The Social Process of International Migration

DOUGLAS S. MASSEY AND FELIPE GARCÍA ESPAÑA

The social process of network growth helps to explain the rapid increase in the migration of Mexicans to the United States during the 1970s. Migrant networks are webs of social ties that link potential migrants in sending communities to people in receiving societies, and their existence lowers the costs of international movement. With each person that becomes a migrant, the cost of migration is reduced for a set of friends and relatives, inducing them to migrate and further expanding the network. As a result of this dynamic interaction, network connections to the United States have become widespread throughout Mexico, and the probability of international migration from that country is high.

THERE HAS BEEN A SUBSTANTIAL REVIVAL OF IMMIGRATION to the United States in recent years. Between 1970 and 1980, 4.5 million legal immigrants (*1*) and at least 2 million undocumented migrants (*2*) entered the United States. The largest single contributor to both flows was Mexico, especially after 1965 (*3*). The gross number of legal Mexican immigrants increased from 258,000 between 1965 and 1970 to 382,000 between 1975 and 1980 (*1*). Undocumented migration also increased, but the extent of the increase is a matter of some debate. Lower bound estimates are that net undocumented migration from Mexico rose from 114,000 persons between 1965 and 1970 to 559,000 between 1975 and 1980 (*2*). Between 1980 and 1983, at least 400,000 Mexican migrants entered the United States (*4*).

The persistence of a sizable wage gap between Mexico and the United States contributes to the large-scale movement northward from Mexico. This economic fact alone cannot explain the spectacular growth of migration between the two countries, however. The volume of Mexican migration to the United States is not strongly related to fluctuations in relative wages (*5–7*), and the upswing of migration in the 1970s occurred in spite of falling real wages, rapid inflation, and high unemployment in the United States and increasing wages and relatively low employment in Mexico (*8*).

Part of the increase in migration from Mexico to the United States reflects the expansion of employment opportunities in the American Southwest, especially in services, light manufacturing, and construction, which occurred despite the national recession of the 1970s (*9*). The increase in Mexican migration, however, is also related to another, more social, trend involving the growth of migrant networks. A migrant network is a web of social ties that links potential migrants in sending communities to people and institutions in receiving areas. The emergence of a well-developed migrant network dramatically lowers the costs of international movement and gives a powerful momentum to the migration process.

D. S. Massey is professor of sociology at the Population Research Center, University of Chicago, Chicago, IL 60637. F. García España is a doctoral candidate in the Graduate Group in Demography, University of Pennsylvania, Philadelphia, PA 19104-6298.

Networks and the Costs of International Migration

In formulating strategies to confront an uncertain economic environment, families in developing countries consider the costs and benefits of different activities that their members might pursue, one of which is foreign labor. The expected costs of international migration include costs of transportation, income forgone while making the move, and the psychological toll of moving to a foreign country. Expected returns include nonmonetary satisfactions such as political freedom and family reunification, but for Mexican migrants the most important returns are usually economic: the higher wages to be earned by working in a richer economy. When the net returns to international migration are perceived as greater than those of local employment or internal migration, one or more family members will probably migrate abroad for work.

Within the theoretical tradition of human capital theory (*10*), migration may be thought of as a form of investment in human productivity, which, like all forms of investment, has costs and returns (*11*). Potential migrants and their families try to anticipate these costs and benefits in deciding whether to migrate. For a time horizon from $t = 0$ to n, the costs and returns to migration can be described by the balance equation

$$ER(0) = \int_0^n [P_1(t)P_2(t)\Upsilon_d(t) - P_3(t)\Upsilon_o]e^{-rt}\,dt - C(0) \qquad (1)$$

where $ER(0)$ stands for the net return to international migration expected just before the planned departure at $t = 0$ (*12*). Net return is a function of seven basic factors that are considered in deciding whether or not to migrate, the first three of which determine the expected gain to be achieved from foreign labor. $P_1(t)$ is the probability of evading deportation from the destination country at different points during the migrant's stay; for the legal migrants, it is always 1.0, whereas for undocumented migrants it varies between 0 and 1.0. $P_2(t)$ is the probability of holding a job in the destination country at time t, which is roughly indicated by the period employment rate. $\Upsilon_d(t)$ is the income that a migrant can expect to earn while working in the country of destination, typically an extrapolation of current average earnings over the interval $t = 0$ to n (minus penalities incurred in the event of deportation).

Balanced against these expected gains are the expected returns from other activities. In reality, various alternative activities are considered, but for simplicity we consider only the option of remaining at home (*13*). $P_3(t)$ is the probability of being employed in the home community during the period $t = 0$ to n; $\Upsilon_o(t)$ represents expected earnings within the community of origin at different points in time. The net gain in earnings expected from international migration is the difference between the earnings that could be earned at home and those expected from abroad summed over the time horizon and discounted by a factor r, which reflects the greater utility of money in the present than in the future. In

figuring these benefits, of course, it is the perceived values of parameters and variables in Eq. 1 that matter. If someone believes that good jobs are available at high wages in the United States but not in Mexico, that person will tend to migrate, regardless of actual conditions.

In studying the migration decision, research has focused mainly on factors related to expected earnings. Studies have considered the influence of relative wages and unemployment rates in Mexico and the United States (*5–7*) and have examined the effect of individual and household characteristics on migrant earnings (*14–16*). Recent research has used econometric techniques to estimate the earnings that migrants would have received if they had stayed at home (*17*). Less attention has been paid to the expected costs of migration, $C(0)$.

The perceived costs of international migration are determined not only by distance, transportation technology, and transit fees but also by social and economic structures that provide a context for decision making. Migrant networks are an important element of social structure that strongly influence the perceived costs of international movement. Migrants and nonmigrants are enmeshed in a complex web of interpersonal ties that transcend the international border. They are connected to one another through a dense network of reciprocal social relationships that carry mutual obligations of assistance and support. In the Mexican context, migrant networks are forged from the ties of kinship, friendship, and *paisanaje* (*18*). When a nonmigrant has a friend, relative, or *paisano* who has been to the United States, the potential costs of international migration are lowered because he or she is able to draw upon obligations implicit in these relationships to acquire assistance in migrating abroad.

The basic cost facing a potential migrant is the direct monetary outlay required to move between Mexico and the United States, which includes transit costs, money paid for food and lodging while looking for work, and, in the case of undocumented migrants, fees paid to guides who arrange surreptitious crossings of the border. Mexican migration is highly circular, and migrants often make regular trips back and forth, often in their own vehicles (*19–21*). For a new migrant, transit costs are sharply reduced by sharing a ride with an experienced migrant who is returning to the United States. Border-crossing fees are also lowered by network ties if, through an experienced migrant, a new migrant is able to locate a cheap and reliable guide. Experienced migrants may even guide friends or relatives across the border themselves, eliminating border-crossing fees entirely. The expenses of food and rent are also minimized by traveling with an experienced migrant and sharing costs or by staying with a friend, relative, or *paisano* who has settled abroad.

Network connections to inactive migrants living outside the United States also have the potential to lower the costs of migration. Although transit fees must be borne in full by the individual, the direct costs of international movement may be reduced to the extent that former migrants can provide novices with valuable knowledge that permits cost-saving shortcuts. Migrants who have been to the United States once or twice know the names of cheap and reliable border guides; they have the addresses of friends, relatives, and other *paisanos* with whom others might stay. They can also provide references to possible employers, as well as information about places to eat and shop, apartments or rooms to rent, and busses to take. They may even provide undocumented migrants with information about how to avoid apprehension and what to do when deported. This information reduces the cost of getting established and living in the United States.

Opportunity costs are a second kind of cost incurred in international movement. They consist of the earnings that a migrant forgoes while moving, searching for work, and learning a new job. Opportunity costs are lowered by shortening the length of time between leaving work in Mexico and securing full-time employment in the United States. Part of this effect is measured theoretically by P_2, the probability of getting a job, but in practice period employment rates do not fully capture opportunity costs. A network connection to an experienced migrant significantly shortens the interval between departure and employment. Through a friend or relative's connections in the United States, a job may be arranged before departure or shortly after arrival. Even if a job cannot be arranged in advance, experienced migrants can provide specific job leads that shorten the length of the job search. If a potential migrant has a connection to a friend or relative who lives abroad, then guaranteed food and lodging permit him or her to devote full time to securing employment rather than to finding a place to stay.

Psychic costs are the last cost category in the balance equation, representing the psychological toll of adjustment to a foreign culture and society, which may be considerable, especially if the migrant is undocumented. The greater the social and cultural distance between two countries, the greater the psychic costs of migration. Network connections reduce these costs because experienced migrants know people living in Spanish-speaking enclaves in U.S. towns or cities, and through them entree can be arranged. Incorporation into the expatriate community greatly reduces the sense of dislocation and vulnerability for new migrants, providing them with a secure and familiar environment within which to arrive, adapt, and find work. Blending into the larger Hispanic community also mitigates the fear of apprehension and deportation for those without documents.

In summary, network connections to experienced U.S. migrants can significantly lower the direct, opportunity, and psychic costs of international movement, represented collectively by the cost factor $C(0)$ in Eq. 1. Networks also affect the returns to migration through their impact on the probability terms P_1 and P_2, substantially raising the probability of employment in the United States and increasing the likelihood that the migrant will escape arrest and deportation. Networks transmit information about employment possibilities and job openings efficiently and rapidly from the United States to Mexican sending communities. Having a tie to the migrant network thus increases the expected returns for a potential migrant by reducing the costs and increasing the gains to be achieved through foreign wage labor, tipping the balance equation decisively in the direction of international movement. These considerations are not simply theoretical possibilities. Mexican migrants report making extensive use of social ties in moving to the United States and finding work (*22*).

Networks and the Probability of International Migration

To demonstrate empirically the importance of migrant networks, we used data collected in Mexico to estimate statistical models that express the probability of U.S. migration among individuals and households as a function of network ties and a set of social and economic characteristics. Two data sets with complementary strengths and weaknesses were used. The first provides nationally representative data but contains limited information about individual migrants. The second provides considerable information about migrants but covers four nonrandomly selected communities located in two Mexican states.

The nationally representative survey is a probability sample of households in rural Mexican communities conducted in September and October of 1981 by the Mexican Social Security Institute (*23*). It covers communities of 2500 or fewer inhabitants (which contain 35% of Mexico's population), and properly weighted it is representative of all households in rural Mexico. In all, the sample covers

approximately 8000 households in 410 communities. Although designed as a fertility survey, the questionnaire contained an emigration module that solicited the age, sex, departure date, and place of residence of family members who left the household after 1976 and were living elsewhere at the survey date. From this module, households containing active U.S. migrants were identified. The module underrepresents international migration because it excludes migrants who left between 1976 and 1982 but returned before the survey date. The survey, however, was conducted during a time of year when most seasonal migrants are abroad, so that migrants who left during 1981 were relatively likely to have been counted (*24*).

The second source of data is a simple random sample of households conducted in four Mexican communities in the states of Michoacan and Jalisco, the two largest U.S. migrant–sending states (*25*). The four communities include a rural town of 6100 inhabitants, an agrarian center of 9900 people, a factory town of 9400 inhabitants, and an urban neighborhood of 4800 people. The sample was taken in December 1982, when seasonal migrants were most likely to be at home. Within each household, the survey identified all persons with U.S. migrant experience and solicited detailed information about their first and most recent trips abroad. Data were compiled at the individual, household, and community levels. Community-level data are of limited statistical value, however, because of the small number of communities studied (*26*).

These two data sets were used to study the determinants of U.S. migration by means of logistic regression analysis, which predicts a dichotomous outcome by estimating the following equation: $P = 1/(1 + e^{-\mathbf{bx}})$, where P is the outcome of interest (migrating to the United States or not), $\mathbf{x}$ is a vector of explanatory variables, and $\mathbf{b}$ is a vector of coefficients linking each variable to the predicted outcome (*27*).

Table 1. Logistic regression of selected personal, household, and community characteristics on the probability that a rural Mexican household sent one of its members to the United States between 1979 and 1981 (outcome). Dichotomous variables are coded as 1 if the household or community possessed the trait in question and 0 if not.

Predictor variable	Outcome	
	Coefficient	Standard error
Head's characteristics		
Age (years)	0.082*	0.026
Age squared (years)	−0.001*	0.0005
Education (years)	−0.068*	0.031
Farm worker (yes = 1)	−0.517*	0.116
Household characteristics		
Land owned (yes = 1)	0.077	0.211
Business owned (yes = 1)	0.052	0.164
Dependents per member (proportion)	0.092	0.271
Has 1976–79 U.S. migrants (yes = 1)	1.643*	0.221
Community characteristics		
Grades of schooling offered (number)	0.039	0.036
Transportation and communication links (number)	−0.032	0.059
Households using machinery (proportion)	−1.259*	0.297
Landless families (proportion)	−1.601*	0.741
Agrarian density (persons per hectare farmed)	−0.041	0.026
Prevailing minimum daily wage (pesos)	0.006*	0.002
1976–79 U.S. migrants (proportion)	15.936*	1.584
Agriculture only employment (yes = 1)	0.210	0.178
Indians in community (yes = 1)	−0.671*	0.320
Intercept	−4.435*	0.940
Reduction in χ^2	1987.530*	
Number of cases	7873	

*Coefficient significant at $P < 0.05$.

Table 1 presents maximum likelihood estimates for a logistic regression analysis of the national survey of rural communities. The household was the smallest unit for which data were available, so that the outcome variable is whether or not a household contained a U.S. migrant who left during 1979–81. The exercise predicts the probability that a household sent migrants to the United States as a function of the head's socioeconomic background, household characteristics, and community variables.

The choice of independent variables was limited by data constraints but was guided by economic and sociological theory (*28, 29*). Since the principal migrant in most cases is the household head, economic theory led to the selection of variables related to the head's potential productivity, such as age, education, and occupational skill. Economic theory also suggests that labor supply is governed by the balance between a household's needs and resources, so that indicators of dependency and wealth are also included. Sociological theory focuses on the social and economic context within which migration decisions are made; the analysis therefore also includes indicators of community wealth, local economic opportunity, and geographic and social isolation.

Connections to migrant networks were measured in two ways. At the household level, a network connection was indicated by the household's having a member who left during 1976–78 and was still outside the country in 1981. Such a migrant provides a great deal of social capital to other household members contemplating a foreign trip during 1979–81. The second indicator is the proportion of the population within each community that migrated during 1976–78 and was still abroad in 1981, which indicates the general availability of network connections to members of the community in 1979–81.

The results of Table 1 show that both network indicators have strong positive associations with the likelihood of migration to the United States and are highly significant statistically. Respondents from communities with a relatively large number of prior (1976–78) U.S. migrants were much more likely to send migrants abroad during 1979–81. Likewise, households containing expatriate members who left during 1976–78 were considerably more likely to send migrants abroad during the subsequent interval.

This pattern could also reflect the effect of unobserved heterogeneity in the data, involving a serial correlation between population characteristics and migration across communities. That is, places containing residents with characteristics positively associated with migration in the past will continue to have such people in the future and will continue to send migrants abroad. This interpretation is made somewhat less tenable by the fact that characteristics of migrants leaving a community tend to shift over time, becoming less selective and more representative (*22*). Nonetheless, the set of community controls is too limited to eliminate the possibility that unobserved heterogeneity accounts for the results, and it must be considered an alternative explanation.

The potential impact of networks on the probability of U.S. migration is suggested by Table 2, which predicts migration probabilities during 1979–81 for an average rural household with selected network connections. To generate these probabilities, mean values were given to all variables except the two network indicators, which were varied systematically. Assumed variable values were multiplied by the estimated coefficients from Table 1 and combined with the intercept to estimate the probabilities shown (*30*). This procedure holds individual, household, and community characteristics constant to reveal the effect of network variables by themselves.

According to the estimates of Table 2, a typical rural Mexican household in a community without migrants had a 0.015 probability of sending someone to the United States during 1979–81, other factors being equal. When prior (1976–78) U.S. migrants made up

5% of the population, this probability rose to 0.032; when they made up 10%, it climbed to 0.069. At 15% and 20% of the population, the household migration probabilities were 0.141 and 0.267, respectively. When the effect of having a migrant in the household is factored in, the probabilities rise substantially, to 0.277 in communities where prior migrants were 10% of the population and 0.459 in places where they were 15% of the population. Access to network connections in households and communities appears to effect a strong increase in the likelihood of migration to the United States from Mexican rural areas.

This finding is corroborated by Table 3, which repeats the analysis using data from the four local communities. In contrast to the preceding analyses, this equation uses individuals as units of analysis. It predicts whether or not males aged 15 to 64 migrated to the United States at any time during 1980–82. Because the outcome variable includes migrants who returned as well as those who were still away, it does not understate the incidence of U.S. migration to the same extent as the preceding analyses (*31*).

A greater variety of individual- and household-level variables is available from the community samples, but only one community-level variable is included, and this indicator should be interpreted with caution because of the small number of data points. As before, the analysis includes variables related to personal productivity (age, education, labor force experience, and occupational skill) and labor supply pressures within the household (dependency, headship, and resources for local support). Network connections are measured at three levels: (i) at the individual level a connection exists if a respondent reported U.S. migrant experience before 1980; (ii) within the household a network tie is indicated by the presence of another family member with pre-1980 migrant experience; and (iii) within the community the relative number of pre-1980 migrants indicates the extent to which network ties are generally available to community residents during 1980–82. To generate more variability in the latter indicator, we expressed the number of migrants relative to the number of households rather than the number of persons, giving a variable that ranged from 0.24 to 0.67.

In each case, network connections strongly elevated the probability of migration to the United States, other factors being equal. Having migrant experience before 1980 markedly increases the likelihood that a man will go to the United States after 1980. (The effect of prior migrant experience is not entirely due to network connections, however, since knowledge and confidence also increase with experience.) Similarly, the presence within the household of another family member with prior migrant experience increases the probability of U.S. migration during 1980–82, and residing in a community with a relatively high prevalence of migrants strongly raises the probability of emigration. If the equation of Table 3 is used to generate predicted probabilities of U.S. migration in the same manner as that of Table 2, sharp increases in the probability of U.S. migration are also observed as network connections multiply.

Table 2. Predicted probability that a rural Mexican household sent migrants to the United States during 1979–81 given selected connections to migrant networks.

Presence of 1976–78 migrants in household	Proportion of 1976–78 migrants in community				
	0.00	0.05	0.10	0.15	0.20
No	0.015	0.032	0.069	0.141	0.267
Yes	0.072	0.142	0.277	0.459	0.653

Networks and Migratory Momentum

The existence of networks and their role in channeling migrants from particular origin communities to specific destination areas have long been recognized (*32, 33*). Less widely understood is how social networks dramatically lower the costs of international movement and give a powerful momentum to the migration process. Once the number of migrants reaches a critical level, expanding networks cause the costs of international movement to fall and the probability of international migration to rise; these two trends feed one another, and over time international migration becomes a mass movement involving all segments of society. Networks provide a social infrastructure capable of supporting international migration on a mass basis.

International migration may begin for various reasons. It may be initiated by private recruitment (*34*), by intergovernmental arrangement (*35*), as a response to economic dislocation (*22, 36, 37*), or as part of a conscious strategy of self-improvement by highly motivated families or individuals (*38*). In each case, a change in the status quo usually tips the balance equation in favor of movement by increasing the net returns to migration. Studies observe that, in its early stages, international migration is usually confined to some narrow segment of the population clearly distinguishable in social, demographic, and economic terms. Once begun, however, it displays a strong tendency to expand outward through the social structure (*22, 39*).

The first migrants have no social ties to draw upon, and for them international migration is a risky proposition. The first international migrants are typically not from the bottom of the socioeconomic hierarchy but from the lower middle ranges (*40*). People in these strata have sufficient resources to risk a trip but not enough local earning ability to make foreign employment unattractive. Families at the bottom of the socioeconomic hierarchy cannot afford to risk their meager resources, which are often borrowed, on a hazardous journey and an unproven economic strategy.

When the first migrants return, however, they are not the same as when they left. They have acquired valuable experience abroad, and their tastes and expectations have changed. Evidence shows that once someone has migrated internationally, that person is likely to return for subsequent trips (*21, 41*). Friends and relatives are likely to accompany repeat migrants on these journeys, since the presence of an experienced migrant substantially reduces the costs and risks of international movement, especially if it is undocumented (*19, 20*). When these new migrants return home, they also have valuable international experience and important contacts with foreign employers and institutions. And they too are likely to return with other friends and relatives.

Because of the nature of kinship and friendship structures, every new migrant creates a set of people with social ties to the destination country. Migrants are inevitably linked to nonmigrants through a network of reciprocal obligations based on shared understandings of kinship and friendship. Nonmigrants draw on these obligations to gain access to foreign employment. Once the number of migrants in a community reaches a critical level, migration becomes self-perpetuating because every new migrant reduces the cost of subsequent migration for a set of friends and relatives. By lowering the costs of migration, these people are induced to migrate, which further expands the set of people with ties abroad and, in turn, reduces the costs for a new set of people, inducing some of them to migrate, and so on. The U.S. immigration law reinforces this dynamic interaction between networks and migration because it grants immigrant visas primarily on the basis of kinship to an immigrant alien or citizen (*42*). Thus every legal immigrant admitted in a labor-certified category creates 0.6 to 0.7 new adult immigrants and an additional 0.5 immigrant children within 10 years of entry (*43*).

As the migration process develops, some migrants eventually establish roots in the receiving society and settle to form the nucleus of daughter communities (*22, 41, 44*). These communities consist of migrants from specific parent communities who have established residence in a U.S. town or city. Daughter communities develop slowly at first, but like networks they grow rapidly over time. Their emergence reinforces the operation of migrant networks by providing a stable anchor within the receiving society. A growing community of resident out-migrants provides a secure and stable environment within which new migrants arrive and adapt.

Through the progressive elaboration of migrant networks, international migration spreads throughout a sending society. Its expansion is made possible by an earnings differential, but the rapid growth of international migration is not fully explained by the earnings gap itself, which fluctuates around a trend. The probability of migration is steadily increased by the rapidly falling costs of international movement that follow from the geometric expansion of the migrant networks. Eventually, virtually all members of a sending community have access to foreign employment. For Mexicans from communities at this stage of network development, it is easier to migrate and find work in Los Angeles or Chicago than in Mexico City or Guadalajara (*19, 20, 22*).

Summary and Discussion

International migration is a social, as well as an economic, process. Networks of interpersonal relationships between migrants and nonmigrants are important social institutions that bridge the distance between sending and receiving societies, allowing families to take advantage of the economic potential created by a persistent earnings differential. Networks operate to lower substantially the direct, opportunity, and psychic costs of foreign labor, and they shift the calculation of expected net earnings decisively in the direction of international movement.

By progressively altering the social context within which the costs and benefits of migration are determined, migration feeds back on itself to become self-perpetuating. Each new migrant lowers the costs of migration for another group of nonmigrants, inducing them to take up international movement and reducing the costs for yet another set of people. Because networks persist and grow irrespective of social and economic trends, international migration acquires a strong endogenous momentum. Over time it tends to become independent of the conditions that originally caused it (*44*). International migration may be curtailed by an external shock (a depression, war, or draconian enforcement) or in the long run by a reduction of wage differentials, but in the short term it tends to be self-perpetuating. An appreciation of the social nature of immigration thus suggests that Mexican migration to the United States will persist and that it will be more difficult and costly to control than many Americans believe.

Table 3. Logistic regression of selected personal, household, and community characteristics on individual probability of migration to the United States during 1980–82 (outcome): males aged 15 to 64 years interviewed in four Mexican communities.

Predictor variables	Outcome	
	Coefficient	Standard error
Personal characteristics		
Age (years)	−0.089	0.086
Age squared (years)	0.001	0.001
Education		
1–3 years (yes = 1)	0.161	0.452
4–5 years (yes = 1)	−0.382	0.524
6+ years (yes = 1)	−0.325	0.554
Mexican labor force experience (years)	−0.068*	0.026
Prior U.S. migrant experience (yes = 1)	7.643*	1.119
Household head (yes = 1)	−0.902*	0.476
Farm worker (yes = 1)	−0.328	0.411
Service worker (yes = 1)	−0.785	0.511
Unskilled worker (yes = 1)	−1.360*	0.672
Nonmanual worker (yes = 1)	0.627	0.704
Household characteristics		
Land owned (yes = 1)	0.478	0.521
Business owned (yes = 1)	−0.362	0.447
Dependents per member (proportion)	0.806	0.874
Monthly income in Mexico (pesos)	−0.020	0.021
Pre-1980 migrants in household (yes = 1)	0.807*	0.303
Community characteristics		
Households with pre-1980 migrants (proportion)	3.124*	0.994
Intercept	−6.129*	
Reduction in χ^2	446.000*	
Number of cases	1047	

*Significant at $P < 0.05$.

REFERENCES AND NOTES

1. U.S. Department of Justice, *1985 Statistical Yearbook of the Immigration and Naturalization Service* (Government Printing Office, Washington, DC, 1986), table 1.2, pp. 3–5.
2. R. Warren and J. S. Passel, *Demography*, in press. This figure is a lower bound since it includes only those migrants who entered during the decade and remained to be counted in the 1980 census.
3. According to (*1*) and (*2*), Mexicans constituted 14% of gross legal migration and 59% of net undocumented migration during the 1970s.
4. This figure combines legal entries tabulated by the U.S. Department of Justice in (*1*) and an estimate of net undocumented migration by J. S. Passel and K. A. Woodrow (paper presented at the Annual Meetings of the Population Association of America, Boston, MA, 27 to 30 March 1985).
5. P. Frisbie, *Int. Migr. Rev.* **9**, 3 (1975).
6. J. C. Jenkins, *ibid.* **11**, 178 (1977).
7. M. I. Blejer, H. G. Johnson, A. C. Prozecanski, *Res. Popul. Econ.* **1**, 217 (1978).
8. P. Gregory, *The Myth of Market Failure: Employment and the Labor Market in Mexico* (Johns Hopkins Univ. Press, Baltimore, MD, 1986).
9. J. A. Chalmers and M. J. Greenwood, *Soc. Sci. Q.* **61**, 624 (1980).
10. G. S. Becker, *Human Capital* (Univ. of Chicago Press, Chicago, 1975).
11. L. A. Sjastaad, *J. Polit. Econ.* **70**, 80 (1962).
12. M. P. Todaro, "A Theory of Illegal International Migration from Developing Countries" (Center for Policy Studies Working Paper no. 126, The Population Council, New York, 1986).
13. For a theoretical treatment of migration that incorporates several alternative activities, see J. E. Taylor, "Differential Migration, Networks, Information, and Risk" (Migration and Development Program Discussion Paper no. 11, Harvard University Center for Population Studies, Cambridge, MA, 1984).
14. B. R. Chiswick, *J. Polit. Econ.* **86**, 897 (1978).
15. ———, in *1977 Proceedings of the American Statistical Association, Business and Economics Section* (American Statistical Society, Washington, DC, 1978), p. 222.
16. R. Morales, *Int. Migr. Rev.* **17**, 570 (1983).
17. O. Stark and J. E. Taylor, "Testing for Relative Deprivation: Mexican Labour Migration" (Migration and Development Program Discussion Paper no. 26, Harvard University Center for Population Studies, Cambridge, MA, 1986).
18. *Paisanaje* is the sharing of a community of origin, and a *paisano* is a fellow townsperson; see D. S. Massey, *Ann. Am. Acad. Polit. Soc. Sci.* **487**, 102 (1986).
19. J. S. Reichert and D. S. Massey, *Int. Migr. Rev.* **13**, 599 (1979).
20. R. Mines and D. S. Massey, *Latin Am. Res. Rev.* **20**, 104 (1985).
21. D. S. Massey, *Am. Soc. Rev.* **51**, 670 (1986).
22. ———, R. Alarcón, J. Durand, H. González, *Return to Aztlan: The Social Process of International Migration* (Univ. of California Press, Berkeley, 1987).
23. Instituto Mexicano del Seguro Social, *Encuesta Rural de Planificación Familiar, 1981* (Instituto Mexicano de Serguro Social, Mexico City, 1983).
24. Seasonal Mexican migrants tend to leave in January and February and return in November and December; see (*19–21*).
25. W. T. Dagodag, *Int. Migr. Rev.* **9**, 499 (1975).
26. A more detailed discussion of the sample design is given in (*22*).
27. E. A. Hanushek and J. E. Jackson, *Statistical Methods for Social Scientists* (Academic Press, New York, 1977).
28. For a review of microeconomic models of migration, see J. DaVanzo, in *Migration Decision Making*, G. F. DeJong and R. W. Gardner, Eds. (Pergamon, New York, 1981), pp. 90–129.
29. For a review of sociological models of migration, see R. W. Gardner, *ibid.*, pp. 59–89.
30. Following the procedures recommended by T. Petersen [*Am. Soc. Rev.* **50**, 139 (1985)].

31. The enumeration still omits families in which all members migrated to the United States during 1980–82 but did not return by December 1982 and those families that returned to a different location in Mexico.
32. J. S. MacDonald and L. D. MacDonald, *Milbank Mem. Fund. Q.* **42**, 82 (1964).
33. C. Tilly and C. H. Brown, *Int. J. Comp. Soc.* **8**, 139 (1967).
34. L. Cardoso, *Mexican Emigration to the United States, 1897–1931* (Univ. of Arizona Press, Tucson, 1980).
35. E. Galarza, *Merchants of Labor: The Mexican Bracero Story* (McNally and Loftin, Santa Barbara, CA, 1964).
36. F. Alba, *Int. Migr. Rev.* **12**, 502 (1978).
37. L. Arizpe, *ibid.* **15**, 626 (1981).
38. J. S. Reichert, *Soc. Prob.* **29**, 422 (1982).
39. ——— and D. S. Massey, *Int. Migr. Rev.* **14**, 475 (1980).
40. A. Portes, *Soc. Prob.* **26**, 425 (1979).
41. D. S. Massey, in *Immigration Statistics: A Story of Neglect*, D. Levine, K. Hill, R. Warren, Eds. (National Academy Press, Washington, DC, 1985), pp. 255–292.
42. C. B. Keely, *U.S. Immigration: A Policy Analysis* (The Population Council, New York, 1979).
43. G. Jasso and M. R. Rosenzweig, *Demography* **23**, 291 (1986).
44. D. S. Massey, *Am. J. Soc.* **92**, 1372 (1983).

The Large Crater Origin of SNC Meteorites

A. M. VICKERY AND H. J. MELOSH

A large body of evidence strongly suggests that the shergottite, nakhlite, and Chassigny (SNC) meteorites are from Mars. Various mechanisms for the ejection of large rocks at martian escape velocity (5 kilometers per second) have been investigated, but none has proved wholly satisfactory. This article examines a number of possible ejection and cosmic-ray exposure histories to determine which is most plausible. For each possible history, the Melosh spallation model is used to estimate the size of the crater required to produce ejecta fragments of the required size with velocities ≥5 kilometers per second and to produce a total mass of solid ejecta consistent with the observed mass flux of SNC meteorites. Estimates of crater production rates on Mars are then used to evaluate the probability that sufficiently large craters have formed during the available time. The results indicate that the SNC meteorites were probably ejected from a very large crater (>100 kilometers in diameter) about 200 million years ago, and that cosmic-ray exposure of the recovered meteorites was initiated after collisional fragmentation of the original ejecta in space at much later times (0.5 to 10 million years ago).

A CONSIDERABLE AMOUNT OF PETROLOGICAL, GEOCHEMICAL, isotopic, and noble gas information (*1*) strongly suggests that the shergottite, nakhlite, and Chassigny (SNC) meteorites originated on Mars. The major problem with the martian hypothesis has been the dynamic one of how large, coherent masses of rock might be launched to martian escape velocity, 5 km sec^{-1}, especially since many of the SNC meteorites show little or no evidence of extensive shock damage. This article investigates a number of possible ejection histories to find the most plausible one.

One of the most unusual characteristics of the SNC meteorites is that they are very young. The nakhlites and Chassigny have well-established crystallization ages of ~1.3 Ga (1 Ga = 10^9 years) (*1*). The isotopic systematics of the shergottites are complicated and difficult to interpret because of heavy shock damage. There is some evidence for a ~1.3-Ga crystallization age in the samarium-neodymium system (*2*), but Chen and Wasserburg (*3*) found no evidence for a 1.3-Ga event in the uranium-lead system. Rubidium-strontium and uranium-lead internal isochrons (*2–4*) give ages of 180 to 200 Ma (1 Ma = 10^6 years), which these investigators (*2–4*) believe dates the shock event. Chen and Wasserburg (*3*) interpreted the old (~4.5 Ga) rubidium-strontium whole rock ages and the differing initial lead ratios among the shergottites as indicating that they were closed systems between ~4.5 Ga and 200 Ma ago; that is, the whole rock ages are the crystallization ages. Other investigators (*5*) postulated that the shergottites crystallized as recently as 180 to 300 Ma ago. In sum, the nakhlites and Chassigny are 1.3 Ga old, and the shergottites may be the same age, much older, or much younger.

The ages of the SNC meteorites are important to the dynamic problem of the ejection of rocks from Mars because only 10 to 15% of the surface area of Mars, on which the largest crater is ~30 km in diameter, is believed to be less than 2 Ga old (*6*). Thus, if all the SNC meteorites are ≤1.3 Ga old, they must come from a restricted portion of Mars and must have been ejected from a crater or craters ≤30 km in diameter; alternatively there might be a young volcanic center in terrane that is classified as old, or the hypothesized chronology of the martian surface is inadequate. The most severe dynamic problem for a martian origin of the SNC meteorites is that shock pressures great enough to accelerate material from rest to 5 km sec^{-1} or more are generally expected to melt or vaporize the material (*7*). Melosh (*8, 9*) demonstrated that near-surface material, subjected to low shock pressures but high stress gradients, is ejected at high velocity and may be in the form of relatively large fragments. If the source crater were ≤30 km in diameter, however, the largest spall from the near-surface zone that is ejected at ≥5 km sec^{-1} would be ≤1 m in size (*10*). A study of the drag acceleration of solid ejecta by an impact-generated vapor cloud (*11*) similarly showed that the maximum size fragment that can be accelerated to ≥5 km sec^{-1} is ≤1 m. Nyquist (*12*) proposed that high-velocity, ricocheting projectile debris from a very oblique impact could accelerate entrained rocks to very high velocities, but numerical modeling of this process (*13*) showed that only small (≤10 cm) rocks lying on the surface before the impact could become entrained in the downrange jet and survive acceleration to martian escape velocity. Thus, if all the SNC meteorites are from the young terrane of Mars, they must have been ejected from a crater or craters ≤30 km in diameter, which is only possible if the original fragments were ≤1 m in diameter.

Two kinds of evidence can constrain the sizes of these original fragments. The most straightforward is based on recovered mass. Nakhla has the largest recovered mass, ~40 kg (*14*). The velocity

The authors are at the Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721.