Articles

The Impact of Foreign Graduate Students on Engineering Education in the United States

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Surveys of chairpersons and faculty members of engineering departments of U.S. universities were conducted in the fall of 1985 to examine the relation between the high proportion of foreign graduate students and the operation and quality of engineering education in the United States. Information was obtained on admissions criteria and policies, financial aid, and the performance of U.S. and foreign students as teaching and research assistants. Overall, the survey respondents believed that foreign students are an asset and that, without them, training and research would suffer. Language and communications were the problems most frequently mentioned as adversely affecting the performance of foreign students.

IN 1981, THE PERCENTAGE OF RECIPIENTS OF DOCTORAL degrees in engineering from U.S. institutions who were foreign citizens (on either temporary or permanent visas) exceeded 50% for the first time, and it has remained above that level since then (*1*). We conducted surveys to determine how the large proportion of foreign graduate students affects (i) the quality of the graduates of engineering programs, (ii) the instruction received by undergraduates (who are predominantly U.S. citizens), and (iii) the amount and character of the research produced in U.S. engineering schools.

This survey also examined the availability of financial support to U.S. and foreign graduate students and the extent to which the access of foreign students to certain kinds of research is restricted. We provide data to permit an assessment of the impact of foreign graduate students on U.S. engineering education.

Study Design

Two survey questionnaires were developed and mailed to engineering departments in the fall of 1985, one to chairpersons and the other to faculty members in engineering departments. The first questionnaire was sent to all 651 chairpersons of U.S. graduate programs that contained the words chemical engineering (ChE), civil engineering (CE), electrical engineering (EE), or mechanical engineering (ME). Of these, 441 usable replies were received (a response rate of 67.7%). The second questionnaire was sent to a stratified sample of 14.6% of all faculty within departments or other entities represented by the chairperson's questionnaire; each individual faculty member had an equal probability of being selected (*2*). In all, 1757 faculty questionnaires were mailed, and 943 usable replies were received [a response rate of 53.7% (*3*)].

The faculty questionnaire was stratified by three variables: (i) the engineering discipline, (ii) whether the university was public or private, and (iii) the quality or research intensiveness of the program (*4*). An index for the last variable was developed as follows. Two strata consisted of faculty in departments or programs that were rated in either the top (QRI-1) or the bottom (QRI-2) halves of an assessment of U.S. doctoral programs that was published in 1982 (*5*). A third stratum (QRI-3) consisted of faculty in those departments that were not included in the 1982 assessment but were listed in an American Society for Engineering Education directory of graduate programs published in March 1985 (*6*). In general, the QRI-3 schools are likely to be less research intensive than the QRI-1 or QRI-2 schools.

Chairpersons' Responses

Enrollment and financial aid. Enrollment data provided by the chairpersons indicated that during the fall 1985 term, 46.6% of the master's degree students, 53.1% of the doctoral students, and 48.8% of all graduate students were foreign students. Foreign graduate student representation was highest in CE (50.6%) and EE (50.0%); QRI-1 programs (43.7%) had fewer foreign graduate students than QRI-2 (58.4%) or QRI-3 (52.2%) programs. More than 80% of the foreign students came from East Asia, South Asia, or the Middle East; the five places of origin having the most students in the United States were (in descending numerical order) Taiwan, India, the People's Republic of China, Iran, and the Republic of Korea.

During the past 4 years (*7*), 86.5% of the departments have experienced a shortage of U.S. citizens who applied to be full-time graduate students. However, QRI-1 programs have been able to attract more well-qualified U.S. graduate students than the other programs (*8*). Over the next 4 years, 46.9% of all the chairpersons expect no change in the number of U.S. applicants, 16.4% expect fewer, and 33.9% expect more. The large proportion of foreign students is also related to the nature of the supply: 86.1% of the chairpersons reported either a surplus or an adequate number of well-qualified foreign student applicants during the past 4 years.

Only 15% of the chairpersons indicated that limits were imposed on the maximum percentage of non–U.S. citizens admitted for graduate study; the percentage of chairpersons who worked under such a policy was substantially higher (32.1%) for QRI-1 programs than for QRI-2 programs (8.4%) and more than twice as high for public (18.1%) than for private (7.1%) institutions. The mean maximum percentage of foreign students indicated for departments with such limitation policies was 31%.

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Table 1. Foreign students who received various forms of financial aid from all sources (internal or external) as a percentage of all students who received aid.

Type of financial aid	All programs (%)	QRI-1 (%)	QRI-2 (%)	Public (%)	Private (%)
Fellowships*	29.2	26.1	35.9	26.9	32.3
Research assistantships	49.0	46.5	56.1	48.5	50.4
Teaching assistantships	54.0	49.8	63.0	53.3	57.3
Tuition support	54.3	55.9	55.8	53.6	56.6
Other	57.7	49.9	77.3	55.0	68.1
Total	48.9	44.9	58.1	48.8	49.4

*Includes traineeships and scholarships (full tuition and a stipend).

A large increase in the percentage of students in EE and a decrease in CE and ChE students reflects the current job market. Thus, fewer EE (17%) than ChE (24.2%) chairpersons reported a sufficient pool of U.S. graduate student applicants to meet their needs for research assistants (RAs). However, all of the engineering disciplines have had a significant shortage.

Table 1 summarizes data on the distribution of graduate student financial aid for the fall of 1985. With one exception (full tuition plus stipend), foreign students received about half of the financial aid awards (by number; information about dollar amounts was not obtained in this instance). Foreign students in QRI-2 received more financial aid awards than those in QRI-1 departments, and more aid was provided to those in private than in public institutions.

The chairpersons were asked whether nationality was a factor in awarding financial aid. Given students judged to be of equal quality, 87.1% of chairpersons said they would prefer a U.S. citizen, 11.3% would have no preference, and 0.2% would prefer the foreign student. If the foreign student was judged to have "slightly better qualifications for graduate study than a U.S. citizen," 56.9% would still prefer the U.S. citizen, 13.3% would have no preference, and 26.5% would prefer the non–U.S. citizen.

The chairpersons ranked sources of support (based on dollar amounts) for U.S. and foreign students as RAs in the fall of 1985 (Table 2). Rankings of funding sources for research assistantships for both U.S. and non–U.S. citizens were roughly similar, although foreign sources of funding ranked fourth for non–U.S. citizens and were negligible for U.S. citizens.

Teaching assistants. Engineering schools have suffered from a shortage of full-time faculty; 59.2% of all department chairpersons reported such a shortage during the past 4 years (91.5% of EE chairpersons). About 31.6% of respondents noted that more teaching assistants (TAs) have been hired than usual and that the shortage has been met in part by hiring foreign TAs. The chairpersons reported that 46.7% of their TAs were foreign students. Only 22.6% of respondents indicated that the pool of U.S. graduate students sufficiently meets the TA needs of their departments.

Table 2. Sources of financial support in the fall of 1985 for students (U.S. and foreign) who were RAs, as ranked by chairpersons (1 indicates the largest amount of funds). Numbers may not add up to 100% because of rounding.

Sources of support	Ranked 1		Ranked 1, 2, or 3 (total)	
	U.S. (%)	Foreign (%)	U.S. (%)	Foreign (%)
In-house university funds	29.8	34.2	29.1	29.8
U.S. government funds	51.6	45.7	32.5	30.1
U.S. private foundations	2.7	0.6	8.8	5.7
U.S. corporations	12.6	9.4	26.1	19.9
Foreign sources	0.3	7.2	0.3	11.3
Other	3.0	3.0	3.1	3.1

A higher percentage (38.9%) of chairpersons in QRI-1 programs reported an adequate pool of U.S. TAs (compared with 17.1% of QRI-2 and 16.6% of QRI-3 programs). However, in QRI-1 programs more foreign TAs were used to grade examinations, lead classroom discussions, and conduct problem review sessions than in QRI-2 or QRI-3 programs (Table 3). This finding may indicate that the faculty members in QRI-1 programs tended to shift their teaching obligations to TAs more than those members in QRI-2 and QRI-3 programs did.

In 60% of the departments surveyed, foreign TAs were required to show greater proficiency in English than the minimum level required for admission (*9*). A higher percentage of public institutions (64.6%) than private ones (50.0%) required foreign students to demonstrate English language competency before becoming TAs.

Chairpersons' opinions. The administrative work associated with a foreign student was considered to be greater than for a U.S. student by 66.0% of the chairpersons; only 1.4% said it was less. Although 52.1% of the chairpersons thought that both U.S. and foreign students took about the same time to complete their degree programs, 37.8% believed foreign students took longer, and only 6.0% said the opposite. More than two-thirds (67.5%) believed that the percentage of U.S. and foreign students successfully completing their degree work was the same; in this case, more chairpersons thought that the foreign students had a higher completion rate (19.4%) than U.S. students (6.9%).

About two-thirds of the chairpersons answered "yes" when asked if the presence of foreign graduate students had any positive effects on their department; only about one-third answered "yes" when asked a similar question about negative effects. On balance, 54.2% considered foreign graduate students in their department to be an asset; only 7.9% thought of these students as a liability. Responses to an open-ended query about problems faced in dealing with foreign students indicated that language and communications are the most frequent problems, followed by difficulties with finances, academic performance, and social and cultural adjustment.

Faculty Responses

Faculty characteristics. During the past 4 years, foreign citizens were selected for 41.4% of full-time faculty appointments in the surveyed departments. The appointments in the EE departments exceeded this average (47.6%). When foreign faculty members were hired, 67.2% held temporary visas; of the engineering postdoctoral RAs, 75.1% were foreign citizens.

About 37.9% of the faculty respondents indicated that they had had special involvement in advising foreign students; 27.0% had taught abroad. Of foreign-born faculty members (30.6% of all faculty), 81.7% received at least one graduate degree in the United States, compared with 93.7% of all faculty. On average, foreign-born faculty members tended to be younger than U.S.-born (44.2 years compared with 47.5 years) and tended to be more research-oriented. Some 54.3% of foreign-born faculty had devoted more than 25% of their time to externally sponsored research over the past 3 years, compared with 41.7% of U.S.-born faculty. Almost half of foreign-born faculty (46.1%) had taught abroad, compared with only 18.1% of U.S.-born faculty.

Teaching foreign students. Most faculty members (87.3%) responded that they had similar expectations for U.S. and foreign students. Faculty respondents were aware, however, that in academic tasks that depend heavily on writing skills, substantial percentages

of those graduate students whose native language is not English do not perform as well as U.S. students (Table 4). However, few faculty members modified what they taught because of foreign students; only 10.3% tried to make teaching examples relevant to the background of foreign students. Almost all faculty (96.5%) said they used the same standards in grading U.S. and foreign students.

About 39.6% of the faculty spent more time advising or assisting a foreign student than a U.S. student, and about the same percentage (38.0%) felt that more effort was required for teaching foreign students. Some 35.4% indicated that they dealt with language problems, and 48.4% said that they made special efforts to help foreign students with oral comprehension.

About 60.6% of faculty did not favor establishing a maximum percentage of foreign students in graduate courses in order for them to teach most effectively. About 55.3% of those who favored such a limit would set it at 30%; another 37.0% would set it in the 31 to 50% range. Two-fifths of the faculty questioned had more foreign students in their graduate courses than they preferred. Yet about one-fourth of the respondents (26.4%) derived some kinds of satisfaction from teaching foreign students, such as cultural interactions, that differed from the rewards derived from teaching U.S. students.

Foreign-born faculty were more favorably disposed toward foreign graduate students than U.S.-born faculty and were more willing to help with communication and other problems faced by foreign students. Foreign-born faculty believed that foreign students were less of a burden to teach and that their handicaps were of less magnitude than did the U.S.-born faculty. Only 16.1% of foreign-born faculty, compared with 47.8% of U.S.-born faculty, claimed that the effort required for teaching a foreign student is greater than that in teaching a U.S. student. More foreign-born faculty (47.1%) than U.S.-born faculty (33.6%) had special involvement in advising foreign students, yet only 25.8% of these foreign-born faculty, compared with 43.5% of U.S.-born faculty, thought it necessary to make special allowances for the language problems of foreign students. Furthermore, compared with 44.5% of U.S.-born faculty, only 23.1% of foreign-born faculty wanted a percentage cap on the number of foreign students in graduate courses. In fact, foreign-born faculty attracted more foreign students into their courses than U.S.-born faculty. The mean percentage of foreign students in the classes of foreign-born faculty was 49.7% and in the classes of U.S.-born faculty members it was 40.8%.

Foreign students as TAs. For those faculty who reported some use of TAs, the mean percentage of foreign TAs was 53.4% (50.0% for QRI-1 programs and 59.5% for QRI-2). The overall performance of U.S. and foreign TAs was reported to be the same by 59.6% of the faculty respondents. About 32.5% thought that U.S. students performed better and 7.6% said the opposite. For many of the specific functions performed by TAs, faculty members preferred U.S. TAs to foreign TAs (Table 5), although for grading homework assignments and exams "no preference" was the most frequent response. When asked if the main problem faced by foreign graduate students as TAs was proficiency in English, 74.1% responded affirmatively. Another problem encountered more frequently by foreign TAs than by U.S. TAs was a lack of familiarity with U.S. undergraduate culture (Table 6).

Faculty in QRI-1 programs reacted somewhat more favorably to foreign TAs (only 26.9% thought that U.S. students performed better) than faculty in QRI-2 programs (in which 37.4% thought that U.S. TAs did better). Faculty respondents in private schools were somewhat more positive about foreign TAs than those in public schools. Some 73.0% of foreign-born faculty stated that the performance of foreign TAs was about the same as that of U.S. TAs;

Table 3. Percentage of chairpersons who indicated activities performed by TAs in the fall of 1985. For each entry, the percentage of all TAs is given above the percentage for the foreign TAs.

Task	All (%)	QRI-1 (%)	QRI-2 (%)	QRI-3 (%)	Public (%)	Private (%)
Giving classroom lectures	36.2 23.7	35.7 23.0	40.2 27.6	34.4 22.1	41.2 25.8	23.8 18.9
Grading homework	93.8 93.0	93.8 93.8	97.2 93.3	92.1 92.5	93.5 92.9	94.4 93.4
Grading exams	49.0 44.6	66.1 59.3	58.9 51.4	35.0 32.7	49.4 43.4	48.0 47.6
Leading discussions	32.0 24.0	43.8 35.4	34.6 24.8	24.7 17.1	33.8 25.4	27.8 20.5
Leading review sessions	65.8 56.6	81.3 70.8	71.0 60.0	55.1 46.7	65.3 55.6	67.2 59.0
Conducting laboratories	94.5 84.9	93.8 87.6	95.3 88.6	94.4 81.4	95.8 85.1	91.3 84.4
Other	14.3 12.4	14.3 11.5	14.0 12.4	14.4 12.9	13.0 12.1	17.5 13.1

Table 4. Responses by faculty on the performance of foreign students whose native language was not English as compared with U.S. students.

Task	Performed as well as or better than U.S. students (%)	Performed less well than U.S. students (%)	No judgment (%)
Homework	76.8	15.9	7.1
Examinations	71.1	23.9	4.9
Laboratory reports	25.1	45.0	29.8
Research papers	34.1	50.2	15.4
Theses	39.6	46.4	13.7

Table 5. Preference of faculty members for using foreign or U.S. TAs.

Task	Preferred foreign TAs (%)	Preferred U.S. TAs (%)	No preference (%)	Did not use TAs (%)
Grading homework	3.2	24.2	67.7	4.8
Grading exams	1.3	14.6	33.2	50.6
Giving lectures	1.0	39.3	11.7	47.4
Leading review sessions	0.8	43.0	31.4	24.8
Advising students	0.3	22.6	17.7	59.2
Conducting laboratories	1.3	46.5	36.2	15.6

Table 6. Problems encountered by faculty members more frequently with foreign than with U.S. TAs.

Responses	Problems of foreign TAs
305	They have problems communicating with undergraduates about their performance.
244	They do not understand U.S. undergraduate culture.
189	They are not familiar with academic norms, for example, concerning cheating or plagiarism.
179	They have problems telling undergraduates what is expected of them.
155	Undergraduates have complained about grades.
153	They have problems with laboratory sections.
150	Their expectations of undergraduates are too high.
124	They are too authoritarian with undergraduates.
119	Undergraduates have asked to be transferred out of their sections.
60	They are too permissive with undergraduates.
28	Their expectations of undergraduates are too low.

15.2% said the foreign students performed better; only 11.3% said they did not perform as well as U.S. TAs. This finding compares with 43.2% of U.S.-born faculty, who said that the performance of foreign TAs was not as good as that of U.S. students.

Foreign students as RAs. Faculty members reported that during the past 4 years foreign graduate students constituted 50.5% of all RAs. About 87.6% of the faculty members reported a shortage of U.S. graduate students to serve as RAs. Shortages that exceeded this level affected the QRI-2 faculty (93.2% compared with 84.0% for QRI-1) and EE faculty (89.4% compared with 82.1% for ChE faculty).

A majority of faculty (61.0%) thought that foreign students were more theoretically oriented than U.S. graduate students. As many as 66.0% of ChE faculty and 67.8% of the ME found foreign students to be more theoretically oriented, compared with 55% of CE and 57.0% of EE faculty. About 33.4% of faculty saw no real difference between the two groups; some 4.3% believed foreign students were more oriented toward practical problems. Correspondingly, faculty reported that U.S. students were more adept at such tasks as designing equipment, performing experiments, and writing research reports (Table 7). The respondents thought foreign students were somewhat better at developing analytical or conceptual models, although "no difference" was the most frequent response to this question, as it was for such tasks as recording data and using computers to analyze data.

Overall, 66.6% of the faculty respondents said that foreign RAs worked harder than U.S. RAs; 31.8% concurred that foreign students brought a fresh perspective to problems. However, 36.4% felt that foreign RAs did not know how much work was expected of them, and 31.9% of the faculty believed that it was more difficult (because of cultural differences) for faculty to establish a good working rapport with foreign RAs. Some 64.1% agreed with the statement that foreign RAs were less likely than U.S. RAs to question faculty judgment.

About 83.2% of foreign-born faculty believed that foreign students worked harder than U.S. students, compared with 57.9% of U.S.-born faculty. Only 15.8% of foreign-born faculty felt that it was more difficult to establish a good working rapport with foreign students than with U.S.-born students, compared with 39.5% of U.S.-born faculty. Again, 91.7% of foreign-born faculty responded that foreign students have played either very important or somewhat important roles in their research over the past few years; the corresponding percentage of U.S.-born faculty was 73.0%.

Overall, 79.1% of faculty respondents indicated that over the past 4 years foreign graduate students contributed in either a very important or somewhat important way to their research. Only 20.8% felt that contributions of foreign graduate students have been either not very important or not important at all. About one-fourth (24.6%) indicated that foreign students have provided ideas for research areas or problems. Only 5.2% of the faculty indicated that some of their studies had been done in the foreign student's home country.

Table 7. Responses by faculty to the question, "For each of the following, would you say that, in general, U.S. students have more of the skills needed as RAs, foreign students have more of the necessary skills, or there are no differences between the two groups?"

Task	More skills		No difference (%)	No judgment (%)
	U.S. students (%)	Foreign students (%)		
Designing equipment	63.1	3.6	23.1	9.7
Running experiments	62.2	3.4	25.0	9.4
Recording data	19.2	9.6	62.1	9.1
Analyzing data with computers	19.5	18.4	56.1	5.8
Developing models	13.5	36.3	47.3	3.0
Writing reports	72.0	3.2	23.0	1.8

More-research-intensive (MRI) faculty (*10*) tended to view foreign students in a more favorable light than their less-research-intensive (LRI) colleagues. However, the MRI group had a higher percentage of foreign-born faculty (MRI group, 37.4% foreign-born faculty; LRI, 25.6% foreign-born faculty). A higher percentage of the MRI faculty (53.3%) thought that over the past 4 years foreign graduate students had been very important in their research, compared with 38.6% of the LRI group. However, if the "somewhat important" responses are added to the "very important responses," the difference narrows to 82.8% (MRI) versus 76.0% (LRI).

Restrictions on research participation. The access of foreign graduate students to some laboratories and research projects has been restricted. Some 12.7% of faculty and 12.6% of chairpersons reported that foreign students were frequently or occasionally barred from access to laboratories, and 17.6% of faculty reported that they had been prohibited from using foreign graduate students on certain projects. Slightly more than one-fourth of the faculty said they were discouraged by outside funding sources from using foreign graduate students as RAs. However, only 8.9% of the faculty stated that these restrictions were detrimental to their research. Prohibition against the use of foreign graduate students or discouragement of their use has been more prevalent in public universities than in private ones, in EE and ME than in ChE and CE, and for MRI faculty than for LRI faculty.

About 14.2% of QRI-1 chairpersons reported restrictions on non–U.S. graduate student research participation on national security grounds, compared with 11.4% for QRI-2 chairpersons. A majority of QRI-1 schools (55.9%) would not accept classified research, compared with 36.2% for QRI-2 schools. Exclusion on grounds such as economic competitiveness and proprietary restrictions was somewhat less frequent than exclusion on national security grounds.

Conclusions

The responses provided by engineering chairpersons and faculty indicate that foreign graduate students have assumed an important role in U.S. engineering schools, given the shortage of U.S. graduate students. Foreign students were predominantly seen not only as necessary substitutes for U.S. students but as generally satisfactory substitutes. Faculty in the higher quality QRI-1 group along with more-research-intensive and foreign-born faculty were even more favorably inclined toward foreign students than the total faculty population.

In spite of the additional administrative work entailed for foreign students and the greater effort required of faculty in teaching them, both chairpersons and faculty viewed foreign graduate students, overall, as an asset. Language problems of non-Anglophone foreign students did have negative consequences for their work, both written and oral. However, if it were not for language and cultural problems, chairpersons and faculty would generally regard U.S. and foreign students as almost interchangeable. Furthermore, without foreign graduate students, faculty in engineering schools would have suffered a severe shortage of research assistants, and research productivity might well have declined sharply. Restrictions on the access of foreign students to laboratories and research projects for security reasons have so far proved detrimental to the research

efforts of only a small percentage of faculty (8.9%), but this matter requires monitoring.

There is currently little reason to be concerned about the effect of foreign students on the continuing capacity of U.S. engineering schools to provide training and produce research. On the contrary, evidence suggests that without foreign students and foreign-born faculty, U.S. engineering education would suffer considerable damage. Nevertheless, it may be desirable for universities, for broader policy reasons, to attract greater numbers of well-qualified U.S. citizens to graduate study in engineering, thereby reducing the current dependency on foreign graduate students.

REFERENCES AND NOTES

1. *Foreign Citizens in U.S. Science and Engineering: History, Status and Outlook* (National Science Foundation, Washington, DC, 1985), p. 157.
2. For details, see A. Russo ["Selection of a faculty sample for a survey of the impact of foreign graduate students on U.S. engineering education," *Report CDT-86/1* (Center for Development Technology, Washington University, St. Louis, MO, 1986)].
3. If 20 undeliverable faculty questionnaires are excluded, the response rate rises to 54.3%.
4. Differences in response rate occurred among disciplines; only 47.2% of the EE faculty responded, compared to 60.1% of ChE faculty. Of the 11 faculty strata, the fewest responses came from ChE (128). As a consequence of surveying all department chairpersons, the chairperson population in the QRI-3 category was roughly twice that of either the QRI-1 or the QRI-2 population. The smallest number of chairperson responses was in ChE (96).
5. *An Assessment of Research-Doctorate Programs in the United States: Engineering* (National Academy Press, Washington, DC, 1982).
6. *Eng. Educ.* **75** (no. 6), 324 (March 1985).
7. Several questions pertained to this time period (approximately September 1981 through August 1985).
8. The percentages of respondents who indicated either a shortage or few, if any, well-qualified U.S. applicants were as follows: QRI-1, 70.4%; QRI-2, 88.8%; and QRI-3, 90.4%.
9. Almost all the chairpersons (99%) indicated that foreign citizens are required to demonstrate proficiency in English as part of the graduate admissions process, usually by achieving some minimum grade on the Test of English as a Foreign Language, which is produced by the Educational Testing Service.
10. The MRI faculty (45.8%) are defined as those faculty members who, over the past 3 years, said that they spent 26% or more of their time on externally sponsored research. The LRI faculty (54.2%) are those who spent 25% or less of their time on externally sponsored research.

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Global Images of the Earth's Interior

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The three-dimensional maps of the earth's interior now span regions from the bottom of the crust to the inner core of the earth. Although a wealth of new information on the dynamics of the earth has been discovered, the inner core offers the greatest surprise: it appears to be anisotropic with the axis of symmetry aligned with the axis of rotation.

THE PACE OF PROGRESS IN SEISMOLOGY HAS QUICKENED recently. Thirty years elapsed between the discovery of the fluid core by Oldham in 1906 and the discovery of the inner core by Lehmann; it took another 35 years for a rigorous proof that the inner core is solid (1). Only 2 years separate the publication of the first three-dimensional maps of the upper mantle (*2, 3*) and the presentation at the 1986 spring meeting of the American Geophysical Union of two independent results on the aspherical structure of the inner core (*4, 5*). (The terms "aspherical" and "asphericity" will be used as synonymous with "lateral heterogeneity"; the ellipticity of the figure due to rotation described by the hydrostatic equilibrium theory is considered implicitly.) Studies of the earth's aspherical structure have now matured to the point where some of the results can be confirmed by independent techniques and where important conclusions can be drawn by the intercomparison of different models.

The primary reason for this rapid development was the accumulation of a sufficient quantity of high-quality digital data from two global networks (*6*) that began operation in the mid-1970s and achieved their full strength by about 1980. Theoretical developments during the last three decades provided the framework of formal analysis, and the availability of computers, including supercomputers, made feasible the handling of immense amounts of data and the large-scale calculations necessary in three-dimensional problems. Reports (*7, 8*) demonstrated that certain functionals of the earth's structure reflecting its asphericity can be retrieved and mapped on a global scale.

If the internal properties of the earth were spherically symmetric, our planet would be tectonically dead. Both short (earthquakes and volcanoes) and long time scale (mountain building and sea-floor spreading) observations indicate that this is not the case. This dynamic behavior must be driven by lateral differences in temperature and density. However, the internal distribution of these parameters cannot be uniquely inferred from observations at the surface.

The velocities of compressional and shear waves depend on temperature and composition and, therefore, density. Seismologists can determine the variations in the wave speeds. Regional studies, addressing relatively shallow structures whose tectonic nature is understood, demonstrate that the hypothesis of linking high seismic velocities with low temperatures, and vice versa, is justified. High seismic velocities have been found under continental shields, older than 1 billion years with very low heat flow, whereas the material in the vicinity of mid-oceanic ridges has very low velocities at the same

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