	
$E = \Delta H$	if	$\Delta H > 0$
$E = 0$	if	$\Delta H \leq 0$
	Leaf production	
$P = \Delta \text{Net}$	if	$\Delta \text{Net} > \Delta L$
$P = \Delta L$	if	$\Delta \text{Net} \leq \Delta L$
$P = 0$	if	$\Delta L \leq 0 \geq \Delta \text{Net}$
	Leaf senescence	
$S = \Delta D$	if	$\Delta L \geq 0 \geq \Delta D$
	or if	$\Delta L < 0$ and $\lvert\Delta L\rvert \leq \Delta D$
$S = \lvert\Delta L\rvert$	if	$\Delta L < 0$ and $\lvert\Delta L\rvert \geq \Delta D$
$S = 0$	if	$\Delta L \geq 0 \geq \Delta D$
	Leaf abscission	
$A = \lvert\Delta D\rvert$	if	$\Delta D < 0 \leq \Delta L$
$A = \lvert\Delta \text{Net}\rvert$	if	$\Delta \text{Net} < 0$ and $\Delta L < 0$
$A = 0$	if	$\Delta D \geq 0$ and $\Delta L \geq 0$

Study sites and species were (i) Sullivan, Maine—*Spartina alterniflora* Loisel and *Spartina patens* (Aiton) Muhl.; (ii) Lewes, Delaware—*Phragmites communis* Trin., and *Spartina patens*; (iii) Sapelo Island, Georgia—*Spartina cynosuroides* (L.) Roth and *Spartina patens*. Each site represented a unique climatic regime along the eastern coast of the United States. On 5 May 1975, 50 live culms representing each species were selected at random and tagged with plastic cable ties (Ty-Rap No. TY-553M). Each culm was then measured from soil level to the tip of its tallest vegetative component to determine its height to the nearest centimeter. Live leaves, defined as any leaf having green color, were counted as well as dead leaves, having no green coloration. The three variables were monitored at 8-week intervals for each of the tagged plants during the growing season. Inspection of *Spartina patens* in Maine in May 1975 revealed dead culms; consequently, tagging of *Spartina patens* in Maine was not begun until June 1975.

We determined the change of each variable for each culm by subtracting the initial datum from the final datum of any one interval. Both positive and negative changes were computed for each interval. Algebraic summation of the changes in the numbers of live and dead leaves for a given interval resulted in a net change (ΔNet). Leaf production, senescence, abscission, and culm elongation were calculated according to Table 1. Annual leaf production is the sum of the initial number of leaves and the leaf production for each interval. Leaf production, leaf senescence, and stem elongation for each interval were based on the number of the live culms evaluated during the interval. Leaf abscission included the leaves of tagged stems that died during the intervals.

Annual leaf production of single culms is summarized in Table 2. The three ecotypes of *S. patens* are evident by the increasing leaf production in the southern latitudes. The remaining three species exhibit unique leaf production proportional to average culm height.

The Maine *S. patens* (Fig. 1A) experienced an accelerated culm elongation in the spring with leaf production continuing into August. *Spartina alterniflora* (Fig. 1B) manifested a concurrent decline in culm elongation and leaf production and a late-season increase in senescence and abscission rates.

The Delaware *S. patens* and *P. communis* (Fig. 1, C and D) showed similarities in elongation and senescence patterns. Dramatic seasonality of leaf abscission was absent in *S. patens*.

Table 2. Annual leaf production of individual culms (mean ± standard errors of the mean).

Species	Location	Leaves per culm
S. patens	Maine	5.4 ± 1.0
S. alterniflora	Maine	4.5 ± 1.4
S. patens	Delaware	7.0 ± 2.2
P. communis	Delaware	18.2 ± 3.5
S. patens	Georgia	9.5 ± 1.7
S. cynosuroides	Georgia	13.7 ± 4.6

Both *S. patens* and *S. cynosuroides* (Georgia) (Fig. 1, E and F) portrayed attenuated elongation rates attributable to the late start of the tagging project. *Spartina patens* showed independence of leaf production from culm elongation and no seasonal leaf abscission increment. *Spartina cynosuroides* paralleled the leaf senescence and leaf abscission rates of *P. communis*.

Spartina patens in Maine experienced minimal culm mortality until October, when 78 percent of the culms died. *Spartina alterniflora* had a 58 percent mortality rate by August and 100 percent mortality of the tagged stems by October. Analogous patterns of mortality would be expected from an annual plant. The mortality of *S. patens* in Delaware climbed to 28 percent and of *P. communis*, to 36 percent by October. In Georgia, *S. patens* and *S. cynosuroides* maintained constant mortality rates throughout the growing season, culminating at 12 and 32 percent, respectively. Constant mortality rates seemed to be a function of normal culm maturation and mortality rather than responses to environmental stimuli.

All three study areas were revisited on 26 May 1976 to determine culm survival over the winter season. In Delaware, 28

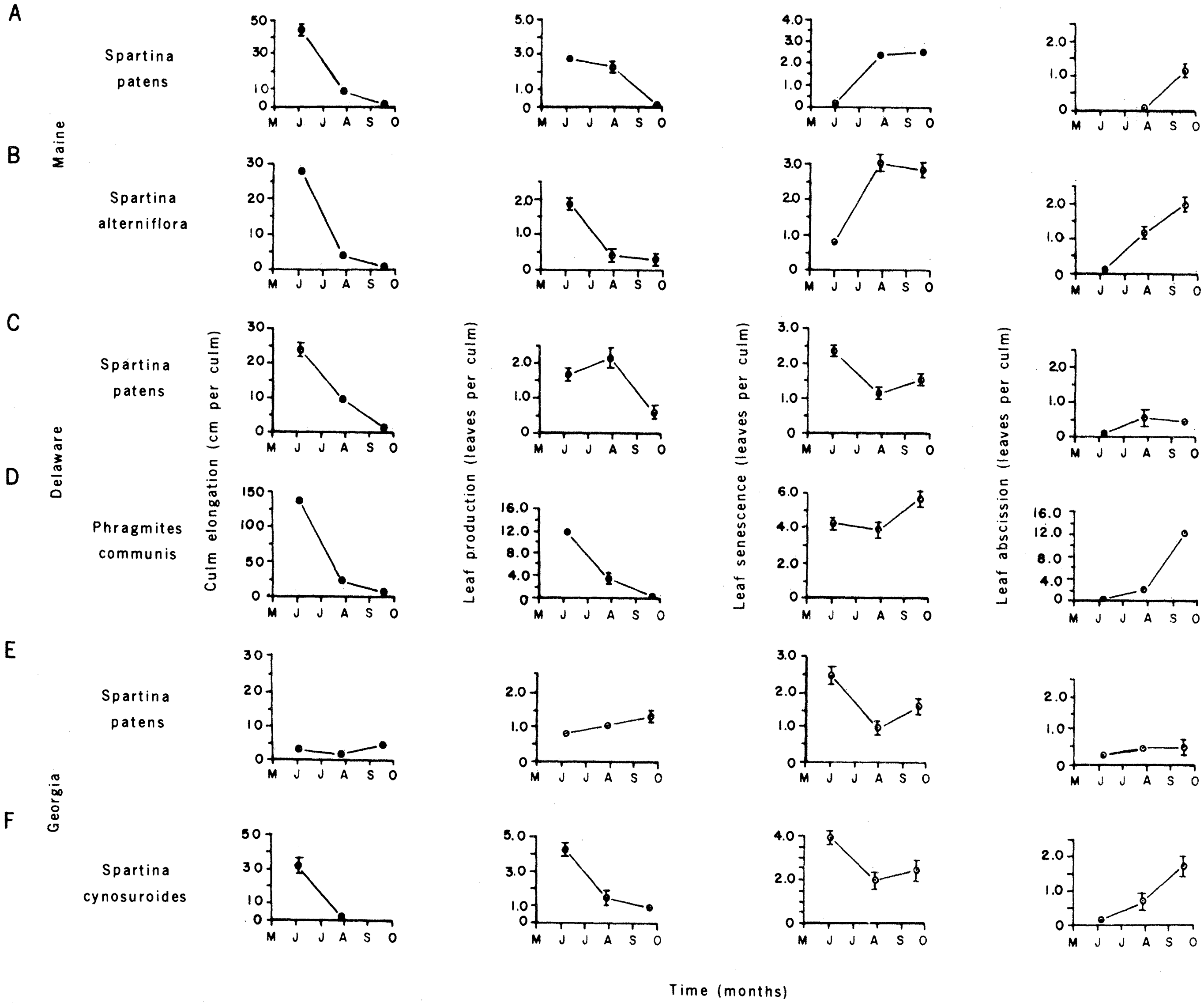

Fig. 1. Rates of culm morphology change for each species and location from May to October 1975. Each point bisects the interval with standard error bars shown wherever it exceeded the point symbol.

percent of the tagged *S. patens* from the preceding fall survived, and in Georgia, 27 percent survived. The remaining four species had no over-winter survival of individual culms. The morphology of the surviving culms differed from most stems tagged in May 1975. These culms represented a new age class having unique production and senescence rates.

The data represent one age class of individual culms from the whole plant community. Recruitment during the growing season was evident by the measurement of stem densities (*2*) from quadrat counts performed concurrent with the monitoring of tagged plants. Elongation, leaf production, senescence, and abscission-pattern similarity for the younger culms must be determined before the entire population can be characterized. For plant species that die completely over winter, the initial group of tillers is the most important with respect to ultimate productivity. *Spartina patens* from Delaware and Georgia represent a different situation in which approximately 25 percent of the population survives to the succeeding growing season. The problem of assessing annual primary productivity is complicated by this carry-over of material. The importance of studying individual culms is essential to an understanding of the spatial and temporal variation in overall community production.

Estimates of leaf-abscission and stem-mortality time and numbers indicate some independence of primary productivity from peak standing-crop biomass. The importance of plant biomass additions before peak standing-crop biomass has been suggested (*5*). Attempts to quantify the primary production using the midseason addition would require biomass measurements of each dead leaf and each dead culm of various heights. Calculation of rates of turnover from live to dead standing crops would enhance and validate traditional harvest methods. Geratologic studies of plant tissue within a plant community varies spatially and temporally, demonstrating the need for specific rate measurements for each community.

The continual addition of plant tissue to the marsh system by individual culms indicates the independence of peak standing crop biomass from annual primary production. The effect was more pronounced in the southern latitudes where seasonal climatic changes are less abrupt in controlling plant growth and senescence. The carry-over of plant tissue from the previous year and the production of leaves after cessation of culm elongation in *S. patens* further substantiated the continuum of plant tissue losses.

The dependence of leaf production on culm elongation was evident for *S. alterniflora*, *P. communis*, and *S. cynosuroides*. The similarity of the seasonal pattern of leaf senescence in Delaware and Georgia suggests climatic control of this process. High spring senescence rates were not met with immediately increased abscission rate; rather, a time lag of varying duration existed. Plants with a culm longevity of 1 year had increased mortality rates near winter, and plants with a culm longevity exceeding 1 year had constant seasonal mortality rates.

Each of the growth processes dictates the time and quantity of tissue transition from live to dead and the addition of detritus to the estuarine food web. Residence time of leaves, continual culm mortality, and pulses of detritus export are species dependent and constitute the essential processes controlling primary production that ultimately dictates the value of each plant species to the ecosystem.

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6. Supported by the Office of Dredged Materials Research, U.S. Army Engineer Waterways Experiment Station, Corps of Engineers, Vicksburg, Miss., under contract DACW 39-73-C-0110. We especially thank Dr. J. L. Gallagher and R. A. Linthurst for their contribution to the tagging study. We also thank W. B. Kinter, K. S. Price, and H. Church for logistic support.

25 April 1977; revised 22 June 1977

The Charnockite Geotherm

Abstract. *Charnockite, a hypersthene-bearing granite, and other associated rocks of the charnockite series have a global distribution. These rocks, according to evidence from mineral-chemical and experimental phase equilibrium relations, formed or recrystallized at temperatures between 800° and 900°C and at relatively shallow depths of 6 to 12 kilometers. This evidence indicates the existence of geothermal gradients of 70° to 100°C per kilometer probably at various times, the latest being around* 1300×10^6 *years ago.*

Charnockites are granites containing hypersthene $(Mg,Fe)SiO_3$. Generally they occur in association with rocks or other bulk compositions, and the name "charnockite series" is used for the group of rocks that is related in time and space. In this report I demonstrate that rocks of the charnockite series have formed in chemical equilibrium and provide information on the pressure and temperature of formation. The results may have an important bearing on models of the thermal evolution of the earth.

Charnockites occur in many parts of the world (*1*); they are generally closely associated with metamorphic rocks of the granulite facies and anorthosites. Figure 1 shows the distribution of charnockites and of the rocks of the granulite facies (*2*). However, on the basis of this map, it should not be inferred that charnockites are related in space since they are much older than the time when the breakup of the Pangaea began [200×10^6 years before the present (B.P.)] and the configuration of the continents at that time is unknown.

Petrologists generally agree that charnockites are metamorphic rocks which could be of either sedimentary or igneous origin (*3–5*). Hubbard (*5*), for example, has described the in situ charnockitization (*6*) of sedimentary rocks in the Varberg area of Sweden. On the basis of extensive fieldwork, he has distinguished these rocks from a separate charnockite-granite association that is clearly of igneous origin (*7*). Similar field relationships in the occurrences of charnockites have been described from many parts of the world.

The chemical composition of coexisting phases in a rock can be used both to demonstrate the approach of a system to chemical equilibrium during recrystallization (*8*) and to estimate the pressure and temperature of crystallization of the phases (*9*). According to chemical thermodynamics, the distribution of two components A and B in coexisting binary solid solutions α and β, which equilibrated at a certain pressure and temper-