posited and hence Al at the rim is being used up. Thus r [which is proportional to the melt Al at $R(t)$] drops. This proceeds until point b is reached. Then Al decreases further at $R(t)$, causing a jump down to point c. Now a growth more rich in Ab occurs, and hence the amount of Al can increase since less Al is being used up; but the crystal is still advancing, pushing the excess Al ahead of it. This continues until point d is reached, at which time a jump to point a occurs, completing the cycle.

This qualitative description was verified (see Fig. 2a) by means of a numerical simulation of the Stefan problem with the phenomenological laws given above. The numerical simulation was carried out by discretizing Fick's law and the equation of motion for the rim. The values of $A^{\cdot}$ and $S^{\cdot}$ ($x \gg R(t)$) were chosen consistent with data from whole rock samples wherein zoning of plagioclase was observed. The discontinuities in the solid composition profile correspond to the jumps $b \rightarrow c$ and $d \rightarrow a$ of Fig. 1. Before the oscillations set in, there is—as in naturally occurring plagioclase samples—a "normal trend" wherein f decreases monotonically.

For a second example we take the expression for $N(f)$, $B(f)$, and $C(f)$ as above but choose $C(f)$ via the parameters given in the legend to Fig. 2b. A transient oscillatory zoning situation is produced (Fig. 2b), as is commonly observed.

With our model for crystal growth from the melt it is possible to quantitatively simulate the oscillatory zoning which occurs naturally in plagioclase feldspars. Oscillation is found to result from the interplay of the following factors: (i) the dependence of the growth law on melt and solid surface composition, (ii) the stoichiometry of the solidification reactions, (iii) the diffusion of melt species, and (iv) the motion of the growing crystal rim. The particular dependencies of the growth law on solid surface and melt composition were based on a number of reasonable conjectures. However, this facet of the approach can only be put on a more solid foundation when more complete experimental growth data are available. Our goal here was to show that the phenomenon can indeed be explained in a growth kinetic-diffusion model. Furthermore, the detailed form of the growth rate law is, from the above qualitative description based on Fig. 1, not expected to be crucial for our theory (although it can clearly affect the wave form).

Oscillatory zoning in plagioclase feldspar is an excellent example of a structure that is far from equilibrium (*10*) resulting from an interplay between nonlinearity and nonequilibrium conditions. Such phenomena have been recently found in many biological, chemical, and physical systems.

C. S. HAASE*
Department of Geology, Indiana University, Bloomington 47405

J. CHADAM
Department of Mathematics, Indiana University

D. FEINN, P. ORTOLEVA
Department of Chemistry, Indiana University

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* Present address: Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tenn. 37830.

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Agrarian Potential, Population, and the Tarascan State

Abstract. *Estimates based on potential maize crops and maize consumption patterns of the 15th-century Mesoamerican protohistoric Tarascan population living within its geopolitical core (Lake Pátzcuaro Basin) indicate that this population had not maintained itself through agricultural- and lacustrine-carrying capacity alone. It was through having to obtain basic resources such as maize from outside the basin that the Tarascans developed mechanisms that formed the particular character of their state.*

In A.D. 1519, the year of the European entry into the central highlands of Mexico, much of western Mexico was dominated by an independent entity named by the Spaniards the Tarascan kingdom. Tarascan society, contemporary with the Aztec, has been compared with it in generalizations made about the evolution of the state in Mesoamerica. It has been concluded that the Tarascan political system represents a simpler form than the Aztec political organization (*1*). Such a conceptual construct has presumed a comparability in Tarascan human ecology. However, as far as we know, until now no investigators have attempted to evaluate the role played by environmental variables in the development of the Tarascan political system. We designed a project to model the protohistoric cultural ecology of the geopolitical core of the Tarascan state, the Lake Pátzcuaro Basin (*2, 3*). One part of this study has as its goal the estimation of the actual maximum population that could have been supported primarily by the local resources during the florescent Tarascan state in the last century before European contact. These figures, based on potential maize crops and maize consumption patterns (*4, 5*), indicate that the population of the Tarascan core was well above the local carrying capacity of the Lake Pátzcuaro Basin. The Tarascans of the basin obtained basic resources from outside the basin through both economic and political mechanisms that contributed significantly to the particular character of the Tarascan state.

The paleoecological reconstruction for the protohistoric period shows a slightly wetter, perhaps warmer, climate associated with a lake level about 15 m higher than the present (*3, 6*). When the climatic data are combined with data on water resources, it has been possible to determine broad classes of agricultural land (Table 1). As the modern agricultural land classes are based on studies of land subject to simple hoe and plow cultivation, with no systematic use of fertilizers and with traditional varieties of maize and beans, it is believed that these broad classes are applicable to the protohistoric period. Thus, we have projected the nature and extent of agricultural land classes during the protohistoric period by combining the protohistoric distribution of soil and water resources with information on the nature and distribution of modern land classes (Fig. 1). Class I land includes permanently and seasonally irrigated ground on the most fertile land of the basin (*7*). Class II land includes the floor of the basin and the small alluvial basins of the sierra cultivated by rainfall agriculture. Class III land includes the lower and upper mountain slopes with thin soils and long frost seasons (*8*). In the protohistoric projection (Table 1) the upper slopes and alpine zones have been considered nonagricultural. At least portions of these zones are documented for the early Hispanic period as nonagricultural, and their recent use for pasture and cultivation has produced severe soil erosion. The projection incorporates both known utilization and ecologically sound land use strategy.

In order to determine the maize-carrying capacity of the basin, two other classes of information are needed: maize productivity per hectare for each agricultural land class and per capita consumption of maize. We determined the productivity and fallow cycle for land class (Table 2) by averaging ethnographically recorded harvests (*9*). These figures reflect no substantial use of either natural or artificial fertilizers. We have assumed in this analysis that soil fertility has not changed substantially since the 16th century, that plow technology used in some parts of the basin does not basically alter productivity, and that the fallowing cycles of this century can be projected into the protohistoric period (*10*).

The per capita consumption of maize in this century is known from several studies within the basin (*4, 5*). The average daily intake is reported to be 700 g, although Brand (*4*) found variations from 700 g per person per day in the hamlets (ranchos) to 560 g per person per day among the urban lower class. The lower figures represent diets that are either calorically deficient or supplemented by wheat intake (as bread). In a diet of 80 to 85 percent maize, as is ethnographically recorded for at least the last 40 years, an intake of 700 g per person per day provides a reasonable diet of 2400 calories per day.

Thus, with an adequate maize intake by the entire population (700 g per person per day or 255.5 kg per person per year), with full fallowing of the agricultural land and with a nondegrading land use strategy (that is, the upper slopes and alpine slopes projected as forest) and with the most productive soils covered by a higher lake level, the maize production potential is approximately 10,421,200 kg/year, supporting a population of 41,000 persons.

Our estimates of the actual protohistoric Lake Pátzcuaro Basin population show it to have been considerably over 41,000. On the basis of historical and archaeological data, we recorded 92 settlements for the early Hispanic period (A.D. 1520 to 1550). Population size and function were found for 40 of these settlements and function for almost all of the other 52. The 40 settlements fell into five distinctive nonoverlapping population size-function categories: category I, 25,000 to 30,000; category II, 3,000 to 5,000; category III, 1,000 to 1,500; category IV, 100 to 500; and category V, 30 to 80. The 52 other settlements were placed into these five categories on the basis of documented function. In this way the 92 settlements of the early Hispanic period were classified and their population sizes determined. To project the population of the protohistoric period settlement, we also used data on population per settlement in the basin for modern periods (1940 to 1945 and 1970 to 1975) on the assumption that there are similarities in the way any agriculturally based complex society will organize itself in the basin. The population size-function categories for the modern periods were found to be the same five categories as those determined for the early Hispanic period. (The number of settlements in each category differed in each period, however.) The three sets of figures (for 1520 to 1550, 1940 to 1945, and 1970 to 1975) were used to project by linear regression the figures for the protohistoric period. These were adjusted on the basis of available primary data for the protohistoric period (*11*). The results are as follows: category I, 1 settlement; category II, 3 settlements; category III, 22 settlements; category IV, 40 settlements; and category V, 25 settlements. These categories give a minimum total population of 60,750 and a maximum to-

Table 1. Lake Pátzcuaro Basin: land use. Numbers are from planimeter measurements of data plotted from aerial photographs (1942, 1974) and field observation (1976 to 1977) and adjusted for geomorphic and hydrologic conditions associated with the protohistoric lake level.

Land class	Land use (ha)	Land use (%)
Agricultural		
Class I land		
Permanent irrigation	321	0.34
Seasonal irrigation	212	0.23
Total	533	0.57
Class II land		
Lakeshore (less class I)	10,807	11.6
Alluvial basin	1,115	1.2
Total	11,922	12.8
Class III land		
Lower and upper slopes	29,600*	31.9
Forest		
Lower and upper slopes, alpine	36,045†	38.8
Tule-reed marsh	1,190	1.3
Open water	13,600	14.6

*Only lower slopes zone projected. †Upper slopes plus alpine less alluvial basins.

Table 2. Maize productivity.

Agricultural land class	Productivity (kg/ha)	Fallow cycle
Class I, permanent irrigation	2200	No fallow
Class I, seasonal irrigation	2000	No fallow
Class II	1000	1 of 2 years
Class III	450	1 of 2 years with alternation of maize and beans; effective maize yield is 1 in 4 years

Table 3. Protohistoric population potential based on varying consumption and land use.

Land use	Consumption rates of 255.5 kg per person per year	238 kg per person per year*	160 kg per person per year
Full fallow (see Table 1)	41,000	44,000	65,000
Reduce fallow	54,000	58,000	86,000
Reduce fallow and use half forest land	62,000	66,000	98,000

*This figure is an average of 248 for commoners and 146 for the elite.

tal population of 105,000. Therefore, the population for the protohistoric period is estimated at 60,000 to 100,000 (*12*).

Table 3 summarizes the supportable populations under variable conditions of land use, fallow schedules, and consumption patterns. These represent options available during the protohistoric period based only on the resources that were available within the basin. Unlike the case for the Basin of Mexico where the Aztec civilization flourished, strategies of agricultural intensification such as extensive terracing, extensive irrigation, or chinampa production may not have been ecologically feasible in the Lake Pátzcuaro Basin and in any case were not chosen. Reducing the fallow cycles would have added an additional 3,300,000 kg of maize that could have supported 13,000 to 21,000 more people depending on per capita consumption. However, this option would have had negative effects on long-term productivity.

If additional forest land were brought under cultivation, the base figure would rise by another 8,000 to 12,000 persons. Although this is a commonly chosen option among agriculturalists, in the Lake Pátzcuaro Basin markedly decreasing productivity of these soils would have been an increasingly inefficient and "costly" solution. In addition, it would have meant decreasing the size of the important forest zone. Forest resources, both wild animals and wood products, were extremely necessary to the Tarascans as building materials, food, religious offerings, and fuel (*5*). Economically, that ecological strategy would have only served to substitute one valued resource for another.

Lower consumption levels, a current adaptive strategy, would have allowed the support of up to 50 percent more people. Consumption at 160 kg per person per year is recorded for the modern Basin of Mexico, although for a diet of 80 percent maize this would be an average of 1800 calories per day, currently considered highly deficient in a nonindustrial agricultural society. The urban lower class in the Lake Pátzcuaro Basin today consumes at least 204 kg per person per year (*4*); this result suggests that the population of the Pátzcuaro region has had relatively high maize intake or that the figures for the Basin of Mexico reflect unusual stress.

We suggest the latter, and, although we have included the low-intake diet as an option in Table 3, we doubt that it ever reflected a Pátzcuaro regional pattern. Ivanhoe (*4*) used Aztec tribute records to reconstruct actual dietary patterns of the early 16th century. If we use his figure of 248 kg per person per year (very close to the ethnographic figure of 255.5, used above) for the commoners and 146 kg per person per year for the elite (who constituted 10 percent of the population and whose diet was only 54 percent maize), we find that a somewhat higher population could have been supported.

Although all these figures are approximate, they do suggest a pattern of population-environment relations. Optimal land use and consumption rates would have supported 40,000 to 50,000 persons in an average year. The estimated population of the basin in A.D. 1519 is between 60,000 and 100,000. This means that the population was between 10,000 and 60,000 over the carrying capacity. The only ecologically sound, long-term solution, in view of the known technology, was to import maize into the region.

There are two mechanisms by which

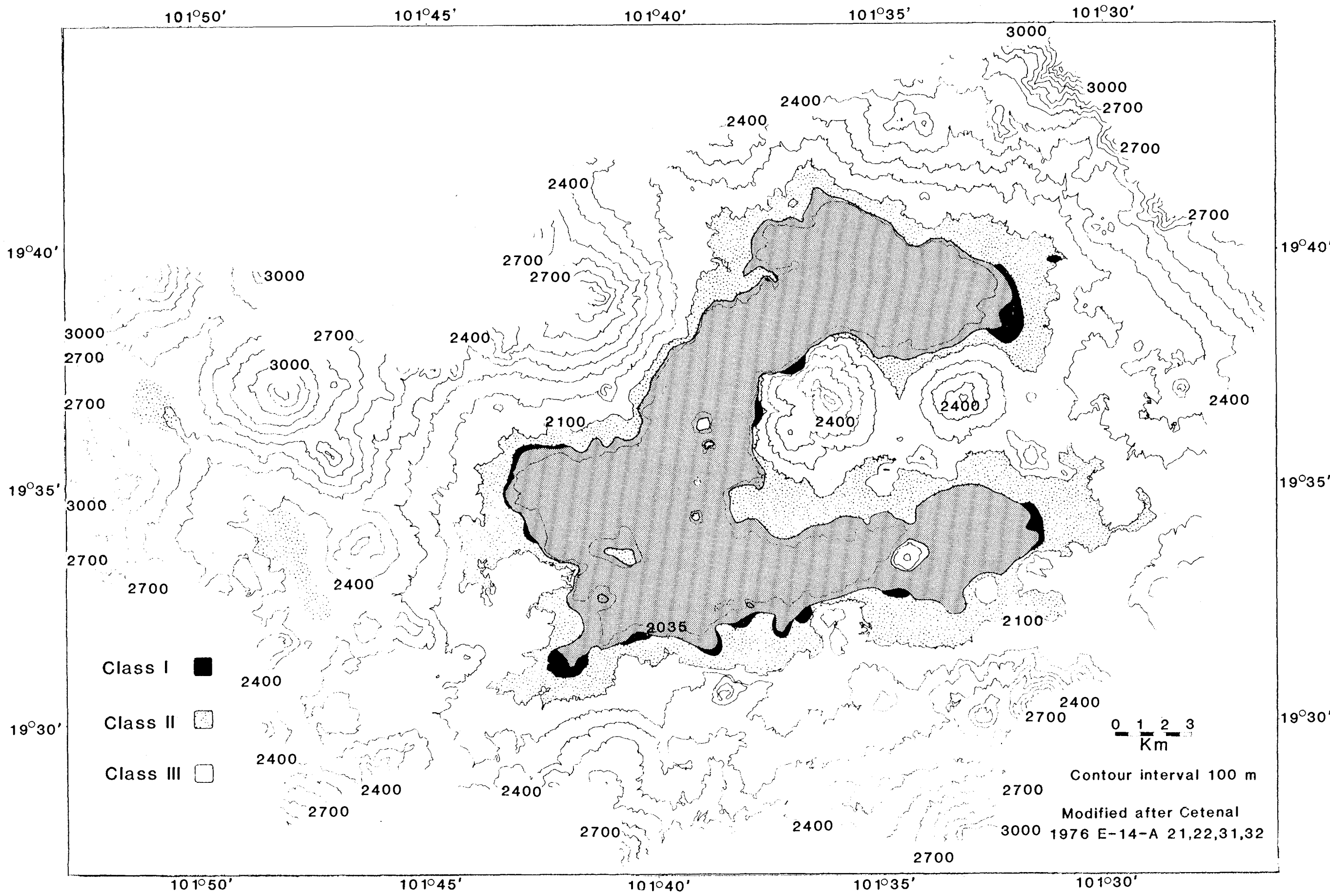

Fig. 1. Agricultural land classes of the Lake Pátzcuaro Basin, Michoacán, Mexico: protohistoric (projected). The inner fine line represents the present lakeshore, and the outer heavier line represents the higher protohistoric lakeshore.

maize came into the Lake Pátzcuaro Basin, through tribute and through market exchange. Tzintzuntzan was the center of a tribute network that covered the entire Tarascan territory. Except from zones of unusual resources (such as near the copper and silver mines), a major item of tribute was maize. Maize was used for religious offerings and state gifts, and also to maintain the army and the king's household. The amount of maize obtained in this way was apparently insufficient to maintain the Lake Pátzcuaro Basin population, and residents are known to have traveled outside the basin to exchange lake products for maize (*5*). This exchange of maize for lake products demonstrates not only the need for maize from outside the basin but also indicates that a significant proportion of the maize exchanged in the Pátzcuaro markets of Tzintzuntzan and Pareo also must have come from outside the basin.

Tzintzuntzan was both administrative and market center for the Lake Pátzcuaro Basin. In wielding power not only on behalf of the city of Tzintzuntzan but more importantly on behalf of the Lake Pátzcuaro Basin, the governing elite developed and intensified Tzintzuntzan's centralizing political functions which they used in widening their economic and political base in the Tarascan kingdom. In the development of these functions, Tzintzuntzan differed from the florescent Aztec capital of Tenochtitlán, in part because of ecological differences between the Lake Pátzcuaro Basin and the Basin of Mexico. For these reasons, understanding the development of the Tarascan political system is important for understanding the evolution of state systems in Mesoamerica.

HELEN PERLSTEIN POLLARD
Department of Anthropology,
State University of New York College,
Plattsburgh 12901

SHIRLEY GORENSTEIN
Department of Anthropology and
Sociology, Rensselaer Polytechnic
Institute, Troy, New York 12181

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13. This research was supported by the National Science Foundation (grant BNS 7609556) and the National Endowment for the Humanities (grant RO-25159-76-803). We also acknowledge the aid and cooperation of G. García Cantú, director of the Instituto Nacional de Antropología e Historia.

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Saturn's E Ring Revisited

Abstract. *Saturn's E ring is revealed by image processing of direct photographs of the 1966 edge-on presentation of the planet's ring plane. Two different techniques were used: scanning with an image quantizer operated in the derivative mode and computer-enhanced background subtraction from digitized images.*

The current edge-on presentation of Saturn's ring plane and the recent Pioneer 11 encounter have caused renewed interest in the E ring, which is external to the planet's visible rings. The existence of a ring extending to twice the diameter of the A ring was first reported by Feibelman (*1*) during the last edge-on passage (1966 to 1967). A somewhat similar report was given by Kuiper (*2*) in 1974. Originally called the D ring, and variously referred to in the literature as the D^1, E, or Z ring, it has now become established as the E ring.

The optical thickness of the E ring, derived from the 1966 Allegheny Observatory (University of Pittsburgh) photographs, was estimated by Smith *et al.* (*3*) to be 10^{-6} to 10^{-7}. Although the imaging photopolarimeter on the Pioneer 11 spacecraft did not detect the E ring directly because of its faintness, its existence was inferred from particle measurements (*4*), trapped radiation data (*5*), and magnetosphere measurements (*6*).

Because of the difficulty of presenting very faint images in halftone reproductions, the original photographs of the 1966 observations were never published, but microdensitometer scans derived from them were shown (*1*). Recently, two different methods of image processing were applied to the 1966 photographs in order to enhance the faint image of the E ring (Figs. 1 and 2). Figure 1A, a 30-second exposure taken on 27–28 October 1966, shows the visible rings edge-on; Fig. 1C, a 2-minute exposure taken on 14–15 November 1966, shows four satellites west of Saturn and two east of Saturn (additional satellites were photographed outside the field shown); and Fig. 1E shows a 30-minute exposure, also taken on 14–15 November. All prints were enlarged to the same scale. Figure 1, A, C, and E, shows $\times 5$ enlargements that were scanned 1 : 1 by means of a Tech/Ops image quantizer operated in the derivative mode to enhance edge contrast. The scanning aperture, referred to the original negative, was 25 by 25 μm (width and height). The resulting patterns are presented in Fig. 1, B to F. Figure 1G is identical to Fig. 1F, but was scanned in the reverse direction. In addition to the overexposed disk of the planet, a straight line is seen extending to the west of the planet on the 30-minute exposure taken on 14–15 November (Fig. 1, E to G). The line extends to roughly twice the diameter of the visible rings shown in Fig. 1A, and is interpreted as being the E ring.

The second method for image en-

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