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PROCEEDINGS OF THE CONFERENCE ON THE CHANGING IDENTITY OF GRADUATE EARTH SCIENCE EDUCATION (ATLANTA, JANUARY 25-26, 1965).

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DISCUSSED ARE THE CHANGING IDENTITY OF GRADUATE EARTH SCIENCE EDUCATION, THE FACTORS WHICH PRECIPITATED THESE CHANGES, AND THE RESULTING PROBLEMS. THE CONFERENCE PARTICIPANTS INCLUDED EARTH SCIENTISTS WITH DIVERSE SCIENTIFIC BACKGROUNDS FROM A BROAD GEOGRAPHICAL AREA. SPECIFIC TOPICS COVERED INCLUDED--(1) PRESENT DEVELOPMENTS AND FUTURE OF EARTH SCIENCE RESEARCH, (2) GEOLOGY TODAY, ITS NEEDS, AND THE TYPES OF DEPARTMENTS THAT MAY FULFILL THOSE NEEDS, (3) SURVIVAL OF GEOLOGY, METEOROLOGY, OCEANOLOGY--DEPARTMENTS WITHIN A UNIVERSITY STRUCTURE, (4) BUILDING A GRADUATE DEPARTMENT WITH COMPLETE FREEDOM OF CHOICE AND FUNDS, (5) THE GEOLOGICAL EXPLORATION OF THE MOON, (6) THE PROBLEM OF PROFESSIONAL DEVELOPMENT, (7) THE POSSIBLE DOVETAILING OF "CLASSICAL" AND "MODERN" GEOLOGY, (8) ORGANIZING A MODERN GRADUATE PROGRAM, (9) RENOVATING A "CLASSICAL" DEPARTMENT, (10) INTERDISCIPLINARY PROGRAMS, (11) CHANGES IN GEOPHYSICS EDUCATION, AND (12) THE SMALL COLLEGE AND GRADUATE EDUCATION. AN ANNOTATED BIBLIOGRAPHY IS INCLUDED. (RS)

The Georgia Institute of Technology

Proceedings of the conference on the

CHANGING IDENTITY OF GRADUATE EARTH SCIENCE EDUCATION

Jan. 25-26, 1965/Atlanta, Georgia

Sponsored by the National Science Foundation

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Charles E. Weaver, General Chairman

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TABLE OF CONTENTS

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FOREWORD

AT GEORGIA TECH we were faced with the problem of starting a graduate program in the Earth Sciences. In trying to decide what constitutes a modern research-oriented graduate program, department heads and professors from a number of institutions were contacted. As was expected, these discussions indicated that a major change in graduate-level education is taking place. Though the direction of evolution is generally similar throughout the country, there has been relatively little interinstitutional discussion of this change and the problems involved. Many societies and committees have been concerned with updating the undergraduate Earth Sciences curriculum. But, though a much more fundamental change is taking place in graduate education, little effort has been made to specify and evaluate it.

We requested and obtained funds from the Special Projects in Science Education Section of the National Science Foundation to invite 30 Earth Scientists to Georgia Tech for a two-day symposium on "The Changing Identity of Graduate Earth Science Education." A committee consisting of Dr. E. D. Goldberg, Dr. J. R. Goldsmith, Dr. R. Siever, and Dr. C. E. Weaver was organized to plan and implement the conference. Dr. W. E. Benson of the National Science Foundation kindly acted as a consultant to the committee.

An attempt was made to bring together a group of earth scientists with diverse scientific interests and who afforded a broad geographical representation. Most of the participants are actively engaged in reorienting and revitalizing graduate education in the Earth Sciences.

About half the time was used for formal presentations and half for discussion. The entire proceedings were recorded and most of the material survived the final editing. The titles of the "formal" talks are given in the Table of Contents. The discussions had considerable

influence on the presentations; in some instances, there is little relation between the titles and the actual talks. The discussions ranged far and wide and though few, if any, problems were "solved," many were defined and evaluated. The discussion contains a wide variety of ideas concerning most of the major problems confronting present-day graduate school. Many of the participants described exciting experiments with courses, curricula and organization, that are being instigated. A number of areas peripheral to the graduate field were explored: secondary school geology courses, undergraduate training, recruiting, courses for non-majors, cluster courses, joint appointments, institutes, the role of the earth scientist in society, specialization, publicity, faculty-obsolescence, field training, new departments, astrogeology, etc.

An annotated bibliography was kindly prepared by Frank T. Dolan of the School of Information Science and is included as an appendix.

It would be presumptuous to give a consensus viewpoint in other than a very general way. Most would agree that we are on the threshold of an explosive growth in the Earth Sciences. Part of this we can claim credit for, but perhaps to a large extent it is being thrust upon us by the newly awakened interest of the physicist, chemist, engineer, the politicians, and general public in space, the oceans, water, resources, and geologic hazards. Whether we ride the tiger or hold on to its tail depends upon how thoroughly our graduates are grounded in the basic sciences. It will no longer be enough to "talk the language" of the physicist or chemist—we must also "think the thoughts," understand their principles and concepts in depth. Conversely, the inundation of the Earth Sciences by the "non-geologist" must be faced, and methods for preserving the integrity of the earth sciences developed. These and similar problems and methods of surmounting them were discussed in considerable detail. The sources of students were a continuing concern. This concern may be relatively short-lived. The public's increasing awareness of the planet they live on should assure a continually increasing supply of earth science students. However, we must continue to upgrade the geologic image and stress the essential role of the earth sciences in our modern industrial civilization.

It is difficult, if not impossible, for a department to maintain a complete coverage of the earth sciences and achieve a level of excellence. Development in depth was considered to have a better chance of success than development in breadth. Though many schools have common roles and problems, there are at least four types of schools (Ivy league, large state universities, small schools with little or no graduate program and technical institutes) and each has their indi-

vidual problems and objectives. Even many of the common objectives must be approached by different means.

Unfortunately, relatively little thought was given to the long-range effects of some of the changes which are taking place. There is one such problem that will become increasingly critical. If half the earth science courses that the present-day graduate student takes are taught by non-geologists and the other half by young geologists who have had only a minimum number of "core" courses in geology, what are the chances of the second and third generation graduate students understanding the concepts that are intrinsic to geology?

Many will conclude that the ideas and problems presented at this conference are not representative of the whole field of graduate earth science education. This is probably true. The title for the conference was *Changing Identity* . . . and a deliberate effort was made to include representatives of those institutions where most of the change and experimentation is going on. Thus, the philosophy generated does not characterize the whole. Rather, it portrays the beliefs of the more rebellious faction in the earth sciences. After reading these proceedings, I think you will agree that many of the changes are more revolutionary than evolutionary. Progress in education, as in science, is possible only through innovation and experimentation, and even negative results can lead to formidable improvements.

The concern of the conference was more with questions than answers. There was some measure of success and I believe you will find much that is stimulating and thought provoking. For those of you who dissent, I quote Mark Van Doren, "Tradition is never so healthy as when it is being fought."

I wish to take this occasion to thank my considerate colleagues for participating in the conference and giving generously of their ideas and opinions. I also extend sincere appreciation to our sponsor, the National Science Foundation.

Charles E. Weaver

WELCOME

By Paul Weber, Georgia Institute of Technology

WEBER—Thank you Dr. Goldsmith, gentlemen and ladies. It is a pleasure for me to welcome you to the Georgia Tech campus on the occasion of this opening session of the Conference on the Changing Identity of Graduate Earth Science Education. We are pleased that so many of you could take the time not only to come here to attend the meeting but also to take part in the formal program. As you know, this conference was made possible by a grant from the National Science Foundation and we are most appreciative to N. S. F. and to Dr. Benson, Head of the Earth Science Section, for their support, and we thank Dr. Benson also for taking part in the program. At Georgia Tech, in our efforts to strengthen our long established programs in the physical sciences and engineering, we have somewhat neglected the area of earth sciences and as you probably know, Dr. Weaver has joined our faculty not long ago and is in the process of building up and strengthening the programs in the earth sciences field. We are considering some programs at the undergraduate, as well as the graduate levels, and we are hopeful that they can be developed in the near future. In discussing this matter with Dr. Weaver, and in reviewing his proposal to N. S. F. for the support of this conference, it was indeed evident that changes are occurring in the educational programs in this field and along with the expansion at a number of places. Also, I have been aware of this as a result of being a member of the education and accreditation committee of E. P. C. D. for the last four years, at which in meetings, discussions were held on the curricula in the programs in the earth science field. Dr. Weaver's idea of assembling you people here in one place to exchange views on the many facets of the problems involved was an excellent one, and I am sure that he, as well as the rest of us from Tech will benefit from participation in this conference, and I hope that all of you will also benefit from your participation, and as a result the earth science education program can be strengthened particularly at the graduate level.

For those of you who have not been on the Tech campus before, I would like to especially invite you to see any of the other of our facilities here that you might like to see, and I hope that your stay here is a pleasant one. And in conclusion, I would like to say again we are delighted to have you on the Tech campus, and we hope that you will come back again often. Thank you very much.

INTRODUCTION

By Konrad Krauskopf, Stanford University
President, American Geological Institute

KRAUSKOPF—In asking me to make some introductory remarks, Dr. Weaver suggested that I might say something about the history of the development of graduate work in the earth sciences. Probably the history is sufficiently clear in your minds so that I can treat it rather briefly, and then go on to air some opinions about the current and future status of graduate training and to raise a few questions that I hope will lead to future discussion.

The earth sciences, it seems to me, are suffering from a bad case of what the psychologists call schizophrenia or split personality. On the one hand, some earth scientists feel that the days of classical geology are over, that the earth sciences should become geophysics, geochemistry, and geomathematics. At the other extreme are the "old fogies" who cling to the idea that we still have much to learn from the methods of traditional geology, that geophysics and geochemistry are simply minor aids to the investigation of the real problems of earth science. Such extreme views we seldom actually encounter; I suppose they are usually "strawmen" set up to knock down, but I am sure that each of us in his own mind feels the pull from the two opposite directions, when we set out to establish or to plan for new programs in graduate work.

A major question in planning is how much of the old to retain and how much of the new to introduce. The problem is hardly a novel one. Perhaps it was not even novel 170 years ago, when James Hutton voiced his famous complaint about the people who "judge of the great operations of the mineral kingdom from having kindled a fire and looked into the bottom of a little crucible." Hutton, you remember, even tried to dissuade his friend, James Hall, from peering into the bottom of a little crucible; but Hall, after Hutton's death, used exactly this technique to provide some of the best evidence for the hypothesis on the origin of basalt which Hutton has advocated. From that time to our own this polarity of interest in the earth sciences has persisted a polarity between experimental, quantitative work on

the one side and field observation on the other, with the advocates of either extreme sometimes showing bitterness or suspicion toward the work of the opposite camp. Despite the occasional misunderstanding, I think most of us would agree that the progress of earth science over the past two centuries has been largely a result of the interplay between these two complementary methods of attack.

The outstanding new feature of the last few decades is the enormous blossoming of the quantitative side of the subject. If you think back over the really significant advances of recent date in the earth sciences, I think you will agree that most of the advances have resulted, at least in considerable part, from applications of physics, chemistry, and mathematics. Inevitably, therefore, the quantitative approach has come to seem the new, the glamorous, the forward-looking side of the subject. Advances in old-fashioned field geology are necessarily slower and less conspicuous. I think all of us would pay at least lip-service to the idea that applications of chemistry, physics, and mathematics really have meaning only insofar as they apply to problems that the field geologist turns up. Still, field geology, as an activity in itself, seems progressively less glamorous in this day of rapid change in experimental and mathematical techniques. It is a difficult matter for planners to guess how much classical geology should remain in our curricula and how far we should yield to the currently fashionable trend of making earth science chiefly a study of applied basic science.

My memory goes back to the 1930's when most geology departments were concerned largely with field problems, and when the apparatus used commonly by most geologists was little more elaborate than a petrographic microscope. I recall predictions from those days that the application of chemistry and physics would be important to geology in the future. But I don't think many geologists quite anticipated the sudden, almost explosive development of more quantitative techniques that we have seen since the Second World War. It is the suddenness of the change that makes the problem so troublesome.

Another aspect of the history of earth science is the long-time separation of the fields of meteorology, climatology, oceanography, and planetary science from the study of the solid earth. Philosophically, I suppose, geologists have always claimed these subjects as belonging to the province of earth science, but the methods used in the problems of major interest have been sufficiently different so that these disciplines have grown up, for the most part, far outside of geology departments. In the last two or three decades it has become apparent that subjects like meteorology, oceanography, and planetary science have close relations to parts of solid-earth science, in that some of the quantitative mathematical methods useful for attaching geo-

logical problems are similar to methods that have long been used in these other sciences. So another major question that faces planners of graduate work in the earth sciences is the optimum administrative and working relationship between solid-earth science and sciences that deal with the fluid envelope of our planet. Should they be in the same department? Should they be separate or related departments? Just how much interaction between them is healthy or useful for the general progress of the study of the earth?

To return to the field of solid-earth studies, in which I am more at home, it seems to me that the general tendency over the last 20 or 30 years has been to add the new material that we feel graduate students should know onto a curriculum already overfull of traditional subjects. With the passage of time, even more physics, chemistry, and mathematics seem to be necessary. When limitations of time and the capacity of our graduate students make some curtailment necessary, we have reluctantly sacrificed parts of the older curriculum; but in general the amount of work required for our students has steadily increased. Our problem is not only to find the proper balance between classical and modern subject-matter, but simply to find ways of squeezing into a few years of study the enormous amount of information we expect graduate students to acquire. Some schools have tried to solve the problem by abandoning the classical program almost entirely and building a geology curriculum largely out of the basic sciences. In a few places this approach has succeeded, but I am sure I don't need to remind this group that in other institutions it has led to serious problems, including even the disruption of long-established faculties. A common result has been the fabrication of elaborate and beautiful paper programs which fail to attract more than a handful of graduate students. Another consequence of overemphasis on quantitative work is extreme specialization resulting from the fact that big machines often require so much undivided attention that the interests of faculty and students are channeled into very narrow fields. On the other hand, the consequences of resisting the trend toward emphasis on basic science are certainly as bad and probably worse. This could be illustrated by citing the uneasy consciences and feelings of frustration of many faculties, especially in the smaller schools which find it difficult to obtain the instruments necessary for a full-fledged program of quantitative study.

These are some of the problems that arise from the recent history of study in the earth sciences, and that I hope will be discussed at length during this conference. Let me now bring to light a few of my own prejudices about desirable future trends in graduate work.

One prejudice is simply that classical geology, meaning especially

training in field work, is still a matter of great importance. It seems to me that field work is important not only as a basis for more quantitative approaches, but also for its own sake, in that many new facts and hypotheses are still coming out of field investigations. Field work is a kind of activity that cannot be learned overnight. It is one of the more difficult things that geologists do—difficult to learn and difficult to teach. There is a very real danger that in emphasizing the quantitative aspects of earth science we will lose sight of the necessity of adequate field training. Lest I be misunderstood, let me make it clear that I have no objections to an increasing emphasis on quantitative work. This is inevitable; this is the way that progress lies. I would plead only for attention also to the classical basis of geology.

I am reminded of one of my graduate students, an eager young geochemist who had little patience with field work when he came to Stanford. Last summer he had an opportunity to go with a party from the U. S. Geological Survey into Utah to work on an area near Bingham Canyon. He was hoping to get started on a problem in geochemistry for his thesis, but found he was to be with a party that would do a great deal of straight geological mapping in addition to work on metal deposits. Last spring he was not very happy about wasting his time in this manner. When he came back to Stanford in the fall, he had been for some time in close contact with his party chief, a man who is not an expert in geochemistry, but who has spent many years in field work. The student expressed great admiration for the ability of his party chief to go into a new area, to size up the geology rapidly, to see the important problems, and to outline the work that was necessary. My student ended by saying, "I never realized before how much there is to field work."

To expect that a student during his few years of graduate work will acquire both a thorough grounding in field methods and a real facility in the use of physical, chemical, and mathematical concepts seems to me unrealistic. With a few brilliant exceptions, graduate students do not have this combination of talents and interests. My feeling is that earth science departments should recognize the widely differing interests and special abilities of their students, and should not expect each candidate for a degree to become proficient in all the many branches of modern earth science. Certainly a student should learn enough about each important branch so that he knows where to get information and so that he learns respect for the people who work in different fields. But I think we should not expect him to acquire depth of knowledge, except in the parts of earth science for which he himself has enthusiasm.

Although I do not think that intensive training in both field work and quantitative studies should be required of everyone, and although I do not regard one as in any sense "better" than the other, I think there is one fundamental difference between the two opposite poles of earth science that needs emphasis. This is the simple fact that quantitative learning is more easily acquired at an early age than later on, while the timing on field experience is less essential. Any student who shows a real aptitude for the quantitative side of things should be strongly encouraged to take as much physics, chemistry, and mathematics during his graduate years as he can work into his schedule. Field experience he can pick up later on, but if he neglects the basic sciences while he is a student he will find them exceedingly difficult to master on his own. It just seems to be a characteristic of the human brain that quantitative, symbolic science is more easily learned by a younger man than by an older man.

Perhaps we should encourage not only specialization of students within a department, but specialization of departments themselves. Perhaps some departments should deliberately cultivate one aspect of earth science and others a different aspect. Of course there is a strong trend in this direction already—in a field as broad as the earth sciences it is almost inevitable. Some departments are widely known for their prowess in paleontology, in field geology, or in some one of the highly specialized fields involving applications of physics and chemistry. Oceanography is an extreme example: it is a branch of earth science that requires particularly specialized knowledge and particularly expensive equipment, so institutes of oceanography must necessarily be limited to a few institutions. I think this tendency toward diversity of emphasis among earth science departments should be encouraged rather than deplored. In particular, I think it would be a mistake for all new or rapidly changing departments to model themselves after the few departments that have been so eminently successful in applying sophisticated techniques borrowed from physics and chemistry.

Looking a bit further into the future, I might suggest that the trend toward diversity could lead ultimately to the establishment of research institutes in earth science, like the well-known institutes at Brookhaven and Oak Ridge that serve chemists and physicists. Such institutes would have a permanent staff of research workers, and also would house all manner of modern instruments that could be made available to students and faculty members from surrounding schools when they encounter problems requiring the use of very specialized equipment. This would help solve a number of difficulties that often plagues the less affluent departments of earth science—the enormous

initial expense of much modern equipment, the maintenance of instruments in good working order, and the difficulty of keeping big machines in sufficiently continuous use to justify their presence.

These are some of my general thoughts about the current status of graduate programs in earth science. I would like to mention two other subjects of a rather different nature.

One is the problem we will face in the immediate future posed by the current upsurge of enthusiasm in many parts of the country for introducing geology or earth science into the curricula of high school. Earth science, in my opinion, is a subject which could be a very excellent high school course. I am worried, however, by the suddenness with which such courses are spreading, because earth science unfortunately lends itself all too easily to a very sloppy, superficial, descriptive approach that can give geology and earth science a poor reputation. If geology is going to find its rightful place in high school curricula, and if geology is going to win a place in popular estimation as a science with the depth and usefulness of the other sciences, I think it is important that we do our part in helping to make high school courses as rigorous as possible. The American Geological Institute has made a long step in the direction of rigor by developing new teaching materials. But the most important thing is the training of teachers to give these courses, and responsibility for this training rests, in part at least, on our shoulders. To a large extent this is an undergraduate problem, but many high school teachers go on for master's degrees. To accommodate these teachers will require special programs in our graduate schools, since their needs will be rather different from the needs of students aiming for careers in research or university teaching or industry.

Then one final matter: I am concerned by the extreme narrowness, the tendency toward overspecialization on the part of our graduate students. In the last few months I have had occasion to sit on several committees and informal groups concerned with picking men for positions of responsibility—men with geological backgrounds, but who should have in addition a knowledge of economics, of people, of psychology, of the place of the earth sciences in the general scheme of things. I have been surprised, and other members of these groups have expressed surprise, at finding how few geologists there are who have this kind of perspective, this broad knowledge of fields outside their own. They exist, of course, but they are not as numerous as I think they should be. Geology, of all the sciences, should be the one most suitable for giving its students breadth of outlook, yet all too often in our graduate training we demand so much specialized training on the part of our students that breadth is impossible to acquire. Not only

do we deny them time to explore other fields, but even with geology itself we keep them too busy to see things in perspective. One symptom of this narrowness is the disturbing fact that in some parts of the country geologists play a disproportionately prominent role in organizations of the radical right. Evidently we have turned out students who are so narrow and have so little knowledge of the world around them that they fall easy victims to the cliches of political extremists. I hope that somehow in our own courses, or by encouraging students to take courses in other departments, we can implant the idea that specialization should be tempered with wider interest.

In summary, my major concerns with graduate training in the earth sciences are the baffling question of striking the proper balance between traditional and utramodern approaches to geologic problems, the need to provide adequate training for prospective high school teachers, and the danger that our zeal to provide students with adequate knowledge may lead to overspecialization.

DISCUSSION

OSBORN—I would like to make one brief comment in complete agreement with Konny and I hadn't thought of its being connected with high school or junior high school courses in earth science. In Pennsylvania all the high schools, I guess, have earth science taught now. They are doing some good missionary work for geology, presumably, by having this course. I am inclined to think it is a mistake. This course may be doing more harm than good until there are well qualified earth science teachers and I don't know when this will be. Instead of the students getting an idea of the historical development of geologic thought and some of the fundamental principles of the science, they come out with a distorted idea of earth science taught as a descriptive subject at this junior high school level. They would be better off to take a math course instead. You didn't say it in quite that way but I think that is the same apprehension.

GOLDSMITH—I think that is correct. Let me inject just one comment —Jerry Wasserburg had his hand up. There is a distinction between a cultural program and a vocational program, at least in my mind, and often this is forgotten. If it is taught at the high school level or for that matter even at the freshman or sophomore college level in a cultural sense, I think it is useful in many cases and perhaps should be available but whether it is properly interpreted as a lead-in to an advanced degree is another matter altogether, and I agree entirely with you on this, Konny.

WASSERBURG—I think the whole conference is seriously misdirected.

It is directed toward the identity of graduate education in the earth sciences. All of you are quite aware of this but indeed the real problem is not in the high schools and it is not in the graduate schools, it is in the undergraduate training across the whole United States that is the real problem.

It is a question of overspecialization which you talked about in graduate school, Konny, and is more reflection of the generally poor undergraduate training which is offered on a national scale. This situation demands resurrection of training in both the field and laboratory and in that fundamental science which is needed at the graduate level. This is presently not available to the students because of an almost universally poor undergraduate training in the earth sciences. I think that most of the problems are derivative from the undergraduate program and not from the graduate program.

SIEVER—I want to make some comments partly related to what Jerry has said and partly on what Konny said about the breadth of interest of geologists. I think there is a question of history that is involved here too; if you look at the general area of science, there was a time when geologists were very broad in their scientific interests, largely during the first part of the 19th century. I think that if you use the criterion for breadth or the achievement of breadth that comes about us the result of interaction between the various areas of science and the current state of new sciences, then you find that geologists in the 19th century were interacting with biologists who were working on the material evidence for evolution and a great many of the other sciences. That has proved not so true of geology in the 20th century. It used to be true of physicists very largely and as a matter of fact the broad philosophers of science were physicists up until relatively recently. If you look at the recent literature, however, you will find that the people who are the philosophers of physics tend to be in their 60's and perhaps in their 70's; much more is now written by biologists. I think they are generally taking over the stage, you might say, and I don't think we should shake a finger. There is much that is wrong with undergraduate education in this case but I think that with respect to specialization and breadth of knowledge it also relates to the place where geology fits, or earth sciences fit, with the other sciences.

GOLDSMITH—Well, I think it is quite apparent that there is something wrong with undergraduate education in all fields at this particular moment in time. It is becoming rather well evidenced by incidents taking place here and there and I don't think that we should discuss this at the moment.

WASSERBURG—I don't think that is true. I think you can look at undergraduate education in physics and chemistry; there are enough

competent graduate students in many of these fields, in comparison with the earth science where I think that every graduate school which Konny referred to before suffers from a real problem of no students.

GOLDSMITH—I agree, don't misread me, Jerry, there is certainly no breadth of qualified kids in undergraduate schools now. In view of this we are almost in a renaissance and don't realize it. It seems to me there is more power and more ability and greater numbers in the undergraduate area than we ever had before and I think the outgrowth of how to handle this one of the serious problems we face. I think there is no question about that. I don't know how far we want to get into the whole matter of where we go in graduate education as compared to what is happening to the undergraduate level but I think more of this will come up as time proceeds. Any further discussion on Konny's paper?

MAXWELL—May I just make one comment. I think we all feel some concern about the adequacy of the new earth science programs, but we also should remember that one of our problems is that we do not have students entering geology. At least in the East, this is partly because they have never heard of geology. In our local high schools, which are reported to be rather good, it is also true that the chemistry and physics teaching may be poor. Nevertheless these schools do turn out people interested in chemistry and physics in spite of the teachers. I think there is something to be said for exposing them to earth science. From this exposure we are going to get some good students. Through the efforts of people like Bill Hambleton, hopefully these curricula will be built up to the point where they really are respectable, where they will attract more of the top students. In any case I think we ought to expose them to this experience.

PINSON—I would like to make a comment relative to Dr. Krauskopf's observation of the John Birch Society in California. I gather you attribute this to overspecialization in the earth sciences and medical profession and I would not agree with that. I can't imagine that any of our earth scientists' training with greater overspecialization, for example, than physical chemists or physicists or any other field. I think it more than likely has something to do with the motivations of going into medicine or the motivations of going into the oil industry rather than a condemnation of overspecialization in the earth sciences.

BENSON—Although I agree with Ozzy and Konny that there is a danger of having sloppy courses in the secondary schools, we are going to have the courses, sloppy or not. The interest has been awakened. It has been awakened by the sputniks, and it has been awakened by the I. G. Y. Instead of us saying we disapprove of, we might as well face up to it and try to make the courses better.

OSBORN—I know I am crying in the dark about this, it's almost like being against motherhood to say that earth science is not for high schools but I have talked to some of the kids that have taken it and looked over textbooks. They would be better off taking biology or mathematics or anything, I think, but that course, unless an unusually able teacher is available.

BENSON—There are some 39 or 40 states where geology is taught in the high schools, with a total of about 7,000 teachers. Of the teachers applying for these jobs, something like one-third have never taken geology; the majority have taken a course in biology or some other science outside of geology; so there isn't any question in my mind that geoscience is not properly taught, in many places.

GOLDSMITH—But you hear the same complaint from people in all the specialties. Really violently, from the people in physics, for example. The people in physics continuously point out that teachers are incompetent and the level of training at the secondary school level is totally inadequate in physics. This is true in many elementary courses in our colleges and is a universal problem, I am sure.

OSBORN—I think I can correctly quote from a conversation with a person highly placed in the system of education in Massachusetts (what is thought of as a progressive state compared to some states). In its public education over one half of the physic teachers in Massachusetts public schools have never had a course in calculus.

GOLDSMITH—I think an equivalent figure could be quoted in many areas in terms of not even having a master's degree in physics. It goes that far, if you want to look at a formal degree as being a qualification.

DEVORE—There were several points that Dr. Krauskopf made about classical geology. There are a lot of subjects in classical geology like mineralogy, paleontology and structures that are certainly classical today that wouldn't have been recognized as classical geology 15 years ago, because we have changed these courses by making them sophisticated, quantitative and this sort of thing. So I rather imagine that each of us is pouring into these classical courses a great deal of quantitative sophistication so that these courses are evolving along with the "so called" brand new area. We might throw the baby out with the bath here if we don't pay attention to this point.

GOLDSMITH—I have an idea that more of this will come up later, and as time goes on why don't we turn on to the next speaker and continue the discussion after he says what he wants to say.

PRESENT DEVELOPMENTS AND FUTURE OF EARTH SCIENCE RESEARCH

By Elburt F. Osborn, Pennsylvania State University

OSBORN—I have been involved in the matter of administration of earth sciences groups for almost 20 years now and have worried and thought an awfully lot about it, often pretty much by myself. This is the first conference I have ever attended where we talked about the problems. If there is anything I have learned it is that it is a very complex subject and I think the longer you are in it the more humble you are and the less inclined you are to give advice. For example, I think the organization itself of a department or division is important, but what is suitable for one place may not be at all suitable for another place. One also finds that there are a great many constraints, as for example, just space. During the last few years I have made many site visits for the National Science Foundation, in connection with its Institutional Grants Program, to geology departments. It is common to find that the geology department is in the oldest building on the campus and the number of square feet isn't adequate. Furthermore the space is just unsuitable for most of the things that the department would like to do. Then there is the problem of salaries for faculty. You might have great ideas on what you would do, but you just can't—the money isn't there. Also you may have an unfriendly dean around the corner or across the campus or a Vice President that doesn't see eye to eye with you or a Broad of Trustees or a legislature; there are all kinds of things that can cramp your style. So that when you look at a geology department or an earth sciences division some place, what you are looking at may not be that administrator's notion of what a geology department should be. This may be the best he can do with all the troubles he has got. Certainly the National Science Foundation has been very helpful to many earth science groups in the last few years on many of these problems.

Anyhow, I have been extremely optimistic about the earth sciences and I think for good reasons. If there is one thing I have never done it is moaned about the present or future of this field.

That graduate education has changed greatly in the earth scien-

ces is without question if one but looks back say about 30 years—when some of us were graduate students in geology.

From a student's standpoint he was in school because he was interested and wanted to learn—not because he was preparing for a job he expected to step into. There were no jobs, at least not in the sense that there are today. When I finished my Ph.D. work in 1937, I went to Canada to work in the mines, and a little later happened to be offered a job at the Geophysical Laboratory of the Carnegie Institution of Washington. Earlier I had tried to get any kind of a job on the U. S. Geological Survey but there was none available. Some friends of mine with Ph.D.'s took jobs with geophysical companies in those days as computers, where a background only of elementary math and geology was needed.

The geology departments in the 30's, I now feel, were coasting along, largely unaware of developments in allied fields which were of the greatest importance in geological research. Interminable courses were given describing and classifying land forms, different types of ore deposits, myriads of fossils, hundreds of minerals and igneous rocks, and all possible kinds of faults and joints and folds. We were learning what existed, or what was thought to exist, but there wasn't very much of a base for understanding the why of things, not much in the way of simplifying generalizations, as far as the graduate students could learn, except those developed a century or so before. I remember for example, we memorized the formulas of minerals—Kaolinite was $H_4Al_2Si_2O_9$—and by golly mineralogy was tough in those days because you just had to memorize nonsensical things as compared to now when a person can look at the whole field of mineralogy from a structural standpoint and get something out of it. How can important advances be made if new concepts and new tools are not available, or are not being made use of? Although x-ray diffraction had been in use for over two decades, and incidently, by mineralogists in some places, geology departments in the early and mid-thirties were not introducing their students to this most powerful tool. Last night when Tom Bates and I came together on the plane we got to talking about this and we think that in the early mid-thirties, which is the period I am talking about, there were three geology departments that had x-ray machines, Harvard, Columbia, and Minnesota. I don't think there were any others although there may have been. Application of Gibbs' thermodynamics was not being made. The graduate students of the early 30's were not being told of V. M. Goldschmidt's fabulous work first in physical chemistry as applied to metamorphic geology, and then in the application of crystal chemistry to mineralogy and to the distribution of elements in the earth and the universe. I found out about these

important developments only after leaving the University.

How does a science develop? We observe that any particular field advances in spurts. If rate of progress in a science is plotted on a curve, this may rise steeply for awhile, then level off. It is steep when new concepts become available which may be applied to the problems, and/or when new tools are developed which may be used. As these become more or less fully exploited the curve levels off.

Graduate and research work in physics in the 20's and 30's was in the main moving along on a classical plateau. Although exciting new concepts and tools were being developed, they were not yet widely applied. Applications came suddenly during the 40's and 50's as physics research advanced at a tremendous rate. The concepts especially of nuclear physics and of solid state physics opened up large new areas of research; and tools such as accelerators, cloud and bubble chambers, mass spectrometers, lasers, superconductors and semiconductors were developed. The change in nature of physics departments was not something that was planned or legislated. It just happened. Wise university administrators recognized the change at an early period and moved. I saw these changes in graduate programs in physics take place in the 30's at Cal Tech and at Berkeley, but some physics departments really haven't awakened yet.

Somewhat similarly, meteorology research languished on a plateau until the 30's when some new principles arrived in this country from abroad. Since then, atmospheric sciences research has been on a steep climb.

In geology great concepts were being developed in the last part of the 18th century and the first half of the last century by James Hutton, James Hall, Charles Lyell, Charles Darwin, William Nicol, Henry Sorby and others. These men developed principles of the most fundamental importance to advances in geology. "The Origin of Species" I consider one of the most significant of all contributions to geology. Sometime in every geologist's life, this should be read carefully.

Darwin's was a great unifying concept, breaking down formidable barriers to advancement. Hutton's principles similarly provided the theory and the philosophical base for advances out of the straight jacket which had been restraining geological thought. Hall's experiments around 1795-1800, on basalts at high temperatures and on limestones at high temperatures and presures were the necessary spark to opening up thinking about rocks from a modern, experimental standpoint. Nicol and later Sorby developed thin-section techniques and the petrographic microscope, as tremendously important tools in geological research. Chemical analysis of rocks and minerals became an

indispensable tool.

With these powerful concepts and tools available, the last part of the last century became a period of steep ascent for the curve marking progress in geological research. The curve inevitably flattened out, however, as this century was entered, because the steeper climbs must be fueled by new concepts and tools and these were not being adopted by geologists. To be sure, interesting contributions were made in the study of ore deposits, metamorphic rocks, geomorphology and other fields, but they were largely descriptive, not quantitative, and not sufficiently fundamental to keep the field of geology moving upword strongly. Unifying, basic concepts were not being applied.

New concepts and tools were, however, becoming available to those in geology who would and could use them. For example, the thermodynamics of Willard Gibbs was being understood in chemistry departments in this country in the early part of this century, and this was just the important and fundamental type of concept needed for important advances in research in some aspects of geology. X-ray diffraction and emission spectroscopy joined the petrographic microscope and chemical analysis as valuable tools. A few people, e.g., V. M. Goldschmidt at Oslo, and the staff at the Geophysical Laboratory in Washington, used these and made great contributions. But general understanding and use in geology departments of these principles, and of x-ray diffraction as a tool, did not come really until the 40's and 50's. It was not until then that geological research could again move upward on a steep ascent.

In this post-war period other important tools became available, and now geological scientists in many of our universities picked them up quickly. The electron microscope, electron diffraction equipment, mass spectrometers, the electron microprobe, and electronic computers have been especially significant. Experimental techniques became available that could be applied to geological problems on almost a routine basis, such as differential thermal analysis, and high temperaature and high pressure experimental apparatus. The classic work after the war of Bowen and Tuttle on the system MgO-SiO_2-H_2O opened our eyes to the relative simplicity of hydrothermal laboratory research. Anybody could now do it, not just the Geophysical Laboratory, and at the same time, and very importantly, the ONR and later the NSF provided funds to help support this research. Obtaining deep sea cores, which had been a pioneering undertaking by C. S. Piggott and his colleagues at the Carnegie Institution of Washington during the 30's, became practically routine after the war, as did heat flow and various other types of geophysical measurements; and now a hole to the Moho seems just around the corner. The principles of modern

solid state physics were picked up by many of our people and applied to mineralogical and geochemical problems; and statistics became an important tool in various geological fields.

In short, opportunities for pushing earth sciences research ahead on a broad and steeply rising front are now here—a revolution similar in significance to that in geological research a century ago. The scale is different, but the rate of acceleration is similar. One gets an idea of the exciting possibilities of these times if he reads the excellent U. S. Geological Survey release of 1964 entitled, "Long Range Plan for Resource Surveys, Investigations and Research Programs of the United States Geological Survey." Or if he reads the report just issued by the National Academy of Sciences, "Solid-Earth Geophysics, Survey and Outlook."

With all of these prospects, what does an earth sciences graduate department do in these times? Obviously if it is alive it jumps in—just about anywhere in the program. The prospects are fabulous.

After the war at Penn State we moved ahead principally in three areas in graduate work in the geological sciences: in high temperature and pressure experimental geology, in clay mineralogy, and in sedimentary petrology. Powerful concepts and tools were available. To be sure, we were weak in some areas, but I think it is a mistake for a single department of geology, or of earth sciences, to try to be strong in all fields. One university just does not have the resources. But this is no necessary handicap to graduate education. A graduate student can pick the university where there is strength in the field he wants. Two or more universities can complement one another and cooperate in graduate student training.

I think that size of graduate department, however, is of some importance; that is, a person needs associates with whom to talk about his research and others with whom to team on some problems and with whom to share specialized or elaborate equipment. Two or three people working as close associates in a field, I think, can ordinarily accomplish more than they could working separately. It is, of course, possible for a person, even though isolated somewhat during the academic year, to join the U. S. Geological Survey or other research groups for the summer and thus gain the needed association and inspiration of others.

A most important consideration, I feel, is in the early recognition and adoption of the new concepts and tools applicable to geological problems. These basic aids will come largely from the mathematicians, physicists, and chemists, but also from electrical engineers, materials science people and others. Close relations with these people, I thing, is very important for an earth sciences faculty. I know there

is disagreement on this, but this is what I think. Interdisciplinary programs will help, as will close physical association.

In conclusion, I think that the immediate future of graduate programs in the earth sciences was never brighter. All we need are bright people on the faculty and qualified graduate students. We have the concepts. We have the tools. Science receives popular as well as good financial support. Let's make sure that our graduate students get the base they need in mathematics, physics and chemistry and a proper appreciation for the tools and methods of research. But let's have professors that keep abreast of modern developments. Let's not be afraid of cooperating with the physicist and chemists, and statisticians and ceramists. Then we can burst into this Great Society we've been hearing about.

DISCUSSION

GOLDSMITH—There are a number of points that Ozzy made that I would like to elaborate on but I would welcome first some other comments.

WASSERBURG—First, I think there is a minor historical fact which is that the major advances in physics did not come after the war when people were building a number of universities but in the 30's—but I think that is more of an incidental matter. I think I would like to reemphasize the point that was made by you and Dr. Krauskopf as well as referring to Hall's paper of 1812, in which in the introduction he discusses the important fact, in beautiful but archaic English, that it is impossible to make satisfactory advances in understanding in the problems of orthogenesis unless we understand something about normal physical processes, namely physics and chemistry. This is said again and again. Clearly said beautifully in 1812 as it has been said in 1964 and 1965. The practice of this as Dr. Osborn has pointed out is not so good. In 1926 or 1927 Bowen published a book called, *The Evolution of Igneous Rocks*. In 1965 I don't think there are a dozen schools in the United States which adequately teach this material in a manner which is as sophisticated as it was written. That is a long time and the ability to fill in this gap in the great society is a funny thing in geology. From a historical sense it has managed to isolate itself from being able to fully utilize the genius of its own workers, men like Bowen and I think that Ozzy put his finger on this in a very general but very fair way. I think this is really what we hang up on every time.

GOLDSMITH—Well, I think that this is correct and my feeling is that in part this is due to what I would call the sin of coverage that so many

institutions insist upon. In so doing, they give superficial treatment to a great many things. I wholeheartedly agree with Ozzy that one should jump into those areas that are hot at the time, productive at the time or interesting at the time. Both from the point of view of research and teaching.

SIEVER—Nobody ever answers the question of how do fields get hot. Who starts them? If all the better departments of geology are going to be working in the hot and the new, are they going to be the ones who develop new areas? Is this the idea—that they will be the ones who develop the new areas and new interests? How do new areas get moved into?

GOLDSMITH—That is a very good question Ray, and it is one that I don't think can be answered. The whole of science and the whole of life goes along developing from day to day. You cannot predict at any one time what is going to happen tomorrow and I think it is foolish to attempt to, to a large degree. I would like to talk more about that later also. I don't think your question can be answered and I think perhaps *fortunately* it can't be answered.

STRALEY—I think Bonaparte answered the question of "Who gets them started" many years ago. When asked to name the qualities that go to make a successful military commander, he placed luck high on the list. By this, I think he meant being at the right place, at the correct time with the proper preparation.

OSBORN—Speaking of the University of Chicago, I really think it's people who got the program going there that Bowen started and Julian and others joined.

GOLDSMITH—Absolutely.

OSBORN—You never would have had that program without Bowen. Bowen went just before the war and then again after the war and started the whole school. There was a guy that understood the important concepts in a particular field. Chicago did a very good job in this area. On the other hand, take Princeton, it has been famous from time immemorial almost—the time Buddington had been there—for its excellent field geology. Every Ph.D. student, I think, has to do a field problem for his thesis.

GOLDSMITH—Well, of course, the man is all important. In line with what you were saying Ozzy, I would like to mention a specific man and give an indication of how he was essentially lost to the earth sciences, if you can use that phrase. I speak of Willie Zachariasen. I am sure that many of the people here who know anything at all about crystallography will know the name Zachariasen. He is still exceedingly productive. He was trained under Goldschmidt and is probably one of the best mineralogists in the world and yet few people

would call him a mineralogist. I think that there was a weakness in the general area of earth science at the time he came through that steered him directly into research in physics.

WASSERBURG—That is a special situation, Julian.

GOLDSMITH—But I think there have been more than one.

WASSERBURG—Mineralogy is an exception. The whole history of mineralogy and crystal physics is tied together so I don't think this is a legitimate example.

GOLDSMITH—Well, Jerry, I would counter that by saying he is evincing a much greater interest in the earth sciences now than since his student days.

WEIMER—I would like to comment about the paper. I believe that Dr. Osborn equated the tremendous advance in geology research almost purely to the development of more sophisticated instruments and the application of mathematics, chemistry and physics to geology during the 40's and 50's. New techniques that have been developed in field work and new observations in the field cannot be overlooked. As an example, developments in the area of photogrammetry provide more accurate recording of observations of materials on the earth crust. More accurate observations of materials in the field by better trained geologists has defined more sharply problems which have taken to the laboratory for investigations of important geologic processes. Many of these processes may be chemical, etc., but I refer to them as geologic processes because of the environment in which they are believed to operate. A new emphasis has also been placed on using the natural laboratory of the field as the proper place to observe geologic processes when possible. All of this work, the field and the interplay of field and laboratory, has given us concepts which we now think of as new, or at least they are in contradiction with a lot of the early ideas of the processes which are operating in the earth's crust.

OSBORN—I couldn't agree with you more. For example, another one that I might have mentioned is the work on streams, that Leopold and others are doing where they are really working with energy relations, etc. It is very important. Maybe they will get to the point where we can do something with geomorphology again.

BATES—There are new tools coming up that will supplement present quantitative methods in use in field geology. For example, I understand that instrumented planes are now making use of various portions of the electromagnetic spectrum to measure the depth of the water table. I think an important future aspect of field geology is to get at the third dimension. I am not criticizing what we have been able to do from the standpoint of working on the surface, and predicting from this what goes on under the surface, but we could use a lot

more drill holes located all over this country and also make greater use of remote sensing techniques.

GOLDSMITH—Of course, it is not clear to me what quantification of field geology means nor what its significance is. After all a map is as quantitative as anything we have and if one can not make predictions from the outcome of quantitative measurements on one area, shall we say (and one obviously cannot) that one could understand another area at least as far as superficial geology is concerned? I am not at all clear what the value of quantification is. I think it would be wrong to emphasize the necessity to quantify field geology.

OSBORN—Or anything else.

GOLDSMITH—Exactly.

OSBORN—Well, don't you think Julian, that part of it is as Tom says, it is third dimension and with the possibility for drilling deep holes now we are going to get at this.

GOLDSMITH—That is different. I agree that it is not quantifying anything to look at things in depth which obviously has to be done.

MAXWELL—I would like to cite one instance to indicate how important it is that field geology, geophysics and geochemistry are correlative mainly the so called alphopolites or ultromathics, the bases of the Moho as I understand it is that geophysical evidence indicates very clearly that the certain stratification on the bottom of the ocean and if we drill through this we will just keep right on going down into mantle stuff. Yet in the field in the true alpholites what we here in America call ultromathics, it is very evident that we have precisely this startification exposed and utromathic sheets, differentiated sheets which may be seven or eight kilometers thick would give precisely the size and response that we find in the deep oceans but which are lying on deep ocean sediments and quite obviously were in some manner or other implaced on top of these so that I think this puts an entirely new dimension on something like the Moho and some of our ideas of how deep we might have to drill to find out what is there and perhaps on our ideas of the connection between ultromathics and lavas in the surface and what is in the mantle. This could be found only from field studies.

GOLDSMITH—We may be making a mistake now in talking too much about science rather than how to learn about science. I didn't mean to imply, by the way, that I in anyway disapprove of any type of field geology. I certainly do not. I just wanted to make my point that I didn't think it was necessary to worry about quantification in field geology in the way some people may be worried about it. Any other discussion?

MCCAULEY—I would like to try to answer in part the question of how

certain fields within a profession expand or blossom quickly and in some cases expand almost explosively. Frequently the critical decisions are made outside the confines of the profession itself. In many cases these are political decisions such as a national commitment to land on the moon or to expand oceanographic research for military purposes.

This, however, simply sets the stage for rapid growth but for it to actually take place, scientific leadership is required. It may take only one person or it may take many, but someone has to look ahead with vision, seize the opportunity and then stimulate others into carrying through. Without this leadership little of scientific importance results from these decisions; with it and the available money to support research there is a rapid flowering and expansion into new and scientifically profitable areas.

GOLDSMITH—You can sometimes get a critical mass with one man very beautifully. In fact, I feel that some of the greatest advancements that have been made have been by the single individual and there is in my mind too much of an attempt throughout the world in science today to build up units and institutes. Any other discussion before we break for coffee?

GEOLOGY, TODAY: ITS NEEDS, AND THE TYPE OF DEPARTMENTS THAT MAY FULFILL THOSE NEEDS

By William Benson, National Science Foundation

BENSON—The title assigned to me by Dr. Weaver is: "Geology today, its needs, and the types of departments that may fulfill these needs." I should like to approach this in terms of the needs of the students, not just the students who are destined for research careers, but also those who hope to work in industry and those who may become teachers in secondary schools. The universities must somehow accommodate all these. They have different needs, and herein lies part of the problem in designing a modern geology department.

Science as a whole has undergone rapid evolution and expansion in the last thirty years and progress in many fields has been significant and spectacular. It is hardly surprising, therefore, that research aims and educational needs in all the fields have undergone a similar rapid evolution. I think, though, the change has been felt especially in the natural history sciences and by that I mean the environmental or field sciences, including all of the earth sciences and those parts of biology that depend on the natural environment for their basic data.

The rapid advances in physics and chemistry, especially along the instrumental lines, have made it possible to design laboratory experiments to check and supplement field observations. Geology is becoming more and more the physics and chemistry of the earth, and biology is dealing more and more with the physics and chemistry of living systems. But as geology is moving more toward becoming the physics and chemistry of the earth, it is also complicating the requirements and demands that it imposes upon the university. It's a question of how much time and how much effort can you put in a limited educational system. A lot of courses are required. We should have more math, more physics, more chemistry; but we still need the geology and there just isn't time enough in the day or the year.

It wasn't so complicated 30 years ago when a geologist was pretty well-trained, or thought to be well-trained, if he had a basic understanding of the fundamentals of chemistry and physics (and by that I mean elementary courses in each) and if he was grounded in mathematics through trigonomentry and analytic geometry. It is quite true

that a few forward-looking people saw that these were not enough. But most departments didn't feel that way; and, although the calculus was recommended by a few of the more advanced departments, in reality few geologists used it after they graduated. Indeed this was true, whether the student was designed to be a practitioner or a research geologist. (I use those terms in a deliberate analogy with medicine. By practitioner I mean one who is trained in the principles of geology and applies these to the problems of engineering construction or to the search for oil, minerals, etc., and by research geologist I mean a man who puts his main effort in the looking for new facts and thoughts on the constitution of the earth and the processes involved.) At about that time, say in the 1920's and 30's, the main difference between the practitioner and the research geologist was chiefly in the desires of the individual and to some degree the amount of training he received. Most of the practitioners were employed by the petroleum industry and a smaller number went into mining. Most of them had bachelor degrees, some had masters' a few had doctors' degrees. The research geologists found their homes primarily in universities, in government, where the U. S. Geological Survey was the big user, and in industry. Here again I don't have the exact figures, but I think that no more than half of the research geologists had doctors' degrees, and the rest had masters' and bachelors'. But even here the main difference between a bachelor's and a doctor's degree in geology was in quantity rather than in quality of training. The graduate student would delve more deeply into the basic field data with special emphasis on facts and inferences regarding geology processes, but with the exception of mineralogy and the beginning of modern geochemistry at the Geophysical Laboratory, nearly all the evidence was accumulated in the field with an assist in the laboratory mainly from petrographic microscopes.

Today the situation has changed drastically. We have now accumulated a vast amount of field observations, and this plus the development of experimental apparatus has opened the way for the geologist to bring many of his problems into the laboratory. I use that phrase deliberately—that the geologist *bring* his problems into the laboratory—not for the laboratory to set the problems for the geologist. Certainly one of the most important steps was the development of high-pressure and high-temperature apparatus by the late Percy Bridgman at Harvard, which has made it possible to reproduce under controlled conditions the range of temperature and pressure that must operate deep within the earth's crust and down into the mantle. Again there was the development of the mass spectrometer and the proportional radiation counters, which have enabled the geologist to determine "absolute" ages for rocks and minerals and to study the

isotopic composition of minerals in different geologic settings. We could go on and on but these examples should suffice.

One result of all this has been that the research geologist today needs a far better grounding in physics and chemistry and mathematics than his father did (or at least than his father *thought* he did). But this isn't all—some of the most spectacular advances in geologic research have come from scientists with Ph.D's in physics and chemistry, who became interested in applying their knowledge to the study of the earth. They, in turn, could not apply the physics and chemistry effectively without the knowledge of the field conditions. Therefore despite all that has been said on the subject, I still feel that the major problem facing geologic research today is the effecting of a happy and stable marriage between the field and the laboratory.

The laboratory geologist—in many cases will be called a geochemist or geophysicist, I don't care about the terminology—can study earth processes in miniature. He can check inference by experiments. But the basic parameters for these experiments have and always will be found in the field. Without the field work to set the framework, the laboratory studies may be good chemistry or physics, but they are not likely to contribute much to the study of the earth. Let's ask, just for example, what if any is the essential difference between an inorganic chemist who is interested in silicates and a geochemist who is interested in silicates. The essential difference is probably not in the instruments he uses, and probably not in the experiments he performs. The difference, it seems to me, is that the inorganic chemist is interested primarily in either the thermodynamics, or in the surface chemistry of crystals, or in the kinetics of a certain type of a reaction, whereas the geochemist is interested in how nature has formed a particular kind of rock. In other words, it is the question one is asking of nature that is important, and without sound field data the proper questions can't be formulated. It all boils down to one premise: there are problems to be solved and there are tools which can be used to help solve the problems. To ignore any of the tools, either in the field or in the laboratory, is myopic.

With all these new techniques available we have about reached the point where ideally the research scientist in geology ought to have two Ph.D's—one in physics or chemistry (or biology, if he is going into paleontology) and the other one in geology. But since life is finite and few can afford or want to be students until middle age, a compromise has to be reached. Thus, many of the larger or better geology departments in the United States now try to produce Ph.D's who are geologists with some laboratory training on the one hand and geochemists and geophysicists with some field training on the other.

If these increased demands in educating the earth scientists have created many problems, I think they have also opened up many new opportunities for many schools. As Dr. Osborn has said, there are, and will be, few colleges or universities who will be able to afford complete research competence in all sub-fields of the earth sciences. Since so many specialties are needed, smaller departments can indeed excel in one or two areas, while making sure they provide adequate background in the others. For example, there is still plenty of room for the "classic" geology department, providing that students get enough training in math, physics, and chemistry, or biology, along with their geology so that they can communicate with the people who have their primary training in geochemistry or geophysics.

So far I have focused on the research geologist. Now, what of the practitioner? Today's practitioner also needs some additional skills, but probably not as varied or sophisticated as his research colleagues. The practitioner is still primarily a field geologist and he needs thorough training in "classical" geology. He should also have better grounding in math, physics or chemistry, than his predecessor of 25 years ago, but he probably doesn't need as much as the man going into research.

The next question is: Since the practitioner requires somewhat different training, is he needed in enough numbers to justify catering to him? I believe so. During the last few years there has been a large drop in undergraduate enrollment in geology. This drop is obviously related to fewer job opportunities in the petroleum industry, a situation that I believe to be real and permanent. Certainly, the petroleum industry is always going to need *some* geologist (and sure enough now they are hiring some again), but the golden age of petroleum geology has passed and we might as well face it. I don't foresee that the industry is ever again going to need as many geologists as it employed, say from 1945 to 1950, and I think the employment curve in petroleum geology is currently going through a series of fluctuations that will finally stabilize at a level of about half or maybe two-thirds that of a few years ago. I believe also that the petroleum industry will concentrate increasingly on recruiting those with advanced degrees and especially those with adequate training in physics or chemistry.

On the other hand I do believe that the dip in total employment of geologists is temporary, because applied geology does have a rather large future in two other fields. One is water resources, hydrogeology if you will, and the other is in engineering geology.

Hydrogeology is just around the corner. The problems of water resources are receiving increasing attention, and many people are now

aware that water is our most critical resource problem. In the next two decades we will need a significant number of new hydrologists or hydrogeologists.

Engineering geology has demonstrated its value many times in the last 3 or 4 decades, and it is at first thought quite surprising that engineering geologists are not already in greater demand. I suspect there are two reasons for this. One is that the consumer market for engineering geologists is dispersed among smaller and varied companies spread out over the country, and "the word" hasn't got around yet. The other is that engineering geology is like preventive medicine. The petroleum geologist and the mining geologist *make* money for the company, whereas the engineering geologist is *saving* money; and this is always a harder concept to sell. I conclude, therefore, that education in geology does have to accommodate the practitioners, and that undergraduate enrollment will again increase as the employment opportunities in hydrogeology and engineering geology increase.

In addition to training both research scientists and practitioners, education in geology today has one additional task that barely existed 30 years ago. Since World War II, spectacular events such as the explosion of nuclear devices, the launching of satellites, the advent of space science, the IGY, etc., have created an increased awareness of the effect of scientific discoveries in the lives of everyone. This in turn has created a demand for a better teaching of science in the elementary and secondary schools. A simple course in earth science is becoming increasingly popular, especially at the secondary school level, and there is nearly as great a need for high school teachers who are adequately trained in the earth sciences as there is in physics and chemistry. I am not disagreeing with Dr. Osborn when he says many of these courses are poorly taught; I am saying I think the courses are here to stay and we have to recognize them. Ten years ago I too resisted the idea of teaching geology in the high schools, and advocated that the students should take mathematics, physics and chemistry, leaving the earth sciences to the colleges, but I can't hold to that position today. In contrast to the research geologist or the practitioner, the potential teachers don't need the same rigorous training in mathematics, physics and chemistry in order to be able to teach a high school course in geology or meteorology. They can do their job adequately by taking less rigorous and more descriptive courses. So I think there is a need in a number of schools for a bachelor's degree in earth science, designed to be terminal, that does not equip its holder to go on to graduate school for research. This degree might be designed primarily for prospective elementary or secondary school teachers; it could also be open to people who are interested in a

liberal arts major with a specialty in one of the sciences as a cultural subject.

As the title of my talk implies, I don't think there is one type of geology department that is going to satisfy all three needs, yet they are not mutually exclusive either. There are three main objectives and a department may try for one, two or all three. One is the department focused primarily on the production of Ph.D's and on research. This is the department that can concentrate more on the laboratory side, without, of course, ignoring the field problems. It is also a department that will probably not have many undergraduate majors. Two is the department focused on training the practitioners. An undergraduate curriculum for this department could be much the same as for the research department, but many of its students might stop at the bachelor's or master's level. Three is the department that offers a cultural major for those who do not intend to make a career in science but who wish to major in geology. This would include students who intend to become secondary school teachers plus liberal arts majors who want geology as a cultural subject.

All three types can, of course, be combined in one department, but this obviously requires a fairly large faculty, and could probably not be done well except at a large university. The smaller department can choose its target, and its choice must be governed by the type of institution plus the resources and desires of the staff. In other words there is no one ideal blueprint for building a modern geology department, but there can be a number of attractive and fruitful alternatives.

DISCUSSION

HUNT—I would like to comment on what Bill called today's practitioner. I think it has been traditional that the oil industry has hired something like 75% of the geologists that go into industry. Certainly, right after the war and until about 1957, there was a very rapid expansion in exploration. New fields were being opened up all over the United States and all over the world. This required geologists doing traditional work, such as examining cores, correlating sections, using geophysics, fine structures, etc. Most of the geologists hired had bachelor degrees and were used in field operations for standard work. In 1957, however, the competition became stiffer because we ran into a period of oversupply and a lot of states went over to pro-ration. We still face this situation today, i.e., an excess of oil. The cost of finding a barrel of oil went up. With this, of course, there were fewer job openings; hence, companies could require higher standards in the people they hired. Instead of hiring bachelor degrees, they began

looking for doctorates for field operations. This was important from two standpoints. Not only did they get better qualified people, but also, these people frequently had additional training in physics, chemistry, mathematics which they were able to use. For example, the shift in emphasis in geophysics went from finding structures to finding stratagraphic traps. This meant that the geologists could help the geophysicists in changing their methods of geophysical exploration to suit the new situation. The chemist could help the geologist in such things as the origin and migration of petroleum. There actually was some application and still is today of the different sciences combined with geology, and this, of course, has required the higher degree going into what Bill called the practitioner. So I think there has been a very definite change in emphasis in the requirements—certainly of the petroleum industry, and this has been brought about by increased competition and greater difficulty in finding work.

GOLDSMITH—I certainly agree with you, John. I am sure glad he amplified the history of these swings in the petroleum industry. I didn't realize what these were doing but you agree though, John, don't you, that we probably are not going to have the huge numbers we had in the past?

HUNT—You mean with the same kind of training they used to have?

GOLDSMITH—That's right.

HUNT—This, of course, has more than one reason, one of which is that the United States is getting pretty well drilled out. Abroad, we now are running into nationalization. Most countries are requiring their own nationals to be trained in the fields. Formerly, it was all American geologists all over the world and there were many of them. Now, these countries require so many of their own nationals that only a small number of Americans are needed and this is, you are right, limiting.

GOLDSMITH—Dr. Wetherill had his hand up.

WETHERILL—I think it is true that we must train geologists with more physics, chemistry, and mathematics background, etc. On the other hand, I think this is only a limited part of what needs to be done. I am afraid that at best this increased training in science will make it possible for our students to understand what, say Bowen was doing in 1925, rather than getting people into the field with the kind of background that will enable them to do the things that we couldn't ever think of doing ourselves. I think that there is an enormous potential for contributing to earth science from people who have not had any geological training whatsoever. I think that one of the real important things in the development of earth sciences is to work out means of entrapping these people in the earth sciences without worry-

ing too much whether they are properly balanced between field and laboratory and whether they have had the ideal education or not but simply to get people with completely unusual and probably completely unbalanced training.

GOLDSMITH—I am looking down the throat of several people whom I have known for some time who have followed this course of training and I would like—

WETHERILL—There are serious disadvantages to this approach, I will admit.

GOLDSMITH—continues—I would like to discuss this in a little more detail, maybe 30 seconds worth, this afternoon as I think this is a most important point.

BENSON—I don't disagree with that at all. I touched on it very briefly, and what I was saying was—"yes, we do need these people from the other disciplines, but we have to ensure that they and the geologists have enough experience and training in common so that they can communicate."

WETHERILL—I think we can worry enough about balance to kill this thing.

GOLDSMITH—I agree. As a matter of fact there are several areas that I have thought about in the past in which I think this has been well exemplified. Ceramics that Ozzy mentioned is one, oceanography is another. If you look at the top people working in these fields and making major contributions today, you will find they were trained in other areas, not trained as oceanographers nor as ceramists. I think it is a dangerous thing to assume any one department that calls itself an earth sciences department or anything similar is the department that necessarily is going to train the people who are going to be at the forefront of knowledge or will make the major contributions to this field. I feel this to be an important point. There is another thing that has happened along with all of this—Bill mentioned the drop off of undergraduate enrollment is geology in particular. Most of us are aware that in a sense there has been a proportional drop in graduate enrollment in this area. Certainly in the larger and perhaps better schools. Now why? I am not at all sure that I know. But I think one of the reasons might be a consequence of just some of the things discussed. I feel that the tightening up of "training," I hate to use that term—education would be better, in the earth sciences is responsible for frightening off a great many students who would have come into the earth sciences, say 20 years ago. I think this is a very good thing—in the long run it might be a very healthy thing. Let me give you one example of something that surprised me several years ago. In our beginning or elementary course in geophysical sciences, usually

about the junior level in undergraduate work, we took a look at the grades and the people getting the grades. Curiously enough we found by large that the people who had majored earlier in their career in mathematics or physics or in chemistry were the students who did the poorest in this course. The answer is fairly obvious when you realize that the students at the time who had proclaimed majors in chemistry, physics, and mathematics were not doing well in physics, chemistry and mathematics and, therefore, upon transferring weren't going to do well in our program either. I think this situation is changing right now. Hopefully more students will come into the earth sciences with a modern point of view without having been steered at the undergraduate level from courses they found to be too hard for them, too tough for them. I think there is more of a tendency now to bring people trained on other disciplines into the earth sciences in an honest way and I feel this to be very, very important.

WASSERBURG—We currently have a program going where we make a considerable effort to attract undergraduate students into the field of geology—students with an undergraduate major in physics or chemistry. We are attempting to change and formulate a graduate program to train these people and to get them some field experience and insight into geological problems but that has to be done at a high and sophisticated enough level in these other sciences so these students can make some scientific contributions. It is not yet possible to evaluate the success of this program.

MOSS—Could I ask Jerry a question? How many fellows can you steal that way or can you bring in?

WASSERBURG—Most of our present entering graduate classes (about 80%) are made up of students with degrees in physics and chemistry.

MOSS—That's good.

WASSERBURG—That's tragic, because we wish we had more geology majors, men with geological backgrounds and good basic training in physics and chemistry. We want them, but we can't find them. The students we could get were men who were physicists and chemists; they are good men.

GOLDSMITH—The problem that I am sure Cal Tech as well as several other schools have relates to students coming at the first year graduate level from a smaller classical department. Both the school and the student have a serious problem in terms of time, assuming he is a good student. There is a period of time—

WASSERBURG—If he is a well trained student, I don't think there is a problem. I think that the problem which you see is the undergraduate problem again and we don't see the trouble as a graduate problem except as a reflection of the undergraduate problem.

GOLDSMITH—That is exactly what I am saying.

WASSERBURG—Whether it is a big school or a small school, there are very few small schools that are much smaller than Cal Tech. The difficulty you have is that calculus is not even required by the majority of people getting a geology degree in the United States. At those schools where it is required, it is a course given in the sophomore year which is then never used in the science until they graduate. They then enter graduate school and someone attempts to use physical chemistry or calculus in the solution of a petrologic problem suddenly we have "blood on the floor."

GOLDSMITH—That's correct. These are most difficult problems. The break between the graduate and undergraduate department is often a severe one in this respect.

WASSERBURG—This is where I think the use in this discussion of the word "classical" is in abuse.

GOLDSMITH—You're right, you're right.

WASSERBURG—It is an extremely serious business. It is impossible to conceive that there can exist a modestly competent undergraduate training which was purely classical in the sense that it abrogates the willingness to know current knowledge or to make it available to the students. But it is possible for a department to indeed be "classical" and damned competent if it makes the students able to move ahead and into the modern fields of knowledge but without actually practicing the art which they are applying in understanding the processes of nature.

HAMBLETON—For the past several years, I have been associated with Geo-Study, an educational enterprise of the American Geological Institute. Some of the discussion has for me an element of playback, and I feel as though I have heard it all before. In thinking about the problems of geology, I have attempted comparisons with other sciences in an effort to understand our current development. It occurs to me that no one has recently written a book entitled "Giants of Geology," describing the efforts of modern geologists. One could write such a book for a number of other disciplines. Physics has its Mossbauer and the Mossbauer effect or the discoverer of the new nuclear particle. This is not true of geology, although students know of Van Hise and CIPW. Despite the talent assembled at this meeting, I dare say that few students could identify any of you with any particular discovery or investigation. In a way, geology has lost its personalized sense of identity. Without being derogatory, I conclude that we have become a science of nit-pickers. We look at the fine structure of subjects that we already know and this kind of investigation does not produce giants.

Nevertheless, we are scientists who provide the correlation functions between cause and effect. We are engaged in a probabilistic science and a predictive art. Perhaps we should recognize anew our concern with systems and that a systems approach to problems affords opportunity. If problems are approached in this way departments of geology can do many things within their own context. Relations with chemistry, physics, and mathematics are evident, but such relationships may be difficult for a given department. Alternatively, there is great opportunity in such fields as economic analysis and modeling of economic systems related to geology. Many socio-economic problems demand our attention and I judge that one of the most viable fields of geology lies in environmental urban development problems. These problems demand knowledge of political systems, political science, or sociology. I think that there is a very broad area in which geology can function, depending upon the context of the school and its faculty.

SIEVER—I want to take off from where you left off and compare and contrast two different kinds of things. First of all, I have had some discussions with some economists about the question—"Who should do mineral economics?" As you know, Lovering wrote a book on mineral economics and other people have written books before. Now it seems that the mathematical mapping of economics is an interesting subject. The geology part of mineral economics is relatively so trivial as to be really inadmissable as a thing for a geologist to do as geology. On the other hand the economics is extremely important and extremely difficult at the present time. I would say that any geologist who tried to go into the economics of it would be making a very bad mistake unless he was terribly interested in the economics rather than the geology. This is something which I think is not a proper field for geologists to go in, and we should not try to be all encompassing in our interests. We might find a little bit more similarity to geology in biology. Incidentally, I notice that around this table there is not one paleontologist, unless there is somebody I don't recognize. The fact is that biology has made a rather important number of decisions in this country with respect to their future. Biology has had to make a choice between classicism and modernity. They have made a conscious decision in a number of places that I know. They are saying—"we are only going to tackle the problems that we can tackle in a very satisfying way and that means molecular biology." All agree that they still need some taxonomists. They still need people who do systematics. They do not necessarily have to be in the same department and often are not. The molecular biologists have also got themselves into difficulty because—"we need," as they say jokingly, "one taxonomist

in each department of biology—that is, one man who can tell us what an organism really looks like." The trouble is you can't get one in a place where he is considered to be a service man. So they have got that problem but the important thing is that with respect to picking people from other fields, biologists started out in the same way as geologists. After World War II there was a wholesale entry into the field from other sciences, people like Leo Szilard and too many other names to mention. On the other hand it was not very long before biologists themselves got this training. Watson and Crick are examples—Watson got his undergraduate degree at the University of Chicago in biology and then went on in biology. Crick is a physicist. The two found very little difficulty in working together. The same thing is going on now. It does not have to be either/or, and the biologists seems to be making a pretty good job of training undergraduates in a field that demands, I would guess, just as much basic science as ours do.

GOLDSMITH—I think you are right. I think many of the problems of biologists are closely parallel to those that have been discussed today. They seem to be under greater pressure because of the blossoming and blooming—and there is a conflict in non-clinical biology going on right now. Any other discussion?

McCAULEY—I think everyone would agree that it is very important to attract people in from other disciplines. I just wonder what the secret is. How we can bring into geology at the undergraduate level some of these people from other disciplines. It seems that the situation quoted at Cal Tech is a little unusual; 80% of an incoming graduate class from other disciplines. I just wonder what the Cal Tech secret is and how you manage to get the "word," so to speak, to these people. I think one of the real problems in earth science education is that we haven't really been doing a very effective job except in a few institutions of proselytizing peoples from other disciplines.

WASSERBURG—There are some ladies present—but I would say it has something to do with hustling. A conscious effort is made to attract these people and I might add there is a spectrum of levels. Wetherill's comment is very well taken in that it is often desirable to attract people from the full professional level and who are already in the business for example, Watson, Crick, and George Wetherill.

On the other hand there is a whole spectrum of levels in which you want to attract these people. What they must be aware of is that the earth science is a field in which they can make a major contribution. I don't have a letter with me which the division sent out, but I can paraphrase it quite well. It is called "The intention of geophysics, the major in geophysics, graduates in geophysics"; there is a wide field

of application and these people can make a very remarkable contribution if they are particularly good.

GOLDSMITH—There is a need for publicity of sorts.

WASSERBURG—It never fails. We just had a student who was a B.S. in physics, from Rensselaer—one of the best men in his class who went one quarter and then left. He just did not like earth science and when he found out he had to go out in the field and look at rocks and that such things were sort of complicated, he left.

GOLDSMITH—I hope another aspect of earth science will come more to the forefront in our discussion. The atmospheric sciences have been neglected, but if you look at the enrollment in the atmospheric sciences you will find that almost invariably the students at graduate levels have come through physics, chemistry or mathematics. Almost all of them in this particular branch of the earth sciences come up through this route.

MCCAULEY—What you are saying here is that one should be selective in the proselytizing.

GOLDSMITH—I think that is right.

FREDERICKSON—It is more than that. Students will come to people and to programs in which the students can really work. Students with good physics and chemistry backgrounds seldom come to a classical geology department and stick there even though the contrary is true. On the other side some young people from classical school, find that they just can't make it in a graduate program in competition with people that are basically science oriented and are used to quantitative thinking. These students just don't have the thinking tools; hence, they don't have the ability to manipulate things. So this is much more than just a recruiting program; you have to match the students coming in with the people in the programs. Qualified young people can pick and choose and, hence, go to those places where they can get what they want. To attract qualified young people, departments have to be really good. It is very difficult for any department to be all things to all students. The only thing that they can do or should attempt doing are those things that they can do very well. Because all of the departments have to live with budgets, with Deans and Presidents and other administrative realities, different institutions obviously should take different courses. I think this is the only viable kind of a program that a first-rate school should try to develop. It is a big mistake, I think, to try to set up a "general geological" training program. There is no such thing. You can't implement large programs, high-quality programs even if appreciable amounts of money were available simply because enough highly qualified professional people with experience are not available.

McCAULEY—I wonder what sort of mechanisms are actually in existence, say in the departments that are classically oriented, to get the word out to the physicists, chemists and the like regarding the research opportunities in the earth sciences. I also wonder if these departments are honest enough to direct these "recruits" off to other institutions where their talents might better be utilized if they, themselves, cannot meet their academic needs.

FREDERICKSON—I don't know what other people do but I know what we do. When somebody with an excellent biology background writes to us and wants to get a fellowship to do work in paleontology, I give him the names and addresses of some very good paleontology schools in the country and send him there. On the other hand, if he is picking an area that we have developed and are interested in and I think we can handle quite well, we try to encourage him to come. In other words we direct him where we think he can very honestly get the best work training in the field he is interested in. We don't encourage some of these young people to come to us in a field where we are not able to teach them in sufficient depth because they will get disillusioned and leave anyway.

MOSS—This problem is fairly sticky—stealing students, I think. It does not make you very popular on your campus.

FREDERICKSON—My compliments. There is nothing wrong with going after good students anywhere you can find them.

MOSS—Well, no, but this isn't easy, that is the point I tried to make and Jerry perhaps can do a fine job at this without, I guess, causing friction inside.

WASSERBURG—Oh, no, I didn't say that!

MOSS—Does anyone else want to give any personal testimony about—

OSBORN—Well, I would like to say that you have been pretty darn successful whether the chemists get mad or not.

PINSON—It seems to me that one of the big problems is that undergraduate students are generally misinformed about the job opportunities in the geological sciences. They are mightily impressed by statements and articles about the great depressions in employment for geologists.

They need to be made aware of the favorable realities of employment for any well-trained scientists. I don't know what sort of program would do this, but at an institution like MIT there has been no slump whatsoever in job opportunities for the type of person that we turn out. Our people don't generally go into field geology for oil or mining companies, where the fluctuations in employment are greatest.

GOLDSMITH—Do you think the really good students permit this to bother them? I don't think it concerns really good students. There

has never been a shortage of—

WASSERBURG—They start learning it at the high school level.

PINSON—They have profound conversations on what job opportunities there are and what the comparative salaries are in the different fields and they really talk seriously about this. It is a very strong determative factor in their selection of a career in science.

BENSON—They find out quicker than we do, and generally they are very badly misinformed.

SIEVER—Incidently, this raises a point about how early they do decide. You start getting the impression that the decision as to what area of science a student will go into starts being formulated somewhere as early as the 9th or 10th grade. There are two real tragedies that go on, for example, with respect to mathematics. It is fairly obvious that there are a lot of bright kids who think that they are going to be mathematicians. When they get to college they suddenly discover that "this just isn't for me." It seems that high school mathematics, as good as it may be, is not a proper prelude to the kind of effort and ability that one needs to put into college mathematics, and I wonder maybe if the same thing isn't going on in geology. We may be losing out because in high school there is both an inappropriate and improper way of helping people to decide their interests.

GOLDSMITH—I have some figures on this in physics at Chicago and I can speak only of this one situation. Seventy percent of the students at the freshman level who have expressed an interest in physics as their major do not finish physics. In fact, almost the entire 70% are wiped out after the first year.

PINSON—This problem is very serious. We have an undergraduate selection system at MIT which virtually excludes the possibility of getting a person who is primarily interested in geology. Occasionally we get a young man who is. Almost invariably he is a natural scientist whose interest was formed back at some very early time in his childhood. As an example of this, I was at a lawn party for our new freshmen, attended by their parents. I was talking to one young man and I asked him which school he was from, and he said he had attended a very good high school in the Bronx. I started talking about his background and what he wanted to be and he said he wanted to be a mathematician or a theoretical physicist, and he informed me that his whole math class, five of them, were there at MIT from this particular high school in the Bronx. Now all of them were members of the advanced math class there. I thought to myself, what chance do we have of recruiting a geologist when this type of selection system goes on? And yet, none of us want to change it because this is the exact kind of background we want to draw upon to get our best kind of

students. Therefore, we are willing to take the occasional one that does come along and somehow is diverted into earth sciences or already has an interest in it.

ESCHMAN—One of the points I would like to make though is that you say 70% of these so called physicists from Chicago don't make it.

GOLDSMITH—Not necessarily. Let me correct that. It is not that they don't make it, they change their minds.

ESCHMAN—Well, they change their minds. I think some of us in geological science would be quite happy if we were able to get 30% of most any group who enters college as a freshman with the goal in mind of going into the earth sciences. I think this is one of the things that speaks for our full involvement in secondary schools education and the training of decent teachers to get earth sciences into the secondary school, if only to give an early exposure to some of the very students who otherwise might go into mathematics, physics, or chemistry. We want the ones who are capable of doing that. Somehow we have to reach them.

GOLDSMITH—Let's let Ed Goldberg get a word in.

GOLDBERG—I have recently been involved in this problem of undergraduates transferring from one major to another after they are enrolled. We have gone into this situation in some detail but have had quite a time getting significant data. A general trend of the behavior of transfer students is as follows: Students transfer out of science and out of humanities into social sciences as they progress through college. An interpretation of this behavior is that the students are exposed to social sciences at the university level rather than at the high school level. Some students are attracted to social sciences once they realize its subject matter. I think you can extend this argument to suggest how to get top rank people into geology or earth sciences. Somenow early in their college career you expose them to the problems, the ideas, and the concepts of earth sciences or geology in their curriculum. Now how do you do this? This can be accomplished if your staff has contact wth the students at an early period in their college career. It is uncommon to have most students enrolled in a geology course in their first or second year. One solution being attempted at San Diego is to have the chemists and physicists within our earth sciences department involved in the teaching program during the first two years.

GOLDSMITH—I think one of the best ways to do it is perhaps this way or something similar. To introduce, shall we say, problems of earth sciences that are in fact problems of physics, chemistry, or mathematics in conjunction with the programs in physics, chemistry, or mathematics. Not necessarily training in the earth sciences but merely

some use of problems will often stimulate a person to go into the problem areas.

WEIMER—I would like to comment about students getting early exposure to geology in college. At Colorado School of Mines, we have about 350 entering freshman and all students have to take freshman geology. The student also takes one geology course in the Sophomore year but does not have to choose an option field until the Junior year. When jobs became scarce in recent years, student enrollment declined. Now there are job opportunities again and 40 freshmen have indicated geology as their field of study. I endorse the comments made here that one of the most important factors to the student is the job opportunities available when the *undergraduate program* is completed. An easy way to kill undergraduate interest in a geology program is to tell the student when he is a freshman that he must plan for six to eight years of college training before he can get a job. Monnet Brown of Oklahoma State University made a survey of the recent decline in undergraduate enrollment—perhaps many of you remember the study as the subject for his distinguished lecture of the AAPG. He attributed the decline of enrollment in part to the lack of job opportunities in the Mineral Industries. The study also showed that with the decline in geology enrollment across the country, there was a decline in the quality of the student in the undergraduate program. Apparently the better students can change easily from one field to another and, like it or not, they are very sensitive to the business of job opportunities. After all the *main reason* most students go to college is to be able to make a better living when they have finished the program. I would, therefore, second Bill's appeal for a strong program at the undergraduate level which can train a student to do a job at the end of four years. Such an approach assures a healthy undergraduate enrollment out of which a good supply of people for the graduate schools can be obtained. We need to review undergraduate curriculum to remove duplication and to develop integration of materials where possible. But the review should not eliminate the geology curriculum as advocated by some people. The geology curriculum needs more and better geology which will provide an adequate background to the student who desires work at the end of four years. Without strong undergraduate programs, the graduate schools will become sicker!

STRALEY—This is in the nature of a question. We have just heard one statistic on freshmen expressing interest in majoring in geology. I wonder where the majority of majors come from and when they make their decision. When I was at North Carolina, we made a casual study and discussed that the majority came as second-semester sophomores transferring from the engineering school or from liberal arts. Rela-

tively few of them came into the University with the intention of studying geology.

MOSS—Do you want that question answered? I could just say at our college one big change has been that since earth science began being taught in the 9th grade, we are getting incoming geology majors. This year we had ten of them. Now some are actually boy scouts who are just sort of fringe students but we may keep seven of them. This is a big change. These courses are feeding students in, some of which can be thrown out (laughter) but they still will give us something new. I think this is a very critical period.

PINSON—What do you do though if you have a selection system that excludes all of these?

MOSS—I think some have that problem, we don't.

WASSERBURG—Technical institutes are a very highly specialized case. In this case—

PINSON—I think that's right.

WASSERBURG—continues—In this case, I think it confuses the issues as we have discussed them and I don't think our problems are as serious as they seem.

PINSON—Yet I would defend it that the kind of core curriculum in mathematics and physics that we require at MIT is the proper kind of undergraduate training for earth scientists. It is the rigorousness of this core-curriculum that necessitates the high selectivity of our undergraduates. We want all earth scientists that we train to have a minimum of two years of college math (beginning with calculus), two years of physics and two years of chemistry, including physical chemistry. This is the minimum. We also have a rather heavy basic science requirement besides this core curriculum, which ensures that a student will take several other courses in some field such as electrical engineering, mathematics, or more chemistry and physics.

BENSON—I think for you that may be true but it isn't necessarily true for everybody.

PINSON—It is not true for everybody, no.

BENSON—It's not true for everybody and I think maybe Jerry, and earlier George DeVore, have identified one of the real critical issues—that is, we could probably still have a geology department which on paper looks just as "classical" as it did 30 years ago but whose courses, under the same old titles, have the new concepts and delve into the application of physics and chemistry to geology. It is not enough for the students to take courses in the physics and chemistry departments and then not use them in the geology courses.

WASSERBURG—I hope we don't have any more low-class graduate schools which are created supposedly to do modern research so that

every school in 1969 will have a mass-spectrometer which is as incompetently used as the abundantly distributed opticaispectrographs were. We need competent centers of graduate research very firmly seated and undergraduate education with real insight and understanding which permits emphasis on fundamentals and encourages and prepares the students to become contributing scholars. We have been discussing at Cal Tech the reverse type of problem; namely, the establishment of a humanities department which is fully functional. So we are on the other side of the stick and the question was, do you start with the graduate school or with an undergraduate school; the decision will unquestionably be to start with the undergraduate school and establish really sound training at the undergraduate level and present a degree in that rather than get a bunch of dead bodies up with the name of professor attached to them—prop them up in chairs and say this is a research institution in economics or English literature.

SURVIVAL OF GEOLOGY, METEOROLOGY, OCEANOGRAPHY, ETC. DEPARTMENTS WITHIN A UNIVERSITY STRUCTURE

By Edward D. Goldberg, University of California, San Diego

GOLDBERG—I probably have the best excuse of anyone at this conference for making inappropriate statements and pronouncements. First of all, I am not a geologist. I am a chemist. I have never taken a course in geology. Also, I am no longer associated primarily with a graduate department; most of my interests today are in undergraduate teaching. My only excuse for being up here, I would suggest as I once served a term as chairman of an earth science department. After my three year tenure, I realized a psychiatrist rather than a scientist was a more suitable person to run this group of scholars.

I would like to discuss the development of the earth science curricula at the University of California at San Diego.

First of all, I would like to clear up what I mean by a curriculum in earth science as opposed to a curriculum in geology. I think you can look at the program in earth science in one of two ways. One, as an undergraduate and/or a graduate program in geology with a thin panache of mathematics, chemistry and physics. The way our department has considered an earth sciences curriculum is a deliberate conjunction of observational studies on the solid earth, liquid earth and the atmosphere and the relationships and principles of the studies interpreted on the bases of chemistry, physics, mathematics, biology, etc.

Now there are a number of anachronisms that one initially is faced with in considerations of the state of earth science education today. First of all the earth sciences and geology departments throughout the country have a number of unique qualities.

Usually the number of graduate students outnumbers the undergraduate students. Let me give you the numbers for the campuses in the University of California system. At Berkeley there are 65 graduate students and 37 undergraduates. At UCLA there are 86 graduates and 40 undergraduates. At La Jolla we have 26 graduates and five undergraduates. The only case where there are more undergraduates than graduates is Santa Barbara. Here there are about 46 under-

graduates and nine graduates. The general situation at most large universities is that the Geology, Geophysics, and Meteorological Departments combined usually hold less than 1% of the total college student body.

A second peculiarity of geology or earth science departments is that the undergraduate training very often bears very little relationship to graduate research and graduate teaching. Many of the graduate departments demand a set of entrance requirements that generally are not a part of the course work at other universities and colleges. Clearly we all have an obligation to produce graduates from our specific universities or colleges that are acceptable for advanced work at other universities.

Now with such a background, I would like to consider the factors that we have thought determine the development of a graduate program in earth sciences. Essentially the conclusion I reach is the one that Jerry Wasserburg had dynamically presented. The first order problem is with the undergraduate curricula. If you establish an appropriate undergraduate curricula, the graduate curricula can take care of itself, I think.

Now what are the restraints that look reasonable today in an undergraduate curricula in earth sciences—the studies seeking those general principles that can be used in all environmental studies, meteorology, oceanography or geology as opposed to a purely solid-earth oriented department.

The first restraint in undergraduate education is the devlopment of strong background in mathematics, physics, and chemistry. Now this isn't a unique problem to the earth sciences, this need for the strong undergraduate emphasis in mathematics, physics and chemistry. Our biologists and our engineers have the same feeling—there is a common core of scientific knowledge that is necessary for the training of students in derivative sciences. Our biology department, for example, is strongly oriented toward molecular biology. I am sure we will never graduate a taxonomist in the foreseeable future. There are six quarter courses in biology for the attainment of the major requirement and the requirements in chemistry, physics and mathematics are essentially the same as those in the earth sciences department, and as a matter of fact in our two existing engineering departments, mechanical and aerospace engineering, and electronic engineering. Thus, one constraint upon graduate work is this development of a strong basic background in the natural sciences.

Now another constraint upon an undergraduate program is the tendency at universities today to increase the general educational requirements. More and more students are being forced to go outside

their major interests in their education. When you add these two requirements—one in natural sciences and one in general education—there really is little left for the earth science department to demand in the way of course work during the four-year tenure of an undergraduate student. We feel it is most appropriate that the courses we give in earth sciences at the undergraduate level have the following characteristics: a strong emphasis on field studies, demonstrating in nature the first order problems that have been solved or maybe appropriate for attack; and to associate the field and laboratory studies with the courses that they are taking in chemistry, physics and mathematics.

There has to be clear associations, if you are going to hold people in geology or earth sciences, chemistry and physics taken in their core program in the solution of important problems in earth science.

Now, at this stage I would like to digress a little bit and point out another peculiarity, common to biology, earth science, and engineering departments which has a profound effect upon the graduate curriculum. Certain courses in physics and chemistry are being dropped or de-emphasized as the departments evolve. These include thermodynamics, radio chemistry and solution chemistry. Often such courses are not being taught to satisfy the needs of various ancillary departments. For example, the chemists treat thermodynamics as one course, solely involving first, second and third laws of thermodynamics and that is it with few considerations of subjects of interest to earth sciences, such as the phase rule and the chemistry of electrolyte solutions.

The earth scientists and the biologists need strong courses in electrolyte chemistry and phase rule chemistry. Here, this constraint, arising from changes in chemistry and physics curricula helps determine graduate school programs. For example, nuclear physics is not taught in the detail needed for earth science by physics departments. Thus, we spend some time in our graduate courses developing concepts in nuclear physics.

Classical physics has been pared down drastically in most physics curricula. The geophysicists in our department give two quarters of graduate courses in continuum mechanics. Courses in classical electricity and magnetism, which formerly were given in the physics department but now have been deleted so more modern types of physics can be introduced, have become the burden of the earth science department to incorporate into their curricula.

Our undergraduate students will have a core curriculum in chemistry, physics, and mathematics which is similar to the core curriculum in the physics, biology and engineering departments and

will come into contact with earth sciences only in their junior and senior years. We see this as a vehicle to attract chemists and physicists into our earth science department. We can try to do this in a lot of ways. First of all, the first sequence in earth sciences which will be a three-quarter course, a quarter of geology, a quarter in geophysics, a quarter in geochemistry, demanding as prerequisites the core program in natural sciences, can be made attractive to all scientists by giving it some of the teachers of these earth sciences programs who have been involved in the teaching of the elementary chemistry and physics sequence. The students may become familiar with the problems of earth science, since teachers usually teach what they do.

Our feeling about graduate work, then, is that by the time a man has had our science sequence and earth science sequence, he can appropriately enter a graduate school and then choose his specialization. We argue that earth science graduate students need this common core knowledge. Whether you are a geologist, a geochemist, an atmospheric chemist, or geophysicist, the necessity to communicate exists on such concepts as heat flow, the evolution of continents, geochronology, turbulance in the atmosphere, etc. among the graduate students. In the first year in graduate work, we hope to give more of the general principles in earth sciences and thus the second and subsequent years are left for specialization.

I don't know what measure of success will evolve from this proprogram. Only time will tell. Cal Tech which has a similar program, and I suggest that by all standards it is a success. I should like to emphasize the need in graduate work for extensive field programs. All our students spend about two months a year in the field. Since we did derive from an oceanographic institute, this can involve about one month at sea and about one month on land.

This is the direction we are taking at San Diego. I think it is a little different and I think it will be a nice experiment to judge, but give us about five or ten years.

DISCUSSION

Moss—Could I ask what the science core is? How many science courses are in it? What courses are they in?

Goldberg—Well, in Revelle College, where one earth science department is, chemistry and physics have been combined into a single course. That is, the normal freshman and sophomore chemistry and physics have been combined into one series of courses which take two years. There is also a course in modern biology. Mathematics goes through differential equations in the first two years. The first two

years in our college (a common program for everybody whether a chemist, biologist, political scientist or poet) also has one modern language, and humanities and social science sequences.

GOLDSMITH—About this matter of departments such as chemistry and physics dropping courses—a specific example of this is in Chicago where the Chemistry department has literally dropped all teaching of thermodynamics.

SIEVER—This is going on all over the country.

SCHEIDEGGER—We also notice this is not only in chemistry but even in mathematics. It is difficult to get good applied mathematics courses from mathematics departments these days for all applied groups. For instance, it is difficult to get a tensor analysis course oriented toward continuum mechanics, say at Illinois.

SIEVER—We teach our own tensor analysis; the mathematics course just won't do it. A number of schools have had applied mathematics curricula that have been developing within schools of physics or applied physics or something like this which is essentially the same kind of proposition.

NELSON—Ed, did I understand you to say that the people in your staff were teaching these general courses in chemistry and physics?

GOLDBERG—Yes. We have a very peculiar department. This is why I said to you that I needed a psychiatrist rather than a scientist to run it. We have people who graduate in physics and chemistry as in with geology. We also have split appointments. We have Professor Gordon Goles who is 50% in the chemistry department and 50% in the earth science department. Then a number of us are associate members either with the chemistry or physics departments. Then through a series of very unusual circumstances, some of the members of the chemistry department could just as well be in our department. Hans Suess and Jim Arnold are geochemists and Stanley Miller, who works on the origin of life on earth, certainly is closely oriented with our group.

NELSON—It is a very interesting solution. In less prestigious universities we have this same problem of general science education. Geology, historically, has assumed this role in many places and one of our difficulties from the standpoint of public relations, I think, is that this elementary geology always has been a course that one takes when one can't pass a good science. So I think, one of our central problems is to change the character of that first course. We are moving into this area of giving a general physical science course for the general student which will be centered in the geology department, and which will allow us to give an introductory geology course that, like yours, is based on physical principles to a much greater degree than ordinarily

would be possible. We also look on this as an opportunity, to add people to our staff who have competence in physical science, because we can justify their teaching role. So it would be very interesting if you are successful in continuing your interdisciplinary science associations. We are in a very much more rudimentary state right at the moment, but we certainly are going in that same direction.

BUSINGER—I think I am the only meteorologist here among the group and because meteorology is also part of the earth sciences, I would like to comment that we have essentially the same problem which, I think we have more or less solved. Our undergraduate program in atmospheric sciences is at the same time an undergraduate program in classical physics. A student who graduates is essentially a type of physicist who knows something about the atmosphere. The problem is that you have to do two things at once. Dr. Benson pointed this out. You can teach the classical course in meteorology or in geology, or in any of the geophysical sciences but you have to develop the tools of physics and mathematics at the same time. After the student has had the introductory courses in physics and math through calculus, we continue to teach him physics with immediate application to the atmosphere. This method has been successfully applied for physical oceanography as well as for the atmospheric sciences. It seems to me there is no reason why it wouldn't work for solid earth geophysics. The graduate student who has had this type of preparation will have the necessary background to start research work almost immediately.

SIEVER—Do you teach synoptic meteorology and all of the classical tools at the same time?

BUSINGER—Sure. We get students who know nothing about thermodynamics so that we have to teach them thermodynamics which is a big problem, but it can be solved. Similarly tensor analysis is taught in engineering school—

DEVORE—Did I understand you to say that your poets take molecular chemistry?

GOLDBERG—Sure. We do, as a matter of fact, have people who are majoring in humanities who are taking mathematical analysis. When we first described this course in our bulletins as calculus, it terrified the students. Now we call it mathematical analysis. They take it and they enjoy it. We expose the students to the beauty of mathematics and try to associate their course work with problems in the humanities, where possible.

GOLDSMITH—There is an interesting correlation here between synoptic meteorology, classical meteorology, as Dr. Businger has mentioned and geology. Though I am not a meteorologist, I at least live with them

all the time and they have exactly the same problems—exactly the same thing as we hear often from classical geology; namely, the fear that meteorology or atmospheric science is getting away from the consideration of the real atmosphere just as the way the geologists feel that too many geologists are getting away from the field—from the real earth. These are exceedingly parallel things and, I think, are deserving to be mentioned. I think they are symptomatic of the times.

WASSERBURG—Amplify that—I didn't understand—

SIEVER—Well, I can amplify it by our experience at Harvard. Our meteorology, which was ultraclassical up until a number of years ago, with observatory and everything else that goes with it—when the senior man and essentially the only man left passed on. The whole place became vacant. At that point they introduced a man who had started as a classical meteorologist, who considers that meteorology is really the dynamics of irrotational fluids. If that is so, one might just as well get people trained in physics and applied mathematics and let them go on from there. He has essentially dismantled the observatory for teaching purposes, (it is kept to some extent by the weather bureau). The same kind of approach has been taken in some geology departments.

WASSERBURG—No, I don't think so.

GOLDSMITH—I can amplify it further if you want Jerry. You can look at a number of top departments of meteorology in the country today and you will see people strong in atmospheric dynamics or in fluid motions, shall we say, in a large sense. You will also see groups strong in what is called cloud physics which covers a variety of things such as principles of nucleation, etc. is not too far removed in part from crystal chemistry. Many of these people really have no feel for the real atmosphere. They can read a weather map—they may have a course in synoptic meteorology but they don't care to pursue it beyond that. They are not really concerned with weather phenomena per se. They are interested in broader scale aspects of the atmospheric sciences that they hope will ultimately lead to a better understanding of the weather but they really are not concerned with the weather at all. This is what I mean.

BUSINGER—I don't think I quite agree. I think, well—

GOLDSMITH—I overstressed—I am overstressing—

BUSINGER—Yes, I think you do because I think the solution is in cutting down on map plotting, and that sort of thing—but not in eliminating it. I think we find that people are still very much interested in the atmosphere and want to obtain the dynamic picture using the proper technique and the proper tools. I think that is still a

valuable part of meteorology.

GOLDSMITH—Oh, sure.

WASSERBURG—The situation that meteorologists are not working with the "real" atmosphere may be true of meteorology, although Dr. Businger just said that it is not. If we were to say that about the earth scientists—that the new fangled guys are not really working in geology—that is hogwash—they are really still doing geology, they happen to be doing a different aspect of the problem. I think if the field of meteorology was just filled with guys who solved the Navier-Stokes equations in toroidal, coordinates for exercise all of the time it wouldn't be very good for the science, but if they are ultimately interested in atmospheric problems this is a perfectly healthy thing.

GOLDSMITH—I am not saying that this is bad, mind you, I am just saying there is a split parallel between the two and it shows up very nicely if the department of meteorology goes out looking for a modern synoptic man; they are not being trained in very many places.

SIEVER—It raises a rather difficult question. I think we are talking around the edge of the question of whether a science should only attempt to tackle those things which it can tackle in a very rigorous or otherwise satisfying way as compared with more fundamental sciences like physics. I am suggesting here that there are certain meteorologists, certain geologists, and earth scientists who feel that it is better that we concentrate on those problems on which we can do a good job. They may not have much to do with the very fine details of the real world but they do attack the real world in an abstracting way. The question is, do we have to tackle everything? Is it perfectly admissable for a man or for a whole department to say—"we are only going to tackle those things which we can do very well and will leave all the rest, which is very difficult and not easily tackled, to somebody else or to another generation."

PINSON—I think the problem presents itself continuously to departmental chairmen. Should an earth science department be staffed with scientists strongly oriented towards some aspect of earth science and who possess a pretty good knowledge of the physical sciences, or should it be staffed with men who are indeed highly competent in some field of physical science or mathematics, with the hope that such a person may direct his interests towards aspects of earth science? Of course, we all agree that ideally we want a man whose first interest is earth science, and who is *highly* competent in physical science. There are a few such people around, and I could name quite a few, but indeed they are extremely rare.

SIEVER—Ed, did you say that your introductory course, rather than earth science, is a course in physics or a course in chemistry or were

you emphasizing the physical science survey type of course?

GOLDBERG—We don't have a survey course, as normally defined. Our group feels that teaching these superficial courses (that's your word, Konny) is a waste of time. If you are going to teach chemistry it should be taught from first principles that are understandable by intelligent high school students who can get into a university. If you have to teach two types of chemistry, you are in trouble. This gets a little deeper. One of our concerns has been the problem of creating black box earth scientists. That is, all of us talk about x-ray machines or infrared spectroscopy. There are two ways you can use an x-ray machine or an infrared spectroscopy. You can use it from the manufacturers instructions—by plugging in something and getting something out. Or the person can really understand the physical principles underlying the machine. Unless they get these physical principles from hard core courses, we feel that one is producing black box scientists. There was one point I was discussing with Jerry Wasserburg a few minutes ago. The Mossbauer effect—now five years old or four years old—is now being applied to geological problems primarily by a Russian name Goldanshi. I can't argue that he is solving first order problems, but the point is the Mossbauer effect is being used. If it is as successful, I think in ten years or five years the Mossbauer will travel from physics and will become the tool of earth scientists. Now to understand the Mossbauer effect, I would suggest that you need at least the normal two years of college physics. If we don't educate our earth scientist students to be able to understand the Mossbauer effect, I think the science is going to be impeded.

WASSERBURG—I think there are some questions about the teaching of "double" courses. We don't have this problem at Cal Tech, so it's easy to talk about, but it seems that one possibility is to teach a single series of courses—all courses at a professional level—so you don't ever teach a service course, and a student whose major is not in that field, can get out of it what he can. This avoids the problem of offering a service course which is a hell of a way of crucifying the faculty and also each student can seek his own level so that a physics major can get all the physics he needs out of the course and a poet, maybe he gets a D-. This is okay; it's no reason to throw him out of school. It saves you from teaching two types of courses and means that everybody can take as much as he can get.

TUREKIAN—An overwhelming proportion of students at Yale go into one humanities and social studies. One solution to the science education problem is to put all these people through a history of science or philosophy of science courses and keep the science courses tough. Another is to have different levels of hard science courses into which

all students can find their level.

WASSERBURG—I would agree to have one hard bunch of science courses. I do not agree with the thought that we can train people who will make policy decisions by having them learn the history of science from people who don't understand it at all.

SIEVER—Could I suggest that we are getting off into the subject of general education for undergraduates which is not really appropriate to our expertee.

NELSON—Let me just summarize it if I may because it comes up in different contexts. The idea was that this might be a mechanism whereby we could justify more technical staff within earth science departments or more quantitatively trained people with better physics and chemistry backgrounds in geology departments. If we had this kind of role on the campus, it would help the staff problem and it would help our image problem.

BUILDING A GRADUATE DEPARTMENT WITH COMPLETE FREEDOM OF CHOICE AND FUNDS

By Julian R. Goldsmith, University of Chicago

GOLDSMITH—That is Chuck Weaver's title also, (laughter) and I will not really talk directly to that point. Furthermore, as I suspected anything that I could say has already been said and I find that Ed Goldberg in particular covered many things in respect to graduate education that are almost parallel to happenings at Chicago, and therefore he has taken a lot of wind out of my sails.

Of course, if we knew the answers to these things, we wouldn't be here. Furthermore, last night Fritz Koczy and Jerry Wasserburg and I settled all the remaining problems anyway. (Laughter)

It would be redundant to go over some of this ground now. I don't even know what earth science is anymore and I think there is a general tendency in many departments of earth sciences and in many institutions throughout the country for increased fragmentation. I think this is happening at La Jolla perhaps, it is happening, I know, at Los Angeles and several other places that I am not too familiar with. I get the feeling that fragmentation has been going on at MIT for a long time. Frankly, it is precisely what I, at least, am trying to avoid with whatever influence I may have in Chicago and I think that the faculty by and large agrees with me because we have done something that other people consider idiotic. We have gone from several departments back to a single department, and have created (about three or four years ago) a department called the Department of the Geophysical Sciences. People ask us what it means and all I do is read off the initials D. O. G. S. and that ought to be fairly clear. (Laughter) Nevertheless, we have abolished the department of geology and we have abolished the department of meteorology and in so doing we have created certain problems and we have certainly produced many enemies throughout the country, particularly in terms of old grads and alumni. Nevertheless, I think that the tendency toward integration is a healthy one. It has hurt us in the sense that people have said—well, you don't have a department of geology anymore, therefore, you don't have any geology, and meteor-

ologists have said—well, you don't have a department of meteorology any longer, therefore, you aren't teaching any meteorology. Our student enrollment initially dropped when we formed the new department, but is now increasing.

OSBORN—Graduates, or both?

GOLDSMITH—Undergraduates have almost been nil, Ozzy. To go further with Ed's figures, the current enrollment in our department is either 61 or 65 graduates and three undergraduates. We are planning to strengthen our undergraduate program but I don't want to go into this matter now, other than to say that since the war the undergraduate program has been de-emphasized.

Bill McNeil, an eminent historian who wrote a rather well-known book called, *The Rise of the West* (I am sure many of you may have heard of it), collared me about six months ago and asked, "How in the hell did you swing this one?" I said, "What do you mean," and he said, "Do you realize that as a scholar of history I examine departmental structures in universities and yours is the very first that has successfully abolished two departments to form one." He said "that destruction of autonomy is unheard of—I don't believe you really did it." There are several factors he didn't consider. One is that a single large department carries more "clout" than several smaller ones. This relates to how you plan for the future and that is difficult because I really don't know how you plan for the future much less "control" the present situation with respect to a department. I think it is a mistake to go too far in planning. Planning for the future of science is not only difficult, it may be impossible.

GOLDSMITH—The best thing to do may be to go along from day to day and do what you see best today. This is certainly true in recruiting faculty and it is obviously true in obtaining students. You operate on a day to day basis and always face the danger that you can get yourself locked in—the whole tenure system tends in this direction. Of course, you can get yourself locked in with what looks like a good faculty today and find yourself in big trouble tomorrow; this can happen a lot faster than most of us think.

When you take good people who are available today, you are really in a sense locking yourself in for the future. Thus, it is most difficult not to endanger your future in a very rapidly changing world.

Also, in terms of planning for a department it has been said five or six times today on what's good for one department or university obviously isn't good for another. Again the familiar phrase—you can't be all things to all men—either to students or faculty. There has not been so far in the discussion I have heard today any distinction between the faculty point of view and the student point of view. In

fact, I am not sure there should be a difference between faculty point of view and the student point of view because we are discussing graduate departments. Here, in terms of research men on the faculty, it is fitting that they have their fingers right down under the students and that they should intermingle to a point where the students' point of view and the faculty point of view should come as close together as they possibly can.

Then again in building a department what do you go for? Do you go for coverage? Do you attempt to cover fields or areas, or do you choose good men with little or no concern for their field? In the sense that every department is limited in terms of science, you have to make a choice of sorts in this direction. Many departments of geology, I know, and also meteorology at many institutions attempt to maintain aerial coverage, shall we say, and this is certainly necessary to an extent in the instructional program. However, if we attempt to maintain aerial coverage in terms of a first-grade research program, I don't know of any institution in the world that could adequately have full coverage with the right people—with the really first-rate people. Thus, I think it is ridiculous to emphasize coverage at the research level in a good graduate department. I would much rather see imbalance heaviness in one area at the expense of others if good people are available in that area. The relative shortage of good people that exists today make it difficult to build a sizeable department of top quality and the market has become so competitive that it is essentially cut-throat, as all of you know.

It is a simple matter of fact that there just aren't enough of the good people to go around. There aren't *nearly* enough good people to go around, and here we speak of both students and faculty. Of course, one of our goals is to train good students so there *are* enough good people to go around, so that we come right back to the student problem which leads into the faculty problem.

Another problem relates to the source of students. Do you "train" a man who comes up through the earth sciences, or do you take a man who comes from some area of science outside of the earth sciences?

As I mentioned this morning, I am looking down the throat of three people who came from the "outside." Really only 2½, for Jerry Wasserburg is really only a half of a guy in this respect, but certainly George Wetherill came through in physics and Ed Goldberg came through in chemistry. As I see it, it is necessary for the man to have a real—the best way I can describe it—a real *feel* for the earth and its problems. He has to develop this at some time in his career either when he comes into the earth sciences from some other area

or he must come through earth sciences, then into another specialized area and then go back into the earth sciences. There aren't too many that do it successfully either way, as yet. I think there are more and more people trained in the basic sciences coming along and the big hope for the future is that there will be more of them. I can't think of very many people who have come through a classical training in the earth sciences who have become well enough versed in the handling of other physical techniques, (and I use techniques advisedly, I don't mean only laboratory techniques), to have the same ability as the man who is an outstanding contributor in the fringe field to begin with. I think this is an important problem we have to face. There are always exceptions to this rule, of course. There are many I have seen come into the earth sciences from the "outside" who have never developed a real feel for the earth problems. Now this is truly a tragic situation because many of these are brilliant people and would contribute a great deal more if they *really* had feeling and understanding of the earth as a physical body.

George Wetherill also made this point that I think is very important—there are a very few—a very few people I know of who can work in the area of the earth sciences and who have a real feeling for the earth and its surroundings, who are also at the *forefront* of research in an area of physics, chemistry or mathematics. He mentioned the Mossbauer effect. That is why I asked you, Ed, to bring this point up again.

I know a young man who intends to pursue the Mossbauer effect in mineral systems. He has been recently working in NMR, (Nuclear Magnetic Resonance). This happens to be a very unusual man because he started life as a geologist, but is now actually working in the very forefront of NMR, in the sense that he is doing productive research work in nuclear magnetic resonance phenomena and not just in NMR as applied to an earth science problem. These are the people that are really rare and these are the people we have to welcome with open arms. Harold Urey is another example of a man at the forefront of his field working in the area of earth science, even if a bit "far out." These people are very rare. We are speaking of a few men in the country really—unfortunately not enough to staff even a small percentage of the departments of earth sciences but these are the people I think we have to look out for.

Getting back specifically to our department for a moment to some of the problems and some of the benefits, I would like to speak of some of the benefits. It has only been in existence for several years but I think already results have begun to accrue. For example, the interaction of atmospheric sciences and solid earth people has pro-

duced an interest in both of them that I wouldn't have foreseen even a very short time ago. Solid earth geophysicists who had come to Chicago to give seminars were astounded, I think, at not only the interest shown but the real feel for their subject on the part of several atmospheric scientists. It turns out, of course, that much of the mathematics are the same, and wave equations used in seismology are precisely those used in some of the atmospheric work. But unless you actually bring these people together and let them talk to each other, they often spend a lifetime without finding this out and I think this is an unfortunate situation. We have been criticized by some people for bringing meteorologists and geologists together. I think it has worked out very well and I have higher hopes for the future. There are many things in common. I mentioned earlier the subject of cloud physics. The bringing together of people working in cloud physics with some really top-flight crystal physicists and crystal chemists, I think, has already produced a great deal of mutual interaction which will be very important in the future. Many of the problems are identical. Problems that relate to nuculation in silicates or carbonates that I have been concerned with are precisely those problems that some of the cloud physicists were working on independently.

I stand against the fragmentation of departments and disciplines and am wary of the institute concept because it tends to produce fragmentation and tends to separate students from the faculty. However, one has to take into consideration the size of the university of research unit; what is good for a small school isn't always good for a large school, and some of the problems of large schools can be adequately handled in the case of small schools. Coming back to Chicago —we are fortunate in being a small school by any modern definition of size and we are attempting to keep tightly-knit—in terms of our own department and to do much of the same in the case of the entire division of the physical sciences. We hope that in not too many years that the entire division of the physical sciences will be a single interconnected unit (in terms of building) so that interdepartmental interactions now missing will be, at least in part, not hindered geopgraphically. We are also handling the situation in the same way that Ed mentioned at La Jolla by the route of joint appointments. We have a number of them and this is an important way to get students as well as faculty into the earth sciences. This works more easily in a small school than it does in a large school.

I think that is about all I can say that hasn't in a large part already been said.

DISCUSSION

BUSINGER—At the University of Washington we have made an effort in the same direction as the University of Chicago. We have not succeeded in the same way. Instead of a department, we have an interdepartmental committee on geophysics which administers a graduate program in geophysics. This graduate program in geophysics has a similar curriculum as the department of geophysical sciences in Chicago. Our program is younger and does not represent a merger of departments. We still have departments of atmospheric sciences, oceanography, and geology. The interdepartmental geophysics committee consists of faculty from these departments and the departments of physics, chemistry and electrical engineering. The graduate student who enters the program has more or less the same possibilities and needs the same background as the graduate student in Chicago. A difficulty of our program may be that there is no strong administrative organization to administer it. I would like very much to hear opinions concerning the organization of a geophysics program. Should it become an institute, or a department or a whole school of geophysical sciences.

SCHEIDEGGER—As to these interdisciplinary programs administered by committees, we have not tried this in Illinois in geophysics and geology, but it has been tried in biophysics which has a similar problem. The danger is that the committee members never really can agree what a student would have to know, and so, since one needs five people for the Ph.D. qualifying exam, this means the poor student may have to satisfy everyone; thus, he has to get about three Ph.D.'s at the same time. It is likely that such a program is not very popular because it is almost impossible to satisfy a committee consisting of members from five departments because in effect, what is required is that the student has to satisfy the requirements of all five departments.

SIEVER—We have several interdepartmental committees in biophysics and biochemistry at Harvard, in the medical school and the main department of Arts and Science, all of which have produced students. One hundred and sixty-five people a year are coming out of these courses. They seem not to have the difficulty. My impression is that interdepartmental committees can work under favorable circumstances. Certainly Chicago has had a very favorable experience in interdepartmental committees of some kinds—in my understanding.

GOLDSMITH—That's right.

WASSERBURG—The real danger though is that a student has to have a home. It is a thing you can't ever forget. If a student doesn't have

a home, he is in trouble and a committee isn't a home.

GOLDSMITH—That is a very important point—not only to the student but to the faculty, Jerry. You have to have a home—you have to have a unit—but in addition, as soon as you start getting interdepartmental committees or for that matter—different departments that treat fringes of the same area—you begin to get competition. This is bad and it gets even worse when you look at some of the larger schools that not only have competing departments but have competing campuses. California has this, Ed, and I think it is unfortunate.

WETHERILL—That goes in the record, you know.

GOLDSMITH—Not my nod.

PINSON—I should think that appointments in two departments would often lead to difficulty. Does this mean that half of his appointment might come from the chemistry department and half from the geology department, for example?

GOLDBERG—We have this.

PINSON—Does this create any difficulty?

GOLDBERG—It works out fairly well but, of course, this depends upon the man in question. A man who must be sort of a schizophrenic—he works half the time with chemistry and half the time in earth science. He must be at home in both departments. I don't think you have too many problems arising here—especially where the university pays his salary. What difference does it make? I just want to make one point on the remark that Julian made. Environment is the most important thing—you create the proper environment and it affects the students and the faculty in the same way. We have brought two pure geologists to La Jolla: Al Engle, whom most of you know, and Al McBinney, who is a volcanologist and a student of Al Williams. When they came, both of them knew little of marine geology. Once he became involved in our shipboard work, Engle became an oceanographer. He just returned from sea about three days ago. The same occurred with McBinney. Now if you have a healthy environment among departments, collusion between them develops normally. Arnold, who is in the chemistry department, works with certain of our staff members in a very healthy way. Now my final point on this is that such collaborations result in a high morale that can transfer down to the students. If you have geology students who won't even talk to each other, you are in trouble. If you have geology students who, through the atmosphere established by their professors, can talk with chemists and physicists, I think you have a much healthier situation.

GOLDSMITH—As a matter of fact, we now have students working in more than one field, certainly across the boundary into the atmos-

pheric sciences. We have at least two or three students at the research level whose major problem is in one field, but who are working with a faculty member in the other.

WEAVER—Boundary lines in science no longer serve any useful purpose, if they ever did. We presently have a chemist, a ceramic engineer and a chemical engineer doing research under our supervision. which will be acceptable as a basis for thesis in their respective fields.

BATES—One of the largest graduate programs at the Pennsylvania State University at this time, namely that of Solid State Technology, was developed by and is now run by a committee. I will spend a good deal of time tomorrow afternoon talking about some of these things, so I will save my remarks for that time. I think we have plenty of examples around the country of good interdisciplinary, academic and research programs that are working—some of them under the direction of committees.

FREDERICKSON—May I go back to Jerry's point: not only does just the student have to have a home but staff members also have to have a home, especially the younger people. Difficulties on this point often arise and cause no end of trouble at universities where a young staff member has a joint appointment and half of his salary from one place and the other half from some place else. All of our joint appointments have a clearly identified administrative home. *All* of his salary comes from one place and, therefore, the staff member is responsible basically for his promotion and those other things that are so important for his professional growth to only one place that seeks the advise, however, of the other portion of the appointment.

GOLDSMITH—Well, we do the same. It really makes no difference as the faculty members don't know where the salary comes from.

WASSERBURG—It does in a division; if the division people have one or two departments, each of which is paying half of the guy's salary, you have a different matter on your hands.

FREDERICKSON—There is a scramble for research money, for equipment money, and other resources unless you centralize the budget part of this, and then some of these things work pretty good. Hardly anyone is likely to donate salary money or equipment funds to a joint appointment if the man concerned does most of his teaching or research in another group. This is particularly true where salary increases are concerned. It is not a good policy to force a man to live with two bosses. Only one should have the basic responsibility and the other can provide advice to insure that both portions of a joint appointment task are being handled properly.

BUSINGER—But even if the salaries come from one source for a split appointment, promotions are apt to come from both sides and some-

times that makes it very difficult.

GOLDSMITH—With a good manager you don't have this problem. We are dealing with good men—

WASSERBURG—Except for the usual attitude—"If he is just very good in my business, he'd better be damn good in your business."

GOLDSMITH—This incidentally is a very excellent way of insuring quality in the faculty.

WASSERBURG—Both faculties examine him—this is really very tough. The problem of split teaching responsibility is also very serious.

WETHERILL—Are you sure this is an example of fragmentation? I don't agree with you. I think it would be impossible administratively to have all the astrophysicists, all the meteorologists, geologists, and geophysicists, etc., which would be something like 60 or 70 people, on the other hand, in one department. Through the practice of joint appointments, I think we have much more integration than we have ever had before. More so, than I think that exists in most places. In some cases we have people who get all their salary from one department and may have appointments in two other departments and altogether have three appointments. Then there may be some that get half of their salary from one place and half their salary from another place. I don't see why the source of the salary is of prime importance. In any case, for promotion they still have to be evaluated by several groups of people regardless of where the money comes from. To some extent this sometimes makes complications if one group says that this man should be promoted and the other group says he can't be promoted. On the whole, I don't think it hurts people any more than it helps them—I think it averages out.

GOLDSMITH—That's right. I think it's probably the same at UCLA as at Chicago—a man is a member of a division, the physical science division in the case of Chicago and his salary comes from the division. Whether or not one department is budgeting his salary is unimportant.

SCHEIDEGGER—At Illinois, as far as I know, the joint appointments work rather well and this is a large school. Bordeen, for instance, has a joint appointment between physics and electrical engineering, several people—two or three—have joint appointments between geology and civil engineering and also between us and physics. In some instances, this even crosses boundaries of colleges so that different division heads or deans are involved. This seems to work much better than the committee approach to programs. Naturally, it is impossible to generalize, but it seems that one has to play this by ear to see what will work in a particular place.

SIEVER—We have a very simple device that we use at Harvard. We make it a matter of practice that any time that anybody is appointed

at Harvard, whether a meteorologist or oceanographer or any of the things that impinges on geology, we make them a member of our division even though we don't pay his salary. He may be associated with quite a different department or division. Nevertheless, he is asked to meet with our department at departmental meetings and to take part in the affairs. Interdisciplinary communication works well if there are people in the geology department who are willing or rather anxious to talk to and work with people of other departments. There is one well known university on the East Coast that has provision, certainly, for communication, and yet their geology department has practically no communication with anybody else, as no one in the department feels the necessity for it. In such cases you can set up interdepartmental committees and it's not going to do any good.

BATES—How far out do you go? Where do you draw the line with regard to people who are associated with and close to earth science—I am just curious.

SIEVER—Well, not really very far out. The people who are in meteorology and geophysical fluid dynamics are included. In paleontology we extend to the department of biology. We have an entomologist who is interested in ancient insects, and who has been invited, although he is not a formal member of the department. We don't, however, go very far afield.

WASSERBURG—You don't go very far at all. It doesn't make any real difference.

SIEVER—You are right. We don't have physicists, we don't have chemists or people like that.

WASSERBURG—I think one of the problems which is not really being discussed directly here is the problem of fragmentation. I prefer to think of geology as a whole science, although I might not object too much if someone said to me meteorology was a separate department (although from hindsight I might). For the fields of geophysics and geochemistry in geology, I think that one is seeing a tendency in certain places for fragmentation of these units into separate divisions where geophysics is considered to be separate from geology and geochemistry is considered to be separate from geology. The ability to examine and train with some relatively uniform standards so as to guarantee some communication with the science is very important. This ability is in certain instances vanishing and there is certainly pressure made to make these vanish. This is the cause of some concern as to whether or not one can have geophysics as a separate institution or separate division or school from geology or geochemistry as a separate school from geology.

BATES—Anyone familiar with our Penn State setup knows that we

have varying degrees of separation between Earth Science departments with a unifying College of Mineral Industries. Different places are going to have different organizations. I was amazed when I went to Penn State from Columbia. I never knew the mining engineers at Columbia. They were on the other side of the quadrangle there, and I didn't have occasion to run into them. In the College of Mineral Industries you just can't help but become acquainted with related disciplines because of their proximity. This is simply one of a number of ways of having autonomous but related departments which are brought closer together under some unifying larger structure.

HUNT—Ray, I would like to bring up a slightly different subject. Almost all of this discussion has centered around fragmentation and interdisciplinary problems. Another concern we have is the quality of graduate students, and I am bringing this up because for many years I was on the other end of recruiting, where we were trying to find out at which schools we could get the best students. There have been some factors that have come into effect in recent years which I think are not good and they are affecting the graduate student. One is that many universities which formerly had a faculty, now have a faculty plus a research staff, and frequently, the research staff is paid better than the faculty because it is they who raise the money. The result is that some of the better qualified people go into the research staff and rarely, if ever, teach. I say this not as a matter of general condemnation, but am merely pointing out that it does occur in several places. Another thing is that in many universities there is inbreeding. That is, the best students end up at the same universities they attended in some kind of appointment on the research staff or faculty, one or the other, and stay there. It is rather interesting that at the larger universities (and I can include MIT, Harvard, Columbia, Princeton, and Chicago in this) over 45% of the present faculty received their graduate degrees at that university. I think this inbreeding will not improve the quality of graduate students, nor do I think this over-emphasis on placing the best people in research is a good thing either.

GOLDSMITH—This is a very good point. I can't speak for other institutions but I think in the case of Chicago you are pointing out a situation that was locked in 20 years ago—certainly around the time of World War II.

HUNT—In other words, you are saying in the last 20 years this has changed.

GOLDSMITH—Completely.

HUNT—Okay.

GOLDSMITH—In fact I know that many schools now look with great

disdain about taking on their own Ph.D.'s but it was almost impossible—
HUNT—On the research staff—
GOLDSMITH—We don't have a research staff.
MAXWELL—There is another side of this though which we talked about this noon. Julian mentioned when you choose a man, you effectively set the course of part of the department for the next 20 or 30 years and the problem is to identify the man that you want. Among your own students you can spot somebody that you think is going to be a world beater and then it is rather hard to resist the temptation to take him, although you know perfectly well this is not generally an advisable thing to do. The difficulty is to identify topnotch people from other universities when you need a man.
WASSERBURG—The danger, however, is that what you recognize as genius is a somewhat remade version of your own image.
MAXWELL—You are absolutely right, Jerry.
SIEVER—Julian made the statement that there are a number of superb scientists in other fields that have no feel for the earth sciences or the real problems of the world. You could also say that this is Julian Goldsmith's conception of what the feel for earth sciences is; in fact, their ideas might be quite valid and you can't recognize it. The same is true for me or anybody else here. So it is a little bit dangerous, I think, to put the constant emphasis that we do put on this point. You may talk to these people and they are simply operating at a higher level of abstraction than you are. This may not be true all of the time, I agree; there are some people that simply don't know anything.
SIEVER—You are talking about problem orientation versus method orientation. There are a good many people who say, "I would like to try out something in fluid dynamics and the earth happens to be a good place to do it; really I am interested just in the dynamics of fluid no matter where they are." A different approach is, "I am interested in the atmosphere and I don't care what tools I have to use on it; I am interested in the atmosphere." The difference between the two is the difference between physics and geophysics. In many areas you may have to work on very difficult and messy problems, and you can't do a very good job with them but you're stuck with the problem. You can't just go off and leave it because you can't solve it in a satisfying manner.
DEVORE—The problem here comes in staff. For example, there is a great need to get something done in oceanography, and because of this need anyone who is doing anything at all might be considered a pretty good candidate. Then when he comes up for a joint appointment, we

would look at him as a chemist or physicist and he is usually pretty second rate, so we kill the appointment.

SIEVER—I will quote a counter problem. We have had some discussions about organic geochemists. It's an interesting field and the question is, whether to add an organic geochemist to geology, earth science, or other type of department. Do you want a really good organic chemist, do you want a geologist who had a couple courses in organic chemistry? What do you want and who can you find? If you have next door to you a very good department in organic chemistry and people who have some rather high standards, the chances are slim of finding anyone satisfactory. As a matter of fact, a number of people have come to the conclusion this field isn't ripe yet for university research and teaching. Tomorrow it may be, if good, well-trained students get interested. I can give you the example of a man whose chemistry is somewhat amateurish. Yet, he is the only man who is looking at this kind of problem and he might do great things with it. But as fundamental organic chemistry, it would be laughed at by the entire chemistry department.

GOLDSMITH—We get right back to the point that I tried to make earlier, Ray, that the best way to obtain mediocrity is to try and fill a slot.

WASSERBURG—That's right.

GOLDSMITH—I can't think of a better way to kill a department than to attempt to find men in particular fields. If you can find a good man irrespective of what his specialty might be—grab him for gosh sakes.

WASSERBURG—And now would you define a classical department.

GOLDSMITH—How would I define—

WASSERBURG—And *now* would you define a classical department.

GOLDSMITH—"A classical department is a one man department." I don't know how to define a classical department.

PINSON—I would like to raise the question again of whether or not it is advisable to make permanent appointments of research personnel on a doctoral level. I would like to give some opinions on this. I do not think we have any clear-cut policy on this at MIT, but in the geology department, we do not have such permanent, research department personnel. However, there are institutions that do have permanent appointments of this type, and I would like to hear some comments on this.

HUNT—Are you talking about MIT?

PINSON—I am talking about whether or not such permanent, non-teaching appointments are advisable in graduate schools teaching earth sciences.

HUNT—I talked to some people at MIT a few weeks ago, and I got the impression that they do have people who come on temporary research appointments and stay long periods of time. Some of these research people are paid better than the faculty.

PINSON—Well, we have the research associates who come on temporary appointments and don't get tenure. I am talking about the permanent research personnel who tend to enhance the stature of a department in research. One way to do it is to appoint very competent people and give them no responsibility in teaching. This is an obvious way to do it but there are difficulties. Is it advisable from the standpoint of graduate training and education—I just want some opinions on that?

GOLDSMITH—This is something called hoarding by some people—hoarding of research personnel which I think is bad from several points of view. I don't think there is any place in any university for this sort of thing. I think it is depriving many other institutions well-qualified people who should be on a faculty, and my opinion is that no department of any significance should hoard research personnel for any signficant length of time. I see no objection to a three-year appointment as a research associate, but I think the idea of having supplementary research personnel is a degrading thing for a university.

PINSON—Why so? Where is the degradation?

GOLDSMITH—Let's put it this way—why have them? Give me one good reason why you should have them.

FREDERICKSON—I think the function of the university ought to be specified clearly. A university is in the education or personnel-development business. Teaching and research are essential parts of the educational process. I am concerned about the proliferation of strictly research appointments. If such appointments isolate either a graduate student or a staff member from the teaching aspect of the institution, I feel that the appointment is not in the best interest of the university and, therefore, the number of these appointments, their cost and their contributions should be watched closely.

GOLDSMITH—That is exactly what I am saying.

FREDERICKSON—On the contrary, practice in some of the California schools which have a large number of research appointments for people who have very little, if any, contact with students is not a very good use of federal money—at least of good use to the country.

PINSON—I suppose some of the benefits have rubbed off on the graduate students.

FREDERICKSON—Very high-level research goes on. But graduate students seldom come in contact with some of these people if they don't have some sort of teaching obligation.

WETHERILL—I don't know what California schools you mean, but

there are a number of appointments in geophysics at UCLA, for example, which might have been called research appointments. On the other hand, with the exception of a very few individuals, many of these people do more teaching that some of the other academic appointees with regular departmental appointments. It is true that they have more freedom of choice in their teaching duties, which is perhaps resented by some of the other appointees, but I think the net effect on these people in the university is quite stimulating with regard to the teaching function—not just in research.

FREDERICKSON—Well, that was the qualification I made: it is not a good practice if it separates the student from these people.

WETHERILL—There are people who exercise the option to do no teaching; they have no contact with students whatsoever, but I can only think of one or two such people.

OSBORN—I think I would like to answer that. In my experience, the best research people are usually the best teachers.

WETHERILL—Even though they have a research appointment, sometimes they can't stand it when they see what is going on in the teaching—

GOLDSMITH—In some schools they are in a non-teaching capacity.

WASSERBURG—What is the situation in Columbia? I always hear rumors that there is a fair staff of pure research people in Columbia.

NAFE—There are. But we have two large Oceanographic Research vessels to keep running. To keep these operating and producing worthwhile results, a large research staff is required. These people are not isolated from students, however.

BENSON—I think the oceanographic institutes and departments are special cases in the earth sciences because they are big facilities, and running them takes some full-time professional scientists that have been built up largely since World War II with outside support funds because no university could afford to build a a really big oceanographic laboratory without some sort of special support. Therefore, we simply had to pay full salaries even though we didn't do so in other departments. I don't think this should be viewed as just a sort of "professor hoarding"—you need the staff to run institutions. So I wouldn't agree with your criticism if applied to oceanographic laboratories. I would agree with the criticism as it pertains to most conventional-type departments where teaching is or should be a major activity.

PINSON—But it is very easy for operations within a department to become very big.

BENSON—Oh, yes.

PINSON—Not as big as a ship and the ocean, but they still can become quite big.

BENSON—I think the caveat is to be very watchful, and only allow the "big operation" to develop when that's the only logical way that a particular activity can be carried on.
SIEVER—Our final speaker today is John McCauley.

THE GEOLOGICAL EXPLORATION OF THE MOON AND ITS EFFECT ON GRADUATE EDUCATION*

By J. F. McCauley, United States Geological Survey

I have been asked to discuss the geological exploration of the Moon—a subject of considerable interest to the profession at this time and a subject that has, I think, a direct application to the general theme of this conference, namely, the changing role of graduate education. The U.S. Geological Survey is heavily involved in lunar geological exploration. This discussion will give you an idea of the scope of the total lunar and planetary program and how geologists are now utilizing their training—be it classical or nonclassical—in this very large scientific undertaking.

At the present time there are some 150 people with offices in Menlo Park, California, Washington, D.C., Denver, Colorado, and Flagstaff, Arizona, engaged in the program. The headquarters of the organization is presently in Flagstaff and most of the staff is stationed there. Because of its size and diversity, the program is currently divided into three units: astrogeologic studies, unmanned lunar exploration, and manned lunar exploration.

The astrogeologic studies group is primarily concerned with the development of lunar stratigraphy, cratering studies both in the field and laboratory, and the chemistry of extraterrestrial materials as applied to lunar and planetary problems. It is primarily a basic science group developing w knowledge about the lunar surface.

The unmanned lunar exploration studies are primarily concerned with the three major support programs that will precede the Apollo—the first manned surface mission. These include reduction of the imagery for geologic and engineering data—first, from the highly successful Ranger flights; second, from the Surveyor flights which are designed to soft land on the Moon and provide high-resolution textural information, and third, from the Unmanned Lunar Orbiter that will be used in conjuncton with the Surveyor to select the Apollo landing sites.

The manned lunar exploration group has a number of broad re-

* **Publication authorized by the Director, U.S. Geological Survey.**

sponsibilities, including the geological training of the current group of astronauts who will be the first ground-based lunar geologic observers. It is important that these individuals be trained as thoroughly as possible between now and the first missions in order to function as qualified observers and sample collectors. This particular program is being carried on by U.S. Geological Survey personnel in cooperation with a group of geologists at the Manned Spacecraft Center in Houston. In addition, we have a program underway in lunar geophysical methods which is attempting to develop techniques that will extend the astronauts' observational range. This group is now primarily concerned with the problem of seismic refraction and reflection in very low porosity rocks such as unconsolidated ash and tuff—materials that we might reasonably expect to encounter on the lunar surface. The group hopes to develop techniques and instruments that might actually be used in the early lunar field missions. The manned lunar exploration studies group is also concerned with scientific mission development, and with time and motion studies of geological field operations. This is something that geologists have never done, i.e., test the efficiency of different ypes of field operations in order to determine which is the most productive from the overall scientific standpoint. During the early lunar missions, there may be only two hours or so for scientific observation; therefore, those two hours must be well spent. The work now being done will provide the overall guide lines for the scientific part of the Apollo mission itself, and consequently, is of fundamental importance.

I would like now to discuss the work of each of the sections in somewhat more detail in order to show specifically how geologists are contributing and can contribute, even on a larger scale, to the Nation's lunar and planetary exploration program. Geologists are uniquely qualified to make important contributions to this effort. The problems to be solved are of a "geological nature," and many are of fundamental cosmological significance. In fact, we cannot hope to solve some of the fundamental problems of earth science if we do not extend our interests and activities to the rest of the solar system, of which the earth is a relatively insignificant sample in terms of mass and volume.

Under the astrogeologic studies group, terrestrial craters are being mapped in fine detail in order to increase our understanding of cratering mechanics. Geologists have, until very recently, paid little attention to these structures and no really adequate large-scale geologic mapping had been done. Our work has ranged from Meteor Crater, Arizona, to Henbury Craters, Australia, to the Ries Basin, Germany. This type of work has, of course, a direct application to the

Moon since craters are the Moon's major topographic form. This program is also experimental in nature. Craters are produced by hypervelocity impact into different materials and are studied in the laboratory by slow-motion photography and micromapping techniques. This work has led to a number of very significant advances in the understanding of the cratering process, and the results have been applied to interpretations of the lunar surface. The lunar mapping program is concerned with the production of 1:1,000,000 scale geologic maps of most of the visible disk of the Moon. The primary tool is a moderate aperture telescope which is useful for visual, photographic, polarimetric, and infrared studies to help define the stratigraphy and structure and in turn the physical history of the lunar surface. The Survey has been using the excellent 36 inch refractor at Lick Observatory, California—one of the better visual telescopes; the 60 inch McMath reflector at Kitt Peak Observatory near Tucson, Arizona; and a recently completed 30 inch reflector of its own at Flagstaff. Thus far, 13 geologic quadrangles have been completed, and a detailed regional stratigraphy for the visible part of the Moon has been established.

The classical concepts of geology such as superposition, facies change, isostasy, and the like are important tools in these interpretive studies. One reason so little progress has been made in this interpretation is that astronomers, until very recently, simply weren't looking at the Moon with the eyes of a geologist. However, over the past several hundred years, astronomers have done a fair amount of descriptive work, such as cataloging craters, which has contributed to our present studies.

Another type of mapping is strictly morphologic in nature—classification of the surface according to such statistical parameters as average slope, dispersion of the slope values, and the like. The end product is a terrain map, the units of which have no chronological significance but express the roughness characteristics of the surface. Such a map can be used to choose spacecraft landing sites or to plan surface-exploration traverses. Systematic regional geologic mapping at the 1:1,000,000 scale is also being done. This work might be considered engineering geology of the Moon rather than basic research.

In the field of unmanned lunar exploration, I would like to mention the variety of instruments that are being used primarily for geologic purposes. These systems can be considered as geologic tools not very different from the microscope, X-ray unit, or electron probe. The Ranger spacecraft, much in the news of late, had six cameras aboard with different focal lengths and pointed in different directions from the axis of the spacecraft. These cameras provided a wide range of

coverage as the craft approached the Moon. Conventional photogeologic mapping can be done from these pictures and a certain amount of photogrammetric information also can be obtained. This is, however, a difficult task because the spacecraft came in at such an oblique angle that serious rectification and scaling problems are present.

Photometric techniques, or what we now call photoclinometry, can also be applied to this photography, and detailed topography, and detailed topographic maps can be prepared from monoscopic photography. The technique we have developed is based on the fact that the reflecting characteristics of the lunar surface are such that the brightness of an element of the surface depends on its tilt or slope toward or away from the sun. Such studies are fundamental to understanding the detailed structure of the lunar surface and are also important in selecting landing sites. The map prepared from the last Ranger VII frame and published by the U.S. Geological Survey shows that the surface is "saturated" with craters and is moderately rough—but not too rough for manned landings.

Following Ranger, an unmanned soft-landing system called the Surveyor, is planned. This system will provide high-resolution stereoscopic views of the area surrounding the spacecraft and will also take bearing-strength measurements. We have been field testing this system and developing mission operations and data-reduction procedures in cooperation with the Jet Propulsion Laboratory in Pasadena, California. We are also anticipating an active role in reducing the data to be received from the Unmanned Lunar Orbiter scheduled to fly in about a year and a half. This system will give a million times more coverage at the one-meter scale than did the ranger.

In the area of manned lunar exploration, we also have been active in proposing and developing geological equipment that might be utilized by an astronaut on the lunar surface. This includes a surveying staff that would contain a camera, a sun compass, a sampler, and an orientation sensor. The staff would be used both to help the astronaut keep his balance and to facilitate the field work. Our main objective here is to develop both the techniques and tools necessary to obtain the maximum amount of useful scientific information from the early Apollo flights.

Our group in Flagstaff has grown very rapidly over the past two years, and, as previously mentioned, there are now about 150 people, including geologists, astronomers, physicists, chemists, and technicians of various types. The geologists in the program have been, for the most part, trained in the classical manner and have had no previous experience in lunar work. On the one hand this is a dis-

advantage, but on the other hand it is an advantage. The better grounded an individual is in the fundamentals and the broader his general experience, the more he can contribute after an appropriate training period. Since our work and that of other geological groups now in the space program is really an extension of established techniques and principles to new areas, I think it important that young people coming into this work have good backgrounds in so-called "classical" geology obtained either at the undergraduate or graduate level. Ability in mathematics and physics is of course desirable, just as it is for the terrestrial geologist, but it is equally important to have adequate field training and experience. What we really need is a well-balanced geologist.

If we were to add anything to the usual spectrum of courses for the graduate student interested in this type of work, we would recommend courses in general and planetary astronomy, to familiarize him with the general laws and tools of the domain in which he will work, and an exposure to the field of electronics. Electronics is becoming more important to terrestrial geology, too, as the instrumentation becomes more sophisticated. By and large, geologists are particularly weak in this subject. It is particularly critical in planetary exploration since all of the imaging systems used to date and those proposed are electronic. In order to use them effectively they have to be thoroughly understood.

I hope this brief summary has given you some idea of the scope of this new and exciting field of geology.

DISCUSSION

MOSS—Would you want to comment?—I have heard that chemists and physicists get very frustrated in this work, whereas geologists seem to sail into it quite well. Do you want to comment on why that should be and what it is about geologists that makes them well suited to this type of work?

MCCAULEY—I think it is their approach to problems as a whole. Fundamentally the problems we are attacking are of geologic nature even though they may be on the Moon. The unique training of a geologist equips him for solving these problems. The chemist or physicist, with no training in the earth sciences, just does not have the tools necessary to even recognize the problems, to say nothing of solving them. The main reason why progress has been so slow in this area is that geologists until very recently were not actively involved in lunar research. The recognition of this fact has led to a considerable influx of geologists into the space field not only in our group but in NASA head-

quarters, the regional centers, and in industry.

OSBORN—What are the finances?

McCAULEY—The great bulk of the money at the present time is NASA money, either directly from headquarters for the support of pure research or from space-flight projects such as Surveyor or Apollo for engineering oriented studies.

GOLDSMITH—Is any of the mapping program that the University of Arizona at Tucson conducted related in any way or are you using any of their resources?

McCAULEY—Oh yes, indeed. Kuiper's group represents the other end of the scientific spectrum. His people are primarily astronomers and they are still greatly concerned with the business of collecting good pictures, cataloging craters, etc. However, we use much of their material. They also are in the data-reduction business but primarily from an astronomical standpoint.

OSBORN—How many geologists roughly would you say are in the program—contractors, NASA, and Survey?

McCAULEY—I tried to make a quick mental estimate the other day, and my best guess is about 500.

OSBORN—Mostly what; Ph.D.'s, Masters?

McCAULEY—I would say that about 90% of the people are at the Ph.D. level.

NELSON—That's an amazing number, isn't it? Five hundred.

McCAULEY—Yes, it is, and this has all come about within the last two or three years.

NELSON—Are these geochemical-type geologists, geophysical-type geologists, or just ordinary geological-type geologists?

McCAULEY—The complete spectrum! Just as in terrestrial geology, where you have people with different training and talents applying themselves to similar problems, you have the same situation in lunar research. We have classical stratigraphers, structural geologists, even "retreaded" economic geologists. In other words, the complete spectrum of the profession is involved now in one way or another.

PINSON—You mentioned that the geologists picked up what astronomy they needed as they went along and also that they were somewhat inept at electronic gadgetry. Would you recommend in such a program that this be remedied in formal training?

McCAULEY—Well, I think that if a young man did show interest in going into this work he certainly should have access at the graduate level to such courses. I think, at the present time in most schools, that courses in electronics are more inaccessible to the graduate geology student than one in astronomy. This should be corrected.

LUCAS—I'd like to take this discussion off to a thing that is likely of

some interest here; one of the things that occurred to me is that there is some divergence of opinion among graduate departments as to whether geology or the earth sciences are the proper place for planetary sciences or the study of the Moon. There have been a number of types of solutions to this question. It used to be a fairly simple kind of division of labor between astronomers and geologists; sometimes we got together, however, not very frequently. Now there are all sorts of things; astronomy has changed into space science and I don't know whether the extent of the solar system is limited to astronomy, inner space or what, but there is some question. There seems to be some strong feeling on the part of geologists that this is their business, and I think this is an example—that one can apply simple methods of stratigraphy, structural geology, etc. to the photographs of the Moon. There's another question which is quite away, and that is concerning astronauts. I gather the decision has been made that rather than sending geologists to the Moon to do geology, we will send astronauts to the Moon and train them in geology. And I gather that there are a number of people in the U.S. Geological Survey who are training astronauts in geology. Now, these are people who have had no previous geological education as I understand. There is an attempt being made to do something that we talked around the edges of, which is, how do you train someone in classical field geology in a hurry without wasting much time about it. In other words, presumably you're training an astronaut to go out and make a map on the Moon. Are they doing something from which we may learn? I don't know whether you want to discuss this or not.

McCAULEY—Perhaps I can answer that question by describing very briefly the astronaut training program. It started off with a series of encapsulated individual courses in general geology, mineralogy, petrology, etc., that were followed up quickly by numerous field trips. The orientation of the program now is primarily toward field geology. In fact, the group just returned this weekend from Hawaii where they spent some two weeks actually mapping structures in the field. It's amazing, I might say, how fast these people catch on. Even on some of the early field trips they were discovering subtle relationships that some of the instructors themselves had overlooked. So I think that with continued training, primarily in the field, these people will be reasonably effective geological observers on the early missions.

GOLDBERG—The thought suddenly occurred to me that this might be a more reasonable way to train people (if you want to use the word train), in the field of geology. That is to train someone in the geology of an impersonalized planet, not the earth, but the Moon or any other celestial body. Perhaps some of the so-called "evils" in the training in

the so-called "classical departments" in the past has been that there is too much personalization of phenonema to actually identify the formations by name as in Iowa, another as an index fossil observed in New York. I feel certain that there might be a much better way to begin a program of training.

McCauley—Unfortunately, we haven't done this completely. In fact, the Code of Stratigraphic Nomenclature has been followed pretty generally in our lunar mapping program, and of course, as you might expect, it turns out that some of the type areas are poorly located. We also have quite a few new time terms such as Imbrian, Eratosthenian, Copernican, and the like. I'm afraid that we are beyond help in this regard; of necessity we have duplicated many of the errors of terrestrial geology.

Osborn—What sort of problems do they work on?

McCauley—Straightforward geological problems. In other words, detailed mapping and genetic interpretation.

Devore—This must be done with considerable skill.

McCauley—Right! What they are doing now is primarily learning geological field techniques and gaining some practice in their use. With regard to the early missions themselves, they will be operating under very, very severe constraints and will be able to perform only certain preselected operations.

Goldsmith—Are they going to be mainly observing or mainly interpreting?

McCauley—In the early part of it they will be mainly observing, but they also will have to do a fair amount of interpretation. The problem of how closely their work will be monitored from earth has not been resolved.

Goldsmith—Well, in this connection, wouldn't it be a lot cheaper and more effective not to worry about bringing these people back, but to send over some well-qualified scientists on a one-way mission? This sounds brutal, but what about those who are doomed to die of cancer or some other incurable disease? I'm sure we could find qualified volunteers.

Straley—How much teaching do you do before you take them into the field?

McCauley—I think that they had three or four lectures on general principles of stratigraphy and then were taken to Grand Canyon. They then had several lectures on volcanism and off they went to San Francisco volcanic field in northern Arizona to see what they had been hearing about in class. This sort of thing can't be done, unfortunately, in our graduate schools.

McCauley—Well, actually they went very quickly from the hand-led type of field trip, where they were taken onto the outcrop and had the thing described to them, to actual problem solving. This took about three or four trips, but then they were ready to start solving certain simple problems; so the answer to that is yes. In other words, in very short order they were taken to areas with no prior explanation and simply turned loose to see what kind of a scientific reporting job they could do.

Hambleton—I hope they are not ideal areas.

McCauley—Well, they range from some of the very complicated structures around the Big Ben country in Texas to the Valles Caldera in New Mexico. I think this is perhaps the ideal training program. I think, if nothing else, from this effort will come useful information on how to train people from other disciplines. I don't know whether it has actually been considered or not. I suspect that no one has considered it very seriously.

Goldsmith—It seems to me to be much more practical than training people and then worrying too much about bringing them back.

McCauley—I think that we are committed to a long-range lunar exploration program and consequently return-trip techniques must be developed. We could probably send such people right now, but this would be a one-shot proposition with little long-term scientific gain.

The unmanned program slipped somewhat. There are now some fairly firm launch dates but they are classified. Let me just say that we expect to have information from these systems within two years.

END OF FIRST DAY

THE PROBLEM OF PROFESSIONAL DEVELOPMENT

By O. T. Hayward

Originally, I intended to review for you the Geo-Study program. In fact, this was my "assignment." However, the talks and discussions today have emphasized the overall importance of one specific Geo-Study activity more than any other. Therefore, I will confine my remarks essentially to that one aspect—professional development.

In my comments, I am going to speak as the average instructor of undergraduates in North America, as this opinion has been expressed in response to interviews and questionnaires.

You have read (or should have read) the summary reports on Geo-Study. These appeared as supplements A and B to GEOTIMES, late in 1963 and early in 1964. Basically, the conclusions of the Geo-Study investigative phase were: (1) Students do as faculty demonstrate. (2) Graduate schools take what undergraduate departments produce, no matter what they may say to the contrary. (3) If graduate departments want different or better material, then they must aid in the design and development of curricular change in small departments and in small colleges, all over the country, for small colleges supply the students to graduate schools. (4) The greatest weaknesses in undergraduate training are in the areas of interdisciplinary applications—the application of physics to geology, the application of math to geology, the application of chemistry to geology. The cognate fields must be made relevant to geology or they are merely hurdles. Real appreciation of their value never develops. (5) This weakness cannot be corrected by graduate department directive. It cannot be corrected by catalogue regulation. In the present framework this weakness will not be corrected by anything but long periods of time. (6) If the product of the undergraduate department is not the one the graduate school likes and if it does not want to wait years for improvement, then it appears that it will be the graduate school's responsibility to aid in the development of the machinery to change the training of the undergraduate student.

What can be done to change the presentation of geology at the

undergraduate level? This is the principal question of Geo-Study.

As a result of the study, the Geo-Study Steering Committee recommends the establishment of the Council on Education in the Geological Sciences. This is to be the action agency to accomplish the recommendations of Geo-Study.

To aid the Council, the Steering Committee recommended the creation of five separate panels:

(1) The Panel on Interdisciplinary Cooperation;
(2) The Panel on Course Content and Sequence;
(3) The Panel on Geology in the Liberal Arts Program;
(4) The Panel on Earth Science Teacher Preparation;
(5) The Panel on Professional Development.

These panels were assigned the task of examining specific problem areas and generating recommendations for corrective action.

What did they recommend?

The Panel on Interdisciplinary Cooperation first considered the case of Mathematics and Geology, in cooperation with the Council on Undergraduate Preparation in Mathematics. Specific recommendations concerning modification in the present training in mathematics of undergraduate geologists were made. However, they concluded that such recommendations could not be adequately implemented without a major modification in the background of the faculty. The undergraduate faculty (and much of the graduate faculty) is not prepared to utilize mathematics more extensively in geology, because to a large degree the faculty does not appreciate the need for mathematics in *their* presentation of geology.

The Panel on Content and Sequence of Courses for the Major in Geology concluded that there is no sacred geology curriculum. Each school must solve its curricular problems within the framework of the purpose of the school and the department, and within the capabilities of the staff. They further concluded that significant change in curriculum is essentially impossible without a change in understanding on the part of the faculty. No faculty member knowingly conceals necessary knowledge and information from a student. Therefore, if the curriculum is to change significantly, there must first be a change in the background of the faculty.

The Panel on Geology in the Liberal Arts Program recommended some highly intriguing experimental approaches to geology for nonmajors. It further concluded that these approaches, even though excellent, generally cannot be adopted without significant change in faculty training and background. If the faculty does not now offer what they consider adequate courses, it is because they do not know how to modify them effectively.

The Panel on Earth Science Teacher Preparation recommended a three-stage approach to the secondary teacher development program. They recognized the immediate need for a rescue operation to aid those teachers now teaching. They recognized the need for training in depth for teachers who need more than minimum knowledge in order to teach adequately. They recognized the need for the development of a curriculum in Earth Science, to become a regular part of the offering of geology departments across the nation. However, they also recognize that the major obstacle in the training of earth science teachers is the lack of a faculty trained in the teaching of Earth Science. Earth science teachers cannot be taught until the faculty is ready to teach them.

The Professional Development Panel concluded that no significant change in undergraduate geology is possible without a major change in faculty preparation.

Who is the professorial clod who impedes the progress of our science? When I looked around to find the reactionary fink who holds us back, everyone was looking at me.

The fact is that we are all in this together. If I hold the science back, so do the two people seated on either side of you at this moment.

This appears to be a condemnation of the faculty of the nation.

This it is not.

It is merely a realization, on the part of the faculty members themselves, of their own limitations. They have done very well in the past in teaching the geology which we now use. Their training however is from a few years to a few decades out of date in many areas. This is simply an acknowledgment of the fact that from now on, regardless of the level on which we teach, we can anticipate that there will be a continuous re-education program essential to effective teaching.

A great deal can be done to correct the situation.

We can examine the various needs of undergraduate teaching, and we can design programs to aid them. We can implement these programs, and with mutual recognition of need, and mutual acceptance of responsibility, we can solve the problem of undergraduate improvement. The graduate department can have the student it says it must have only if it aids in his development at the undergraduate level.

We can separate the present faculties of universities arbitrarily into three principal categories: (1) the "Young Turks", with strong backgrounds in cognate fields but without experience, and largely without personal knowledge; (2) the "middle-age group", such as myself, long out of school, with weak backgrounds in allied fields, with a modest experience record, and with recognized feelings of inade-

quacy; (3) the "Elder Statesmen" of geology, whose firmly established reputation and recognized contributions place them in a category apart. To this a fourth category might be added—the "rare exception", who really needs no apology.

The first and second groups are the targets for any major faculty re-education program.

In almost all faculties, tenure precludes periodic purges of my group—thank Heaven. This means that I will be around for another 30 to 40 years, and whatever you do for my students, you must do through me. If we insist on hiring Young Turks—and these are the hope of the profession—we must also accept their lack of personal experience, but do what we can to correct this for the benefit of the student.

Two factors contribute to the faculty inadequacies in these groups. The first of these is a lack of time and the second is the lack of incentive for organized efforts toward improvement.

In normal teaching schedules, in smaller schools, there is little time for study in areas outside the immediate teaching field. In larger schools, the requirement for published research imposes obstacles between the teacher and any study for self-improvement which does not yield a publication.

In all schools, recognition for self-improvement activities is hard to obtain. Self-improvement adds no title to a personal bibliography—it brings no grant to the school. In a way, it is an admission of weakness, which our strange profession hesitates to acknowledge, though our purpose is to recognize and correct such weaknesses in others.

What then can be done?

We can attempt, periodically, to remove the faculty member from the day-to-day duties of a college or university, and permit him once again to become a student.

We can acknowledge efforts at self-improvement, as we now acknowledge publication and research. We can recognize that teaching is a significant part of any university program, and even unwashed undergraduate students deserve a good teacher, moderately competent in peripheral fields critical to the understanding of geology. We can see what can be done to make it financially possible for a faculty member to take a month or two simply to review and refresh his mind in areas of admitted weakness. There are a number of things we can do, all of which will aid in solving the problem we have outlined, and which we have created.

The basic needs of all factions of the faculty are for information and experience.

Information involves an awareness of new trends, an appreciation

of new areas, and knowledge, contributed by study and experience in the newer fields.

Experience begins with an awarenss of the existance of a field. Interest is generated through research participation by individual faculty members. Competence is obtained through personal experience in various phases of investigation of a research area.

There is no one program which will solve all needs. Therefore, we must develop a complex of programs which will have something for everyone. Geo-Study, through its successor the Council on Education in the Geological Sciences, is attempting to work with you toward this goal of better students, through better faculty.

The problems which we have described for geology are recognized in the training of undergraduate chemistry, physics, and biology students. It is a part of all fields in our day.

We cannot solve the problem by ignoring it. We cannot say "that simply won't do" unless we are also willing to replace it with something "that simply will do". We cannot solve the problem by substituting the dual inadequacy of a chemist teaching geology for the single inadequacy of a geologist teaching geology.

We must recognize the value inherent in the present faculty, and realize that we start from a position of enormous strength—provided we start.

DISCUSSION

WASSERBURG—It is necessary to have younger people to bring in new blood into the departments. Every department must have this. We have to look to young blood to change this point of view to something which is different, not necessarily always good or always new. On the whole, I should hope that there would have been associated with this a more enthusiastic notion of understanding of things which are happening in terms of new contributions and old, rather than the general antagonism of "I'll be damned if there is going to be any change, you rascal, you."

HAYWARD—I don't think it was arrogance, rather it was awareness of the fact that we cannot change our students, until we can teach them the things they need to know. No one knowingly keeps his students in the dark. It is very difficult for me to prepare my students in an area in which my understanding is weak. The argument that anyone can improve himself is a very good one. The major limitation to the argument is the limitation of time, and it is particularly a limitation in smaller schools. There is not time enough for an organized review program, and in many cases there is no opportunity for study in areas

outside those encompassed in existing local curricula.

There is a great deal that can be done and I hope when the Professional Development Panel report is published there will be a general approval for the programs they have recommended.

The opposition to the idea of Professional Development has come largely from faculties of larger schools and graduate departments. In a very real sense this program is for the benefit of the graduate school, just as much as it is for the undergraduate department. With an adequately trained faculty we will have less of a problem with inadequately trained students. Furthermore, it is not always the student of the smaller school who is ill-trained, and therefore, I include all here in the group who periodically need revitalization—even those from the prestigious institutions.

The argument that we can hire young and vigorous faculty is a good one, when it works; but it is difficult to make it work. It has distinct limitations. I know departments that have not had an addition to the faculty in 12 years. I know one individual who has applied on several occasions for fellowships, and has not yet been successful. Faculty training programs have to be expanded so that more people may be accommodated in the program.

DEVORE—I think we are missing the whole point here. I made some notes on Dr. Hayward's talk last night and there are some things which annoyed me. I take it there are two kinds of departments in Geology. There is, to use the old expression, a Mickey Mouse Department and there is the Mighty Mouse Department. And Mighty Mouse was throwing bricks at Mickey Mouse. We all want to be Mighty Mouse Departments, but I don't think this is the real problem. What we are concerned with is the definition of what Mighty Mouse is. For example, some Geologists I know get all their fun out of life by sifting sand. Now if they use a piece of window screen to sift the sand, this is Mickey Mouse, but if they use a mass-spectrograph that is Mighty Mouse technique. I don't think there is one bit of difference between sand sifting with a piece of screen or with a mass-spectrography. If the fellow in charge is expecting solutions or answers to questions that he has not formulated or even asked, no amount of window dressing in chemistry or physics is going to change it one bit. What we ought to be striving for in undergraduate education is not highly sophisticated overtrained, over-specialized or overfilled graduates who can't cope with everyday living.

This is just as ridiculous as the older philosophy of filling them up with the formula of minerals or the names of long dead bugs. I think what we have to do is to teach them enthusiasm for science, curiosity for science, the thrill of ideas and the fundamentals of the

science. This can be done just as well in the "Mickey Mouse" leagues as in the "Mighty Mouse" leagues. In fact this is rare in both. We are not going to transform Mickey Mouse to Mighty Mouse by having them memorize lots of sophisticated chemistry and physics, but only through the emphasis and orientation of the subject matter as a scientific research endeavor. The problem comes first, and the chemistry-physics-math backgrounds then fall into their rightful places.

SIEVER—I think you have to take into account that obsolescence occurs when a person doesn't realize he is obsolete. My feeling is that there are a number of people who are at Mighty Mouse Universities, who have spent a good long hard time getting their education in one way or another, who have never stopped and who are agonized because they can't keep up even though they are trying just as hard as they can. Therefore the problem is that you can't rely on a man's going to retread himself, to use your expression, if he doesn't even know the extent to which he needs retreading. In the case we are talking about, it is not a retreading that is needed because a retreading just won't work any better than it does on automobiles. Retreads don't last as long as an original tire. In this case, it is a question of how many years a professional teacher will remain abreast of a rapidly moving field. I don't see, for example, how an older man can absorb a lot of the things he needs to know, to pick out interesting things to discuss in undergraduate work in one year if he has had a standard Geological miseducation.

HAYWARD—This is not a one-year program. It is a continuing program, which includes training, experience, and publication. While we already have so many publications we can't read them, now we need a review publication, to summarize the publications we have and can't read. With adequate review-publications in a limited amount of time a person can read about an area and become aware of the existence of a field.

A second aspect is the development of a much wider spectrum of summer institutes, particularly in interdisciplinary areas. These are to train faculty, and to acquaint teaching faculty with the application of physics, chemistry, math, etc., to geology.

A third aspect is to make fellowships available to faculty on a wider basis, so that individuals can more effectively pursue an interest. Any one of these approaches is an improvement. All together they form an excellent teaching system. Out of the faculty group which reads the review literature, a certain limited number will ask for summer institutes. Out of the summer institute program, a certain limited number will go on for fellowships.

About the man in the major university who doesn't know he is

obsolete—I am sure he is there—I know several. However, this is a much more real problem at smaller colleges because to a very large degree faculties in smaller institutions are out of the mainstream, and they have no way to know that they are obsolete. At smaller colleges we do not have extensive regular communication with the profession. It is difficult to know when we are obsolete.

PINSON—Well there is one point that I wish to comment on. I have often thought that some high school teachers, and especially college teachers of undergraduate-level courses in earth sciences, are not so much in need of summer institutes in earth science and the association with new ideas in earth science as they are in need of more formal, college level courses in earth science subjects and especially more courses in mathematics and the basic physical sciences. An occasional summer institute is no doubt good for them, and I am an enthusiastic supporter of the summer institutes of the kind that are sponsored by the National Science Foundation. But if these teachers really want to better their teaching ability they should spend *some* of their summers in university summer schools taking really basic subjects that they may have missed in college. For example, if they got a degree in geology, that required no calculcus, and took, say, a year of physics of the kind that requires no calculus, then I think that making up these deficiencies in their science educations is their first need. I think that this kind of rigorous education would be more useful to them and their students than their going summer after summer to earth science institutes.

WASSERBURG—You cannot send a person back to college unless you first convince him that there is a purpose in it.

HAYWARD—That's right! We hope that the summer institutes will convince him that he does need to go back for more calculus or more physics.

PINSON—I think that it may inspire him, that it may serve an inspirational and informational role, but not so much a basic education role.

HAYWARD—It is an informational role. It informs him what can be done in certain fields once you have command of them. This can be done. This has been done.

PINSON—But he can keep attending summer institutes for a long, long time thinking, he is making progress. He is making some progress; it's not useless, of course.

HAYWARD—It gives one a guilt complex to go to a summer institute, and to realize that all things we have been told we can do, we can. This drives one to undertake a review one wouldn't normally consider.

PINSON—I see, you begin to realize what your real limitations are.

WASSERBURG—I think summer institute programs are tremendous.

George's point focused attention on the fact that enthusiasm and interest in new ideas whether by senior men or not so senior men is certainly the most important thing you can generate. By just having a guy redoing in calculus and not being able to apply it to the science himself is to do something that is absolutely useless.

HAYWARD—I am not talking about redoing, I am talking about doing it for the first time.

WASSERBURG—It is useless, he can't use it, and he can't really teach it as part of his being without some enthusiasm for new ideas or for any ideas. There is no question that this approach can really make a contribution. I think it's a question of having people who utilize more modern concepts and apply them—this must come from the younger men which are appointed. What you can get from the senior man is enthusiasm for ideas and a recognition of new vistas. I will have to take exception with one of Dr. DeVore's comments.

I don't think that it is legitimate to imply that there is a Mickey Mouse-Mighty Mouse dichotomy. I doubt that most people have this feeling. It is, in general, a pretty tough business, as Ray indicated, and almost everyone recognizes his continued obsolescence whether he uses a mass spectrometer or a Ro-Tap machine, and I have spent a good deal of time on both. I think if I could do it with a hammer it would be a lot easier and a lot easier on me and a lot easier to do and a lot more fun. The problem is really in directive undergraduate education rather than over specialization in fields which have become partly more fun and imbedded in the sciences by some peculiar name and it is at this level that I think—

DEVORE—I couldn't agree with you more.

CAN "CLASSICAL" AND "MODERN" GEOLOGY BE DOVETAILED?

By Raymond Siever, Harvard University

SIEVER—Let me paint a picture of the future, some years from now, maybe just a few, when modernity in the Earth Sciences fully comes into its own and what we now define loosely as classical Geology has moved into mining and petroleum technical schools, not too dissimilar from the technical hochschule of Europe and some German Universities. The major universities, now in larger numbers, because of the N. S. F. program for new centers of excellence, as envisioned in the National Academy of Sciences Report, are the source of the scientific talent in the Earth Sciences and that talent is largely devoted to research and teaching because the demand for large numbers of Geologists has disappeared. Here I am emphasizing the large numbers, which we have talked about already; that demand for large numbers is from the mineral resource industry. That demand has fallen off and now there are other technical training schools which will satisfy that need. The leaders in Earth Science are either laboratory workers or theoreticians who use the data accumulated by the former. An old alumnus of the Department of Geology would be a little bewildered by the disappearance of field mapping of quadrangles, field studies of stratigraphic structure and the courses he once knew. He visits courses in a department and he finds that courses that may be called structural geology actually concern themselves with subjects that we recognize as rock mechanics. Sedimentation may be low temperature solution geochemistry and fluid dynamics. Economic Geology is the chemistry of sulphides and sulphide systems. Paleontology is bio-geochemistry and bio-metrics, and Mineralogy is solid state physics. Things called geophysics and geochemistry, rather than the meek, shall inherit the earth.

The Thermidor must come to any revolution though, and some years later that same alumnus is likely to be astonished at the sight of a number of young Turks leading clandestine field trips to take a look at real mountains and real rocks and real rivers. Why might something approximating this exaggerated picture come to be? Mainly because

Geologists working today are almost wholly obsolete and do not understand what is happening to this science. In fact, they are so obsolete, I feel in some cases, that they know not how obsolete they are, and it is by their default that this development, if it happens, will happen. Their resistance to change has forced a revolution, and revolutions it seems by their nature overreach themselves. Some of the modern avant garde on the other hand are probably guilty of thoughtlessly rejecting all earlier dogma, thus denying all possibility of communication with their more conservative colleagues. But I do not wish to take the easy way out and say a plague on both their houses, for it has always been true, in any field, that it is the responsibility of a large majority to strive to keep sight of and understand the avant garde, not to have the avant garde look back and wait. It is implicit in my approach that this projection is neither desirable nor inevitable. It is not desirable in that it involves a nihilistic rejection of a great body of science. It is not inevitable in that the Graduate Departments of Geological education recognize their responsibilities.

Before going on to any concrete problems, it is necessary that we define our terms more carefully. I will attempt to define terms in such a way that the title question of this talk can be answered in an obvious way. Trying to use the terms classical and modern forceably reminds me of another area in which these terms are used, that of music. In music, one distinguishes classical from modern and modern from contemporary. Modern refers to a historical development just as it does in political and social history. Contemporary refers to that which is practiced currently. In this sense then, I shall contrast classical and contemporary and ignore the term modern. I shall use the term classical to refer to the field aspects of the sciences that are inextricably interwoven with a purely geologic types of synthesis, namely historical geology. In this case, for example, Astro-Geology as outlined yesterday afternoon by Mr. McCauley, is in my terms, perfectly classical. It is a classical aspect of the science even though it happens to be treating the subject which we normally don't work on in everyday life or hadn't up until now. By the term contemporary, I refer to current descriptive practice in describing the materials of the Universe, and to the use of contemporary physical and biological science in the analysis of geologic problems. If I define the terms in this way, it becomes clear that I do not make invidious distinctions between descriptive and analytical or quantitative and qualitative approaches. I say classical when I refer to the aspects of geology that had their heyday in the 19th century; stratigraphic, structural and petrographic mapping. These aspects are not simply descriptive. They are analytic and synthetic in ways that are perhaps strange to some chemists and

physicists. It remains qualitative in a sense because a time sequence of the geometry of irregular solids, if you want to use fancy terminology, is not readily quantified in familiar terms. I agree with Julian Goldsmith that a map is a quantitative expression of what is present on the surface of the earth; a time sequence of that, a cross section, is also in some sense a quantitative determination, but it is not important that one labels a thing one way or another.

During the classical period, much descriptive practice was compatible with the development of the associated sciences. Analytic chemistry was applied to rock in a most satisfying way as the subject of analytic chemistry of silicate materials developed. Minerals and crystals were described in accordance with prevailing ideas of physics and chemistry by and large. Fossils before Darwin were recognized and described as index fossils that could be likened to so many nuts and bolts, an approach that really wasn't much out of harmony with biology in the first half of the 19th century, as practiced by most biologists. Classical geologists were no more naive than other scientists. In fact, those who argued with Lord Kelvin that the Earth was probably older than 75 million years were less naive than he. Then what is contemporary? It certainly is descriptive, but now we analyze the abundances of isotopes as well as of average chemical elements of the same atomic number and a paleontologist may make a statistical species discrimination on the basis of measured morphologic indices another descriptive measure. A Mineralogist is now perhaps less interested in measuring interfacial angles of large crystal than he is in inferring bond angles from information gathered by x-ray diffraction and other types of analysis, essentially a descriptive measure, of sorts. The field Geologist is more likely to use aerial photogrammetry than a plane table. We do not use a blow pipe any more, not because it is descriptive but because it is inadequate to other available tools. The contemporary geologist is conversant with other contemporary sciences. Why should anyone make a fuss over Thermodynamics when J. W. Gibbs' first published his paper on heterogeneous equilibria in 1876. Quantum theory is more than a generation old now and Watson & Crick's paper on the structure of desoxyribonucleic acid appeared over a decade ago. In my own field, Sedimentology, nonsense has been written by geologists simply because they were completely ignorant of the physics of fluids. I give this only as an example. I could quote, I am sure, from each area of Geology. I see the contemporary geologist then as somewhat of a skeptic but not an iconoclast. He may be a laboratory experimenter or a field mapper. What is important is that he be a man of his time. Historical geology is still a valid subject for investigation, even though its methods have not changed greatly,

but the historical geologist who knows little or nothing about the results and the implications of radio-chronology is an anachronism. I suggest that the field mapper may be misguided in going over the same ground as his predecessor to make even more refined maps. Field mapping methods have not changed that much and one must recognize that there were a good number of extraordinarily competent field mappers in the good old days. After all, the contemporary composer, is not anxious to write music like Bach for a pretty good reason. Why do something less well than the master who preceded you? Given the above, I submit that the graduate curriculum should reflect both classical and contemporary in the sense that I defined them and that the two are inseparable. I submit that the Earth Sciences would be a one-legged ostrich with its head in the sand if it did not include field observation and historical synthesis because this is information that thus far can not be accumulated or analyzed in any other way. The Department of Geological Sciences that follows this principle will probably offer a course in Structural Geology that may be largely rock mechanics in lecture and laboratory but it will be a department in which students will go into the field to see what anticlines and synclines look like. The ordinary material in a course in structural geology, if one looks at the average texts that are used now, I would guess probably could be covered (that is that part of it which relates to the ordinary parts of structural geology and not the attempts to study the theory of elasticity or other things) in about three lectures. You probably will laugh, but think about it carefully. The descriptive geometry which is mainly what a textbook in structural geology is all about is not very complicated. It is complicated to map it in the field if you have no experience. The courses in igneous and metamorphic petrology will be largely chemical in the lecture room. They will be experimental and petrographic in the laboratory and they will be macro-observational in the field. I can describe it in no other way. It has been my experience that field subjects are poorly learned from lectures even when lectures are illustrated with magnificent color slides. It follows that the studies in the buildings on the campus will be primarily of contemporary aspects and those in the field almost exclusively classical in aspect. I am not talking about sampling which as a field exercise is a trivial example. The significant exception to this is the regional synthesis of historical geology which is a map and cross section type of effort. That, though built on field studies, is not such itself. Parenthetically I can conceive of a time when even such studies will become anachronistic. Here I am thinking about the signal to noise ratio in historical geology. If one views the evolution of the Earth's crust as a very

noisy process, it becomes as pointless to attempt to find causality, or inter-relationship, which is what we really mean, in each little historical episode as it is to try and explain each little jiggle on a high background recorder chart. The short term episodes may then prove to be of no particular scientific interest although it is of great importance to distinguish them from the signal that is coming through, whatever it may be. They may be important economically and as such are the business of State and Federal geological surveys. If this view of historical geology should become accepted, we should have to re-examine the work of stratigraphic refinement as opposed to large scale synthesis. This same question, of course, is applicable to organic evolution. I am not suggesting that this is true, I am suggesting that in these ways we may have to re-examine a lot more in earth science than we thought. I have not touched the question of scope of coverage of Geology, the Earth sciences, Geological sciences, Geophysical sciences or planetary sciences, for that is a matter of semantics and fashion. Those Geologists who insist that the business of geology is the study of ancient rock and the Earth's crust and nothing else, should not feel particularly hurt when other departments on their campuses busy themselves with modern process studies, the study of the moon and planets, and oceanography. I only suggest that there is an old tradition among geologists that all of the affairs of the Universe are of much concern, for the Earth is part of it. I doubt that the geologists of 60 years ago found it odd that T. C. Chamberlain, a geologist, and F. R. Moulton, an Astronomer, collaborated to propose a hypothesis of the origin of the solar system and the earth. One point remains, should all graduate students in Earth Science be exposed to the classical aspects of the science? I think yes, for if this subject is one that is related to the real world then the real world ought to be perceived in all of its noiseiness and complexity. It is no great trick to make an abstract model purely deductively. The point of the model is to make one that is an abstraction, an essence of the real thing. If there is an understanding of the several aspects of the science and how they fit together then there will be mutual respect and the criteria for the worth of the geological investigation will be how good and how important the work may be and not in whether it happens to be classical or contemporary. It is now up to you.

DISCUSSION

WEIMER—You stated that you were a Sedimentologist. What is your objective as a Sedimentologist?

SIEVER—In the broadest terms, to find out how sediments are made. Concretely I can tell you what I am working on now, if you want to know.

FREDERICKSON—Maybe we ought to spend really some time thinking about what are some of the important problems in Geology. In 1947, the Lawman report was written. This was an effort on the part of petroleum geologists to assess where they stand in their understanding of geology as applied to stratigraphy and all of the problems related to the oil industry. The report summarized the kinds of research that should be done in specific areas. About 10 years later (1957-1958), Dana Russell restudied the field to see what progress was made and to try to identify the important unsolved problems. By comparing the reports, page by page, you will note that all of the unsolved problems listed in the Lawman report are also listed in the Russell study. In spite of the millions of dollars and the enormous amount of effort that went into the research, I could not find a single problem on which really important progress was made. This must mean that we are spending a lot of time on trival things and should spend more time recognizing and formulating problems in such a way that we can do something about them. Isotope work had been started in the meantime and a beginning was made on the application of isotope techniques to some of these problems. This alone was the noteworthy contribution in the decade mentioned above. Now this means to me that the professional people, and there were some excellent professional people in the petroleum industry, might have been working on a lot of trivial details that really don't contribute to the understanding of some of the important outstanding problems. To illustrate my point in another way let me ask the questions: What does a Civil Engineer do? He builds bridges or structures. What does a Mechanical Engineer do? He builds machines. What does a Geologist do? What kind of product does he make? He makes a picture of the Earth. He develops a two-dimensional picture and then tries using indirect methods to get a three-dimensional model. Both classical and modern scientists whatever name you want to use, direct their efforts to making this three-dimensional model better and not just in getting a picture. He would like to understand the principles and processes involved so he can make rational predictions about phenomena. The check on the quality of his work is the testing of the predictions made. It turns out that the Geologist has been remarkably unsuccessful. He has been so poor at making quantitative predictions that other people are taking over and much of the research effort is going into geophysics and other disciplines. In our training programs we should place a strong—

but certainly not an exclusive—emphasis on those thinking tools that will improve our ability to make predictions. I get the feeling that many of us are working on problems which might be very interesting but we are not really focusing our attention on trying to define what the bigger problems are and making a bigger effort to get at them. I think the Geologist—Geologists as a group are the most poorly organized of all professional people. In great contrast are some of the chemists and physicists societies. It is not too difficult in physics to identify the most exciting topics of the moment and who is working on them.

GOLDBERG—I think you have a terribly important point. My feeling is that the important problems in Geology or Earth Science should be presented early in a student's career, that is in his undergraduate years. I think it is an undue imposition upon students in undergraduate schools not to expose them to such problems so that they can prepare themselves suitably for graduate school. I was sort of amazed at Ray's talk in which he says that much field work, by his definition, is classical. I would argue that much field work today, what I would call field work, is non-classical. For example, gravity surveys, magnetic surveys, heat flow surveys and interpretations of such measurements certainly fit within your contemporary realm. Now if the students aren't exposed very early in life to the problems that can be solved by such techniques, I think you have done them an injustice with respect to a choice of a gradutae school and to a choice of an undergraduate and graduate program.

FREDERICKSON—Adding on to what you have said. Here is the real role of the smaller schools. In the beginning courses the student can be introduced to both the problems and some of the new tools that can be used to help solve them. By joining tool and problem, the need for chemistry and physics courses become apparent to the student hence he will take a great interest in these basic courses as well as retain his curiosity about geology and other aspects of earth science.

SIEVER—You are confusing classical with field and that is what has got everybody into trouble all the time. Take the case of a man who may not know anything about what the real world looks like but who has to run an analysis of a rock because he is interested in finding out something about it. And so he goes out into the field, after someone tells him where to collect. Is he doing field work? No, I don't think he is doing field work. He is collecting a sample. I don't understand how one can make a gravity map if one doesn't make it out in the field. It only makes sense to discuss these things in terms of what kinds of field investigations they are. Gravity, after all, is almost classical too.

GOLDSMITH—There is something here that transcends education and

transcends graduate and undergraduate education and transcends the science of Geology if you want to call it that, and that is the recognition of problems. Now the problems are all here for anyone to recognize. In other words, the cosmos is before everyone. It doesn't take a geologist or anyone necessarily trained in geology to recognize what the fundamental problems may be. I think there is too much of a defensive attitude that other people might impose themselves upon the science of geology, whatever it is, and recognize some of the problems from under us, as it were, and I think it is a mistake to be on this defensive as I think too many people are. I think some of the great contributions to what we now call geology were made by people who wouldn't call themselves geologists and I don't know what difference it makes.

FREDERICKSON—None whatsoever. As a matter of fact, this is where most of our stimulus comes from: people who came in with new approaches from outside the field.

WASSERBURG—I think you touched on several things, possibly on purpose, possibly not. When you talked about Civil Engineers make this or Mechanical Engineers make that and what does a geologist make? That I think represents partially the historical evolution of geology all over the world in which for a long time geology was eminently an applied profession, that is Geologists did in fact make a map and the reason was economic exploitation of mineral reserves. At present Geology occupies a double role which is different from certain other sciences in terms of performing a public service and practical economic matters. It is absolutely necessary that we consistently produce outstanding men in this aspect of the field; otherwise, we will go backwards. However, from a scientific point of view, the nature of the problem is not what does he produce but what does he understand? There was, and still exists within the profession, a philosophy exemplified by a very distinguished, old professor of mine, who is now dead, who said the function of a geologist is to map the Earth. This was part of the philosophy that a geologist's product, was a map, but I think this day is passed and the situation is, as you stated, to formulate the problem and to understand it. There exists a perfect map of the Earth and it is the object itself. It is a one to one map without a single flaw in it. The point which should be before one is, what problem do I wish to understand and what process do I wish to understand? The job of mapping has already been completed by some predecessor of ours.

HUNT—I would like to say that I think maybe Freddy may have given a somewhat incorrect impression. I believe that contemporary geology, as Ray has explained it, is being used successfully in the oil

business. I lived through the era in which we went from "standard" methods of geology to applying successfully modern methods of geology. You don't hear a lot about them because these are very competitive. For example, what techniques were used to solve a problem in field geology right after the war? One went into an unexplored area facing the problem of finding out where the major oil fields were leasing any areas. In other words, you have to enter into competitive bidding with other organizations and try to decide what part of the basin you want to allot for yourself. The only method that geology had in those days was simply to make maps, as you say geophysical maps, geological maps. In most cases, these were based on a few outcrops and very few wells. According to the stories I heard as to what happened, they frequently would go into the area and checkerboard it when they couldn't make up their mind. Or, if they made up their mind based on the position of the hinge line and the philosophy that the oil fields were going to be along the hinge line, they would take a certain section of the land with the result that a competitor would come in and take the rest. It frequently turned out that the oil would be in places they did not predict. By this procedure, they were making mistakes constantly. In the 1950's, oil companies began to use techniques of quantitative lithology (e.g., sand-shale ratios), statistical methods (e.g., operations research), geochemical methods (e.g., distribution patterns of hydrocarbons in sedimentary basins)—all of which are now being used to determine the most favorable areas in which to look for oil. That these methods are being widely used is demonstrated by the kind of people hired and retained, ie., specialists in these fields. An oil company is an extremely competitive business, and these areas of research would be abolished if they were not being usefully employed. Hence, contemporary geology, if described as incorporating geophysics, geochemistry and statistical methods, is not being neglected. Indeed, today it is being emphasized.

FREDERICKSON—Major companies have been hiring one kind of geologist—those primarily with Liberal Arts backgrounds—and hiring other geologists who have had good training in the physical sciences. This has happened because the problems and needs of industry change rapidly. Professional people must also be able to adapt themselves and undertake new problems. To do so, they must be able to discuss problems—quantitative problems—in an intelligent manner with people of other disciplines. The common denominator needed for such conversations in training is the common language of mathematics, chemistry and physics.

For example, a geochemical problem is a problem in geology that will require chemical information for its solution. Earth science prob-

lems are often very complicated and continued interaction between the geologist and the chemist is essential. Both have to learn some of the language and concepts of the other. If the geologist cannot comprehend at least some of the concepts of chemistry involved, he is displaced because he cannot make his share of the contribution to the solution of the problem. This has been going on for a long time and will continue to go on. Industry keeps expecting more than it is getting. We have a long way to go to learn to use geochemistry and some of the other disciplines to really make it pay out or for them to make an important contribution to the major problems facing industry and science.

HUNT—I agree with you, but I think the kind of people they hire now are different from those hired in the late 40's. They are hiring more physical chemists, paleontologists, and other specialists.

HAYWARD—However, faculties *are* at small schools and the current middle-age group is the group that we turned out in the late 40's and middle 50's. They will be there for a long time.

HUNT—Yes.

WASSERBURG—I am confused, I don't understand the practices of industry as pertinent except as a peripheral comment on the problem which is before us.

SIEVER—Jerry raised a point before this, one about mapping. The validity of geologic mapping as fundamental research is a question that has bothered a lot of people for a long time. Now put this in a different light: what kind of problems do I want to solve? For example, one problem that I think is rather important and interesting with respect to Earth Science is the structure and composition of the crust at the edges of continents and the difference between continents and ocean basins. There seems to be some correspondence between things that have been called geosynclines and the edges of some continents although certainly not all. A further problem is that there are not so many geosynclines that we can make a really valid statistical summary of them. The Earth is only so large. Therefore, we have to study individuals and we may have to enumerate all of them, in fact, to get some appreciation of the problem. There are many ways of looking at the Appalachian or Cordilleras geosynclines. One way happens to be the way which is accumulated by field mapping. I will submit that one must compare these two geosynclines to understand the Americas. The Appalachians probably represent an area that is close to being "mapped out" or "mined out," to use Abelson's terminology. Abelson goes so far as to say that essentially all of mapping is a mined out area, but he is quite wrong. Beautiful crustal cross sections of the Appalachian geosyncline can be drawn for most of its

extent now and much extremely interesting and useful information comes from such "maps." The same kind of cross-section can not be drawn for the Cordillera; you will find that the attempt will get you into very great difficulty. In fact you will not be able to complete a certain number of cross-sections except in the grossest possible way. Now it may be that one only needs to do it in the grossest possible way, but if some refinements of those cross-sections are necessary then I say that many more people have to go out and map. In some places you need mapping and some places you don't.

HAMILTON—I enjoyed Ray Siever's paper very much, and I agree that it is possible to blend the old and the new. I am reminded that several days ago I heard the Carmina Burana, a tremendously exciting piece of music written by the contemporary German composer, Carl Orff, based on 13th Century Hungarian Folk Song—a blending of the old and the new.

SIEVER—He is actually a modern composer, he doesn't write contemporary music—Conversation exchanged between SIEVER & HAMILTON inaudible.

HAMILTON—I was particularly interested in Ray Siever's phrase about "a man of his time." I think that it characterizes the problem of many faculties in smaller schools. These people want to be "men of their time," but have neither the time nor the resources to achieve this goal. It is the judgment of many of us who have looked at this problem that there are a great many people who are genuinely concerned about being men of their time and need help. This group assembled here is probably least qualified to recognize this need because most of you are "men of your time" and you come from active, vigorous departments.

As I listened to another question that Dr. Frederickson raised, I couldn't help remembering a question from a physicist on my Ph.D. examining committee. He asked me if I could describe one problem in geology that had been completely solved in the last ten years. I was forced to admit that I couldn't answer the question. My lack of response reflects one of the difficulties of geology. In too many cases, we are not only unable to describe a problem that has been completely solved, we are unable to state the problem itself. Many graduate students turn thesis proposals relating to, for example, the study of the stratigraphy of a certain unit. If one examines the proposal, one finds that no problem is stated. Consequently, the effort tends to be descriptive and does not come to grips with any problem.

OSBORN—The same is true for any science.

ORGANIZING A MODERN GRADUATE PROGRAM

By A. F. Frederickson, University of Pittsburgh

FREDERICKSON—Dr. Weaver is facing the problem of starting a new department or a new program in the Earth Sciences. He knew that we started a new program in the Earth Sciences at the University of Pittsburgh in December of 1960. At that time we had two associate professors and two instructors. We now have 26 professional people on the staff, working either full or part time. Dr. Weaver also knew that there were a large number of problems and headaches associated with such an expansion and asked if I had any suggestions that might help him a bit. From our experience, I can make a few recommendations: (1) Recognize your local situation and round up all the local support you can get. This is an obvious point but one which is not followed in many areas. (2) Make no attempt to be all things to all people. This translates into the dictum of selecting a few fields for research and attempt to do them very well in both your teaching and research. Attempt to be as problem-oriented as possible. Apparently, I think, the apparent unanimity of opinion in this regard has come out continuously during the last couple of days. To really be good, even in a small department in a narrow restricted way, is extremely important because this helps to establish and identify for the school and serve as a reason why someone will come and study with you instead of with someone else. I think that this is a topic that should be given a great deal of consideration not only by people with existing programs but those that wish to develop them. There is another part which I think is essential. You have to recognize that you are in a University and therefore have an undergraduate as well as a graduate teaching obligation. The level at which the undergraduate teaching is aimed should be tailored, in my opinion, to fit the needs of the customer and the competence of the teaching staff. We have mentioned this topic quite a number of times. I think it is a mistake for people to offer courses in geochemistry if the staff really does not understand sufficient chemistry to get the subject matter across. Such a performance is lethal to the teaching process.

I see no conflict at all in teaching an undergraduate program on one level and conducting a research program on an entirely different one.

For example, you may wish to teach geology or earth science for the following purposes:

(1) Background cultural training for Liberal Arts, Engineering and Science Students.
(2) To train people at a B.S. level who will not go on to graduate school but will use this as their terminal degree and
(3) To develop the background needed for advanced professional training.

I believe that there is a need for all three types of training. This does not mean, however, that every Department should attempt to provide all three types of training. If you don't have the resources,—money, staff and space—it is a mistake to get too deeply involved in advanced research programs. I think that relatively few schools can handle all three types of training and handle them well. Quite arbitrarily at our school, we placed our emphasis on the two ends of the spectrum. We use our most senior staff to teach an introductory Earth Science course aimed at trying to stimulate an interest in the beginning students in some of the problems of the earth. This course is not a substitute for the old historical and physical geology where it covers the whole range of topics that were covered when you and I took these courses.

Some schools have made an effort to turn out the B.S. degree people, and I think this is quite appropriate. I come back to the story that you can't be all things to all people. Our major program is aimed at the development of students toward advanced degrees and, consequently, most of our undergraduate curriculum is heavily loaded with chemistry, physics and mathematics. We have been under severe criticism by some of our local people in that we have not included such topics as economic geology, structural geology, glaciology and similar topics as required subjects in the undergraduate curriculum.

In the last two and one-half years of the curriculum, we have made a sincere effort to give as much flexibility in the basic science requirements as possible so we give someone who is interested in geophysics an opportunity to get more mathematics and physics, whereas the geochemistry or crystallography oriented student can get more mathematics and chemistry.

We think this approach can be summarized in a different way by asking a question. How can a new department, or an old one for that matter, stay alive and vigorous? We have spent a lot of effort trying to devise ways of doing this. Most of us recognize that we are in a

very competitive business. We compete with other departments in the University for students, and we also compete with other universities for students and research support. One of the valid reasons for obtaining research support and attracting students is that you have an identity for quality in both people and program. The good students often come to you because you have a good man or a particularly good program. Neither need be related to size.

Prior to coming to Pittsburgh, I spent eight years at Washington University. Many of the best graduate students we got came from a small school: Franklin Marshall. Although these students were poorly trained in chemistry and certainly didn't have enough math, they were problem-oriented and had learned a lot of the elementary things that a good geologist had to know so he could put his physics and chemistry into reasonable context. Some of the best graduate students that we trained had come from a small department that had a very stimulating, problem-oriented teacher. I think some of us recognize the fellow. Imaginative teaching of this kind is extremely important and can be found in little schools as well as large ones.

All of us also live within the constraints of budget and administrative control. There are just not enough good people and money to go around (even if we did have the space) to develop excellent programs in more than just a few areas. This brings me back to my original comment. Do those few things that you can do and do them well. Take full advantage of the support you can get locally.

We have drawn support from several different sources and we have made joint appointments in physics, biology, civil engineering and with our Crystallography Laboratory. The details for these joint appointments are different in each one. This has been one of the most stimulating things that has happened to us. We have also drawn staff support to help us in our teaching program from Gulf Research & Development. Sigmund Hammer has been teaching our elementary geophysics course for 17 years. Prior to that time Nettleton taught the beginning geophysics course so this tradition of having industry give you a hand is well established at Pitt. We have people from the Mellon Institute, from the U.S. Bureau of Mines, the Carnegie Museum, and the joint Earth Science Program with the Carnegie Institute of Technology, where any student in our institution can take courses and do research in the laboratories of the other and vice versa. This arrangement has brought to our program such people as Truman Kohman in Nuclear Geochemistry, Her Toor, Energy & Mass Transfer of Liquid, Y. Y. Shi who teaches Energy and Mass Transfer in the Atmosphere. Another distinguished colleague in this program is Clarence Zeener from Westinghouse who teaches The Physics of Large

Scale Processes. These people add a great deal of stimulation to both our students and staff. We also have an exchange program with the University of Tokyo that I will mention in a few minutes. An additional and very practical point is that we have obtained financial support from local and outside industries. These funds are of great aid in getting programs started and for buying those things that you can't get on contract and certainly can't afford on your own departmental budget. These are old techniques that are not needed by some of you in the large universities that have adequate budgets, but this kind of help is very important for a great number of departments that operate on a vanishingly small operational budget. How well this program is going to succeed can be determined only at a later date. At the moment we have 480 undergraduates taking our freshman course in contrast to 60 a few years ago. We have 36 graduate students now in contrast to 8 a few years ago.

We have been particularly fortunate in that we have a number of close neighbors doing research and so we can take full advantage of cooperational arangements with them. We certainly urge you, Dr. Weaver, to explore your local opportunities to see what you can do. Like anyone else, we have had and still have our share of problems. I should emphasize that because our opportunities and problems were quite different from what yours are going to be, I am sure that some of the details of our approach may not be desirable or possible in your area. Some of the suggestions, however, I know will be quite productive in this progressive University.

I would now like to comment on a number of other points that were made yesterday related to the problem of keeping the stimulus going and trying to avoid being locked in. When you have a relatively small staff, outside stimulus is needed. This can often be obtained from part-time people from industry or elsewhere who handle only one or two courses. The curriculum gets a great deal of stimulus from the people who are "in the stream" in industrial areas involving the disciplines of chemistry and physics. The program that has been most helpful to us in getting our research going and also stimulating our teaching is the program that we have organized with the University of Tokyo. Dr. Takesi Nagata is on our staff. He is also head of the Division of Geomagnetism and Planetary Physics at the University of Tokyo. He comes to the University of Pittsburgh about 3 or 4 months out of the year. This varies from time to time. Dr. Kobayashi is also at our University on the three-year appointment. When he returns to Japan, we will hope to have another Japanese join us. In this way we have a continuing discussion going on between people with great technical competence and certainly with enormous en-

thusiasm. This has helped us a great deal in getting both our research and our teaching programs started and in keeping them going on a continuing basis. As long as we maintain this infusion of ideas from the stream of things, we certainly should keep enough excitement going to bring students in from other areas and disciplines.

Next I would like to comment on classical vs. modern geology. Personally I think this part of the discussion is just a tempest in a teapot. The reason I think so is that some of us equate the word classical to those programs really that are poorly taught. I think all of us can recall courses in geochemistry, for example, that have been taught by someone that doesn't know chemistry, hence, put on a teaching performance that disillusioned any good student with some chemical training. In the same way some of the so-called classical courses such as structural geology, geomorphology or stratigraphy have been very poorly taught or were handled in a purely descriptive fashion that failed to draw on the engineering or other quantitative training of the students. In contrast, other "classical" courses such as the geochemistry taught by Goldschmidt was probably more stimulating than any similar course taught by anyone during the next two decades. I think that the discussion about classical vs. modern geology should be dropped and attention paid the need of continuously relating new concepts and measuring tools to the problems of earth science.

The complaints about field training also seem to me to be out of place. Geologists and even the chemists and physicists who add the prefix "geo" to their names are getting into the field in increasing numbers and putting into use a wide range of measuring tools. Field training has always been required and will continue to be.

The geologist who is content merely to show what rock is where is hardly what should be called a geologist. Field work is not an end in itself but is the data collecting and recording part of a geological program. If these first steps are not followed up, the work can hardly be construed as research. Again, I am surprised that this topic continues to come up so often because most good earth scientists are well aware of both the place and importance of good field work. I firmly believe that it is an essential part of undergraduate training that should be continued throughout the earth scientists' career. The men that come into the earth sciences should take every opportunity to get acquainted with rocks and the problems in their "native habitat."

Finally I would like to add to the comments made yesterday regarding geologists in the petroleum industry. As was emphasized, at the same time the petroleum industry was laying off a large number

of geologists, they were at the same time trying to hire a large group of other ones still called geologists but who were breeds of a different cat. This came about because the needs of the petroleum industry were changing and the needs of the petroleum industry will continue to change so this is a problem that is related to a change in the kind of activity and not just to a decrease in the need for numbers able to undertake the same task. Now on this basis you can deal with the physicists and the chemists and many other people. I think the lesson that the Universities should learn from this action is perfectly clear: if a department is to turn out graduates who hope to find a place in the petroleum industry, schools are going to have to concentrate, whether they like it or not, on developing the thinking tools which means more chemistry, more physics, and more math than they have required in the past. This does not mean that all schools must follow this course of action. Geology is a very valid *cultural* subject for people in the Liberal Arts, the Sciences and Engineering. A lot of people, who enter other professions, can be greatly enriched by an introduction to the earth sciences. I think it is a major mistake to try to teach the freshman courses aimed at cultural objectives in exactly the same manner as the course would be taught for an advanced degree man. Most people involved with Earth Science education appreciate this point. I think most schools are making a very serious effort to redesign the courses to meet these separate objectives. Having been through these curiculum revision struggles situations on a continuing basis for years, I am very optimistic about the future of geology both as a cultural subject and as a key discipline needed by many industries. The profession is well aware of what problems must be solved if we are to become effective teachers, scientists and practitioners. I am sorry that geologists have been so slow in trying to implement some of these problems in terms of upgrading their teachers. In spite of criticism of some of the NSF programs—there are some details that I disagree with too—I think they have been instrumental in making a major step forward and that we can expect a tremendous improvement in teaching at all levels.

DISCUSSION

Moss—Dr. Frederickson, I think your comment about freshmen courses was certainly very interesting. We haven't had too much talk on this subject here because this conference isn't really pointed toward subjects like this but I think it is an extremely critical course. I wanted to ask you what problems you take up in it, and do you have in that course people with strong scientific background and also weak

scientific backgrounds and if so, how much physics, chemistry, math do you work into that course?

FREDERICKSON—As an example, our Freshman course taken by students from the Liberal Arts and those who plan to enter the Geology program is called Geology. We are on the Trimester system so the course is offered three times a year. Three different senior people teach the course. One professor is a geologist, another a geochemist and the third is a geophysicist. The subject matter covered in each trimester is slightly different. Each course is tailored to fit the areas of greatest interest of the professor. When a man is up-to-date and competent in an area, he is often quite enthusiastic about it. Such enthusiasm is contagious and we make a bigger effort to present fewer topics with an insight and enthusiasm than we do to try to cover the whole field.

As you can imagine, these courses are quite different from the older Physical and Historical Geology courses that most of us took in our Freshman year. As you can also imagine, there is considerable discussion among the staff as to whether or not these courses will be accepted as beginning courses for people wishing to become geology majors.

MOSS—Yes, I wanted to follow up with that. How do you handle that?

FREDERICKSON—The answer to that question is that we accept it but we expect the geology major to cover by outside reading a lot of those topics that are more or less descriptive and that we don't cover in the Geology 80 courses. This is also a great problem when you get a student from physics, chemistry and math into the Earth Sciences. How do you get such students problem-oriented in the Earth Sciences? How do you introduce him to the rocks without requiring that he take all of the elementary courses? We have a transition course which is called Earth Physics. We expect these students to take this course and to sit in on some of these other courses on an audit basis. This work is supplemented by a lot of reading. We don't attempt to make good geologists out of these people. We attempt to lead them through the solution of one problem in Earth Science where there is basically a chemical approach, a geophysical or some other approach. We are wide open for criticism in this regard and some of our geophysicists, for example, that have a lot of math certainly are not well-trained geologists by any sense of the word but some of them could really do something about the solution of some important earth problems. We are trying in our school to be good in just a few kinds of areas like this.

WASSERBURG—I don't think any more major problems are currently necessary; the major problem which the country faces in the profession

is establishing adequate undergraduate training and the production of some interested, intelligent men. There are already numerous graduate schools, inadequately staffed which have an inadequate number of talented students entering.

FREDERICKSON—Jerry, I flatly disagree with you on this.

WASSERBURG—You think we need more top heavy institutions.

FREDERICKSON—No, I didn't say that. We need more good graduate programs.

WASSERBURG—Well, where are all the good graduate students?

FREDERICKSON—Most of our good graduate students don't come from Earth Sciences. They are coming in from engineering. Half of our graduate students come from engineering and a good percentage of these come from Carnegie Tech; others come from physics and chemistry. We have quite a number of people from Japan and England and foreign countries. They come in for special graduate work. We also, as you have mentioned, have some very good graduate students along with some that have not proved to be as good as we would have liked them to be. There is a whole raft of well-trained people that could come into the Earth Sciences from other fields.

WASSERBURG—The following situation should be illustrative for you. In physics; every physics department has more qualified applicants than they can handle. They have more qualified undergraduates than they can handle and they are good students. Some of you were telling me that if you got the lower third, you consider yourselves very lucky. So, there are these other fields which are producing undergraduates in great abundance and of high quality. At what institution does this situation occur in the Earth Sciences today, as well as, for the past 15 years?

MOSS—Was this true in physics, say before 1950?

WASSERBURG—Yes, since 1945.

FREDERICKSON—Well, in terms of what is needed by the profession, I think there has to be a great deal more effort put into putting meaning and orientation into the Earth Science courses. To bemoan the fact that they teach very poorly in some of these schools is not going to help this any; these schools are going to continue to teach. Our problem is to find ways to help them do their job better and to help the students become interested in Earth Science problems which can be just as exciting as some of the physics problems. Most of the students in physics never even heard about the Earth Science and are not aware of the possibilities. When they do become aware of them, it makes a big difference. One of the best examples of stimulating teaching is that done by Nagata who gives the same course differently every time, even though it is called "Earth Magnetism." It ranges all

the way from the theory of the origin of the Earth's magnetic field to space magnetic and rock paleomagnetic problems. He is a good enough mathematician to argue with anybody on whatever grounds they choose. As a result we are getting more and more students coming from physics into problems of this sort about which they are very enthusiastic. We just enrolled a straight A student from the Physics Department at Yale who is now working in the magnetism program along with some other very highly qualified students.

But Geology as a whole I believe has been remarkedly unsucessful or lazy in doing leg work in getting other people interested in their program.

I was very interested in your comment about beating the bushes for students in high school or something of that sort.

GOLDBERG—Not in high school.

FREDERICKSON—We do that too.

MOSS—Well, undergraduate people are, I think, high school people right now. I think this field is very good but it takes time, and people don't want to put the time in on it.

FREDERICKSON—That's right.

MOSS—But I think the secondary school courses which are being taught are going to bring to us better people. I am sure of it, because that is happening now. Many of the boys coming in have come through 9th grade Earth Science and they have the spark, you might say, there and some of them seem to be damn good.

WASSERBURG—You people run a fantastic show, though.

FREDERICKSON—But going back to this Franklin Marshall situation, I wouldn't have urged the people at Franklin Marshall to have put more chemistry and physics into their program at all. They can get these subjects at a later time. The stimulus that they were getting was the valuable and unique factor. One never takes a course in any University in a subject. You always take it in a man, irrespective of what he calls it: it was always his analytical approach to the topic that is of value to the student. You have been exposed to that in several different contexts. If a course is, this gets really exciting.

MCCAULEY—I would like to ressurrect a comment that Jerry made here because I don't really think it has been accurately answered and I think perhaps we might benefit from this discussion. We have been talking the last day here about fewer but better geologists and it seems to me that the need for new graduate departments has not been justified. I think what we are doing is simply slicing the pie thinner and thinner, and we won't be accomplishing this end of fewer, but better people; we will just be making more and more mediocre ones so I would just sort of like to hear justification or at least throw the

thing open because we more or less skirted around the—

FREDERICKSON—You mean answer why we justify a new graduate program.

MCCAULEY—At this particular time.

FREDERICKSON—John, I think there is a need for much more *good* graduate training in the Earth Sciences. If you want to get very prosaic about this matter, job opportunities for well trained people are abundant. They can go into the glass industry, the petroleum industry, the space-oriented programs, oceanography and many other places that are begging for really good people. They are certainly needed in the teaching field. There is a great need for excellence in Geology. I don't think the existing graduate programs have a corner on training good people, nor do I believe that the existing Departments, by and large, are doing a good enough job. There are not enough students coming from other fields into the Earth Sciences that have the backgrounds that are needed. And the good backgrounds of many of the students entering existing Departments of Geology are not being effectively used. Yes, I strongly believe that there is a real need for new departments dealing with the Earth Sciences in a more quantitative fashion.

MCCAULEY—What you are saying here is that there is a need to start these new departments and that is to stimulate competitive—

FREDERICKSON—Remembering that we have a teaching obligation from a cultural point of view as well as for the man entering a profession, Earth Science education plays an important role in the University and the community. We play an important function in upgrading the professional people in our area, even for people who already have a doctorate level degree. This function is needed in research and industry to keep people stimulated. It will bring new things to these people. Many of them with different backgrounds attend our courses, and I think get a great amount of good from them.

PINSON—In terms of the general need I agree that professional upgrading of the local professional community is important. We do a lot of this, especially in our summer programs, at MIT. I think that the privately endowed institutions have as much responsibility in this area as do the governmental sponsored institutions.

FREDERICKSON—We are very practical about this. You do those things that you would like to do and those things that you can do well within the restraints of the University budgets and what the University thinks they need. Keeping these points in mind, you develop a viable program. We have a teaching obligation. We don't try to teach a classical curriculum where you have economic geology, glaciogeology and many other courses formerly taught to undergraduates. If you

want to study those topics you go somewhere else. We are trying to develop graduate students that can handle some of the research topics that we think are important; on the other hand we also teach geology as a cultural course, as a service course to the liberal art group at large. This is one of the obligations that I think must be taken very seriously in any new kind of a program.

PINSON—I would like to discuss this a little further. The way I understood it, you stated that the most important thing in undergraduate education was to get the students properly problem-oriented, and I think I understand you to say that it wasn't quite so important that they at first get a good foundation in math, chemistry and physics. If you could get them problem-oriented, you could keep them and later you could give them what they need. Perhaps I misunderstood you.

FREDERICKSON—I think you did, in the beginning courses you try to get students problem-oriented. The rest of the curriculum in our department is to try to provide them with their thinking tools of chemistry, physics and math so they can do something about the Earth Science problems. At the present time, for example, we are giving our first course the greatest amount of attention to make it more interesting and effective.

GOLDSMITH—This matter of not taking courses in a specific field is certainly not unique to the Earth Sciences, it has become general all over. There are many institutions now that give a bachelor's degree in a subject in which a student does not take one single course under the title of that subject.

GOLDBERG—For example.

GOLDSMITH—Many of the fields of the humanities. So I think this is something we are going to have to look to more and more and not worry so much about.

FREDERICKSON—A lot of things the more conservative people scold the living daylights out of you for doing this sort of thing, but there is only so much time and you have to decide what you are going to have these kids spend their time on.

HURST—I just have a question. You stressed the importance of a new department establishing its identity. Wouldn't you say it is equally important for the profession to maintain its identity and are we really doing this?

FREDERICKSON—I don't really care too much about preserving the identities of the Geologist and Geology. People ask me what I am, and I always say a geologist. I have spent a good part of my life in quite different activities. I started out in Mining Engineering and branched out into Metallurgical Engineering, most of which was re-

lated to earth problems. I don't think we have to be too concerned about what we call each activity. What title would you apply to Harold Urey at the moment? Is he a geochemist or a chemist? I think he couldn't care less what you call him. He is interested in problems of some sort. They are all dealing with the Earth. What do you call people working in the field of Oceanography?

GOLDBERG—That's what an Oceanographer does.

HUNT—I think this is a good point, I mean, you are called what you are at the job you happen to be in at the time. I have been called a lot of things.

I wanted to ask Fred a question because I think this will give me a little better picture of his staff. You said this went from 2 to 26, what percentage of this 26 would you say had their earlier graduate training outside of geology? Offhand.

FREDERICKSON—An estimate?

HUNT—For their major training.

FREDERICKSON—More than half of them come from physics, chemistry, or engineering.

WEAVER—The assertion that we do not need new graduate Earth Science programs seems somewhat provincial—assuming the new programs are high caliber. Everyone is concerned about where the graduate students will come from and have also stressed that they are recruiting many of their better students from physics, chemistry, and engineering. This is the obvious source of students for the immediate future, and we need to convert as many as we can. However, I do not think Cal Tech, Chicago or any other Earth Science department is going to have much luck enticing physicists, chemists or engineers from Georgia Tech or from any other school except their own. If good science and engineering students from Georgia Tech are to become interested and enthused about the problems and potentials of Earth Sciences, we here at Georgia Tech will have to do it—and we have 6000 science and engineering students to work with.

Further, with the increasing emphasis on multidisciplinary research, I do not believe a school will be able to maintain strong, up-to-date programs in chemistry and physics if there are not strong, supporting programs in geochemistry and geophysics.

FREDERICKSON—Oh yes.

HUNT—This gives me—

GOLDBERG—Let's break for coffee.

Before we proceed with the more formal part of the session, I think we all owe a vote of appreciation to Chuck Weaver and his associates of Georgia Tech for sponsoring this meeting and providing the wonderful facilities that we have all enjoyed for the last day or so.

RENOVATING A "CLASSICAL" DEPARTMENT

By Karl Turekian, Yale University
Donald F. Eckelmann, Brown University
John C. Maxwell, Princeton University

TUREKIAN—There are certain departments in the country who have ancient traditions in what is called "classical geology." These have had tremendous anguish in the last decade or two undergoing transformations. The transformation is basically one of adding new people to try to balance classical with modern or contemporary oriented discipline. What this means is that the size of the department increases. Now where the student-faculty ratio is not the critical thing, rather the development of the department, it depends upon a high level administrative decision to invest the university money in this way. Then the department can grow, adding people with new ideas. These new ideas happen to be, right now, in the areas where people do experimental and theoretical work.

These classical departments which have had fame in the past, however, get students who are classically oriented. If the complexion of the faculty is changing one would expect the students to follow. This is not the case since students are basically conservative if not reactionary.

In the context of this conservatism somehow the eyes of the students must be opened to the new metaphors that the new men who have some bring with them, and this means, of course, changes in the curriculum. About 8 years ago one came to Yale and took 4 year (8 semester) courses: Stratigraphy, Geomorphology, Structural Geology, and Mineralogy and Petrology. A total of 16 semester courses is required for a Ph.D. It turned out that one was wise to take the required "basic course" in the first year because first year examinations were geared to these courses, although not stated as such. The remaining 8 semester courses were taken very close to home. It was very unusual, in the old days, to go very far outside your department.

What has happened is that in the context of the new people added to the department at Yale a new concept in required courses arises taught by the *whole* faculty. The role of these courses is twofold. One, they require students who came from classical backgrounds to under-

stand that there are ways of looking at rocks other than the ones in which they have been trained classically. Second, the hybridized beginning required courses allow for the introduction of students trained essentially in chemistry and physics to the salient problem of geology. With this device the classical man hopefully gets to see if the world can be treated with another metaphor besides the ones he has been used to and the man who comes from a chemistry and physics background, a little bit naive in the fact that there are significant geological problems, is introduced to the fact that these exist. Now, aside from these required courses which are now 4 semesters in number, there are no other requirements. We have obliterated all other requirements in our department, and so that the device of individual faculty members or clusters of faculty members as they meet the students is focused on how they can meet their deficiencies in clarity, mathematics and other fields. This has resulted in a little bit of growing strain, but the net effect is that the main group of students have been forced out of the department into the chemistry department into the math department, physics and applied sciences and engineering to become familiar with the metaphors that are developed there and to be able to apply them to geological problems.

WASSERBURG—What have you done with your undergraduate curricula?

TUREKIAN—We have revised our undergraduate curriculum, if one can call obliteration revision. The first year a student takes a course called Physics and Chemistry of the Earth. It is not even called geology. The second semester one takes the History of Life on Earth. It is not called Paleontology and is taught by a number of paleontologists. This course can be taken at any time, and it assumes that one is taking calculus at that time or has had one and assumes the intermediate level of chemistry and physics is being taken at that time. It also encourages chemists and physicists to come in and take it when they happen to have a slack quarter or happen to be just tired of standing in line outside the linear accelerators. This course is oriented both to educating people who want orientation toward physics and chemistry, at least on some elementary level, not just random people, plus people who come from other departments who might just want to take a one semester course. The third semester the student takes Structural Geology and the fourth semester a course called Mineralogy and Petrology and finally in his third year, the last course he takes is called the Geology of the United States. That is the geology major. The important point being that there is enough time so that a student could essentially be a chemistry major or physics major or a math major and fulfill the geology requirements. In their 3rd and 4th years

they have lots of time in which to take poetry courses or take advanced graduate courses which are also given undergraduate members; however, he is really perpetually propelled into the chemistry and physics departments and into the biology department.

We hope to get more people to go professionally into the Earth Sciences, to train our own people more effectively in chemistry and physics, and let the graduate schools take care of the more elaborate training. Whether these students go into Oceanography or Geophysics is sort of irrelevant at this point. We just want to show them what geology is like, how to do field work, how to do laboratory work, give them some training in undergraduate research and then turn them over to the graduate schools.

GOLDBERG—Let's continue with Professor Eckelmann from Brown University.

ECKELMANN—This is a departure from the schedule because of Karl Turekian's wish to have a larger sample of Ivy League schools. Maybe too, he is reluctant to face the questions stimulated by his provocative talk.

I would like to take a couple minutes to tell you about the evolving program at Brown as it might be looked upon as something of a case history. Only a few years ago we were in a situation comparable to what Chuck Weaver now faces.

The Department of Geology at Brown has a long history, going back to 1905. It was a small department, consisting usually of one permanent man and 2 other people who were coming and going at two to three year intervals. In the middle 50's, the University appointed a new president who happily was a scholar in his own right. He also was determined to leave the institution infinitely more famous than he found it. Upon looking about the university, he decided there were 4 departments that should either come or go, and geology was one of them. In each case, a decision was made to keep the department and so unknown to the Department of Geology, new and better things were alive clearly in the offering. Now this is the setting in which we found ourselves at Brown in the latter part of the 1950's. One very important factor contributing to the growth which followed was the President who understood the nature of scholarship, for he was a scholar in his own right. He knew what scholarship was and what it cost in terms of money and time. It was this person who took responsibility for gambling money in large amounts and on a continuing basis, to support the development of the Geological Sciences at Brown. He did not expect miracles in terms of student numbers. To our surprise he appreciated that if things really changed, there would be a period of time during which student numbers might well

come down to the vanishing point. This actually happened at one point where the graduating class in geology consisted of one person and he failed his comprehensive exam. Now what kind of people have we appointed to make up the program we have now? We sought to appoint people who were, as someone said earlier, contemporary individuals. Contemporary in terms of training, outlook and research interests. These people conceptually are at the frontier of our science today and to the best of our ability to judge them, they have the research tools necessary for success in the areas they claim to be competent and interested in. We also looked for people we thought could remain contemporary over the long run. People who could evolve with the times and change with the times and be up in the front of things 20 years from now. Then another thing we looked for, and which has been extremely important, is that incoming people have a balance between two things; on the one hand, intense concern about ones own personal success and on the other hand, a genuine concern for the corporate success of the departmet. This means we could not entertain having someone who was a prima donna. The man could have the talents of a prima donna but he could not carry on like a prima donna. I think in initiating a geology program, it would be almost sudden death in the early stages to have someone as disruptive as a prima donna would be. Now what of the long-term goals in our program? I think simply stated, one desire is to retain and cultivate desirable aspects of modern classical geology. The term classical seems to have fallen into disrepute in some of the discussions here, but there are aspects of classical geology that are modern and absolutely essential to the training of Earth Science students. We have sought to define these and to go out of our way to cultivate them and to maintain them among the faculty and in the graduate course program. Then too, we are concerned that we have represented on the faculty, people from the new areas of research and intellectual development in the geological sciences in the last 10-20 years. The third thing that we seek to do, . . . and are beginning now to do, since we have reached a certain size . . . is to build bridges away from geology by joint appointments with other departments. Right now our group is moving into the area of geophysics. Dr. David G. Harkrider is coming from Frank Press's seismological group at Cal. Tech. We are also considering joint appointments with the Applied Math Department at Brown. This is the one internationally famous department in the institution. These real connections with other departments will be made via real live people in the Department of Geology. It has been our experience that other departments are not as interested in these bridges as we are and if these bridges are going to be made with other departments,

they will have to be initiated within Earth Science and Geology Departments. If it doesn't happen that way, it won't happen at all. Over the long run we hope to make appointments in such areas as Physical Chemistry. Such a person would deal with concerns close to problems in geochemistry, experiment minerology and petrology to name the obvious areas. Now, what have we not done? We have avoided making a distinction between classical and experimental geology. Rather we have thought in terms of a man's breadth of interest, whether he is asking fundamental questions and whether he has the ability to carry out investigation of these questions. This kind of thing we try to transfer to students. Whether some of these activities fit into what you call classical geology or not is of very little concern to us. Now what are some of our specific concerns? I will express two in negative terms and one in positive terms. We don't want to turn out geologists who are lacking in awareness of the new research techniques that have been developed in the last 20-30 years and who are, worse yet, lacking in an awareness of the implication of that data, that is, lacking in ability to reason from this data. We want people who, if they are going to be geologists primarily, have sufficient breadth of training, interest and awareness to rule out these deficiencies. Secondly we don't want to turn out experimentalists who are unable to conceive and recognize the fundamental geologic questions. We don't want to turn out people who carry on sophisticated chemical studies in which the geological materials are incidental to what they are doing. Not that this is unimportant, rather it just is not the kind of thing we want to go on in our department. We would like all students to be geologically oriented regardless of whether they are laboratory or field men. That brings me to the third of our concern, the positive concern. We want to provide students with the informational and conceptual framework in which fundamental questions can be asked, a framework in which useful programs of investigation can be conceived, developed and initiated. This goal is something set before all students regardless of their discipline, subdiscipline, etc.

GOLDBERG—We will continue this discussion of Eastern geology with Professor Maxwell from Princeton.

MAXWELL—I would like to agree most heartily with the point Ray Siever made. The change in geologic education is not revolutionary but evolutionary. Geology is certainly becoming more quantitative, as all sciences have become more quantitative through their history; no really radical measures are needed except perhaps in the case of particular departments, or members of departments who have gone to sleep, and then maybe a little surgery is needed. Hoover Mackin

put it very well: regardless of how many people drag their feet the trend toward quantification is going to continue, and those of us who want to turn out a salable product had better take this into account.

At a school such as Princeton, which has had many famous geologists in the past, we are not so much concerned with the problem of attracting good students (thank God we still get them), neither are we much concerned about the precise details of the curriculum. We feel that the students in large part educate each other. Many of them, we know perfectly well, are able to go well beyond us, and obviously we encourage them to do so. There are no formal course requirements, but a lot of private arm twisting does go on. It is only necessary that these men pass two formal examinations. There are weaknesses in this system and we are examining them, but on the whole, I think we are reasonably satisfied with our scheme of graduate education; we are only dissatisfied with some of the details.

Our undergraduate education is not in such good shape. We would like to do the kind of thing that Yale is doing now. Contrary to much of what has been said, the students who are coming to us are vastly better prepared than those we got five or ten years ago. The high schools and secondary schools are giving these young people a much better insight into the sciences and mathematics. They are able to absorb a great deal more than we used to give them in our elementary courses and these are due for a drastic revision. I think we could quite easily give these students the elements of geology, what we would consider the basic philosophy of geology, in three or four courses as Yale is proposing; then lead them on directly, either into the oceanographic or cosmic sciences or perhaps even into graduate geology, or what we now call graduate geology. The contents of our graduate courses of five years ago are moving down to the undergraduate curriculum; this is a tendency which is going to continue as we spread out further and further into exciting new areas.

A difference in approach at Princeton which I don't think has been mentioned thus far, is that we recognize two distinct realms of geology. One of these we have been talking about here. It may be characterized by the phrase: "Geology can be fun!"; we enjoy it, it is important to us, we particularly like to get together like this and yak with each other. But I think we can raise the legitimate question of an outsider: So what? How is it pertinent to modern life? The motto of the second realm is: "Geology can be fun *and* useful." These two fields are not easily and automatically combined. The same person rarely is able to master both. We are attempting to develop both aspects by setting up two paths; one, through our

geology department, and the other through geological engineering, which elsewhere might be called "applied geology."

Thirty years ago physics was much in the position that geology now occupies. It was a very interesting subject; it attracted few majors; it didn't seem to be particularly pertinent to what was going on in the world. On the whole the reaction of the public to physics was massive indifference, very much as it is today to geology. The same could certainly be said of mathematics. In my undergraduate days, mathematicians were regarded as rather queer people who were apt to be interesting, but a little bit off the beaten track. Now, of course, everyone is acutely aware of the importance of mathematics. Obviously the change in public awareness didn't happen because of a suddenly developed appreciation for the fine points of mathematical or physical research. It happened because the tremendous developments during the war and immediately thereafter brought home to the public the importance of applied physics and mathematics in everyday life—in fact, to the very existence of life on this Earth. The image that built up in the public mind has so impressed science-oriented students that they are flocking into mathematics and physics. Our Mathematics Department was rocked back on its heels a few years ago when 70 freshmen declared their intention to major in mathematics. The average group might be 15 per year. Probably no more than 15 survived as majors, but the point is that their declared interest was a reflection of public awareness of these important and challenging areas.

Now, how do we do this for geology? Somehow we must bring to the attention of the public that the health of the body politic depends on continued imaginative development and exploitation of earth resources—minerals, water, hydrocarbons—on land and under the oceans, and on sound development of our remaining living space. The applied geological sciences provide the basis for this continued orderly development, or at least they should. If the people of the country realize and accept the fact that their continuing well being rests so directly in the hands of geologists, then I think we can anticipate an influx of students and a public awareness of the importance of the earth sciences, including research.

There is a large "if" in this reasoning—*if* the applied geological sciences accept the challenge. We have one built-in disadvantage which we may not be able to overcome. Every other scientific field has a well recognized parallel field of applied science—chemistry and chemical engineering, physics and electrical, mechanical and aeronautical engineering, biology and medicine, etc. The pure sciences are engaged in pushing back the frontiers, generally without concern

for applications. The applied sciences and engineering direct research toward more or less immediate applications. Decisions must be made and actions taken even though the scientific bases for the decisions may not be completely worked out.

In our sister sciences different educational routes are available to the scientist. It has long been recognized that the educational philosophy and the philosophy of day to day practice in the two areas are radically different.

How does geology fit this picture? Of course it mostly doesn't. The vast majority of students are educated in the "pure science" departments, such as our own, then shipped out to function as though they were trained to think and work as an applied scientist. The results have not been outstandingly successful. Some of our most promising graduate students who went to industry come crying back to alma mater claiming they are not appreciated, that industry is prostituting their talents. I think their unhappiness stems largely from the fact that they are not prepared philosophically to make the required judgments and decisions. It is hard to slough off the "if, but, perhaps, probably" mentality of our geological science and make a specific and concrete recommendation.

I would like, if I may, to take five minutes and touch on another subject. We have been told by several people today that we need fewer but better students. The implication is that the market is about saturated. I think this is both wrong and a dangerous philosophy because it leads to a kind of pessimism and retreat from responsibility. If we look at the population figures, we see that on any prognostication (except that based on atomic warfare) the population is increasing logarithmically, doubling about every 35 years. If we are simply to maintain the standard of living that we have now, the use and the discovery of raw materials must grow. If we assume that we increase the standard of living of the Western countries by 10%, we would have to increase the extraction of raw materials about 50% above the present rate; and we already have been told that the oil geologist is practically finished in the United States! What will we do? Does this mean that our only recourse is to find substitutes? I think not. The mineral resources field, the ground water area, the field of engineering geology, are open to us; and not only open to us, they are just barely scratched. The question is: will we occupy them? If we concentrate our attention on geological science, of the kind we have been talking about, we just *won't* occupy them. Somebody else may; the civil and mining engineers for example, because they have to have decisions; if the geologists are not there to make them, other engineers and scientists must move in. Soil mechanics

and rock mechanics are good examples of areas where geology has taken a back seat because we didn't move in when these sciences were ripe for development.

On the other hand, the mining industry, (which I noticed hasn't even been mentioned today) is on the verge of a tremendous breakthrough. In places, such as Southeast Missouri for example, they have, by application of basic geology and geophysics, extended the lead and zinc deposits some dozens of miles and some hundreds of feet below the surface, well to the North and West of the present area. We are witnessing the opening of the covered shield area of the United States to mining exploration. The difficulty is that we lack viable theories to account for the localization of mineral deposits. Here is a vast area where geochemistry and geophysics must play their part in developing theories which will permit applied geologists to extend the mineral hunting.

I think we can make a similar point for oil. We have exploited the trap theory to a point where the finding cost approaches the value of the oil in the ground. On the other hand, we have not successfully digested the fact that oil is a fluid whose entire history from origin to final accumulation occurred within a water continum. We should study it as a fluid rather than concentrating our efforts on the rock in which the fluid is found. I am well aware that oil company labs are working on this concept, but it has not yet been developed to a viable theory. When it is, we will open considerable areas in this country and certainly very large areas in the rest of the world to a kind of prospecting that hasn't yet been attempted.

It seems to me that we should not play down the opportunities. We should not settle for fewer graduate students. We should instead do our best to indicate the magnitude of the problems and opportunities to the public and to incoming students. I believe, with John Hunt and others, that there is no lack of good jobs for geological engineers and geologists if they are ready and able to occupy critical fields which are now opening to development.

DISCUSSION

SIEVER—A question that goes back to Karl Turekian's talk is a general one of how much mathematics, physics, chemistry, etc. you use in undergraduate courses. One other thing that impresses me about the line-up of these courses would be the following: in your introductory course you may do a moderately good job of introducing some elementary ideas of the calculus and very elementary physics into some geological problems. I strongly suspect, however, that when

you get into your years two or three that somehow it all disappears, or much of it may disappear, and you are left with a terrible situation in which a student starts out thinking that he is going on to bigger and better things whereas in fact, he may not. It depends of course on how you teach those courses but the use of basic science has to expand upwards as you go because a student presumedly is not going to stop at calculus. He shouldn't. There is some serious question raised about the extent to which you use related sciences in some standard type courses (or those with standard course names).

TUREKIAN—The idea is that the first four courses will orient the student toward using the chemistry, physics and math that he learned at high school and develops at Yale. The third and fourth year, we are going to the Princeton method of requiring a senior essay of everyone in a geology major. We are also encouraging the taking of one graduate course. I hope that these two things will show the student how to use the basic sciences in his own problems. We will have to wait and see if it is successful.

PINSON—I would like to ask Dr. Turekian in what respect the History of Life course, for example, is modernized and how is that different from an ordinary course in historical geology.

WASSERBURG—Well, at Cal Tech we've been doing it for twelve years. Heinz Lowenstamn has taught a course jointly with Harrison Brown which discusses a whole variety of things. I would like to emphasize this problem because it is the one big gap in the whole discussion. Everyone keeps talking about math, chemistry and physics and I don't think a single person has discussed the problem of Paleontology which is probably suffering the world over from inertia more than any other aspect of our science. Modern biology and biological insights and zoological insights have had virtually no effect on this science. I don't see why this isn't emphasized far more. This is obviously one of the major places where real contribution and understanding can be made.

GOLDSMITH—May I comment on that Jerry? We are spending a lot of time discussing at least, on the sidelines, the classity of students, for example, in many areas of the Earth Sciences. In Chicago, curiously enough, one of the largest incoming groups of students each year is in what we call our paleozoology group which encompasses this sort of area. These people are as well trained in zoology as they are in geology and the ecological and similar approaches are used very successfully. I think we are turning out about four Ph.D.'s a year in this general subject matter which is perhaps surprising to some. So it turns out what some people consider to be static areas are in other places very active areas.

WASSERBURG—On a national scale though.

GOLDSMITH—Yes.

BUSINGER—I would like to ask a question of Dr. Turekian about this curriculum. Maybe you have such good freshmen that you can really do this but on the average it seems to me that your undergraduate program is upside-down. Shouldn't the first year's courses be taught the fourth year, when the students may have the necessary background in physics and math? Another question is whether you accept students that have taken poetry and in general humanities during the fourth year as graduate students?

TUREKIAN—Let me elaborate on this. It is true now that a lot of people are coming in from high school that are so well trained that they can finish in three years. That, I think, has been happening at Harvard for quite awhile. There are levels of courses in chemistry, physics and mathematics where a man can qualify on the basis of an examination plus his past credits in high school for one of these levels. We accept only the people that come in on the second highest level or higher. So, there is a natural selection there. The other people go into the normal distributional courses. Some of these may qualify later on and then start the program in their sophomore year.

BUSINGER—We would have to modify this for state schools—

TUREKIAN—We may have to modify this next year for our school.

NELSON—I would like to ask a specific question about the Mineralogy and Petrology course which, I gather, is one semester. Has this been taught yet?

TUREKIAN—No.

NELSON—I would like to inquire specifically what you plan to get across in this course that will serve as a suitable basis in that area for graduate work.

TUREKIAN—In the Physics and Chemistry of the Earth we go extensively through elementary structure analysis and things like that. This is their preliminary encounter, and they get their preliminary encounter with the petrographic microscope and see that they can do something with it. In the second year in the laboratory they continue with the petrographic microscope and learn to be a little more versatile with it in learning problems about how rocks are formed and what the minerals are in them. In their third and fourth year, presumedly when they get involved with their senior essay which can start in the middle of the junior year, they will use these tools and have the aid of the faculty members.

NELSON—Do you expect a student by the time he comes out of this Mineralogy course will indeed be competent to use a petrographic microscope, or do you care?

TUREKIAN—If he is really interested in a petrographic microscope problem by the middle of his junior year or beginning of his senior year, he can take a graduate course in Mineralogy.
NELSON—Oh, so you have the real instruction in optical microscopy at the graduate level?
TUREKIAN—It is at the graduate level or at the advanced undergraduate level— because we hope that some day some of these guys will go into Oceanography in which case they may spend most of their third and fourth years taking applied science and engineering courses. You don't want to restrict them now. This is too diverse, it is sort of like being a quarterback on a T formation, there are so many options that you don't want to constrict this student so early.
BENSON—Karl, I just wanted to ask you about these undergraduate courses. Does your statement mean that there is no elementary course in geology open to a liberal arts major? Does he have to have physics and chemistry first before he can take any geology?
TUREKIAN—This is a future problem but it is not an immediate problem. We have a course called Science II which is a distribution requirement which is taught by Professor Flint.
BENSON—You no longer have Geology 10?
TUREKIAN—No, we obilterated that because it was a functionless study of rocks and stars by the student and that is Science II.
BENSON—But supposing you have a fellow who has come through high school without any science. His only way of contact with geology would be the Science II course?
TUREKIAN—Yes, at the present time.
PINSON—I would like to ask you if these courses are taught by one professor, or do several people cooperate in teaching them and just how successful is this?
TUREKIAN—These are cluster courses—well, all I can tell you about it is Physics and Chemistry of the Earth, its success is wide, and we had fun and so did the students—
PINSON—Some of the most unsuccessful courses I have ever had were courses that were taught by several people—I mean I am just presenting it. It is a real problem to present a coordinated course and one that is appreciated by the students. It is not an impossible thing I admit, but it is difficult.
BENSON—Karl, I want to follow up on this question of timing. Supposing you do get a bright student who had not had physics and chemistry, and he has his first contact with the department in Science II, rocks and stars.
TUREKIAN—Right.
BENSON—Now is there time for him to decide he wants to major in

geology? It looks like the whole major is pretty compressed.
TUREKIAN—No it isn't, that is the whole thing. He can take the first three courses together in the second year, that is he can take—
BENSON—But supposing he hasn't had physics and chemistry first?
TUREKIAN—Well, he can take the introductory course his first semester, then he can start taking chemistry the second semester and until he does he is going to have a very hard time of it.
BENSON—Yes, I can see that, but it still looks like you may be excluding some potentially very good people.
WASSERBURG—Well, our problem is at the other end of the stick. We have to make our graduate students take our undergraduate courses. They have often not been trained in very important areas so that the program we have at Cal Tech is quite the reverse of this, although we try to have a maximum amount of flexibility. However, I think that by permitting an infinite amount of flexibility that there is a grave danger. There is no universal cure-all and so our program is very different. There is no freshman course given in geology, and the fundamental requirements are institutional requirements which are math, physics, chemistry and the humanities. Geology is then taught in an introductory sophomore elective course which is for everybody. This is not really a geology major's course although anybody who wishes to be a geology major would be well advised to take it for general informational background, but then the requirement of courses is fairly consistent and carries through to the fourth year so that integration of the sciences as they are taught with the divisional curriculum is fairly continuous. Subjects like optical mineralogy are not concentrated in one isolated spot but are picked up continuously along with physics and chemistry, or if a man is interested in Paleontology, a series of biology and genetics courses.
McCAULEY—What would a Yale undergraduate have to do in regard to Cal Tech?
WASSERBURG—Take three-fourths of the undergraduate curriculum if that is all he has had.
McCAULEY—What are your undergraduate requirements?
WASSERBURG—Well, like all requirements, they are written with great obscurity just as those presented by Dr. Turekian are since this is really a paper tiger type of program since what Ray calls "dark-alley-arm-twisting" goes on in conjunction with the formal program. This really must be the essence of any program; namely, a student walks down the hall, and Karl grabs his arm and says Buster, you are in Physical Chemistry or Buster you are taking an Optical mineralogy course or etc. Our students take two full years of field geology plus summer field camp. Almost everybody that enters our graduate

3

school, has got to go back and take one year of undergraduate field geology including geophysicists because of the fact that they haven't been trained in this art.

TUREKIAN—Let's speak to that. I can come up with the same sort of statement. Our students go down to Chile and map and write papers, senior essays, which are awfully good, or our students do paleontological work or go down to work with Abelson for a year. These are individual cases; what we had in the old days was a pretty rigid program which in many ways prevented the people from expanding in a direction which would make them capable of doing the things a little bit more way out, research things—

WASSERBURG—It is possible but where are the requirements that guarantee the minimal training? We just had this problem with establishing what in blazes a masters degree is. One serious problem with a masters degree on a national scale is what is the meaning of a masters degree on the bottom side. Is it just for one year in a graduate school, is it just for flunk outs or what—and so the real essence of the curriculum will be what are the minimal standards which you really establish for people which graduate—or if you want to talk about branches, Geo. 5, Paleontology 20, Geophysics 2, Geology and Chemistry.

TUREKIAN—You are not going to regulate that any more by sitting there and talking about it than you will if you put something on a board. This is the sort of stuff which depends upon a paper tiger approach. To put up a program and then depend on arm twisting and things like that to transform a naive student to something hopefully elegant and capable of taking his place in the professional world.

WASSERBURG—I would like to know one list of courses for the major different disciplines in the field at the top end which a student will come out with, and you can leave everything else off but show me minimal confidence at the top end. You know one of the famous tricks is to say no requirements except that you pass Geology 5432.

SIEVER—There is an organized way to do arm twisting as some of you may have known. The thing that Harvard has tried for many, many years now is the Tutorial System, which is borrowed in a slight part from some much older universities in England. It is not that tutorial is used as in Cambridge and Oxford as a substitute for ordinary lecture courses. We have a Sophomore Tutorial and a Senior Tutorial, both of which are quite different things and also Freshmen Seminars. Sophomore Tutorial is essentially a bull session of about three or four people every couple of weeks with a tutor who is a member of the staff. They talk about geological problems that come up from course work and outside reading. The students have diverse

backgrounds; they are not all taking the same courses at the same time. Senior Tutorial is individually study, usually leading to a paper, which is a standard device that teachers have used for a long time. Our experience indicates that, though we have tried this only for a short time now, that it is going to be successful. First of all it is the earliest possible place to start arm twisting in public, and second of all the diversity of the earth sciences field makes necessary an effort at integrating seemingly unrelated subjects: this is the device of putting it together in some way. It isn't put together in one grant scheme or package but rather the tutor points out relationships and dependencies of one subfield to another even though the student sees it divided among different courses. This is all built on top of our elementary course in general education which we also use to satisfy geology requirements in some ways something like the Cal Tech approach. We don't demand anything but a high school level of competence and we are not interested in remedial mathematics at Harvard to bring everybody up to that level, but the important thing is that we think we can teach a rather satisfying approach to various kinds of problems in geology. One indication of success is that our entering graduate students will sit in on it if they have not been exposed to this kind of thing before, including students who come from undergraduate mathematics, physics or another science. Another indication is that it is known around our department that any teaching assistance who has ever taught in that course has never failed to pass his doctoral preliminary examination. This is a pretty good advertisement.

GOLDBERG—Ray, it appears to me that there is a very peculiar state of affairs in some of these undergraduate curricula in geology. If you are a chemist, physicist, or a historian, there is a certain core of knowledge that you get at nearly all undergraduate schools in the country—

SIEVER—It is not true of history any more.

GOLDBERG—It is I think, but I won't argue that point. Certainly in chemistry, physics and mathematics, there is a certain core of knowledge, a certain language that a mathematician has mastered in four years of undergraduate work. There is a certain minimum of proficiencies in this language that are recognized and allow entrance to graduate school. I have a feeling that these catch-as-catch-can courses do not prepare students to enter certain of the graduate schools in geology. There is no pattern of courses that might be applicable to many of these small colleges that are actively searching for an appropriate curriculum.

GOLDSMITH—A simple explanation for this is that you are speaking on the one hand of what is normally called a core subject and the other

a derivative subject. I think it is as simple as that because one has to become educated to the other things first.

GOLDBERG—There isn't even a program—how much chemistry and physics—

GOLDSMITH—No one has ever agreed on an undergraduate program in geology to the best of my knowledge—

TUREKIAN—Wait a minute, Julian, that is good—

GOLDSMITH—That's right, it is good—

GOLDBERG—I think the requirements of many graduate schools to enter the Earth Science program or geology programs are similar today.

TUREKIAN—Maybe we ought to talk about entrance requirements for graduate schools.

GOLDBERG—It's lunch time so we will continue this discussion at 1:30 P.M.

WEAVER—Our first speaker this afternoon will be Tom Bates who will speak on "Interdisciplinary Programs."

INTERDISCIPLINARY PROGRAMS

By Thomas F. Bates, Pennsylvania State University

"Interdisciplinariness," if I may use that term, is old stuff to geologists as one can easily demonstrate by looking at the titles in geology faculty and course lists: geophysics, geochemistry, geological engineering, crystal chemistry, paleobotany, paleogeography, nuclear geology, astrogeology, and so on. In this space age even Earth Science seems too restrictive for planetary minded members of our profession who combine geology, physics and astronomy. Many of our meetings are well salted with scientists, engineers and humanists from other professions, and at the annual conference of the Clay Minerals Society of America, for example, you can't tell whose meeting it is profession-wise, what with agronomists, ceramists, chemical engineers, colloid chemists, soil mechanics, mineralogists, geochemists, x-ray crystallographers, materials scientists and geologists all engaged in a massive attack on those apparently fragile but remarkably refractory particles of clay.

Thus, it is of the nature of our science, and indeed of science in general, to be interdisciplinary, particularly as time and progress tend to erase the sharp boundaries that circumscribed our once well-defined disciplines. But not only is it "in the very nature of things" to be interdisciplinary but external pressures are pushing increasingly hard in the same direction. It is somewhat analogous to marriage. For most people, to get married is simply the natural thing to do. But then, too, there are marriages where it appears the *sensible* thing to do, marriages of *convenience*, and marriages of *necessity*. Similarly, the formalizing of research or instruction activities in interdisciplinary wedlock may, as we said before, simply be the natural result of the growth of science; it may derive from the need to share equipment and facilities; nowadays it commonly occurs because there are problems to solve and funds available to attempt their solution.

A few examples will serve to illustrate the nature of interdisciplinary activities at Penn State. Fifteen years ago, before interdisciplinary activities were "in vogue" at most universities, we formed

the Mineral Constitution Laboratories in the College of Mineral Industries at Penn State. Its structure as of several years ago is illustrated in figure I, an organization chart for the College of Mineral Industries. These laboratories both represent and serve the present eleven Mineral Industries College departments and many others in the university in their instruction, research and graduate training efforts. Approved rates for instrument use and personnel time provide the basis for charges to contracts whereas university funds provide for the costs of instruction and non-contract research. Dr. Sam Goldich is now in charge of the laboratories which are fully equipped with x-ray machines, all types of spectrographs, mass spectroscopes, two electron microscopes, an electron microprobe, and complete chemical facilities.

As an interesting indication of things to come we set up in 1955 a series of undergraduate and graduate interdisciplinary Mineral Sciences courses taught by laboratory personnel having joint appointments in departments of the college. These courses in the theory and application of instrumental analysis are in considerable demand from students from a large number of departments.

Before leaving the subject of the Mineral Constitution Laboratories I should like to emphasize that they operate successfully because they complement the other units of the college. Personnel and equipment operate for the good of all groups; and, perhaps even more important, there is no intent that these labs have a monopoly on the equipment. X-ray machines for example, once centralized in the labs are now found in many places throughout the college, serviced and supplied—if desired—by the Mineral Constitution Laboratories but used by and at the discretion of the professor in charge.

An interdisciplinary program of an entirely different nature grew directly out of the geochemistry program initiated at Penn State by Dr. Osborn in 1946. The development of high temperature-high pressure phase equilibrium research and instruction with attendant emphasis on mineral synthesis, identification and characterization led to the establishment in 1960 of this country's first graduate program to offer the M.S. and Ph.D. in Solid State Technology. Now, five years later, it is still the largest such program, with sixty-four graduate student majors and twenty-five participating professorial faculty with departmental appointments in Engineering Mechanics, Physics, Geochemistry, Electrical Engineering, Nuclear Engineering, Metallurgy, Ceramics, Fuel Technology and Mineralogy.

In this case the acceptance of the graduate curriculum preceded, by about three and one half years, the formal establishment of the Interdisciplinary Materials Research Laboratory as an all-university

research unit; and although many graduate students and faculty are common to both units, there is not a 1:1 correlation between them. Since Materials Research represents an interdisciplinary area which involves many earth scientists, I have included—as figure II—a chart of the activities of our group at Penn State. You will notice that our laboratory is particularly strong in those aspects of crystal synthesis and characterization "inherited" from the geochemistry background.

To give you a more comprehensive picture of intercollege graduate activities at Penn State today I have included figure III. Let me first make clear that there are all kinds of intercollege activities at the University that are not shown here: our nuclear reactor, for example, is operated by the Nuclear Engineering Department as an all-university facility. If an interdisciplinary unit can most logically be administered within the college structure, this is encouraged. The activities illustrated here are those which, in the opinion of the faculty involved, are most logically handled outside the college structure. Thus, the Institute for Science and Engineering is administered in the office of the Vice President for Research and consists of the eight research and graduate training groups shown on the right side of the diagram. The four interdisciplinary graduate programs on the left are in existence or in the process of being set up under the administrative responsibility of the Dean of the Graduate School. The laboratories have directors, and—with a few exceptions—faculty of professional rank have joint appointments in departments. Each interdisciplinary graduate curriculum is controlled by a faculty committee with a chairman who reports to the Dean of the Graduate School.

The close interrelationship between a number of these groups and Earth Science is obvious. To the geologist and mining engineer *air environment* involves the study of mine, quarry, and plant dust; to the mineralogist, problems of identification of small particles; to the meteorologist, concern about the source of nuclei for cloud formation; the palynologist, spores and pollen; the astrogeologist, welding beads versus micrometeorites. Our Center for Air Environment Studies brings to all of these—as well as to scientists in plant pathology, veterinary science, forestry, sociology, human behavior, etc.—modern facilities for small particle analysis, data retrieval in the general subject matter area, training grants for graduate students, and appropriate core courses in air ecology.

The *Ordnance Research Laboratory* is engaged primarily in U. S. Navy-sponsored research on torpedoes. All personnel are members of the Penn State staff and interact at all levels with their colleagues in the other units of the university. Largely because of this laboratory

Penn State has unusual strength in the area of acoustics and a graduate curriculum will be under way by next Fall. Interaction with people in the College of Mineral Industries is strong in areas of oceanography, meteorology and operations research.

The *Land and Water Resources Research Institute* serves as a final example. Here our geographers are working with sociologists, agricultural economists and others in problems of land utilization and the impact of highways on given areas. In conjunction with other groups in the social sciences and humanities a graduate program in regional planning is now being set up.

In the water resources area the links are self-evident and need not be dwelt upon here. You might be interested, however, in a particularly intriguing example of true interdisciplinariness found in our Waste Water Renovation and Conservation Program. Among the many things accounting for the international fame of State College, Pennsylvania, is the fact that one of the Commonwealth's best trout streams meanders past it and incidentally serves to remove its waste water. The effluent from the sewage plant, although completely safe and potable is so rich in chemicals (nitrogen and phosphorous from the detergents) that plant life in the stream grows vigorously thereby using up the oxygen with resultant destruction of the fish. To cut a long story short, an interdisciplinary group of geologists, agricultural engineers, civil engineers, foresters, zoologists, and agronomists have been engaged for three years in basic research on the scientific and economic merits of piping the effluent to an area of university woodland and farms where it is sprayed on crops and trees and allowed to return to the water table. A schematic diagram of the operation is illustrated in figure IV. The results are exciting. The soil does an effective and continuous job of removing the chemicals; plants and trees benefit tremendously; insect, animal and bird life flourish; and the naturally purified water is returned to the water table for reuse. I doubt that one could find a group of scientists who are more enthusiastic about the value of interdisciplinary research for themselves and their students.

From these examples and those on other campuses I think several things are evident:

1. Interdisciplinary graduate activities take all forms and exist in various states of formalization from "across the hall" communication to so-called research institutes.
2. Formally constituted interdisciplinary activities are going to steadily increase in size and number at our universities.
3. Associated problems (joint appointments, non-departmental courses, organization and administration) are being and will

be solved in a variety of ways at different universities, but

4. Many of these problems are lessened if university faculties and administrators remember that education is the primary function of the university and encourage the simultaneous development of research and graduate programs on our campuses. It is my personal belief that most of the so-called problems which we like to lay at the door of intercollege activities have arisen because of the difficulties in setting up appropriate and correctly administered interdisciplinary graduate programs to complement the booming interdisciplinary research activities.

What then of the impact of these increasingly numerous and strong interdisciplinary programs on Earth Science departments of the future? First of all I do not hold for a moment that the trend is for dismemberment or dispersion of our *disciplinary* activities. There will always be plenty of geology for geologists provided, of course, that we don't get too happy with ourselves, and "go to sleep at the switch." Nevertheless, as far as our students, our government, our industry and—let's face it—the formulators of our "Great Society" are concerned, interdisciplinary activities are a vital part of this nation's earth science program. If universities are to play their proper role, joint appointments of faculty should be encouraged, interdisciplinary courses and curricula involving the participation of earth scientists should be promoted, and finally the notion that proper funding for interdisciplinary research and graduate programs automatically endangers university standards and morale should be laid to rest once and for all. In my opinion any geology department head or faculty that either doesn't appreciate and actively encourage participation in these programs or, conversely, tries to take over the show by polarizing the interdisciplinary beam is not only operating to the long-range detriment of his own group but is retarding the progress of his science.

DISCUSSION

SIEVER—I would like to submit, Tom, that knowing the past history of the relationship between the Pennsylvania Geological Survey and the College, that in fact what you are describing here is largely the function of the State or, in this case, because it is almost large enough, a Federal Geological Survey. In other words, we are really talking, I think, about the applied research of a governmental research institution. It has been my understanding that for a number of years now there has been an agreement, formal or informal, that the Pennsylvania Survey must stick to field mapping and the like—essentially the applied work on resources, stratigraphy and related aspects; all laboratory research, work that is carried on in a good many other sur-

veys, has to be done by the State University. So I raise the question as to whether this is a proper function of the university. There is a discussion, after all, among university presidents like Clark Kerr that this is exactly what universities ought to be, this is what they are, and let's not fight it. There are still some old fogies, and I guess I must classify myself as one of them, who say that this is a job of a governmental applied research institution.

BATES—I couldn't agree with you more from the standpoint of the desirability of having a stronger survey and a stronger relationship between the Survey and Pennsylvania State. This is badly needed. I couldn't disagree with you more from the standpoint of the rest of your statement in that I have tried to stress that these are operations where we are engaged in the graduate training program of the students at the Pennsylvania State University. The research is being done when it relates to the solving of a particular problem, say in recycling water. It is perfectly qualified graduate research leading to graduate degrees. In the hydrological area the boys are working on fluid flow through porous media, for example. Survey organizations do not have the same opportunities as universities to train graduate students in programs where both basic and applied research are involved. We are using the basic research aspects of these programs as part of our training operation to turn out graduate students who will then be prepared to move into these areas that are developing all over the nation. I am not saying, however, that the Survey shouldn't do a lot of this and that we shouldn't work together on it. I am saying that the universities have a real responsibility from the standpoint of their graduate training program to have things like this going. The distinction between applied and basic should, of course, be made when thesis problems are selected.

NELSON—This is particularly the functions of land grant universities, is it not, as opposed to some other type of university.

BATES—I would agree that this function is obviously ours. This does not limit land-grant universities, however, to this type of program.

NELSON—. . . But were not the land-grant colleges founded with this particular sort of educational activity in mind?

BATES—That is right, and once again I would say the primary purpose is education and training. This includes, of course, a large number of non-graduate activities, continuing education, and so on. The research activities I have been speaking of, however, are designed primarily for graduate training purposes.

WASSERBURG—I always heard that things at Penn State were really confused and fouled up, and I am sorry to see that the information you have furnished proves this is true. This is a Topological University.

It is focused on lines connecting the Dean with other things. In spite of the distinguished researches that have been done at that institution by a large number of people, there doesn't seem to be a man-focused orientation. I think that as a scientist one would first think of who are the good people, and this plan seems to concentrate itself on the formal arrangements.

BATES—I admit that people are confused by our organization. It is unusual. I am presenting you with an organization chart not a list of people. There are many good people that happen to be related to this particular organization. I see many advantages in our organizational arrangement but, of course, I have had a lot of time to get used to it. As I pointed out the other day, the Mineral Industries College is, in itself, an interdisciplinary operation.

GOLDBERG—How many students do you have and how many faculty members? I see twenty-three kingdoms here, how many total faculty do you have?

BATES—I would guess about two hundred or so.

GOLDBERG—Two hundred faculty members.

BATES—Yes, faculty in the College of Mineral Industries. This is an approximation since I do not have the latest figures. I should point out that the organization shown on this chart (which is the latest available) has been changed. For example, Geochemistry and Mineralogy now constitute a single department as do Geology and Geophysics. In the department of Geology and Geophysics we have about twenty-five professorial people with about the same number in Geochemistry and Mineralogy. Of the other departments; some are larger, some smaller; some are stronger, some weaker.

GOLDBERG—How about the student, what is the total student population, say graduate and undergraduates, a number for each.

BATES—I don't think I can give you that.

OSBORN—Graduates about two hundred and fifty, undergraduates around five hundred. Just the way Cal Tech was when I was there about thirty years ago.

BATES—At the undergraduate level we have one common curriculum for the geology, mineralogy, geophysics, and geochemistry students. As an average in my sophomore mineralogy class I used to have about thirty-five majors before I recently stopped teaching it. The class diminishes in numbers before the end of the four years, but that's about what we start out with.

WEAVER—Would someone care to comment on the disadvantages of interdisciplinary programs?

FREDERICKSON—One thing is perfectly clear for anyone that has tried to develop a program. There is no one pattern that need necessarily

be good for anyone else. Local situations are different and are changing so fast it is hard to keep up with them. It is not a question of desirability in the interdisciplinary programs. You are just able to develop those interdisciplinary programs for which you have interested staff or people in other Departments.

ESCHMAN—I would simply argue, too, that at a lot of places, for example at Michigan, many of the interdisciplinary programs are not really programs as such. They are programs designed around a single individual and the nature of the program is determined by the five, six or seven men who he has on his committee. We don't even go in for joint appointments because the administration has for years frowned upon it. This doesn't mean that Bill Benningnoff in Botany and I don't teach a course together. Until recently it was cross listed, called Botany 826 on one page in the Time Schedule and Geology 826 on another page, but even this has gone out the window now as we are all tied to an IBM Time Schedule. The fact still remains there are a lot of interdisciplinary courses and interdisciplinary programs. At Michigan they are largely designed around the individual and are not set up with a formal committee, etc. We would argue that this scheme allows for greater flexibility.

FREDERICKSON—The good thing about some of these programs is that a variety of programs can be set up without the need of adding extra or new staff or establishing a special administrative framework that requires special approvals and is difficult to change after the student graduates, and you wish to make entirely different arrangements for a new student with different interests and background.

ESCHMAN—Yes, as you graduate the man, you get rid of his committee and the interdisciplinary program.

BUSINGER—Do you design, then, special courses for each student?

ESCHMAN—In a sense you do in that you always have the old catch-all of "investigation," or special course, individual work, or whatever else it might be, if this isn't a special course designed for a particular person, I don't know what is.

WEAVER—I am curious as to where you draw the dividing line in what you call interdisciplinary. By the time you take the undergraduate geology curriculum and cut it down to a core of four or five courses this seems pretty interdisciplinary to me. The students are taking more chemistry courses than they are geology and perhaps more physics and math. Isn't this an interdisciplinary program?

BATES—In presenting you with information on a group of well-established, active interdisciplinary programs, I don't what to leave the impression that all the problems are settled. This is a very live subject. If I gave you the impression that everything was "pat" here, please

erase it because such is not the case. They had a very good conference at the University of Michigan a couple of years ago on interdisciplinary research activities and the problems of joint appointments and so on. There are a lot of people worried about this and many universities are concerned as to how to handle these operations. Any suggestions that you people have arising from your own experience are more than welcome. We certainly don't think we have the answers to all the secrets here.

WASSERBURG—Some of these come back to a commitment that I think Ray referred to before which doesn't have anything to do in a normal direct way with university functions. That is the problem of the universities expanding to maintain research facilities which are really of community, state or national level of interest.

BATES—They don't unless the people involved are using this type of program as one means of realizing some of the purposes for which universities are set up and function. That example that I gave of the Waste Water Renovation and Conservation Program is founded on this thesis.

WASSERBURG—We have exactly the same thing at our institution but these now depend upon a single man. Namely a man who happens to be in sanitary engineering who is interested in this very important problem. He is doing this but this has nothing to do with the institutional idea. The formation of institutes seems to, if anything, polarize the set up and create a confusion of empires. So that, for example, you are at the point where you now have the department of petroleum, natural gas, etc, etc, etc.

OSBORN—What counts is what works. It has been working pretty well.

BATES—I would like to speak on your point, Jerry. If we had left this water operation to our civil engineers or to any single discipline, we wouldn't be on first base from the standpoint of a true, all-university operation. I can't find a more enthusiastic group from the standpoint of people working with one another and getting acquainted with other disciplines that operate near their area.

ESCHMAN—I would say in defense of this, what Tom has presented here, that I think few of us are faced with the problem of having a faculty of two hundred individuals. Any time a certain number is exceeded the staff begins to fragment in one way or another. I would guess that if you have a staff of much over twenty or twenty-five it is hard to handle, to keep working together as a unit. I think more of us aren't faced with this sort of situation.

BATES—In my personal opinion, it was a good deal better when we had separate graduate departments in mineralogy, geology, geochem-

istry, geophysics but it was decided to merge them into two departments. I think twenty-five professional faculty is about the largest number a department head can easily handle without having an assistant department head and so on down the line.

OSBORN—Also, if I can just speak for a moment, the universities differ so in major structure, Jerry,—Cal Tech is just unique. Name another one like Cal Tech. There are quite a few universities like Penn State that have very strong college structures—a very strong college of agriculture, a very strong college of engineering, etc. These colleges can administer certain programs well and can even handle some intercollege programs, but in general a program which the faculty would like to have operate across college lines just runs into one helluva lot of trouble with the Deans. You haven't experienced this, Jerry. I didn't till I went to Penn State but now I see it across the country at state universities—well I won't go into it, it would take all afternoon; so this administrative organization was set up pretty much in desperation in order to handle the intercollege programs that couldn't be handled otherwise. We have intercollege programs administered other ways, and very satisfactorily. Our ionosphere research lab, for example, is administered by the electrical engineering people with whom the physicists cooperate. It just happens that the head of electrical engineering is also director of the ionosphere lab and he happily is a physicist. This is a good arrangement as far as the ionosphere lab administration is concerned. But as Tom says, we are just experimenting. We can cancel one of these out tomorrow, all we have to do is do it, but in the meantime it has been working pretty well.

HUNT—I just have one question. When you do get these college organizations with a very strong structure you run into another problem that hasn't been mentioned, especially when you talk about interdisciplinary problems between colleges, between departments, between institutes, and that is that naturally when you set up a large number of committees and other types of groups to handle some of these problems and you find that all of a sudden you increase greatly the administrative duties of the faculty. I just wondered, I am addressing this to you, Ozzie, to what extent have administrative duties of the faculty, non-research, changed over the last, say, several months.

OSBORN—There are two different things: One is an interdisciplinary Ph.D. program. The other is an intercollege laboratory, center or institute. Each of the former requires a committee. There aren't many of the intercollege Ph.D. programs. I think Tom mentioned four. The intercollege research operations do not add much in the way of additional committee work.

HUNT—In other words there are no communications problems here.
OSBORN—Well, I would say that we aren't wasting a lot of people's time meeting to talk about it. Whereas you have to if you have students in a graduate program. These are two different things, one is a facility whose operation is to be managed and the other is the program of courses that a student takes—the examinations and so on.

CHANGES IN GEOPHYSICS EDUCATION

By George W. Wetherill, University of California

WETHERILL—The title here is Changes in Geophysics Education. I don't know that I know anything about *changes* in geophysics education but quite a few of the things I thought I might say, I am sure have already been quite well covered. I would just like to make a few remarks about geophysics education and most of the things I would say about geophysics could apply equally well to geochemistry. First of all, I think what has traditionally been considered geochemistry and geophysics differs in many ways from what has been called geology in that there really has not been a classical discipline to break away from. Nor do I actually think geochemistry or geophysics are truly interdisciplinary, although we commonly use this word in talking to the administration. As in geology, people working in these fields, are trying to understand things about the Earth rather than the nature of matter which is the subject matter of physics and chemistry. Because of this fundamental similarity, I think it is more nearly correct to say that geophysics, geochemistry and geology are all the same thing, and that it is largely for reasons of expediency that one distinguishes between them. However, it is quite important sometimes to make this distinction for reasons of expediency and one of the ways in which this comes up is in connection with the recruitment and admission of students.

Consider many of the areas which have traditionally been placed in the realm of geophysics, say, Seismology, Geodesy, Geomagnetism, etc. In order for progress to be made on these problems it is necessary for students to have not merely a "good background" in physics or analogous problems in geochemistry but to actually be a physicist or a chemist. For this reason the type of product we heard about last night who will be coming from the undergraduate schools in geology is not simply what we will have to put up with. In fact it just would make no sense whatsoever to consider such people in a graduate program in geophysics or geochemistry. Insofar as people do come from undergraduate departments of geology with more appropriate training,

these actually could in some cases be used to become future geochemists and geophysicists. Of course, we should look at all the applications and bear this in mind in every case, but if we really wanted to get practical about it, we have to recognize that very few of these people could really undertake graduate work in these fields and hope to successfully complete it in the space of a few years. In addition we need people who actually have bachelor degrees in physics and in chemistry and our job is to do all we can to make them into Earth Scientists in the process of their graduate work. We have to recognize they will never be complete Earth Scientists as also those who have come through geology programs never become complete Earth Scientists.

This recruiting of "outside talent" can be made at many levels. At the high school level one might simply forget about what I have just said, about people having had actual training in physics and chemistry, but rather emphasize the intellectual qualities which commonly accompany those students that go into the other sciences, namely having analytical minds. If we look at high school students we see that over the past decade those students that have been especially good students in science in high school have normally been advised by their teachers, their counselors, their parents, and their associates to go into sciences which have commonly been thought to be more demanding, namely physics to a large extent, to a lesser extent mathematics and chemistry and more and more all the time now, biology. In the last ten years, or probably longer than this, geology would certainly not have been included in this list. I think there is quite a bit to be done on this level which has not yet been done. In some ways these students who normally would have gone into physics will still have to become physicists, in order to be geophysicists, however, the Earth Scientists might be able to throw their arms around them as undergraduates and try to keep them in the fold during this time.

The area in which most work has been done and I think that in which a certain amount of success has been achieved is that of recruiting students who have bachelor's degrees or master's degrees in physics and chemistry and at this point getting them into graduate study in geophysics and geochemistry. I would say that counting our total effort in the Earth Sciences at U.C.L.A. (including our interdepartmental program in geophysics and geochemistry and the geology department) something like one half of the new graduate students in the last two or three years have actually had their undergraduate training in physics, these largely being in the geophysics interdepartmental curriculum. These people have been attracted to this curric-

ulum by the lure of "space science." It remains to be seen what these people actually end up doing, since I am not really sure that there is such a thing as space science but rather it is simply a new name to cover some very important problems of Earth Science and Planetary Science. I think there are probably other ways which one could obtain students other than through the fashionability of space science, but I don't think that enough effort has been devoted to this to really know what might be successful and what might be unsuccessful. In any case I think there certainly is a great reserve of talent receiving B.S. degrees in the physics departments. There are more students applying to the good graduate schools in physics than there is room for and I don't think one needs really be pessimistic about the opportunities for obtaining these people in geophysics curricula, if sufficient effort is made to attain them, but, of course, this requires quite a bit of work. I think one may have to take advantage of undesirable motives. For example, a lot of the physicists who have gone into Earth Science in the past have done so under the supposition that this must be an easy field in which to make contributions because the people who are already in it are so incompetent that almost anything a physicist would do is probably better than what has already been done. I think this has been the motivation of a great many physicists who have gone into the Earth Sciences and who have had quite successful careers. Many are motivated more by arrogance than by understanding and you can still see this in some of the students coming into the space science program. We just have to accept this and recognize that many of these people entering the Earth Sciences in the past with such attitudes have nonetheless made very definite contributions.

Beyond the level of graduate school you have the very important matter of obtaining in the Earth Sciences, people who already have professional status, who already have their Ph.D.'s and in some cases have completed some amount of post-doctoral work in these other physical sciences. I have sat on several Ph.D. exams for students in the Physics Department receiving degrees for research in solid state physics, and I have been quite impressed that many of these young men who have done research in solid state physics have a much deeper understanding of solid state physics than anyone that I know of in the Earth Sciences, including those who are doing research in solid state physics of the earth. These are not particularly distinguished students, and they'll go off to work for Bell Labs and may well never be heard of again. I don't think we need very many of them but I think that a few of these people, properly or improperly motivated to work in Earth Sciences, might well do quite revolutionary things,

things which will be qualitatively distinct from things which have already been done and are being done. I don't think we need fear too much the naiveté of these people. I think there are enough people with more conventional backgrounds in the Earth Sciences to keep them from going too far astray. I think we must recognize that such "untrained" people entering the Earth Sciences have in the past, and probably will in the future, be the true avant-garde of the Earth Sciences in distinction to the view held by many Geology Departments, that people who are doing work that was done in the Geophysical Lab in 1920 constitute the avant-garde. I think we must attract these people from physics, chemistry, astronomy, and astrophysics, accept their naiveté and lack of understanding of earth problems, and expect that their new insights and new methods will result in contributions which, imperfect as they may be, will be picked up in more sophisticated form by their students and soon developed into important areas of research.

I've just had these few comments to make with regard to the ways in which geophysics and geochemistry may differ from geology, but I think that the division is by no means clear and many of the things I've said about geophysics and geochemistry will apply to areas which have been more traditionally regarded as geology and certainly areas such as mineralogy and crystallography.

DISCUSSION

WEIMER—I have a question.

WETHERILL—Yes.

WEIMER—When you receive students out of an undergraduate physics curriculum, what type of background do you require the students to take in the area of geology in the graduate program?

WETHERILL—I thought of saying a little bit about our organization, but it was such that I could not pass out our organization charts as others have done here because I would have to be able to make a diagram in which various units were sub-units of one another and other geometrical impossibilities. Our organization scheme is rather chaotic at the present time, and it is not possible to pass out neat orderly charts. This makes it hard to give a simple answer to your question. If a student decided to go into space science, I would say it is very likely that he might well have almost no geological training whatsoever unless he was determined to obtain such training. On the other hand, if his orientation was more toward solid earth problems, including this earth, it is likely that he would be required to have some (little or much) geological training. The programs are flexible and

individual students are treated on an individual basis. I'm not saying this is the most desirable way to do things. However, things (scientifically as much as administratively) are in such a state of flux at the present time that this may be the best we can do.

GOLDSMITH—Are degrees still granted only by the department or are they given by—

WETHERILL—We have several ways of getting degrees. We have departments of Geology. We have an interdisciplinary curriculum which gives degrees in Geophysics. We have an interdisciplinary curriculum in Geochemistry. We'll probably have a new department in planetary and space physics, which may supercede the geophysics interdepartmental curriculum. We have joint appointments linking all of these organizations together. We have Institutes and we also have a Space Science Center which as far as I can see is a part of the Institute of Geophysics, but the Institute of Geophysics is in some sense a subunit of it, since the Space Science Center also includes Engineering and Biology.

GOLDSMITH—What you really have is a four-dimensional sort of thing?

WETHERILL—Yes, it's probably multi-dimensional. And I don't think it's really worthwhile to discuss this in detail, because I think we are in a non-equilibrium state and perhaps in a few years these things will be more understandable to outsiders.

WASSERBURG—Our program is very simple, we don't have a great complicated organization. There is just a division of earth science. When it works, it's great, when it doesn't, it's lousy. For all entering students in the earth sciences, if they have degrees in physics or chemistry, whether they are interested in astrology, geology or any of the other fields, physics or chemistry, we have made up a special course on the graduate level which is essentially elementary geology plus requirements that they take a field course in this and then fill in whatever gaps they have. Some of them have taken our sophomore mineralogy courses, and this applies across the board to whatever their interest—providing a minimal uniform background. They have had a full quarter of review of petrology which consists of a variety of subjects mixed together to provide a broad basis of understanding so that they can recognize what the scientific problems are. Those student who are particularly talented are permitted to take advanced level courses which, in some cases, requires a fair amount of mathematical proficiency. The course is then modified so that these students can come to grips with fundamental problems which utilize their natural proficiencies as a means of learning and understanding Earth Sciences.

OSBORN—I think Wetherill's situation is kind of enviable in a way

because things are changing fast and his operation seems to be in an amorphous state.

WETHERILL—It's extremely amorphous.

OSBORN—You can crystallize in the direction that's needed. I think there are great possibilities in this situation.

GOLDSMITH—There's a difference between crystallizing and petrifying.

WEAVER—Jerry, did you mean to say that you have a special course for transferring physicists or several special courses?

WASSERBURG—No, we've made up one special course since we have a large number of students whose undergraduate training is in physics —the question is, what can we do with them? We decided on the elementary geology course and they were given a series of courses that would indoctrinate them at a modest level with fundamentals of geology. Then last year we used some of the existing courses, like thermodynamics of geologic systems. There were two geologists in it, the rest were physicists and chemists. The course leaned very heavily toward presenting and formulating earth science problems which were thermodynamic or heat-flow problems. These guys could handle the theoretical parts of it and never recognize the geologic problem. So the courses were just used as a vehicle to expand the students' understanding of the earth science field.

WETHERILL—Your space science students—

WASSERBURG—There aren't any space scientists, they may take a degree in this; we're just a plain and simple Department of Geology in which there are all sorts of professors and characters around in abundance. Whether they be geophysicists or geochemists or, I don't know, whatever you want to call them.

GOLDSMITH—Well, we have essentially the same thing in the sense of a single course and, of course, in a way it's even more complex, Jerry. In our case the atmospheric science comes into it—though again under the agency of a single department. Maybe there's a new distinction between private and state universities that has to do with the complexity of the organizations—

OSBORN—I think that Princeton, Harvard, Yale and Brown are quite similar and represent one type. The big state universities, especially those which are also the land grant colleges are another distinct type. Ohio State, Illinois, Minnesota and Penn State are representatives. They all have similar problems. I think one thing this discussion brings out is the fact that we organize differently to do a job at these different types of universities; and then there's the type of which we have heard quite a bit, the small university or college with little or no graduate work; and they're very important in the country. I think some of their problems are very different from those of the schools

just mentioned.

WETHERILL—I think some of the problems arise from the necessity of raising funds in order to do necessary things and sometimes this can be done only by the establishment of some kind of structure that has a new name to it and getting support for this. I think many of the complexities arise from the need to raise funds, which places an additional constraint on the system and does not necessarily lead to what would be the simplest way of doing things.

GOLDSMITH—This is very true. The best example of this I know has been picked up by a great many schools. When DOD came out with the magic word, material sciences, a great many schools began to get into the act of forming separate departments of material science.

OSBORN—Well, what happened was that they underwrote eight universities, and later three or four more on a smaller scale. None of the eight was a state university. They were Stanford, Brown, Chicago, Northwestern, Cornell, University of Pennsylvania, Harvard, and M. I. T., I believe.

GOLDSMITH—That's correct, Ozzie, and I know this very well because we insisted on a quite different arrangement and I'm not sure you were aware of what was done in Chicago with the material sciences. The money that came to the University of Chicago was not expended on a building, nor the creation of a department, but it was put across the board in the division to support those men, irrespective of their department, who are doing what I have to call material sciences.

OSBORN—There are others like Northwestern that now have a Department of Materials Science established, in connection with the program underwritten by D.O.D. I think that the only way to do some of these jobs is to create another organization, at least for a while. Now take the University of Hawaii, for example. I don't know when this university would have gotten on the ball to do some of the research I think it is now going to do, were it not for the creation of its Institute of Geophysics.

WASSERBURG—They created this institute first, NSF raised the money for the building and they finally got worried, but I don't see how the university would have ever moved without it. Don't you agree with that, Bill?

BENSON—I can't remember what I was answering here. It must refer to Hawaii, but I don't know if my rewrite makes sense. I like to think that it might have been done within the existing departmental structure, but in this case, the department simply wasn't active enough. The creation of that institute, just on paper, was quite a forward step, and resulted in progress long before they got the building.

OSBORN—I suspect that U.C.L.A. would have never gotten into its geophysics research if it hadn't been for establishment of their Institute for Geophysics, isn't that right?

GOLDSMITH—I agree with you that we have had to create organizations in order to circumvent certain existing organizations which people didn't like. It is as simple as that.

OSBORN—Well, the departmental organization as set up just wouldn't and couldn't move, it was as simple as that.

WETHERILL—The Institute of Geophysics is a complex structure and it is becoming much more involved in the teaching activities . . . the whole thing is in a complete state of flux and I didn't mean to present the way we are doing things at U.C.L.A. as necessarily the best way of doing them, but I just meant to say some general things about opportunities for obtaining good people to work in the Earth Sciences.

OSBORN—But the question is, I think, how do you do it? And I think at U.C.L.A. that was one way of doing it and I don't think there was any other way, actually.

WETHERILL—That may be, but there must be a simpler way of doing it, which we may be able to find in the future.

WASSERBURG—Many graduate schools tend to perpetuate organizational structure, for two years we have had committee meetings and when I try to get up a motion to dissolve, it is invariably overriden.

OSBORN—But in the meantime they are doing a job . . .

WASSERBURG—No, they are not doing a job. All they are doing is perpetuating themselves.

OSBORN—Well, what is wrong with good research and good graduate work perpetuating itself?

WASSERBURG—The thing that makes the complexity is the separation of the pedagogical and research responsibilities. If we continue on this path, we can get to something which looks a little bit like the modern European institute structure, with the teacher at the apex of the inverted pyramid, the institutes lack this feedback in responsibility for teaching purposes. The question is whether the only way to make a step forward is to found separate institutes and then let them build themselves up and then later to drag them back into the fold of a departmental structure rather than continue as a separate set up. The establishment of these institutes creates power structures that make the problem of assimilation at a later time exceedingly difficult.

OSBORN—Well, the point is that it is doing a job . . . take Lamont for example. Well, this Lamont Lab is really moving. I think it is one of the more reworkable geological developments in this country. And now as a matter of fact with the difficulties that the Geology Department is having, Lamont Lab is going to save the department.

WASSERBURG—I think a lot of the difficulties you mentioned might be on campus.
OSBORN—It is an amazing thing that Lamont Lab works, but it does.
GOLDSMITH—This problem is much greater in the case of astronomy than is the case of anything like our area. The astronomical observatories, as Jerry brought up, from Cal Tech . . . this situation has been found all over in all major astronomy departments and it has been terrible as far as students have been concerned.
OSBORN—But how else do you do it?
GOLDSMITH—Well, there is a move underfoot now if not to nationalize the labs to at least centralize certain major facilities and move the astronomers, right on to the campus. I think it is going to have to be done. Essentially all the astronomers come from physics departments and you have to have physicists in contact with the astronomy faculty.
OSBORN—Well, all I am saying is that I think that these places that are having great problems with organization are having them because they have made moves that are important and very productive and that's why I kind of defend them. I know it is an awful mess out there but at least there is action. I know universities where they haven't had any problems, that that's because they haven't done anything.
GOLDSMITH—Well, that is a most important point. Most universities don't have any problems, haven't done anything, and that can be said several times!

I think that joint appointments and interdepartmental relationships haven't been as troublesome as one may imagine, but as I have pointed out, the administrative structure is such that you can't really explain it to the dean.
OSBORN—Well, I think some of these experiments are really wonderful to watch, and they are doing a lot of good. How in the devil can you build a university starting with an oceanographic lab? But it's happening at LaJolla.
GOLDBERG—Institutes can pose many unpleasant problems. Consider the following situation. One man, distinguished in his field, has a facility for getting money. He decides he is going to have an institute. The reasons to establish an institute include control over funds, and over appointments. He builds himself up a tremendous empire in a very short time and gradually divorces himself from students and from obligations and responsibilities to his fellow faculty members. The problems that an institute creates in a university system today can be far greater than the rewards from such institutions.
OSBORN—Well, I wouldn't say that is true of the Institute of Geophysics at the University of California at Los Angeles.
BATES—I think this is part of the problem. The Institute of Science

and Engineering is simply an "umbrella" that Dr. Osborn holds in his office over some of the intercollege operations. We are not talking about a building with columns in front of it being operated in the classical German tradition. The word "institute" can have many connotations. There was much discussion as to what to call this particular operation.

GOLDBERG—Let me get back to the point of Jerry's. Once you have established the administrative structure, it is near impossible to erase it. And let me point out one further important fact. The Institute of Geophysics is essentially the nucleus for the formation of a department, is that right?

WETHERILL—More or less—it could conceivably turn out that way, but there is no definite plan of that kind.

GOLDBERG—So then you gain two organizations from one because the University of California rules that institutes cannot offer courses for credit.

The point I am trying to make is that the institute is a multiplication of an organization within the university. I think we should minimize such expansions as much as possible.

BUSINGER—The President of the University of Washington agrees with you. They are not called institutes, they are called committees or groups, but they're the same thing.

GOLDSMITH—Well, I think the distinction is whether the institute can be a degree granting body or not, that's why I brought up the question. Institutes, as many as there have been, and I speak from long experience—the University of Chicago, I think, was the first university to set up an institute—the Oriental Institute, many years ago—but the point is that if you had institutes free from pedagogical activities, as somebody poined out, and cannot grant degrees, this type of institute can become a very evil thing.

The Hawaiian Institute doesn't qualify there. This was a device set up to bridge some departments, and the appointments in that institute, even the director, are joint appointments, even some of the subsequent departments. This was an umbrella type of thing . . .

OSBORN—I think it is important for the people in the institute to have department appointments.

NAFE—At Lamont we are not separated from the Department of Geology except physically and to some extent administratively. We share staff and we have graduate students who are registered in the Department.

WEAVER—Our last speaker will be John Moss who will discuss the "small college" viewpoint.

THE SMALL COLLEGE AND GRADUATE EDUCATION

By John H. Moss, Franklin and Marshall College, Lancaster, Penn.

It is indeed a challenge to be the last speaker on this program—in fact, the fourteenth speaker on a twelve-man program.

I am not sure there is anything left to say; on the other hand, it may give me the last word on some of the matters we have been discussing and a chance to make a final summary of a few points in which I am particularly interested.

Being an undergraduate teacher and probably a good example of that "middle-aged clod" described by O. T. Hayward last night, I am not sure I should be on the program. However, a number of speakers have referred to the fact that some of the difficulties in graduate education stem from weaknesses in undergraduate education. Therefore, maybe I should begin with a few comments about undergraduate geology at small colleges and then move on to the question of what these colleges can and cannot do in the graduate education field.

Dr. Wasserburg has stressed his concern with the inadequate scientific preparation of prospective graduate students in geology and geophysics. This is a serious problem. Of equal concern to me, however, is the problem of numbers—or lack of numbers—in undergraduate geology programs. Where are the graduate students of the future going to come from? We cannot rely entirely on capturing physicists as Cal Tech has so successfully done.

Dr. Robert Shrock, in a speech to the National Association of Geology Teachers meeting in Miami this fall, pointed out that we now produce about two hundred and fifty Earth Science Ph.D.'s per year. By 1980, he prophesied that we would need at least three hundred and fifty to four hundred and fifty per year. Since these candidates will probably have to come largely from undergraduate geology programs, let us look at the present output of undergraduate majors.

What size institutions produce undergraduate geology majors today? According to figures collected by AGI, there are two hundred and seventy-one geoscience departments in the country. Seventy-

eight percent of the undergraduate geology majors are enrolled in larger institutions—those with enrollments greater than three thousand; twenty-two percent in smaller institutions, those with enrollments less than three thousand.

What has been the trend of these enrollments in the last six years? The simple answer is: a startling drop. In 1958, there were thirty-six hundred Junior and Senior geology majors; in 1964, the number had fallen to under seventeen hundred. Even worse, last year there were more students enrolled in Ph.D. programs than graduating as seniors. Yet, according to Dr. Shrock's figures, only about one out of ten graduating seniors achieves the Ph.D.

Furthermore, fifty-five percent of the institutions offering geology have fewer than five Seniors—hardly a critical mass—and twenty-four, or nine percent, have none. Only forty-eight, or about eighteen percent, have over ten which is needed for maximum mutual intellectual stimulation.

At what size institutions are the largest groups of Junior and Senior majors? They are at the larger institutions, but not, with the exception of Wisconsin and Stanford, at the institutions which produce the largest numbers of Ph.D.'s.

Lest this measure of success seem unfair to the principal Ph.D.-granting institutions, maybe we should look at an indicator of quality rather than size in undergraduate education. Let us look, for example, at which institutions produced the sixteen first-year NSF Graduate School Fellowship winners last year. They are as follows:

California Institute of Technology	*2*
Franklin and Marshall	*2*
Southern Methodist	*2*
Stanford	*2*
Carleton	*1*
CCNY	*1*
Harvard	*1*
Lehigh	*1*
Michigan Tech	*1*
Penn State	*1*
Washington	*1*
Wisconsin	*1*

Our concern, however, is more with the fate of small college departments. They, too, with a few exceptions, have suffered the same decline in enrollment as larger institutions.

The problem in undergraduate education thus is two-fold: first, the problem of finding more undergraduates and secondly, the question of what can be done to prepare the best of these undergraduates

better for Ph.D. work. The second question is central to this conference.

Can the small liberal arts colleges help?

Their big problem is TIME, time in the curriculum for a student to take all the courses he has to take, should take, and wants to take.

My thesis is that to obtain this time for more basic education before embarking on a Ph.D. program, fifth-year programs, or two-year Masters programs should be revived. At Franklin and Marshall, we are trying to raise money to experiment with this idea at the present time.

Small colleges have special attributes—some good, some not so good.

First, the undergraduate program is the center of faculty attention, and there is only one faculty which simplifies the operation to some extent. Secondly, there is great emphasis on teaching and less emphasis on published research. Thirdly, the faculty provides a great deal of individual attention to students. Class units are small and, in addition, much teaching takes place outside of class. Fourthly, considerable importance is placed on liberal arts and breadth of undergraduate education. It is held strongly that future scientists should be exposed to literature, history, foreign language and fine arts. A fifth characteristic is the high percentage that go on to graduate school. Since 1950, when Franklin and Marshall first began graduating students in considerable numbers, we have graduated one hundred and sixty-one students. Of these, twenty-three have already received their Ph.D.'s and eighteen more have passed the Master's level on the way to the Ph.D. In other words, about twenty-five percent will probably end up with the Doctorate. Colleges like Carleton, Pomona, Augustana, and Williams probably have comparable records. A sixth attribute of small colleges is that increasingly they are becoming staffed by faculty members capable of teaching in graduate schools—which makes them vulnerable to raiding operations by larger institutions.

On the dark side, the small colleges often do not get as able a group of students as top-flight large schools. However, this is not fatal. I remember the Chairman of a leading graduate school extolling the prowess of one of our graduates who had done outstanding Ph.D. work. On checking his college board scores when he entered Franklin and Marshall, I was surprised to see that they were five hundred and ten and five hundred and twelve.

Another obstacle is that many small colleges are poor and have weaker facilities than universities.

Some very kind remarks have been made about our undergraduate geology program at Franklin and Marshall, and since under-

graduate preparation seems to be pertinent to a discussion of graduate programs, I might list a few factors which I believe have been very important in whatever success we have achieved. To begin with, I might say that Franklin and Marshall is a college of fifteen hundred men with about forty geology majors in the Sophomore, Junior, and Senior classes. We have a six-man staff, all Ph.D.'s, one of whom each year is recharging his intellectual batteries at graduate school or working full time on research.

The aim of our program is to provide basic training for three types of individuals: those who will be frontier theory men, those whose interests lie in practical geology, and lastly a small group who wish to be school earth science teachers.

One goal we strive for is to build the student's interest in geological problems—by which we can strengthen his motivation which is all-important. Secondly, our program is heavily field oriented. Virtually every course contains field work and we have a capstone senior field thesis course in addition. Thirdly, we have been able to pull together a staff which is willing to put in interminable hours with the students. Most students perform better if they feel that the faculty is personally interested in them and wants them to succeed. Another characteristic is the large amount of faculty research which the students see going on around them and can participate in. Thanks to the National Science Foundation, we have received a series of undergraduate research programs. Further, we are well located to have visiting geologists stop in to talk to the staff and students. Over thirty did so last year, from which the students were able to gain a remarkable introduction to geological problems under study in many fields of geology. We have also had visitors from universities give courses at Franklin and Marshall. Ten staff members from Lamont journeyed to the campus to give a course in Oceanography in 1963 and last year ten other distinguished visitors lectured in our geomorphology course. We are also near enough to Princeton, Bryn Mawr, and Johns Hopkins so that the staff can attend seminars and lectures at these institutions. Lastly, we devote a lot of time and effort trying to find prospective geology students in secondary schools. The new Earth Science courses are producing an important reservoir that we are trying to tap.

Our geology curriculum, see Figure 1, is made up of two parts: a core of geology and allied science courses and a number of electives. Next year, we plan to urge as many of those going on to graduate school as possible into physical chemistry.

Figure 1.
GEOLOGY MAJOR CURRICULUM AT FRANKLIN AND MARSHALL

Geology Core	Semester Course	Electives
Elementary Physical and Historical Geology	2	Advanced Mineralogy Geomorphology
Mineralogy-Optical Mineralogy-Petrology Sequence	2	Quantitative Geology
Structural Geology	1	Geologic Problems
Sedimentology-Paleontology-Stratigraphy Sequence	2	Tectonics Oceanography
Field Geology and Seminar	2	Geochemistry Pleistocene Geology

ALLIED SCIENCES

Mathetmatics through integral calculus	(3)
Chemistry	(2)
Physics	(2)

We believe it important for a student to have the opportunity to take one geology course each semester to build his interest in the field. Into these courses, we are trying to work an increasing amount of mathematics, chemistry, and physics where appropriate. Courses given by other science departments do not always fill the bill for geology students. Dr. Kauffman is pioneering a course in "Quantitative Geology" in which he has pulled together ideas on the application of mathematics in a number of different branches of geology.

Despite the best efforts in the undergraduate realm, I can sympathize with the graduate schools who feel that they are not getting well-enough prepared Ph.D. students. For this reason, we believe that strong Master's degree programs should be revived to provide students with additional course work before they undertake the rigors of a Ph.D. program.

Dr. Harry Hess has pointed out to us that Princeton each year has to turn down a number of extremely bright students who do not have the background to undertake Ph.D. work. Some of these students of high potential who may come from one, two, or three-man departments slip away from geology. Another group which does not always find a home in a Ph.D. program are mathematics, chemistry, and physics majors who late in their undergraduate careers decide they want to do graduate work in geology. The individual attention found in a small college may well be the best environment in which they can learn geology. A third group are foreign students, most of whom can profit by strengthening in a "parking orbit" before shooting on toward a Ph.D.

Dr. Hess makes another point, namely that if qualified institutions could be found to take over the first-year of graduate work, the Ph.D. granting institutions could turn out more Doctorates. In Princeton's case, it presently takes on the average three and eight-tenths years to earn the Doctorate. If this could be cut to two and eight-tenths years of residence, Princeton could increase its Ph.D. output in geology by around twenty-five percent.

In exploring Dr. Hess's suggestion, we surveyed the present status of Master's degree programs rather carefully. In many cases, it is a dismal picture. At many institutions, the Master's degree is a consolation prize for those not achieving the Ph.D. Generally, graduate faculties are more interested in the Doctoral candidates, and Master's candidates get too little attention. At some smaller institutions attempting Master's degree programs, there are too few faculty members and inadequate facilities. Also, many of these programs are poorly conceived trying to be all things to all men. And lastly, very little effort is being made by institutions to "beat the bushes" to attract strong candidates to their programs.

Franklin and Marshall would like to establish a small program of six to eight students, centered around the idea of flexibility in course program to meet the individual needs of the three types of students mentioned above. We hope that the majority of the students will continue into Doctoral work. We plan to emphasize independent work and the preparation of a thesis and hope to provide the close association between students and faculty that we have established in the undergraduate program. Despite the low esteem in which many Master's degree programs are held, it is our goal to develop a degree with stature. To help us in this effort, the Princeton Geology Department is working cooperatively with us.

We anticipate two by-products from this new program: (1) a better chance to hold our staff; and (2) the further stimulation of our undergraduate program through the presence of a few graduate students in our department. Most important of all, however, we would like to demonstrate that a certain type of Master's degree program, if operated well, can help to solve the problem of supplying better-prepared students to Ph.D. programs.

DISCUSSION

WASSERBURG—Irrespective of how long a student is trained, he is going to spend the same length of time there . . . I didn't mean to imply this was a crack at small schools—this is a crack at Princeton. Irrespective of how long a guy is trained, he will need the same length

of time there.

MOSS—Now, but couldn't the first year of graduate training be done somewhere else, or would you prefer it all be done at your institution, Ozzie?

OSBORN—Northwestern became quite famous for that. Many of us went there for a Master's degree and then went elsewhere for a Ph.D. The work at Northwestern saved time at the latter in obtaining a Ph.D. I think Hess' point is good. Coming to Penn State with some graduate work already done would certainly save time required for a Ph.D.

PINSON—Yes, you mentioned M.I.T. as one of the institutes that you might be interested in sending some of your students to. Actually, the curriculum you have up would be at least a sufficient minimum for getting accepted at M.I.T. That is, if you have a student who has taken math through integral calculus, a year of physics and a year of physical chemistry, and if he were well-recommended by you to us and were strong in his grades, we would probably take him and be glad to get him. The first thing that we would require of him on coming into our graduate program, would be to take sophomore mathematics and physics, and a course in physical chemistry if he had not taken that course. You no doubt have an elective system and it seems to me that the best way to strengthen students in science is in this elective area. See to it that your students who may want to enter graduate schools such as M.I.T. in the earth sciences take at least through differential equations, two years of college-level physics, and physical chemistry. These subjects, in my opinion could well be taken at most schools at the expense of not taking so many courses in geology. I do not think that it is advisable for undergraduate students at a school such as Franklin Marshall to spend an extra year preparing to enter some good graduate school. I think that it is much better to intensify their basic science training during the four normal years of undergraduate training, and send them on. If they have the ability they will make it. It has been our experience at M.I.T. that students generally spend about four and five-tenths years getting a Ph.D. degree, and that the time spent does not seem to depend so much on whether or not they came to M.I.T. with an M.S. degree. Of course, there are exceptions to this. Incidentally, I think that it is worth remarking that students who go to school full time—that is, who do not hold half-time assistantships—do not in general graduate with their Ph.D. degrees any sooner than do the half-time assistants. This is true at M.I.T. Whether it is true at other graduate schools or not, I do not know. Most students are under the impression that holding a half-time assistantship slows them down, but this appears

not to be the case.

WASSERBURG—I would like to distinguish between a fifth year program and a Master's degree.

MOSS—If you don't give them something after that fifth year, you probably can't keep them.

WASSERBURG—For a year and a half we have been re-evaluating the Master's program on a national scale and it is one heck of a mess. You just now mentioned the vices. If a student doesn't make the grade, you just give him a Master's degree. If you were to send students with a Master's degree, I would almost be leery of accepting them because of the fact that if he didn't make the grade, he would have to work an additional full two years to get a second Master's degree. I feel that unless a man comes out with the very highest of recommendations that we would injure him if we were to take him on for two years and just award him a second Master's degree. This is the point that I wanted to stress. I think it is a very important distinction. But I think you are being too modest. I would think that your students would probably be accepted by any good grad school in the country.

OSBORN—But what of the fellows from the smaller schools which have smaller faculties that can't do all the things that we can. These students can't get in Harvard, let's say.

PINSON—They probably will be accepted if the math and physical science departments in the smaller schools have prepared them properly. This is the basis on which we accept or reject applicants. If it looks like the students can meet our basic undergraduate curriculum in math and the physical sciences, then we are glad to accept them. If, in our opinion, it appears that they cannot, and even if they have all A's in their geology subjects, we do not accept them.

WASSERBURG—Then what you look for is a lot longer list in the physical sciences.

PINSON—Yes, and excellent grades and excellent recommendations.

SIEVER—A Master's degree is a consolation prize some of the time, but we take the point of view that this is a sort of professional course competence degree. But there is a point about getting a Master's degree at a place like F & M, particularly for those students who are going to a large university to do graduate work. It is a fact that sometimes they are not quite ready, not quite mature enough for what can be a very fiercely competitive place, a large graduate school. You can say "Well, we don't want this type of person," but then again you may be throwing out a lot of good people. I think there may be some virtue to adding on the fifth year just from this point alone.

MOSS—I think that point is quite well taken.

OSBORN—I think there will be a lot of difference in the standard of

quality of a Master's degree.

If a university has a good Ph.D. program . . . the Master's degree is a little suspect.

GOLDSMITH—How do you do this—how do you put a stamp, this is an honest Master's degree? If a man has a Master's degree and it is terminal, and he seeks employment, then you have to ask, can he have benefited from a Master's degree at F & M which took how long, say a year . . .

: About two years, one or two . . .

: If you take a man who is ripe for a Ph.D. my advice would be to send him on as soon as you can to the school. Four years is long enough and to keep him two extra years for a Master's degree I think is somehow wasting his time.

: I think it is a long haul for a Ph.D.

: He has two years for a Master's degree and another four with us and he could do the same job and he could be out working . . .

: Except Ray Sievers' point is very good . . . some fellas are very young when they come out and they need growing up a little bit.

: I haven't seen this kind of student.

: Well, maybe you don't but we do, maybe small colleges do.

: I think that the question that some of the small schools would like to ask is, is there a program that we might give which would carry through a two years' Master's degree which would prepare a student to go on to a competitive doctoral program in a large university and complete the doctors program in two or three years.

: The answer is yes.

: Now there is an ecological problem—when any student moves to a school it takes one year to know the school.

: Yes, that is right.

: And it takes one year no matter when he moves and if he has a Master's degree, even if he takes thirty years to get it, when he goes to another school, whether it is better or worse than the one he came from, the first question the faculty asks, to my knowledge is, "Well, we'll let this guy cook around for a year and see what he is made out of," and then we'll get him started.

: You're probably right.

: Once you've started that game it takes a year and I've seen too many students transfer and pay the year.

: Yes, that's one thing that's wrong with Cal Tech.

: This, then, is the answers to the query you made yesterday.

: Well, I am talking about a good solid Master's degree and I believe F & M can turn it out. I am not talking about a Master's

degree from a school with a strong Ph.D. program.

: Well, I think it would be lethal to walk into a qualifying exam at any school without spending a year there, for anybody, because you don't even know what the faculty is thinking about.

: Well, unless he starts on his research the day he walks in the door he pays for it, he pays a year.

: Well, it takes four years, whether or not he has a Master's.

: I would like to raise a point here that a Master's degree is valuable as long as it is subservient to the undergraduate degree . . .

: Well, first of all, as other people have said, if one of your students came to us from the background that you have shown, he would certainly be accepted. Having a Master's degree, I don't think would change very much the length of time a man would spend with us . . . the thing that bothers me so much, and has for the past few years, is the man who comes to us with a bachelor's degree from a school with an emphasis on general education and hasn't what anyone would call a proper undergraduate major. I wish sometimes that you could give a man a second bachelor's degree for a year, giving him a real major in physics or chemistry or something, but when they come with one year of mathematics and two years of physics and claim to have a physics major, even if it is a good school, and a fine young man, you have to put him in the undergraduate course.

: We have this problem, too. Some small college geology departments—two-man departments—do turn out extremely weak people and something has to be done for them, too, to build them up.

WASSERBURG—There is a great dichotomy in levels of Master's programs and undergraduate programs. We have now established a Master's program which requires that a Master's candidate cannot be given a Master's simply for surviving for about a year and very likely flunking their orals and being afraid of them . . . rather he would make up those deficiencies of the undergraduate program which we would normally expect of our majors, and then take a certain number of Cal Tech units or whatever you like. They would be upper divisional courses which a guy would normally take at a Ph.D. level. This means now that we would write up in the catalogue that the normal student entering must expect to take certainly two years to do a Master's degree.

: I would like to make one observation, since I feel that I have been an observer here for two days. I have heard an analysis of what is wrong with geology rather than a real changing identity of graduate earth science education. I think that we have already

defined what the earth sciences are . . . In my opinion we have not analyzed a great deal and I think that's good, but one should be aware of our omissions . . . This may be partly caused by the choice of participants. If we had chosen different people, a different emphasis would have been given to the whole thing, but there has been a great deal of agreement on how one should improve. This may be fortunate. I just wonder if there were forty other people if we would have obtained the same agreement.

BATES—I would like to raise a question arising out of the previous discussion. Are we losing students at the graduate level—possibly many who might come in from chemistry and physics—because we have old-fashioned notions as to how long it should take for a student to get a Ph.D. in geology? We are up against competition from chemistry department that are turning out Ph.D.'s, in three years after the B.S. An increasing number of fellowships permits more and more to get through in this period of time. I am not saying that this is the way it should be, but I would like to have your reactions. When we talk about two years for a Master's and another three years for the Ph.D., I wonder if we are not losing boys who are still somewhat uncertain what field they wish to enter for graduate work.

: Anybody have any figures on the three years?

: Yes, indirectly, our Dean of Graduate School has laid down a dictum to the fact that only in special cases should Ph.D. candidates hang around longer than three years. Enforced particularly since in the Physics Department they stay there six or seven. Nevertheless, this is the theory and I think in part it is a product of the fact that the Ph.D. degree itself is becoming maybe the top degree, but not the top of education, because post-doctoral work now is becoming almost commonplace, almost as common as Ph.D. work was when I started in this business. In fact, we are almost at the stage where we are going to standardize the Ph.D. degree and the next thing we will be arguing about is what a post-doctorate is and what he gets and so on.

MCINTYRE—Pomona is an undergraduate college with an enrollment of eleven hundred students; of these about half are men. I suppose that from my position I have a worm's-eye view of graduate education, and no doubt the perspective is a distorted one. Nevertheless, there is one point that I feel should be made before this conference ends. This concerns the attitude of a graduate department towards its students.

I used to recommend that a student first choose the man with whom he wished to work and then enroll at the institution on whose staff this man was. I have since learned that a student who follows

such a course is often disappointed to find that he has little or no contact with the man concerned.

OSBORN—Well, the first thing this man ought to do is to go to this professor's office, knock on the door and say, "Here I am." This would help. The student has to make a little effort, because if he hasn't even seen this man after six months, that is probably his fault.

MCINTYRE—It is easier for a dean than for a student to act on that advice. I am of the opinion that there are too many graduate schools where too little consideration is given to the students, and I have the impression that the situation is not improving.

Appendix

THE CHANGING IDENTITY OF GRADUATE EARTH SCIENCE EDUCATION

An Annotated Bibliography

Compiled by Frank T. Dolan

School of Information Science

GEORGIA INSTITUTE OF TECHNOLOGY

Atlanta, Georgia

This annotated bibliography was prepared for publication as an appendix to the proceedings of the conference on graduate earth-science education held at Georgia Tech in January, 1965. It updates and amplifies an earlier bibliography by Berg, et. al.

The primary sources for material on earth-science education are the *Journal of Geological Education* published semiannually by the National Association of Geology Teachers and "Geotimes." The major societies such as the Geological Society of America and the American Association of Petroleum Geologists also contributed valuable material through their various publications.

This bibliography is arranged alphabetically by author and where an author has written more than one paper, his most recent contribution appears first.

Adkins, John N., (1947), "Training the geologist for geophysical work," Fifth Conference on Training in Geology, (American Association of Advancement of Science in cooperation with Geological Society of America) *Interim Proceedings, Geological Society of America*, pt. 1, March, pp. 77-80.

Emphasizes the recognition of geophysics as a subdivision of geology rather than a separate or borderline science.

Albritton, Claude C., Jr., (1962), "Historical approach to the problem of training geologists," *Field and Laboratory*, v. XXI, June, no. 1, pp. 13-20.

A review of the recommendations presented in the *Interim Proceedings. Geological Society of America* and other publications, compares such suggested curricula with that of Southern Methodist University. A survey of graduates of Southern Methodist University, portrays their success, present positions, and careers as evidence for the worth of the type of curriculum given at Southern Methodist University.

American Association of Petroleum Geologists, (1948), "Report of Committee on Education," Morse, Roy R. (Chmn.), Bulletin, *American Association of Petroleum Geologists*, v. 32, no. 6, June, pp. 1197-1199.

A review is presented of the work of other committees, with which the American Association of Petroleum Geologists has cooperated, and an endorsement of their cooperative findings is emphasized. One recommendation goes further, stating" . . . that this requirement (that of other science and mathematics), where necessary, take precedence over such courses in geology as those dealing in specialized techniques rather than fundamentals." Opposition is stated against any present attempts of furher accreditation of schools. A continuing committee on geologic education is recommended.

American Association of Petroleum Geologists, (1944), "Report of Committee on College Curricula in Petroleum Geology, "Bulletin, *American Association of Petroleum Geologists,* v. 28, no. 5, pp. 670-675.

A further study of the applications of geology in warfare, and the problem of accelerated programs occasioned by the war are the subject of this report.

American Association of Petroleum Geologists, (1943), Report of Committee on College Curriculas,: Bulletin. *American Association of Petroleum Geologists,* v. 27, no. 5, pp. 694-697.

Responses from industry and colleges are based upon data in Report No. 2; military geology and its value is also discussed.

American Association of Petroleum Geologists, (1942), "Report of Committee on College Curricula," Bulletin, *American Association of Petroleum Geologists,* v. 26, no. 5, pp. 943-946.

The second report deals with specific curricula and a survey of 70 geological departments, reiterating some of the points in **Report** No. 1, and also emphasizing the necessity of a 5-year program. **The** following courses were recommended:

Required Geology Courses		*Elective Geology*
Introductory (Struct.)	Economic Geol.	Crystallography
Historical Geology	Field Geology	Petrology
Mineralogy	Stratigraphy	Micro-paleontology
Petrology	Sedimentation	Mineral Deposits
Physiogr. or Geomorphology	Petroleum Geol.	Engineering Geology
Structural (Adv.)	Princ. of Geophysics	Photogrammetry
Invert. Paleontology		

Courses in addition to geology

Math. and Sci.	*Communications*	*Engineering*
Mathematics through Calculus	English Comp.	Mech. Drawing
Physics	Foreign Language	Descriptive Geom.
Qual and Quant Chemistry	Public Speech	Surveying

Humanities and Soc. Sci.	*Some Recommend*	
History	Biology	Differential Equations
Economics	Organic Chemistry	Mechanics
Political Sci.	Phys. Chemistry	Hydraulics
Sociology	Adv. Physics	

American Association of Petroleum Geologists, (1941), "Report of Special Committee on College Curricula," Bulletin, *American Association of Petroleum Geologists,* v. 25, no. 5, pp. 969-972.

The first in a series of four committee reports, is based on a survey of oil company and consulting geologists, and a comparison with the offerings listed in college catalogs. Insufficient grounding in the basic subjects of mathematics, physics, chemistry, and English is noted. Too specialized training in a few branches of geology that apply directly to oil exploration does not produce as efficient petroleum geologists as a broader foundation in all the main branches of the science. Also emphasized are botany, zoology, field mapping, geophysics, logic, and a foreign language.

American Geological Institute. DIRECTORY OF GEOSCIENCE DEPARTMENTS IN THE COLLEGES AND UNIVERSITIES OF THE UNITED STATES AND CANADA: *Its*: Report 11, 1962 ed., 125 p., tables, 1962.

The report was compiled under the guidance of the AGI Educational Committee, Chalmer J. Roy, Chairman. This is the 7th edition of the Directory, replacing the 1960 edition of the same title, AGI Report 11.

A total of 261 institutions in the United States and Canada offering a major in the geological sciences are listed herein. Sec. 1. *Colleges and Universities Offering Undergraduate Degrees in the Geosciences*, is divided in parts. Pt. A is a geographic listing of the departments by the state in which they are located with a code reference to the highest level of degree granted. A code letter also identifies those schools offering a summer field course. The summer field course data are to be found in tabular form in Sec. 4. Pt. B contains the detailed information on each separate department, following a straight alphabetical arrangement of institutions. Sec. 2 is an alphabetical listing of all faculty members of the degree-granting departments, and indicates the institutions where they are employed. Sec. 3 consists of a consolidated listing by states of those 4-year and 2-year colleges which offer some courses in the geological sciences, but do not at the present time offer a major in geology-geophysics.—From forward.

American Geological Institute. SURVEY OF GEOLOGY-GEOPHYSICS STUDENTS IN THE UNITED STATES AND CANADA IN 1959-60: *Its:* Report. 12, 1960 ed., 13 p., 2 graphs, 3 tables, (1960).

The 5th in a series of annual reports. A fairly stable student population in the geosciences remains in Canadian schools, but a serious drop in junior and senior level enrollment is reported in the United States, reflecting the poor employment status of the last few years. Masters degree candidates increased in Canada, but dropped by almost 10% in the U.S.; enrollment in the Ph.D. program showed general increase. A new feature of the survey shows that for every geology major, there are 6 non-major students taking geology as a part of their general education. Statistical presentation relates specific institutions to the number of students, classified ino 6 levels of undergraduae and graduate study. M. Russell.

American Society for Engineering Education. "Objective Criteria in Ceramic Engineering Education," *Urbana*, III, 1963, 16 p.

Study was made with cooperation of *American Ceramic Society* and *National Institute of Ceramic Engineers;* it includes analysis of scope of ceramic engineering education and of level of understanding desired in several branches of mathematics, sciences, engineering, and general education involved; recommendations are made for balance in curriculum content, taking into account proportion of students proceeding to post-graduate courses of study, and demands that may be imposed on graduates in future years.

Bannerman, H. M. and Pecora, William T., (1950), "Training geologists: A U. S. Geological Survey viewpoint," *U. S. Geological Survey Circular No. 73,* Washington, D. C., March, 1950.

For a survey career, the student is best suited who is well grounded in physics, chemistry, mathematics, and biology, before concentrating on any specific field in geology. At least two years should be devoted to graduate study. Irrespective of the specialities they may eventually follow, students should have a sound training in mineralogy, petrography, petrology, stratigraphy, structure, paleontology, geomorphology, map interpretation, and construction, the latter to include the elements of surveying, drafting, and photogrammetry.

Barthel, Christopher E., Jr., "Earth Sciences in Tomorrow's Engineering," *Military Engineer,* v. 56, no. 373, p. 345-346, Sept. - Oct., 1964.

Earth Science research in progress in the U. S. Coast and Geodetic Survey includes oceanography, photogrammetry, geodesy, seismology, tsunami studies, and navigational systems. Tomorrow will see sea-floor mining and earthquake engineering developed by close cooperation between earth scientists and engineers. —H. H. Sullwold, Jr.

Behre, Charles H., (1959), "Problems of the geology teacher and his association," *Journal of Geological Education,* v. 7, no. 1, pp. 13-17, Spring.

Address on receiving the Neil Miner Award. Speculates on some of the problems of the geology teacher: How to improve standards, prevent oversupply

and determine what will be the necessary courses of the future. A plea for planning.

Behre, Charles H., Jr., (1953), "The college geology teacher," *Journal of Geological Education,* v. 1, no. 5, pp. 11-25.

Behre discusses the fine attributes of the college teacher versus the technical school or graduate school teacher, the curriculum, and the importance of summer field experiences.

Berg, J. Robert, and others, "Annotated Bibliography of Geological Education," *American Geological Institute,* (1963), Washington, D. C., 26 p.

Published for the National Association of Geology Teachers, the bibliography includes 76 titles, plus an alphabetical listing of authors. The papers are arranged chronologically and over the years from 1919-1962.

Berkner, L. V., "Graduate Education—Our National Resource," *IEEE Spectrum,* V, I and II, February, 1964, p. 66-73.

Impact of engineering achievements on our society, by quite abruptly transforming its economy to one of plenty; national committment to reliance on resource of innovation for future growth, makes intensive scientific research essential; very advanced and continuing education to support such research, and superior technological training at all levels are imperative; statistical and geographical data on all United States postgraduate training and on proportion of it in natural sciences; proposals for maximizing use of our graduate in natural sciences; porposals for maximizing use of our graduate facilities; apparent lag of social and economic sciences in grasping full significance of these economically-impelled social changes.

Boardman, Donald C., (1957), "Correlating the geology curriculum with the general education requirements of the college," *Journal of Geologic Education,* V. 5, No, 1, p. 1-3.

A survey of a large number of college catalogs indicates average general education requirements as (in sem. hrs.) English Language and Composition, 12; Literature, 8; Social Science, 10; Humanities, 12; Foreign Language, 16. Such requirements must be correlated with the Geology curriculum in order to assure their value to the student in his geologic training.

Boon, J.A., and McNulty, Charles Lee, Jr., "Problems of a new geological department, Arlington State College, Arlington, Texas," (abs.), *Geological Society of America Bulletin,* V. 71, No. 12, p. 1830, December, 1960.

Boutwell, John M., (1945), "Economic Geology," (Presidential Address before the Society of Economic Geologists), *Economic Geology,* V. 40, No. 7, p. 431-448.

Preparation should be based on a broad general college course, including literature, economics, history, business, mathematics, and other sciences. An intensive study of geology should not begin until late in undergraduate or preferably in graduate school.

Bradley, W. H., (1947), "A suggested geological curriculum," *Interim Proceedings, Geological Society of America,* Pt. 2, April, p. 8-13.

This is a report prepared by a committee of U. S. Geological Survey Geologists. It is a recommendation prepared for the department of George Washington University (D.C.), and includes courses in geology (27 hrs.) supporting science and mathematics, a two-fold option for physical vs. biological geology majors, other liberal arts courses, and recommendations for a graduate program.

Brown, F. Martin, (1959), "Earth science training inadequate," *Geotimes,* V. III, No. 6, p. 10-11, March.

A study of 203 teachers of general science showed they were distributed as follows in terms of their background in Earth Science courses (including geography).

Hours	Percent	Hours	Percent
None	46.2	9-11	4.9
1-2	5.4	12-20	5.4
3-5	22.2	21-29	2.5
6-8	12.3	30 and over	1.0

Bullard, Fred M., (1956), "Is there room for liberal education courses in the geology curriculum?", *Journal of Geological Education,* V. 4, No. 1, p. 13-15.

The question raised by the title of this paper brings up four possibilities, namely:

1. lengthen the period of study to five years;
2. leave out some of the geology courses to make room for liberal education courses;
3. set up entrance requirments so that most of the general education courses would be taken in high school; and
4. some combination of the above.

Chapman, Randolph W., (1951), "The training of geologists in Great Britain," *Interim Proceedings, Geological Society of America,* Pt. 1, March, pp. 17-35.

As a result of a Fulbright grant in 1949, the writer lectured at several institutions in Great Britain. This paper presents a comprehensive survey of the curricula at several schools, and a comparison with American educational patterns. Notable in Great Britain is the more limited field of employment, the greater emphasis on field experience, the greater use of technicians to aid the university professor, and substantial government aid.

Charlier, D. H., and Daley, C. J., (1960), "Requirements in geology departments," *Bibliog. Sch. Sci. and Math.,* V. 60, p. 291-298, April.

Authors surveyed 58 geology departments to find out what courses were needed for graduate work. Findings are tabulated. Also a strong plea for geology courses in secondary school. Cites several examples where a practical knowledge of geology would have been very useful.

Childs, Orlo C., (1961), "History and forecast of geological training and employment, *Bulletin, American Association of Petroleum Geologists,* V. 45, No. 8, p. 1461-1470, August.

Presents the results of questionnaires received from 180 colleges and universities and 252 companies or government agencies. Conclusions reached are:

1. MA is the min. academic training for geologists in next 5 years.
2. Major oil companies are interested only in people coming right from college.
3. Independent and mining companies are interested in geologists with five plus years experience.

Cohee, George V., (1956), "General education in retrospect," *Journal of Geological Education,* V. 4, No. 1, p. 16-18.

The writer was presented in his own school with the problem of integrating a program of general education with geology requirements at a time when the oil industry was requiring a minimum of 50 hours of geology before considering an applicant for employment. The difficulty of doing so and at the same time, including the ncessary mathematics and related sciences is described.

Colbert, Edwin H., (1947), "A paleontologist's view of the geology curriculum," Fourth Conference on Training in Geology, *Interim Proceedings, Geological Society of America,* Pt. 1, March, p. 8-14.

A comparison is given on the amounts of mathematics, physics, and chemistry, required at most colleges (at least 1 year of each) for the geology major, and the lack of, or few hours required in the field of biology.

Cooper, Byron N., (1962), "Geology and future employment prospects," *Mineral Industries Journal of Virginia Polytechnic Institute,* V. IX, No. 2, p. 1-4.

Although the need for geologists in fuel exploration has declined in the past few years, they should have increasing opportunities in other fields. Those mentioned are: Development of water supplies; stream pollution control; foundations and soils; tunneling and underground construction; highway planning; minerals beneficiation; chemical industries; cement, lime and ceramic industries; coal mining and processing; land evaluation corporate investment counseling; aggregate producing industries; trace-element studies and diagnosis of land chemistry; mineral economics; municipal engineering; local, state and regional

planning; coastal engineering; geological counsel on legal problems; oceanography. In beginning classes, the complexity of geology should be played up, not down.

Cooper, Byron N., (1958), "Research and effective teaching in the geological sciences," *Journal of Geological Education,* V. 6, No. 1, p. 15-18, Spring.

Most geology teachers poll somewhere between the end points of teacher and researcher. An optimum ratio is difficult to determine, and is not so important in the individual as it is in the department as a whole. This number of the *Journal of Geological Education* contains papers from symposium on teaching and research given at the National Association of Geology Teachers meeting, Atlantic City, 1957. Papers by C. G. Higgins, Lloyd Staples, Ian Campbell, Byron Cooper, Grover Murray.

Croneis, Carey, (1961) "Geological perspective," *Journal of Geological Education,* V. 9, No. 1, p. 1-12.

This is a presidential address to the National Association of Geology Teachers. The author briefly surveys the role of man in his physical environment past, present, and future. Such problems as the tremendously increasing rate of energy consumption, whether or not man is biologically unique, and the possible causes and effects of overpopulation are considered. He concludes that although many such problems have little to do with classical geology, this should not prevent geologists and geology teachers from considering them. In short, widely ranging philosophical reviews are the prerogative of a teacher of beginning or advance geology.

Cronejs, Carey, (1956), "Problems of geological education and of educating geologists," *Bulletin, American Association of Petroleum Geologists,* V. 40, No. 12, p. 2961-2970.

This paper is the most comprehensive recent report on the subject of the problems of getting and holding teachers of geology. A survey of salaries, intangible rewards, and a ranking of schools on different bases presented.

DeGolyer, E. L., (1940), "Future position of petroleum geology," *Bulletin American Association of Petroleum Geologists,* V. 24, No. 8, p. 1389-1399.

This is the sixth of the articles in the symposium mentioned above. DeGoyler states that a petroleum geologist must be essentially a geological engineer; training in field geology is a necessity as an educational measure. Geophysics must not be regarded as a distinct and separate subject from geology; its value is only as great as the interpretations of physical measurements in terms of structural geology.

Delo, David M., (1946), "Better teaching—a geologic necessity," *Interim Proceedings, Geological Society of America,* Pt. 2, March, p. 24-27.

The setting up of a required curriculum alone will not insure a good product; many of the small colleges with a single staff member and other limitations have produced some of the more notable geologists. Hence, the plea is more for "better teaching," than a series of requirements. This article is followed (p. 27-53) by comments of conference participants on curriculum problems. The results of Delo's survey are as follows:

Recommended Curriculum

Physical Geology	4	Economic Geology	4
Historical Geology	4	Paleontology	4
Mineralogy	4	Physiography or	
Petrology	4	Regional Geol. of	
Structural or Geomorphology	4	North America	4
Structural or Geo-		Field Geology	6
morphlogy	4	Senior Thesis	2

Teachers, less than 1-½ per department, most one man
(Based on survey of 14 schools)

California	1	Iowa	1	Ohio	2
Colorado	1	Kentucky	1	Pennsylvania	1
Illinois	3	Minnesota	1	Texas	1
				Wisconsin	1

Ecklemann, F. Donald, (1958), "Physical geology integrated with general chemistry," *Journal of Geological Education*, V. 6, No. 2, p. 3-5, Fall.

Describes a course in physical geology that has a prerequisite, one semester of chemistry. Allows many geologic topics to be studied in a more quantitative way.

Ellison, Samuel P., Jr., (1955), "Costs of geological education," *Bulletin, American Association of Petroleum Geologists*, V. 39, No. 8, p. 1652-1655.

This paper presents a survey of costs per credit hour in geology, in comparison with the other sciences, in 90 representative colleges and universities. Costs range from a low of $3.59 to a high of $200. 19 per student credit hour, with an average cost of $16.25. Costs were given over a period of 4 years in comparison with biology, chemistry, and physics; the average range for all of these sciences is from about $15.00 to $23.00 per student credit hour, with physics usually the highest, and biology usually the lowest.

Fan, Paul H., (1959), "Developing a better geological profession," *Geotimes*, V. IV, No. 4, p. 26, December.

Suggests the elimination of geology as an undergraduate major. Students should major in biology, chemistry, or physics and then do graduate work in geoscience.

Foose, Richard M. (1956), "The humanities: An antidote for over-specialization in geologic science," *Journal of Geological Education*, V. 4, No. 1, p. 9-12.

Emphasizes in a general discussion the need for the humanities in the geological curriculum.

Foose, Richard M., (1956), "Geologic education," *Geotimes*, V. 1, No. 6, p. 9.

Foster, G. L., "Geostudy," *Geotimes*, V. 5, No. 8, p. 18-19, 49, 2 illus., May-June, 1962.

A thorough evaluation of geological education at the undergraduate level is one of the most vigorous activities of the American Geological Institute. Set up as the Geological Education Orientation Study, and referred to simply as GEO-Study, the project is being undertaken in response to criticisms being voiced with increasing frequency—that geology lacks purpose and direction, that its curricula are outmoded and obsolete, that it is static, that it no longer attracts gifted students. In functioning, the AGI-GEO-Study recognizes the validity of some of the criticisms.

The GEO-Study Steering Committee is listed, and the committee's statement of purpose, objectives and program plans are presented.

Fryxell, F. M., (1948), "Accreditation and the liberal arts college," Joint Conference of the (Geological Society of America) Committee and the Association of Geology Teachers, *Interim Proceedings, Geological Society of America*, Pt. 2, March, p. 16-21, and commentary, p. 21-37.

The unusual record of the small liberal arts college is cited, along with the names of some of their eminent products. Major requirements often include no more than a minimum of 24 hours in geology, but with a liberal amount of specified supporting courses in mathematics, other sciences, and foreign language; these are some of the very recommendations made by previous committees. The past record and pattern of the small liberal art college speaks well for a plan of graduate school preparation. An additional value of the liberal arts colleges is the fact that teaching is generally of high quality, with even the elementary courses being taught in small classes, by one assistant to full professor rank, thus maintaining the close teacher-student relationship.

Gates, Olcott, (1961), "The geology major in a small college," *Journal of Geo-*

logical Education, V. 9, No. 2, p. 83-88, Fall.

Geology students need more basic information to succeed in graduate school than a small college can give them under existing course frameworks. This may be remedied by combining courses so as to present the most useful information for the amount of time spent.

Gault, H. R. (1952), "Changing requirements in chemistry, physics, and mathematics for geology majors, *Journal of Geological Education,* V. 1, No. 1, No. 3, p. 13-17.

A summary of various schools, geographically and by type (19 in number), shows the increasing number of course years required in other areas.

	1935	1940	1945	1950
Chemistry	.92	.97	1.10	1.26
Physics	.47	.55	.66	.71
Mathematics	.61	.71	.82	.92
TOTAL	2.00	2.23	2.57	2.89

Gilluly, James (1946), "The training of geologists," *Interim Proceedings, Geological Society of America,* Pt. 2, March, p. 3-8.

The author recommends about 40 hours of basic courses in geology, 32 hours of other sciences and mathematics, and about one-third of the curriculum for the humanities and social studies; faculty teaching loads light enough to allow research; and a staff of at least three teachers.

Gen'l Geol.	6	Surveying and Field Geology	10	Mathematics through Valc.	15
Mineralogy	4	Elective Geology (preferably subordinated to further work in mathematics, physics, and chemistry.)	6	Descriptive Geometry	2-3
Petrology	4			Foreign language (German or Russian)	

One-third (40) hours of college studies for humanities and social studies.

Graduate

Microscopical Petrography
Economic Geology
Metamorphism

Should not displace fundamental and basic science courses.

Accrediting Tests

At least staff of three teachers. Teaching loads must allow research time.

Ginger, Lyman G., and others, (1958), "Science, mathematics, and the humanities: Let's balance the program," *National Educational Association Journal,* V. 47, p. 79-90, Fall.

This article emphasizes the necessity of building science on the humanities.

Hagner, Arthur F., "Geologic education and its influence on approaches to Geologic Problems," *Journal of Geologic Education,* V. 9, No. 2, p. 89-97, Fall 1961, 12 refs.

Students should know something about the various ways in which the interrelated phenomena of geology are currently being studied. Because of the variety and complexity of most geologic processes, no simple method of attack can be successful for all situations. Examples of the approaches being taken by several present-day research geologists are presented. Undergraduate research is suggested as being advisable to increase students' appreciation of the various ways in which geologic problems may be approached.

Hagner, Arthur F., and Henderson, Donald M., "Problems in Geologic Education: The Elementary Course," *Journal of Geologic Education,* V. 7, No. 1, p. 36-39, Spring, 1959.

In August, 1958, the Geology Department of the University of Illinois completed its second Summer Institute sponsored by the National Science Foundation. Since further institutes are not planned by the authors, we take this opportunity to sum up the interactions of 82 participants, visiting lecturers, and staff members to problems of geologic education.

Many problems stem from the fact that geology is both a derivative and a natural science in its own right. To handle it requires the ability to think in terms of several variables at once, to recognize problems and ways of dealing with them, and to appreciate the development and significance of hypotheses and evidence upon which each rests. This calls for the use of judgment. To contribute to the advancement of geologic knowledge requires, in addition, creative ability.

The nature of our science poses problems of student and teacher preparation. Problems imposed by society and our educational system have to do with enrollment and the diverse educational aims of the various colleges and universities.

It was agreed that teachers should stimulate and guide the student in his own development, help him think and write critically and creatively, recognize problems and approaches to them, and appreciate the importance of facts and reasoning from facts. This can be accomplished by conceptual rather than merely informational instruction, by class discussions and reports, and by early research by capable students. The need to attract more of the better science students and for a strong foundation in fundamental sciences was recognized.

Hambleton, William W., "Impact of High School Earth Science Courses on College Curricula," *Journal of Geologic Education,* V. 12, No. 2, p. 69-73, June 1964, 5 refs.

Modern secondary-school programs in physics, chemistry, biology, and mathematics are developing courses that are rigorous intellectual enterprises, and students emerging from these courses are forcing change on colleges and universities. Although earth science has not been in the forefront of these programs, rebirth of interest in the earth and its environs has placed the secondary schools in a position of leadership, and only recently has geology assumed an active role in producng suitable teaching materials. The geological fraternity must anticipate the consequences of the new earth science courses and embark on a program in improvement in undergraduate geological education if it is to attract and challenge students who are the products of the new secondary-school courses.

Hambleton, William W., "Geology and Graduate Education," *Journal of Geologic Education,* V. 10, No. 3, p. 74-78, Sept., 1962.

Certain recommendations in the report entitled "Scientific Progress, the Univeristies, and the Federal Government" by the President's Science Advisory Committee have relevance to problems of present-day geologic education. Of particular importance are the observations that basic research and graduate education go together, and that rules of study often impede the student's access to experience of modern-day science. The geologic profession must recognize anew that geology is the study of the earth, that it is the study of a system, that it is a direction of interest, and that it is not a science unto itself as are physics and chemistry. The department of geology should recognize that basic research and graduate education in geology are inseparable, inasmuch as geologic research is a systematic effort toward an increase or deepening of knowledge and ideas. Further, the department of geology and the graduate school of the university must provide access to experience of modern science by removal of interdepartmental barriers, so that supporting sciences may be brought to bear upon earth problems. Students in other disciplines should be encouraged to devote attention to earth problems without satisfying a host of traditional undergraduate requirements. Geology should encompass a community of scholars with diverse and catholic interests; brought together because all have the solution of earth problems as their objective.

Harbaugh, John W., (1958), "Stanford's School of Mineral Sciences get critical review," *Geotimes,* V. III, No. 3, p. 8-9, September.

A tabulation of suggestions made to a committee of Stanford alumni and friends for the improvements of the school of mineral industries.

Heller, Robert L., (1964), "The Earth Science Curriculum Project," V. 12, No. 2, June 1964, p. 64-68.

The Earth Science Curriculum Project is an interdisciplinary secondary school science program initiated by the American Geological Institute. Its function is to study and evaluate earth-science materials and curricula now in use in secondary schools, and to develop and test new curriculum materials. Support for the initial phase of the program is being provided by the National Science Foundation.

Preparation of new text and laboratory materials for use at the ninth grade level began in August, 1963. This step followed a thorough study of the current status and planning for secondary-school earth-science subject matter, grades K-12. In the materials being developed by ESCP, emphasis will be placed on comprehension of a system of basic concepts and principles, rather than on coverage of the entire body of earth-science knowledge. An important theme that will be used in all text and laboratory materials developed by ESCP is the learning of modes of inquiry. Other themes are universality of change, equilibrium, conservation of mass energy, uniformitarianism, and scale as a frame of reference. Laboratory exercises will stress the role of scientific inquiry, the collection and analysis of data, and the formulation and testing of hypotheses.

In addition to developing text and laboratory materials, it is the intent of the Earth Science Curriculum Project to produce one or more teachers' guides, a series of short teaching films, and several single-concept pamphlets.

Hemingway, Caroline E., (1947), "Training of women in geology," Fifth Conference on Training in Geology, (American Association of Advancement of Science in cooperation with the Geological Society of America), *Interim Proceedings, Geological Society of America,* Pt. 1, March, p. 66-71.

This article includes a survey of women geologists, the organizations in which they are employed, a recommended curriculum in geology, and supporting courses in the sciences and other fields.

Hendriks, Herbert E., (1957), "Basic science and mathematics requirements in the geology curriculum," *Journal of Geological Education,* V. 5, No. 1, p. 6-10.

From a report based on surveys, geology major requirements include: chemistry by 87 per cent, of schools surveyed; mathematics 77 per cent; physics 74 per cent; biology 23 per cent; mechanical drawing or drafting 19 per cent; and civil engineering or surveying 17 per cent. The following numbers of hours appear adequate to achieve goals: chemistry 10-12 hours; mathematics 8-10 hours; biology 6-8 hours; physics 8-10 hours; drafting 6; and surveying 6.

Hendricks, Thomas A., (1948), "The significance to the Geological Survey of accreditation of schools in geology," Joint Conference of the (Geological Society of America), Committee on Geological Education and the Association of Geology Teachers, *Interim Proceedings, Geological Society of America,* Pt. 2, March, p. 7-10, (and comment 10-16).

The U. S. Geological Survey, the largest single employer of geologists in the country, presents the pros and cons of accreditation from the Survey viewpoint. Comment by A. L. Howland (Association of Geology Teachers president, Central Section), states that a survey of geology teachers indicates that two-thirds in favor of some type of accrediting but states personnel is most import, with curriculum second, and facilities third. Comment by O. R. Grawe emphasizes difficulty of teaching geology in a "school of mines" where other curricula are accredited. Comment by J. Singewald, "Geology, as we all know, is but the application of mathematics, physics, chemistry, and biology, (to the study of) the particular object, the earth," hence, "all these fields must be considered in accrediting."

Horberg, C.L., (1955), "Current trends in geology and their relations to geological education," *Journal of Geological Education,* V. 3, No. 1, p. 1-6.

Several trends in geology are discussed, including specialization into subsciences, the adoption of methods of the basic sciences, the expansion of research,

vocationalism, loss of teaching personnel to government and industry, and the forthcoming large enrollments. Suggested solutions include unification of subject matter, a decrease in the teaching of applied geology, provision for training both specialized and general geologists, more rigorous standards, and efforts upon the part of all concerned to keep geology teachers in the profession.

Horberg, C. L., Olson, E. C., and Thiel, G. A., (Chairmen for Committees), (1950), "Geology curriculum in the liberal arts college," by Committee on Curriculum and Standards, Association of Geology Teachers; Committee on Geological Education, American Geological Institute; and Committee on Geological Education, Geological Society of America; *Interim Proceedings, Geological Society of America,* Pt. 2, July, p. 9-17.

This report reviews and endorses many of the recommendations of the above report (Theil, 1949) with respect to the liberal arts college. It is stated that the geology curriculum is comparable in purpose to the premedical or predental courses, and quite different from the chemistry major. Some of the problems of geology arise from the fact that not more than a fraction of the universities and colleges have departments of full-time status, and virtually no secondary schools teach the subject. Departments with the best records have avoided multiplication of courses.

Recommendations are similar to those in the 1949 report but differ in recommending a minimum of one course year each of chemistry and physics, with electives for further study. The beginning course in geology should merit the best teaching talent.

Howell, B. F., Jr., (1957), "Preparation for graduate school—a study based on the needs of geophysicists, and geochemists," *Journal of Geological Education,* V. 5, No. 1, p. 11-18.

An emphasis is placed on more mathematics, physics, and chemistry, even at the sacrifice of extra geology courses for the student planning to enter Geophysics or Geochemistry.

Hussey, Keith M., (1957), "Applied courses will limit our products' potential," *Journal of Geological Education,* V. 5, No. 1, p. 4-5.

Over-specialization on the undergraduate level limits a student for either graduate or commercial work, because such courses are often taken at the sacrifice of more basic or fundamental courses.

Kauffman, Marvin E., "An Undergraduate Course in Quantitative Geology," *Journal of Geological Education,* V. 10, No. 3, p. 72-73, Sept., 1962.

Current interest in a quantitative approach to geology has been demonstrated at many recent meetings. An undergraduate course in quantitative geology has been introduced into the curriculum at Franklin and Marshall College as an upper-class elective. A minimum background in pure statistics on the part of most of the students requires this course to include fundamental quantitative principles as well as the application of these concepts to geologic examples. The lack of a suitable textbook necessitates reliance upon the current geologic literature. Quantitative geology should at least introduce the student to the use of properly designed experiments and to clarity and precision in his thinking.

Kiersch, George A., "Academic Trends and Engineering Geology," *Journal of Geological Education,* V. 12, No. 1, p. 14-21, March, 1964.

Engineering geology is distinguished by being chiefly confined to the physical aspects of geoscience, i.e., to physico-geology. The other branches of applied geology—petroleum, mining, and ground-water—are concerned dominantly with the mineral aspects of geoscience and with the demand for specific resources.

Tomorrow's undergraduate geology curricula will consist largely of preparation in the basic sciences, humanities, and engineering science, with a few strong geological courses. The continued upgrading of preparatory training necessitates that geological courses become more rigorous and provides for an interdisciplinary approach to the study of processes and physical envioronments. Graduate-level training in the geosciences for future engineering geologists is taken for

granted.

The forthcoming sophisticated applications of physico-geology are fascinating. Tomorrow's practitioner must possess a well-rounded training in geoscience, plus certain other attributes, to serve these expanding challenges.

Lahee, F. H., (1938), "Where shall our young graduates in petroleum geology acquire field experience?" Bulletin, American Association of Petroleum Geologists, V. 22, p. 1613-1614.

Concern is expressed for the subject of and experience in *field geology*, which is not acquired in the normal classroom situation, nor in company employment in many cases.

Laird, Wilson M., (1957), "Let's train our geologists," *Geotimes*, V. 1, No. 12, p. 14-15, June.

A recommended curriculum includes:

Geology	*Basic Science*
General Geology	General Chemistry
Mineralogy, including Optical	Qual. and Quant. Analysis
Petrology	Physical Chemistry
Structural	Mathematics through Calculus
Geomorphology	Physics
Paleontology	Humanities*
Sedimentology	English
Stratigraphy	Speech
Economic Geol.	History
Thesis and Seminar	Economics
Field Geology (at least one summer)	Political Science
	Foreign Language

*An error of nomenclature is noted here and also under the 1942 *American Association of Petroleum Geologists*, report. It must be noted that none of these courses, (except history), are actually in the field of Humanities, which by definition, "humanities, includes any and all literature, philosophy, music, architecture, drama, ballet, painting, and quite frequently religion and history," per Dressel, P.L. and Mayhen, L. B., General Education, American Council on Education, 1954.

Langenheim, Ralph L., Jr., (1957), "Language requirements and other regulations for graduate study in geology," *Journal of Geological Education*, V. 5, No. 1, p. 19-22.

Forty of 92 departments surveyed do not require a language for the M. S. degree; all but 11 require two languages for the Ph.D. degree. Northeastern schools are most rigid, whereas north-central schools are most lax in the langauge requirement. The requirements of preliminary and final examinations for advanced degrees is also presented.

Langford, G. B., "Teaching the Geological Sciences," *Royal Soc., Canada, Trans.*, Sec. 4, Geol. Sci., 3rd ser., V. 52, p. 39-43, June 1958.

Geology is a science, and teachers in this discipline must adhere to the methodology of the basic sciences. Purely descriptive subjects have their places in a curriculum. Unless they are built on observation, interpretation, and induction, they are not sciences. The manner in which outside influences affect curricula is touched upon.

Leith, C. K. (1921), Economic Aspects of Geology, Holt and Co., New York, Ch. XXI, "The Training, Opportunities, and Ethics of the Economic Geologists," p. 420-431.

For an article written 36 years ago, we find herein some familiar statements reiterated by students of curricula today. Leith stated that, "The best results have been obtained from students who, before entering geology, had a broad general education or who have followed intensively some other line of study." A plea for more mathematics and science is substantiated by his statement that "Geology is passing from the descriptive and qualitative stages to a more precise

basis."
Levorsen, A. I., (1940), "Petroleum geology," Bulletin, *American Association of Petroleum Geologists,* V. 24, No. 8, p. 1355-1360.

In the introductory article to a series of six papers in this issue, entitled "Symposium on New Ideas in Petroleum Exploration," it is pointed out that in petroleum geology the dominant trend seems to be toward emphasis upon stratigraphy, sedimentation, and historical geological.

Levorsen, A. I., (1946), "Desirable training for petroleum geology," Interim Proceedings, Geological Society of America, Pt. 2, March, p. 8-12.

The author quotes largely from the American Association of Petroleum Geologists reports mentioned earlier, and also recommends a five year program, or one to two years of advanced study (presumably graduate).

Lindgren, Waldemar, (1919), "Economic geology as a profession," *Economic Geology,* V. 14, p. 80-86.

For economic geology as a profession, the author recommends more laboratory and field work in geology, an engineering-like background, with more mathematics (including statistics), physics, and chemistry (including organic). Some background is desirable in hydrology, soil mechanics, agriculture, political economy, and international trade; recommended langauge preparation should include French, German, Italian, Spanish, Russian, and Arabic.

Lindquist, Clarence B., "Geology Degrees During the Decade of the Fifties," *Geotimes,* V. 5, no. 8, p. 15-17, 3 tables, May-June, 1961.

During the decade of the 1950's the number of bachelor's degrees in geology declined from a high of 3,043 in the year ending 1950 to 1,632 in the year ending June 1954, and then rose steadily again to 2,816 in the year ending June 1959. The percentages of geology degrees were higher in the later years (0.762 of 1% in 1958). A total of 23,298 bachelor's degrees in geology were awarded during the period. The number of master's degrees remained steady with a high of 700 conferred in the year ending June 1958. Only 3.7% of the bachelor's degrees in geology, 3.1% of the master's and 2.1% of the doctorates were conferred upon women. Fifty-four institutions awarded doctorates in geology during the 10-year period

Longwell, C. R. (Chmn.), (1947), "Final report and recommendations of the Committee on Geological Education, Division of Geology and Geography, Nat'l Research Council," *Interim Proceedings, Geological Society of America,* Pt. 3, August, p. 16-20.

Recommendations include:

1) Wider recognition of geology in general education and in high school programs;
2) Revision of curricula to include more science and mathematics;
3) Revision of teaching techniques away from descriptive and authoritarian techniques and toward those which incite scientific curiosity and rigorous thinking; and
4) Greater proficiency in foreign languages. There is also a suggestion of an educational journal for geology.

Longwell, C. R., (1946), "Third Conference on Training in Geology," (called by Nat'l Research Council under auspices of the American Geophysical Union), *Interim Proceedings, Geological Society of America,* Pt. 5, July, p. 1-26.

This commentary, by 21 conferees, is concerned largely with training in geological engineering and geophysics.

Longwell, C. R., (1946), "Second Conference on Training in Geology," (called by Nat'l Research Council committee under auspices of the American Association of Petroleum Geologists), *Interim Proceedings, Geological Society,* Pt. 4, June, p. 1-39.

Three principal conferees presented papers: (two of which follows):

Hubbert, King L.: Hubbert discussed chronological developments of geo-

logy from the natural science phase, and reasoned that a curriculum might be organized in the same manner. He feels that sufficient time is available in the four-year program, unless students are loaded down with unnecessary information.

Delo, David M.: The small and liberal arts colleges were surveyed for a summary of their undergraduate major data, which is presented in tabular form, separated into geology and colateral courses; this is followed by an undergraduate major proposed by the author.

Lougee, Richard J., (1947), "Cultural versus the professional approach to geology for college students," Fifth Conference on Training in Geology. (American Association of Advancement of Science in cooperation with Geological Society of America), *Interim Proceedings, Geological Society of America,* Pt. 1, March, p. 71-74.

This paper emphasizes the cultural and non-professional approach not only for the beginning courses in geology but also for advanced courses on the college level, recommending specialization and the professional approach for graduate studies.

McCaslin, John C., (1954), "Give us better trained geologists," *Oil and Gas Journal,* July 12, 1954, p. 146-148.

As an example of the better training now offered by American colleges and universities, the curricula at the University of Kansas is set forth as an example, requirements for the B.S. in Geological Engineering are listed.

McKinstry, H. E., (1947), "Review of previous conferences on training in geology," Fifth Conference on Training in Geology (American Association of Advancement of Science in cooperation with the Geological Society of America), *Interim Proceedings, Geological Society of America,* Pt. 1, March, p. 62-65.

A review and summary of papers and comments from previous conferences of this series.

McKinstry, H. E., (1946), "Desirable training for mining geology," *Interim Proceedings, Geological Society of America,* Pt. 2, March, p. 12-19.

After discussing the responses to a survey of geologists, the author points up the difficulties of obtaining the requirements of geology, engineering, business and the liberal arts in a four-year period.

McMannis, William J., "The Search for a Basic Geology Curriculum," *Geotimes,* V. 6, No. 8, p. 32-35, 3 tables, May-June, 1962.

Replies to a questionnaire sent out by the geology department at Montana State College are summarized. The questionnaire was sent to about 200 geologists in various phases of the profession seeking opinions on the future of the profession, feelings regarding general depth and character of training, and specific thoughts on what a basic geology curriculum should include. Nearly 54% of the 200 geologists answered the questionnaire completely, and these replies were utilized in assembling the accompany tables. Many others chose to answer in the form of a letter.

Melton, Frank A., (1947), "Proposed monograph of historical geology and the geological education controversy," Fourth Conference on Training in Geology, *Interim Proceedings, Geological Society of America,* Pt. 1, March, p. 49-58.

As indicated by the following table of contents, this paper is one of the most comprehensive and searching of this series:

1. Criticisms of geological education.
2. Is Geology a unique science or the application of other sciences to the study of the earth.
3. Faculty competence.
4. The issue of standardization: danger of accrediting power.
5. Advanced level monographs of historical geology.

Monnett, Victor Brown, (1962), "Status of Geological Education in the United States Today," *Journal of Geological Education,* V. 10, No. 1, pp. 22-27.

The author discusses the results of a questionnaire sent to 100 geologists

covering the United States. The responses indicate that in general geology departments have been increasing mathematics requirements during the past few years. A full year of chemistry and year of physics have become the rule rather than the exception, and some schools require even more. It is apparent that the required courses for geology students are becoming similar to those of beginning students in engineering.

The employment stuation and, to a much lesser extent, the additional course requirements, have had three major effects: 1) A four-year program is no longer considered adequate for geology students. 2) The number of students choosing geology for their vocation has greatly decreased. 3.) As a general rule, the better students are entering other fields.

Scientific research in all fields, including geology, has been receiving encouraging financial support from various federal, state, and industrial organizations, and more and more faculty members are becoming at least part-time research scientists. In summary, a shortage of students, particularly at the graduate level which is inevitable, will slowly result in a shortage of geologists. This shortage will gradually become known, and intelligent students will again be attracted to the field with a little effort on the part of the teachers. Until then, most departments of geology will continue to teach large freshman classes, work with dwindling numbers of graduate students, and seek more research projects and funds.

Murray, Grover E., (1958), "Some relations of teaching and research in geology," *Journal of Geological Education,* V. 6, No. 1, p. 19-20. Spring.

A poll of graduate students at Louisiana State University to select the best teachers, shows that 67 per cent of the best had research in progress as against 40 per cent for faculty as a whole. Concludes productive researchers are more likely to be good teachers.

Myers, B. R., "Case for Abolishing Senior Year in American Undergraduate Engineering Education," *IEEE — Trans. on Education,* V. E-6, No. 1, p. 1-8, September, 1963.

Discussion of feasibility of reducing duration of undergraduate training without changing that of college year; comparison of proposed plan with trimester plan of curriculum compression, with European "pass" and "honors" pattern, and with extension of program to five yr.; implication of some radical, though desirable, changes in implementation of proposed plan; advantage of earlier release of best students for advanced studies and of others for specialized training in industry, of type not available academically.

Neilson, James M., "The Teaching and Practice of Engineering Geology," *Can. Mining & Metall. Bull.,* V. 53, No. 584, p. 965-969, 4 tables, Dec. 1960.

A review of the various aspects of the field of engineering geology concludes with a comparison of the development and teaching of this relatively new professional specialization in the United States and Canada. The writer prefers to restrict the designation "engineering geology" to geological applications in the field of civil engineering and its related branches, and to differentiate it from geological engineering. The need for sound geological training is stressed. Such training will likely require at least one and perhaps two years of graduate study.

Neilson, James M., Snelgrove, A. K., Van Pelt, J. R., "Curricular and Professional Aspects of Geological Engineering," *Economic Geology,* V. 55, No. 5, p. 1048-1059, chart, Aug. 1960, 11 refs.

The geological engineering curriculum, recognized for over 30 years by the Engineers' Council for Professional Development, is still suspect in some quarters because of its relative emphasis on basic rather than engineering sciences.

An interdepartmental committee of broad scope at the Michigan College of Mining & Technology has spent a year on a critical study of the make-up of the curriculum in question with a view to putting it on a firmer basis within the engineering profession as well as within the geological fraternity. This

article endeavors to define adequately the scope and function of the geological engineer. To improve the integration of engineering and geology and to establish the validity of this discipline, a quantitative portrayal is advanced of the impingement of each on the other.

Paine, Roland D., Jr., "National Science Foundation," *Geotimes*, V. 6, No., 3, p. 8-11, 40-41, Oct. 1961.

The National Science Foundation is an independent federal agency whose Director is appointed by and reports to the President. The 24-member National Science Board is the governing body. Its members are also appointed by the President from the fields of science, education, and public affairs.

The major programs of the Foundation are centered around the following responsibilities: 1) Support of basic scientific research (not technology or applied research) and research facilities, 2) Support of education in the sciences, 3) Fostering the interchange of scientific information, 4) Maintaining a register of scientific and technical personnel, and 5) Appraising the impact of research upon the economy of the United States.

Parker, John M., III, "Geological Engineering Curricula," *Journal of Geological Education*, V. 9, No. 1, p. 13-18, table, Spring, 1961.

Curricula in geological engineering that have been accredited by the Engineers' Council for Professional Development (ECPD) are analyzed in terms of the categories required by that agency. The engineering nature of geological courses is briefly considered as they relate to professional practice in industry. A wide range of curricular requirements has received ECPD approval. Common to almost all programs are a minimum core of calculus, physics, chemistry, and some 30 credit hours of geological courses.

Pavlinov, V. N., "Nazrevshie problemy podgotovki inzhenerov-geologov," *Sovetskaya Geologiya*, No. 1, Jan. 1963, p. 29-39.

Problems of training engineers-geologists; critical review of system of geological education in Soviet Union with emphasis on coordination of programs between institutions of higher education, research institutes, and practical training.

Proctor, Paul Dean, "Industry and Geological Agencies Evaluate A Curriculum in Geology," *American Association of Petroleum Geologists, Bulletin*, V. 43, No. 9, p. 2228-2237, 6 tables, Sept. 1959, 16 refs.

The Missouri School of Mines and Metallurgy sought an evaluation of the Bachelor of Science in geology by sending questionnaires to employers in industry, geological surveys, consulting geology and geophysics. The study, made in 1958, was designed to test the adequacy of the basic requirements for the degree, to obtain suggestions for revisions in the curriculum and to receive any constructive comments pertaining to the training of students. Of the 105 questionnaires distributed, 85 were completed and used in the study.

Need for greater emphasis on fundamental training in the basic sciences (chemistry, mathematics, and physics) is apparent. "The data and letters indicate the desirability of a core curriculum of basic science and geology requirements. A minor division into petroleum and general geology at the undergraduate level, with the general geology subdivision including the needs of mining industry and geological surveys, would closely fit the evaluation pattern."

Prouty, C. E., "Nagt Reports on Curriculum Survey of Degree-Granting Geology Departments," *Geotimes*, V. 6, No. 3, p. 28-34, table, Oct. 1961.

The result of questionnaries circulated by the Curriculum and Standards of the National Association of Geology Teachers is tabulated and presented. Of the 250 geology-geophysics degree-granting colleges and universities polled, 228 departments responded.

Based on the number of schools indicating required courses, the following would be considered most important at the BS level: physical, historical structural, mineralogy, invertebrate paleontology, lithology, field geology, and general stratigraphy.

The table of courses indicates the extent of various course offerings, the number of credits, the intent of courses, whether required, recommended, or elective, at all three degree levels.

Foreign langauge, mathematics, and chemistry requirements are noted. Questions were also directed toward instructional practices, and an equipment survey.

Quirke, Terrance T., (1947), "Geology for engineers," Fourth Conference on Training in Geology, *Interim Proceedings, Geological Society of America,* Pt. 1, March, p. 16-23.

The value, content, and problems of a course in geology for engineers is discussed.

Roy, Chalmer J., "The sphere of the geological scientist," *American Geological Institute,* Washington, D.C., 28 p., Illus., fig., 2 tables, 1962.

The pamphlet attempts to present the challenge and fascination of the geological sciences. Emphasis is on the abilities and methods used to discover knowledge about the earth. Technical application of knowledge about the earth is essential to the welfare of the society but how and where this may be done is a lesser consideration.

This pamphlet is written for college students who have some interest in, and perhaps some knowledge of, the geological sciences. It is hoped that readers will find helpful information with respect to the following: 1) The nature of the geological sciences and their relations to other sciences; 2) The more common scientific and professional specialties to be found in the geological sciences; 3) Major types of career opportunities and the specialized training most essential in each; 4) General educational requirements for those who would prepare for careers in the geological sciences. The requirements stated here are mainly for undergraduate and first-year graduate students, and do not consider the more specialized programs of advanced graduate work.

At best, readers will be able to better appreciate the reason for certain academic requirements, to plan individual academic programs of superior quality, or to select courses in the gelogical sciences most appropriate to programs in other fields. At least, readers should be better prepared to discuss courses, programs, or career opportunities with appropriate members of the faculty or other members of the geological profession.

Russell, M., "Ratios of Students to Faculty," *Geotimes,* V. 4, No. 6, maps, 2 tables, March 1960, refs.

The ratio of geoscience students, junior through graduate, to faculty in the United States ranges from 5.1 for private New England schools to 12.3 for public West South-Central schools; the average is 8. In Canada the average is 7.8 Charts shows for the U. S. percentage distribution of geoscientists by region of employment; average number of geoscience students per faculty member in departments offering the Ph.D. degree, in departments offering the Master's degree, and in departments offering only the undergraduate degree.

Schuhmann, R., Jr., "Education for Future Engineering," *Journal of Metals,* V. 15, No. 12, Dec., 1963, p. 935-938.

Proposal by others that a master's degree be made first professional engineering degree is countered by suggestion that engineering education within present degree pattern be continued and improved by further development and strengthening of engineering sciences as useful and usable science and as areas for graduate research; and by development and strengthening of engineering design and synthetic thinking to balance present emphasis on scientific analysis.

Shuler, Ellis W., (1929), "Undergraduate preparation for the geologist," *Bulletin, American Association of Petroleum Geologists,* V. 12, No. 10, p. 1317-1322.

An early concern is shown for the subject, decrying the specialization and diversification of geology courses. A survey of 100 geologists recommended from 36 to 42 hours of fairly standard courses, emphasis upon mathematics, and allied sciences, a foreign langauge, and English.

Courses and Hours Most Frequently Mentioned in Survey (Shuler)

Gen'l Geol. (Presum. Incl. Hist.)	6	Field Geol.	3-6
Mineralogy	6	Stratigraphy	3
Petrology (Rocks and Rock Min.)	3	Sedimentation	3
Structural	3	Petroleum	3
Paleontology	3-6	Ad. Gen'l Geol.	3-6
Economic	3	(Physiogra. or Geomorph. Incl.)	

Some Sample Schedules at Different Schools

Gen. Geol. (incl. Hist.)	6	6	6	6
Mineralogy	6			6
Rocks & Minerals or Petrology	3	3	3	3
Structural	3			
Paleontology		3	3	6
Economic	6			6
Field Geology	6	3		6
Stratigraphy		3	3	
Sedimentation			3	
Petroleum		3		
Physiography			3	
Historical (Adv.?)			3	

Smith, H. T. U., (1947), "Use of aerial photographs in geology," Fourth Conference on Training in Geology, Interim Proceedings, Geological Society of America, Pt. 1, March, p. 2-7.

The use of aerial photographs as a teaching aid in many courses in geology is emphasized.

Socolow, Arthur A., (1958), "Bread and butter courses may be fattening," *Journal of Geological Education,* V. 6, No., 2, p. 1-2, Fall.

Introductory geology, course should be a "show-piece" with a wide intellecutal appeal, rather than just a well populated money maker. Choice of instructor is important.

Stevenson, Robert E., (1959), "Geology in an academic year institute," *Geotimes,* V. IV, No. 1, p. 15, July-Aug.

Brief description of the program for geology majors of the 1958-59 Academic Year Institute held by the State University of South Dakota.

Taylor, Ann Richards, (1946), "Geology as a profession," Vocational Booklet No. 1, National Roster of Science and Special Personnel, and U. S. E. S., Department of Labor, pp. 14-16.

A section of "Training" in this booklet lists the recommended pre-college training and the minimum recommendations in geology, in mathematics and related sciences, and in background and related courses.

Pre-College (in high school)

Mathematics (through solid geom.)		2 Modern Languages	
Biology		Advanced English	
Physics		Geography	
Chemistry		Drafting-surveying	
Required College Level		*Science and Mathematics*	
Gen'l geol.	1 yr.	Math. to incl. Trig. and Calc.	
Mineralogy	½ yr.	Biology	1 yr.
Rock types	½ yr.	Physics	1 yr.
Historical	½ yr.	Chemistry	1 yr.
Paleontology	½ yr.		
Structural	½ yr.	*Background Courses*	
Economic	½ yr.	Two Modern Languages	
Mapping and Technique	½ yr.	English	
		Economics	
		Political Science	

Related Fields
Mining, Hydraulics
Geophysics, Elect. & Magnetism

The following series of conferences and committee reports are the results of a suggestion made in December, 1945, by Dr. H. R. Aldrich, Secretary of the Geological Society of America. Although several other committees were later organized, under the auspices of different organizations, all of the reports of this series were published in the *Interim Proceedings,* of the Geological Society of America. The forward to the first conference reiterates some of the earlier recommendations of the American Association of Petroleum Geologists reports. In addition, an accrediting system is recommended, "with minimum requirements for admission of a teaching department into the accredited list"; however, care should be exercised so that such requirements do not exclude small departments, many of which have unusually excellent records in training of geologists.

Theil, Geo. A., (Chmn.), (1949), "Report of the Committee on Geological Education of the Geological Society of America," *Interim Proceedings, Geological Society of America,* Pt. 2, July, p. 17-21.

The summary and conclusions or final report of the committee appointed in December, 1946: The committee feels that the present problem is one of transition from where we are (in a natural history phase) to a new destination which we hope to reach in the near future. Recommendations include one year of communications, one-half year of drafting, two years of one or more foreign languages, mathematics through calculus, chemistry through physical, two course years in physics; in geology, three and one-half course years devoted predominantly to general, mineralogy, petrology, and field geology. Some recommendations are also made for gradaute training.

United States Department of Labor, (1955), "Educational requirements for employment of geologists," *V. A. Pamphlet* 7-8.5, prepared by Bureau of Labor Statistics, Dec., p. 1-11.

Degree requirements, statistics, and employment possibilities are listed, followed by a statement of general qualifications. The latter includes training in each of the fundamental geologic disciplines supplemented by a knowledge of physics, chemistry, mathematics, biology, and engineering. The student must also know the techniques of surveying, map making, note-taking, specimen collecting and training in laboratory methods. Knowledge of a foreign language is desirable, and an acquaintance with economics and business administration prepares employees for advancement into responsible positions in industry.

United States National Science Foundation, (1953), "Report of the National Science Foundation — Beloit Conference on Geologic Research in Colleges," Beloit College, p. 1-16.

The report of a conference sponsored by the National Science Foundation included representatives of 30 colleges. Research possibilities in the smaller college might be enhanced by additional scholarships, support for field training, and additional equipment and library facilities.

Van Siclen, DeWitt C., "Some trends in geological education," *Houston Geol. Society Bulletin,* V. 5, no. 8, p. 9-11, April, 1963.

When the petroleum industry's supply of investment dollars slackened in 1957, it was found that many geologists were so finely adapted to the narrow environment of the petroleum industry that they could not survive professionally as scientists or engineers, in any other. Today's advances in knowledge and technology are so rapid that the professional man must continually add significantly to his education throughout his entire lifetime. Although the better means by which the education of professional people and faculty members can be continued are not yet obvious, the problem is becoming apparent and will have to be faced during this decade and solved within the next.

Walper, Jack L., "The University's Role in Industrial Geological Education," *Journal of Geological Education,* V. 12, No. 2, p. 54-56, June 1964.

So rapid is the pace of changing concepts in modern geology that it has become necessary not only to bring the scientific background of many company geologists up to date, but also to acquaint them with new ideas and developments in all fields of science. To this end, the University of Tulsa, (Oklahoma) has offered two short courses to geologists from industry. These courses are staffed by scientists who are authorities in their respective fields. Over-subscription of the courses shows a need for such continuing education and a desire on the part of company management to take advantage of opportunities to upgrade and stimulate their geologic personnel.

Willard, Gates, (1960), "A new role (sic) for the graduate geologist," *Geotimes*, V. IV., No. 8, p. 14-34, May-June.

A ninth grade course in earth science shows the interrelationship between a number of scientific disciplines. Earth Science teaching is a possible new field for geologists.

Winchester, John W. "Undergraduate Preparation for the Student of Geochemistry," *Journal of Geological Education*, V. 10, No. 1, p. 13-17, March 1962.

Recent developments in our understanding of chemical processes in the earth require the application of a much broader range of skills than is usually developed by students in most geological curricula. These skills must be developed within the framework of either earth sciences or chemistry. A program of study embracing the elements of all the major fields of chemistry, together with an introduction to the principal areas of knowledge in the earth sciences, is recommended for geochemists. This should involve the creation of new courses in the earth sciences which introduce the main concepts and techniques and at the same time make maximum use of chemical methods and especially the problem method of teaching. In addition there should be chemical instruction strongly oriented toward relevance to the earth sciences. The task of complete curriculum development may require several years, and we should probably recommend now that undergradaute students of geochemistry follow a conventional chemical curriculum supplemented with a minor program in earth science, and undertake strictly geochemical study on the graduate level.