Human resources in geophysical exploration

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Chairmen

D. Mabey
U.S. Geological Survey
Washington

G.D. Garland
University of Toronto
Canada

Panel members

J.C. Hollister
Colorado School of Mines
U.S.A.

B.P. Dash
Imperial College
England

J.M. Brown
United Nations
New York

D.S. Parasnis
Boliden Mining Co.
Sweden

Mr. Mabey

I am Don Mabey. George Garland and I are cochairmen of this panel discussion on human resources in geophysical exploration. The panel members are J.C. Hollister, B.P. Dash, J.M. Brown and D.S. Parasnis. George Garland and I will start the discussion with a few brief introductory remarks. I will speak from the aspect of users of geophysical talent and George will represent the institutions producing geophysical talent. Following this, each of the other panel members will make brief statements and the meeting will then be thrown open for discussion involving the audience as well as the panel members.

Dr. Seigel has asked me to discuss the problems encountered in obtaining and retaining an adequate geophysical staff to conduct a program of laboratory and field investigations. My direct experience in this area has been limited to the problems encountered by the United States Geological Survey. Although the problems of the USGS are not typical of many other users of geophysical talent, I assume that the major ones are, to some extent, similar.

Throughout my experience with the Geological Survey as the supervisor of scientific programs, the primary limitations on our programs has been the availability of well qualified professional personnel. Despite a few short-term financial pinches, adequate funds have generally been available to expand the geophysical phase of our program as qualified personnel become available to us. The primary problem is that there is simply not an adequate supply of well trained geophysicists available to meet the expanding demand and also that considerable competition exists to divert the available talent into nonexploration activities. Several things can be done to facilitate the training of additional geophysicists and the continual upgrading of the talent that is already employed in geophysical exploration. Employment in geophysical exploration should be made as attractive as possible so that the people that are adequately trained will select exploration geophysics as a career and will stay with it. Our operations should be continually examined to make certain that the most effective use is being made of the talent that is available.

What can the users of geophysical talent do to increase the number of students that are graduated from the colleges and universities who are qualified and committed to careers in exploration geophysics? Organizations engaged in geophysical exploration should try to obtain more publicity for the profession of geophysics, particularly among young people of precollege age. Most young people select a career without ever knowing what the possibilities are in geophysical exploration. Numerous opportunities exist to make the public, particularly these young people, aware of what exploration geophysics is and what a geophysicist does, but more often than not I think we ignore these opportunities. In the U.S. Geological Survey we have found that programs of part-time employment of senior high school and college students is an effective method in interesting people in careers in geophysics, particularly if we take the little extra effort involved to make this work exciting for them even though they may be doing some very routine tasks. Once the student has become interested in geophysics, financial support, through fellowships, scholarships, research contracts and grants is important to the maintenance of effective geophysics departments. The quality of instruction in exploration geophysics can be improved by involving the members of college staffs in research and exploration programs, either on a consulting basis or on a part-time employment basis, and outstanding geophysicists employed in industry can be encouraged to spend a portion of their careers in the universities in training geophysicists.

The task of making a career in geophysics attractive to a young scientist is a real challenge. Salaries must be offered that will attract and retain scientists with the talent that most of us seek in a geophysicist. Some of us work in organizations with pay scales and promotion policies that are geared primarily to disciplines other than geophysics. It is a fact that a well trained geophysicist can generally obtain a higher starting salary than a comparably trained geologist; therefore, pay scales that are quite adequate to provide competent geologists are not adequate to provide the same competence in geophysicists. The position of geophysics and the geophysicist in the program of an organization is of critical importance in determining how interesting and how challenging a position is and will often influence the performance of the geophysicist in his position. Although considerable progress has been made in this area in the last few years, many creative scientists have left geophysical programs simply because the excitement and interest which can be a part of every exploration geophysics program was being denied him. Today, most mining and groundwater programs provide this desired sense of involvement for the geophysicist.

An important factor that has caused many people to forsake exploration geophysics is the probability of numerous moves and changes of headquarters. Many of these moves seem rather pointless to the individuals involved. Many of the organizations involved in mining geophysics have minimized this problem and shown that it is possible to develop sound world-wide or nation-wide programs while keeping the changes of headquarters to a minimum.

Careful selection of the location for home offices and research centers can ease recruitment problems. The U.S. Geological Survey has found, for example, that the people interested in earthquake research prefer to be headquartered in the San Francisco area of California, while our exploration programs are more easily staffed in Denver. I have found in recent years that an increasing number of people applying for employment make the location of the job a major consideration. Another important aspect of personnel management is the utilization of senior personnel whose training and experience has often been outdated by rapid advances in geophysical technology. We should recognize an obligation to people that have devoted the most productive years of their lives to an organization. I believe that it is morally wrong, and in the long run probably economically unsound, to discharge, or force into early retirement, senior people and replace them with recent graduates who may be better trained or perhaps obtained at a lower salary. Encouraging personnel to continue their education on the job will help solve this problem. In other situations, these senior employees can be shifted into positions where they can continue to be productive in the latter years of their careers.

It is also important that the employers of geophysical talent realize that an important part of the reward of top scientists is recognition by their peers and that recognition for geophysicists is commonly achieved through publication in technical journals. In noncommercial organizations, such as the U.S. Geological Survey, publishing is usually encouraged, but in some commercial organizations it is actually discouraged. This policy should be examined by management. In many situations publication policies can be liberalized without compromising the competitive position of the company. Encouraging attendance at scientific meetings, such as the one that we are attending now, can also be important in keeping scientists happy.

In general, the graduates that we have employed from the major schools in recent years have been adequately trained in the fundamentals necessary to qualify them for productive careers in geophysics. It is unfortunate that more staff members of geophysics departments are not more deeply interested and involved in exploration geophysics so that they will instill an enthusiasm for exploration geophysics in their students. Many universities are becoming increasingly oriented towards the more academic aspects of geophysics and as a result the students are not oriented toward geophysical exploration. On the other hand, universities that have top exploration geophysicists on their staff seem to turn out people that are enthused and interested in exploration geophysics.

I believe that a career in geophysics, both in field and laboratory work, can be made attractive to young scientists. It is a challenge to management as well as educators to interest young people in careers in geophysics. Once these people have been trained, management must realize that top scientific talent can be recruited and retained only by concerted effort to make the work interesting and rewarding both financially and intellectually.

Dr. Garland

Ladies and gentlemen, Mr. Mabey has covered most of the problems that one must consider in this problem of human resources for the mining geophysics industry and I intend here to be very brief, because we have four panelists who can present the points of view of both universities and of the users. The two panelists representing the universities, Professor Hollister and Dr. Dash, come from institutions in which geophysics is recognized as a discipline in its own right. One of the problems in assessing the place of geophysics in universities is that it finds itself in a great variety of homes. In Canada it has been traditional for geophysics to be in departments of physics, although in recent years there have been separate departments of geophysics and in some cases it is in a department of geology or even in a department of mining engineering. But the relation of geophysics to physics has been a very strong tradition in Canadian universities, and I should like to make a few comments from the point of view of one who, in a physics department, sees the opportunities presented to undergraduate students in physics. As Dr. Mabey has said, it is absolutely essential that you as users engage in public relations and put forth a case to the students. The young graduate of today in the field of science is a very sophisticated person, who is looking for a field that has challenging opportunities before him. The question of starting salary is normally of secondary importance to this man. The important thing is to convince him that there is a life of real challenge ahead. From our point of view in the physics department we see undergraduate students presented with a variety of fields in physics, many of them very exciting: the study of elementary particles, astrophysics, the study of the solid state. Geophysics is simply one of a number of exciting new fields. Then when we assemble a group of students in a program that we think is leading towards a career in geophysics, we find that even within this stream there are a great number of opportunities presented to the students today, because environmental science is big, it is exciting and it is heavily supported by governments. Even for the students in geophysics, there are very many opportunities apart from exploration geophysics as such. Let us say that the student has decided to go into exploration geophysics. You still have another competitor in your search for people and that is the petroleum industry, because the student somewhere has to decide whether he is more interested in petroleum exploration or in mining exploration. Of course you could argue that to some extent you offer a greater variety of problems, and possibly more opportunity at an earlier level for individual initiative, than does the petroleum industry. On the other hand, the petroleum industry offers several advantages.

One of the employers of geophysical students which has been most successful in attracting people is Geophysical Service Incorporated, with which I think you are all familiar. They, of course, have worked very hard at it. I don't know if many people have seen this book *A Cooperative Plan in Geophysical Education* produced by Dr. Schrock of M.I.T. For many years GSI have had a cooperative program of taking undergraduate students from various universities in the United States and Canada, exposing them to their operations in Dallas, arranging a training program and employing them for the summer. There is no question, I

think, that they have obtained for themselves through this an extremely good selection of students. I would suggest that the mining geophysics industry has not yet engaged in anything on the scale of the GSI program.

I should not like you to feel that the universities, or even the Canadian government, are completely unaware of this problem. Those of us who are associated with physics are reading these days this volume, known as *The Rose Report*. It is the study of physics in Canada, prepared by the Canadian Association of Physicists under contract with the Science Secretariat of the Privy Council. It is a recommendation of what physicists in Canada, both in the universities and elsewhere, should be doing. One chapter of this volume is devoted to earth science, and I should like to read one of the recommendations: "The Committee notes and accepts the statements from mining and petroleum industries that there is a severe shortage of geophysicists. We recommend that this can best be met by a moderate healthy growth of student classes, particularly at the Bachelor level. The industry itself will have to find ways to make its work interesting and challenging to geophysics graduates who now have a wide range of employment opportunities open to them." The problem is stated clearly to the universities, with the recommendation to seek a growth in those courses, leading to Bachelor degrees with special emphasis on geophysical exploration.

Dr. Dash

Ladies and gentlemen, I would like to present to you a brief summary of the supply and demand of the earth science manpower of Great Britain. Whether we like it or not, we in Britain today are dependent on scientists and technologists. In the general picture, the contribution of geophysicists may be small, but it is certainly significant.

On the subject of output of geophysical personnel from British universities, my personal experience lies only within London University. By and large this could be expanded to the other universities in the U.K. where geophysics is taught only at postgraduate level. Unlike North American universities, we have unfortunately no undergraduate courses in geophysics, and hence the net turnover at postgraduate level is not as high as one would expect. The postgraduate course is broadly divided into three degree courses, namely Master's degree, Master of Philosophy and Doctor of Philosophy. For these, we accept geologists, physicists and mathematicians. The durations of the M.Sc., M.Phil. and Ph.D. courses are one, two and three calendar years, respectively. The M.Sc. course is directed towards teaching and training. The other two are purely research degrees. The M.Sc. course consists of four terms' work. The first term brings the students up to a common level – the physicists are taught geology and the geologists, mathematical physics. There are also common courses in digital data processing, surveying and fundamentals of electronics. In the second term they are taught the general principles of geophysical prospecting. In the third term we tend to spread out into the two broad fields of geophysics, that is, applied and pure, without actually dividing the class into two groups. The reason for doing so is to initiate in the students an interest in either of the two branches. In the last term, from June till September, the students are assigned independent field or research projects of their own choice. Invariably, a person keen on academic geophysics works on laboratory or theoretical problems; an applied geophysicist is sent out to industry to gain experience in field problems. On completion of the course, they are required to write a report or a thesis, and are then subjected to written and oral examinations.

Unfortunately at the present stage I have no complete statistics of the total output of geophysicists from the U.K., with the exception of Imperial College. The following table shows the output of geophysicists from Imperial College during the last eight years.

Year	Ph.D.	M.Sc.	D.I.C.*
1959	2	4	15
1960	2	4	17
1961	1	4	15
1962	2	4	13
1963	2	3	5
1964	1	–	6
1965	2	8	15
1966	3	13	–
1967	2	18	–

*Until 1965 M.Sc. was a two-year course. The postgraduate Diploma of Imperial College (D.I.C.) was a one-year course.

The total number of Ph.D.s awarded in geophysics is not known. However, in the last 15 years there have been 674 Ph.D. awards in the U.K. in the geological sciences, which includes earth science, geology, geophysics and geochemistry.

Fortunately during the past few years the demand for geophysicists has always exceeded the supply, the various channels of employment being with industry, government organizations and universities. In numerical terms, out of the above 674 Ph.D.s, 26% joined the Government Geological Survey, 27% went into industry, 22% stayed on at university, 18% were lost in the 'brain-drain', and the remaining 7% were overseas students who returned home after completing their studies. Geophysicists accounted for only 2% of the 22% who stayed on at university. It is logical to assume that most elect to work in industry, where obviously they expect higher salaries. To meet the increasing demand from industry it is perhaps possible to train more geophysicists each year. Yet considering the number who stay on to teach, it is certainly insufficient for the university to make any expansion in teaching.

Obviously the figures in this survey can not claim to be exact, but it is difficult to see how they can be so far out as to vitiate the conclusions drawn.

Another serious problem is the 'brain-drain'. For the past few years Imperial College has been losing on average 60% of its geophysicists to industry in North America. The following table will show the trend:

Year	% lost to North America
1962	70
1963	25
1964	50*
1965	63
1966	50
1967	80*

*Also to Australia.

Admittedly the answer to the short supply of trained personnel depends on the growth of the teaching department of the university. The university can provide teachers by enlarging the student-teacher ratio, but can not persuade students to study unless sufficient funds are available for their maintenance. Furthermore, the training and research program in geophysics can not be carried out without ample funds. The only fund-giving authority in Britain is the Natural Environment Research Council. The Geophysics Department of Imperial College gets a maximum of six studentships a year. In addition there are two studentships from the industry. A total of eight in one year is certainly insufficient when one envisages a turnover of 20 or more per year. As far as the teaching and training program is concerned the funds available fall very much below the mark. Geophysical field training is expensive as a result of costly equipment basic to any trip. How then is it possible to bridge this gap? My serious contention is that since industry is taking most of our students, they should help us in enlarging our efficiency. Assistance could take the form of studentships, research grants and even donation of equipment. This type of assistance from industry is not unknown in the U.S.A. Oil companies are known to cooperate with universities, giving them modern expensive geophysical instruments and recurrent monetary grants. We occasionally get similar gifts of instruments from the few oil companies in the U.K. With a great deal of perseverence they can be brought into some sort of working order, but regrettably much time on field trips is spent in repairing these instruments.

We are pleased to see that there is a good deal of cooperation, in the form of exchange of students, through personal contacts between individual American, Canadian and British universities. It is most unfortunate that while North American industries take the maximum number of qualified geophysicists from Great Britain, they have not as yet cooperated with British universities on the same basis as with American universities, a policy which is outlined above. There is hardly any instance where we have received anything in return, except perhaps in the form of summer jobs. This is, however, meagre return for what they draw from us. I sincerely feel that they should establish a definite number of studentships in various universities, from which they can draw their manpower, instead of having their geophysicists trained at our expense, both financially and socially. With additional funds from them we could train more students properly, thus benefitting both the university and the respective industries.

Mr. Brown

The United Nations has difficulty in obtaining geophysicists for its mineral exploration programs. The objectives of these projects require experienced men with a sufficiently strong background in geology to be able to orient their work to the location of ore. Too often we find that the geophysicist whose basic training has been that of a physicist, has difficulty in recognizing the geological objectives. To overcome this the United Nations tries to station on a regional basis in the developing areas experienced geophysicists who have a strong geological background, and employ younger men to undertake the actual geophysical field operations. This is a compromise but at the moment it appears to be the best we can do with the people who are available to us.

With respect to the formal training of geophysicists, I think that their curriculum should include more reading of geology than would appear to be included at present – not at the expense of training in mathematics and physics but in addition to this. This type of training is, of course, for those who wish to be engaged in a search for raw materials rather than on purely academic pursuits. (I have found it possible for geophysicists to discuss applied geophysics at length and never mention the word 'geology'.)

This lack of geological experience is reflected in that when looking for managers of exploration programs the United Nations only rarely considers a geophysicist for such a post. This is a narrow but functional point of view. Usually geophysicists work within the framework of an operation designed by a geologist or mining engineer. This is unfortunate – too few geologists and mining engineers appreciate what could be done by the intelligent application of geophysical techniques.

The difficulty in obtaining suitably experienced and orientated geophysicists could perhaps be overcome, in part, by institutions such as the universities seconding their people to the United Nations. This would render assistance to the developing countries and at the same time the individual would gain experience which would be to his advantage.

The United Nations is increasingly making use of academic professionals to examine the conduct of operations and to advise on the application of techniques or the introduction of new techniques in mineral exploration.

Dr. Hollister

Ladies and gentlemen, fellow geophysicists. As I remarked to some of my colleagues this morning, we have been in business at the same stand for a great many years, hence it might be proper to make a few remarks on the background of geophysics at the Colorado School of Mines. I am well aware of the problems that the preceding speakers have enunciated, such as the difficulty of obtaining young people and interesting them in geophysics, particularly exploration geophysics. Geophysics as first taught in the United States, that is, applied geophysics, was a course by C.A. Heiland in 1926 on the Torsion Balance at the Colorado School of Mines. Between that time and 1950 graduates at the School got degrees in geology with what we call geophysics options, and they numbered some 200. In 1950 the degree of Geophysical Engineer was established at the School and about 400 young men left School with that particular degree. We have just made a degree change at the School and we are now offering the four-year B.S. in geophysics and the first graduates carrying that degree will be the class of 1970. The engineering degree will require a fifth year.

Regarding our curriculum, I'll just read a few of the rough percentages required in the various disciplines. Some 15 per cent of the young man's effort is in the humanities, roughly 40 per cent is in physics, mathematics and chemistry. We try to carry our physics through electric circuits, electronics and extended media. Mathematics goes through potential theory, complex variables and operational calculus. Chemistry progresses through physical chemistry. It seems rather surprising to people in the petroleum industry that we require physical chemistry, but I don't think it comes as a surprise to the mining people that we feel this is important. Basic engineering, 9 per cent, extending through mechanics. Geology, through stratigraphy and sedimenta-

tion, accounts for 17 per cent. In geophysics, exploration geophysics primarily, (although the lads have a course in round earth physics), some 13 per cent. The rest is made up of free electives, plus physical education and military studies for the first two years. These details are naturally of interest only to individuals in a university or a department within a college who are involved in the curriculum. We do feel that the important thing is, since the man's education really begins after his formal academic experience, to teach the boys how to learn and how to think. We try to give them a basis in root principles, root ideas rather than the how to do it of today; it's the how to understand it of tomorrow that counts.

We have known the generosity of the various industrial organizations, of our own legislative committee of the state, and certain federal facilities who have helped us build our equipment and apparatus inventory to something rather in excess of half a million dollars.

We have laboratory space of 6500 square feet and office and classroom space of 5000 square feet. The student population in the department numbers approximately 29 juniors, 27 seniors and 35 graduate students, about half of whom are Ph.D. candidates. Roughly 40 per cent of the undergraduates, or those graduating with the engineering degree, will go into exploration. I must say that the majority of these do go into exploration for petroleum simply because the demand is terrific and I'm sorry to say the starting salaries are quite exaggerated. When an average young man after four years is offered 850 bucks a month it seems a little out of order. We do our level best at every suitable opportunity to point out to the boys that if they work hard for a long time they may begin to earn that salary and not to go away thinking they are worth it. Some 40 per cent of the boys go on to graduate school and we often recommend that they go elsewhere to get a different point of view for their graduate work, although some of them still insist on staying on at Mines. The remaining 20 per cent go into the armed services.

Our teaching staff is presently 7 1/2 full-time people. I am sure that Dr. J.E. White of Marathon Oil and SEG's new president would not like to be referred to as half a man – he is certainly not. But he does come out to the school and gives us the benefit of his industrial experience. I was quite surprised when I was once asked how much of the experience of the staff is in the academic field and how much perhaps in industry and government. So I made a quick calculation and found that we have 78 man years in teaching and 78 man years in industrial and governmental experience. For 7 people, or 7 1/2 people, that makes 20 man years apiece. The majority of those are made up by two colleagues of my own age and myself. The other fellows are young, active, full of what it takes.

Now the cost of operating any organization is very high. The cost of education is probably one of the most rapidly rising in any field I know. It is an inflationary business. Some years ago College Life Insurance Company made estimates of the increased costs over the years beginning with 1950 through 1980. At the time it was put out we had a substantiated history to 1960. As of '67 the cost per year is something like $1750 per student for the institutional operation. Add the cost of living of $1200 and we have roughly $11,800 four-year cost per student. As I look at the chart, it shows that the cost as indicated is $12,000 so I think that their statisticians, or prophets, are very accurate.

How do we pay for this? The student, or few students, can afford that much, that is $3000 per year throughout the four year period. Much of that money must come from the institution itself and certainly at the Colorado School of Mines at least two thirds of the out-of-state student's institutional costs have been paid for by the State of Colorado. The in-state student pays perhaps a tenth of that cost.

How can we increase the number of young men entering the earth sciences? We make an effort to travel to the high schools, and have a continuing program of introduction of the several disciplines within the minerals field that the School of Mines is active in. We invite groups of high school students from not just the neighboring cities but from all over the state to come to the School and spend as much time as they can there. We can take them around and introduce them to various departments. We try to show them what we do and interest them, naturally, in our department, in geophysics. If a man likes math, physics and the outdoors he's ideal for a career in exploration geophysics.

The Society of Exploration Geophysicists, as a good many of us I think know, has produced what is called *Careers in Geophysics*. A new edition of that is coming out today, or very soon. It is aimed not so much at the high school student as at the college student who as yet has not decided his ultimate professional discipline. I think the dissemination of information, both for the young college man and for the high school student, should be encouraged.

One final remark – the idea of continuing education, of maintaining a competence among our own profession by further education and a somewhat formal education is an excellent idea. The Seminar that Stan Ward is going to run, I believe in the spring, at the University of California, and the Data Processing Course, a short course that we at Mines have been giving for the last several years, are examples of the sort of continuing edification that I certainly feel is vital to our profession.

Sorry if I have run over my time, gentlemen. It is an occupational malady. I thank you.

Dr. Parasnis

Ladies and gentlemen, at this stage of the discussion I would like to make a few preliminary remarks. I am speaking with a background of experience in Sweden but perhaps this would be of interest to other countries where conditions are similar, like Canada. I mean similar in connection with prospecting. The people we need in our exploration department, as far as geophysics is concerned, could be divided here in two different types. One is the field operator, the other is the geophysicist. Now, the situation at present in Sweden is that we have a dearth of geophysically trained people. The consequence is that we have to train people ourselves. In the case of field operators, we at Boliden Mines recruit people directly out of school, that is, those who have gone through basic school. They come out of school about 16 or 17 years of age and we train them by special courses and tests and so on. These people have sufficient background and sufficient schooling, and easily pick up such things as observation technique, maintenance of instruments, minor repairs to instruments and so on.

Our real need in the mining industry is perhaps for the class of people that must be hired to supervise the field operators and this is the geophysical interpreter. The data the operators are

getting must be accurate and in many cases, of course, the data-collection stage must be supervised closely to get everything straight. It is here that we feel the lack of sufficiently trained people.

I would say that what we really need are geophysicists on the Bachelor level, that is, with a degree corresponding to a B.S. or B.Sc. I find it very hard to imagine that the mining industry, for instance, could absorb geophysics Ph.D.s at a significantly higher rate than it is doing at present. And in this respect I think that the program which Professor Hollister outlined here seems to be a very good program that meets the needs of the mining industry and perhaps also of the oil industry.

Now, in respect of the subjects covered in such a program, I think that this program is near-ideal for our needs. Inclusion of electrochemistry is a happy inclusion since this is a subject which is becoming important for mining geophysics. Questions like the interpretation of SP and IP anomalies imply a fair knowledge of electrochemistry. But I also think that geophysics students at the bachelor level should have a good basic training in electronics.

The situation in Sweden, as far as the construction of electronic instruments in geophysics is concerned, is that we have employed a number of electronic engineers to construct our equipment or to modify equipment bought from commercial manufacturers. I might add that equipment bought ready-made usually falls far short of our requirements of portability, ease of operation, weight, size, water-proofness, etc. However, it is difficult to keep all electronic engineers satisfied in the sense of giving them challenging work all the time (from the electronic point of view) so that after a time some tend to leave to seek jobs in a proper electronic industry like TV. If we had a geophysically trained bachelor who has undergone courses in basic electronics, he could also be used for the construction of simple equipment, for servicing it and so on, whenever there is temporary shortage of specialists.

This, I hope, will give you a general idea of the sort of people we need. Concerning Dr. Dash's remark that industry is not paying anything for the universities to produce geophysicists, this is not the whole story because, of course, industry is paying its share in taxes. In Sweden, where all university training is state-managed, industry taxes imply a significant contribution to all education. Industry also employs summer trainees and apprentices.

Discussion

Dr. Garland. Thank you Dr. Parasnis. The problem is obviously a very complicated one. Dr. Dash has pointed out that an institution in one country may be producing a large number of people who go to work in a different country; unfortunately the taxes paid by their employer may not come back to the institute which is training the men. Mr. Brown has asked for a 30-year-old physicist with 20 years of experience in geology. Dr. Hollister has told of some of the problems his institute has in both financing the program of education and continuing to attract people. I think at this point it would be appropriate to open the meeting to comments on any phase of this subject from anyone in the audience.

Dr. K.C. Dunham, Institute of Geological Sciences, London. Mr. Chairman, I think this must be a unique discussion. It is probably the first time that the problem of the shortage of geophysicists has been discussed internationally.

I have one or two rather widely different points. The first one arises from Dr. Tuzo Wilson's remarks. Like him, I feel strongly that geophysics is now reaching a very exciting stage, especially on what you might call the academic, or the purely scientific side. It is going through a period of breakthrough which is not unlike what happened to other branches of science some time back. Now ever since the end of World War II it seemed to me that the most glamorous variety of science has been nuclear physics. It has grown up and the nuclear physicist has continued to work either in universities or in the few government establishments which can afford the very expensive machines. The man trained in nuclear physics, certainly in our experience in the United Kingdom, has had very little impact on industry. Of course, nothing goes on forever and I don't know whether Professor Garland, for example, would agree with me in saying that there is a suspicion that the end of the great development in nuclear physics is in sight. One of my rather cynical friends in the higher reaches of this subject remarked to me the other day that if they could solve one more equation the whole thing will be finished. I don't know which equation he was referring to. It does look to us in Britain as though there is going to be a big shift in emphasis in physics. This is partly being taken up in solid state work, but I wonder whether there is not an opportunity to be exploitive in favour of geophysics. I would be most interested to hear comments on how this appears to you in other countries.

The second point concerns the background of people who are barely able to become effective geophysicists. Looking at the British people, we do not produce enough youngsters who are well qualified in mathematics and who will be interested to go into the problem of physics. Or indeed enough people well qualified in mathematics who will go into geology, because increasingly the use of these more sophisticated statistical techniques becomes necessary on the geological side as well as the geophysical. I am not sure that one of the problems is not to do something about raising the standard of mathematics in the high schools. I think it has risen to some extent since World War II, but I am sure that it has not risen sufficiently yet.

Speaking finally as an employer of geophysicists, like Dr. Mabey, I am not able to obtain sufficient men with the right qualifications and training, and this of course, is due partly to our considerable exports to this side of the Atlantic. The fact does remain that as far as our small country is concerned, we need to produce more geophysicists. I believe in urging this strongly upon our university grants committee, but I think it is unlikely they will be willing to encourage the growth of geophysics in Britain at a time when they are not going to be very encouraging to the universities in general.

Dr. Garland. If I could make one comment in reply to Dr. Dunham, I should like to point out an article in the *New Scientist,* December 1966, entitled "Crucial Decade for Basic Science". It points out the tremendously rapidly in-

creasing cost of basic research in nuclear physics and space research, and asks "ought the scientists to allow themselves to be carried away by their own enthusiasms to the detriment of underprivileged humanity which needs their brains? ". The author is urging a return to, if you will pardon the expression, 'useful science', with perhaps less emphasis on the very expensive aspect of basic research.

Dr. S.A. Vincenz, St. Louis University. I am very much interested in Dr. Dash's remarks about the brain-drain from the United Kingdom. I would just like to make a few remarks about one of the American schools, since I am one of the current exports from the U.K. We at St. Louis University, in training exploration geophysicists in the undergraduate school, have experienced deterioration in the number of B.S.s that have been produced. On the other hand, the number of graduate students is increasing all the time. Since I have been at St. Louis the average number of undergraduates has been about three every year. We have five seniors this year. Two years ago we had 18 graduate students. Of course, they were not all solid-earth geophysicists, half of them being meteorologists. This year I think we have about 60, most of them are Ph.D. students, working in one or another federally supported research project. I would say about 50% or more are from outside of the United States: from Arab countries, from India, from Latin America, and most of them remain in the United States. They get jobs, usually in the oil industry, or in the universities, very few of them with the mining industry. Professor Garland has mentioned that it is the challenge that is very important, and that appeals to the student. He does not want to make money really. Of course he does want to get a good job. He is really interested in doing research to open new vistas. I think that the mining industry, or any industry, interested in geophysics should try to realize that it must open up some possibilities for these students to use their brains. In this sense, Dr. Dash's remarks, I think, are very good.

Dr. E.M. McNatt, Standard Oil Company, New Jersey. I would first like to make a comment on the question of how to attract people into geophysics, and second to ask a question. I think Mr. Brown presents a very real and difficult problem, because a geophysicist is expected to be a physicist and a geologist, a mathematician, and sometimes a chemist. If I were a young man, I think this would be a little discouraging because any one of these fields is difficult enough in itself. It is a very real attitude that a geologist is expected to be a geologist, but a geophysicist is expected to be all things to all people, and I think this is a difficult situation. What is the magnitude of the problem we are talking about? How many geophysicists are needed? Does anyone have the answer to that?

Dr. Hollister. May I reply in answer to that? An estimate was made about a year ago by one of the major oil companies for their needs. They said, "We will be able to hire one of the ten geophysicists that we will need who is trained in geophysics. We will get one more, perhaps, from mathematics or physics, we will get one more from the engineering (electrical engineering) area. The rest will come largely from geology and have to be trained by us in geophysics".

This is perhaps an exaggerated point of view. I realize that each one of our lads who are undergraduates has at least four or five offers. In other words, perhaps we are training about one fifth of the number of geophysicists that are needed to carry on a continuity of personnel within an organization. But, I must say this, that part of this shortage is due to the shortsightedness of management of a few companies, who indulged one time in the midfifties and early sixties in a wholesale termination of exploration personnel without making the effort of shifting them from one area to another in their own organization. Because of the few, the whole industry is badly in need now of personnel. Young men capable of being good explorationists are capable of getting good scientific positions in other fields, and they were certainly discouraged by the fact I mentioned.

Mr. J. Affleck, Gulf Oil Corporation, Pittsburgh. I am one of the members of the brain-drain if you can call it that. Professor Hollister mentioned what the oil industry did in the fifties. I think our industry learned a lesson from this wholesale layoff. I myself doubt it would happen again, because I am sure we would have to agree that we find ourselves with a gap in our age group – there is a big hole. We have people elderly, such as myself, and then kids coming along, and we don't have any replacements in the next echelon. So I think we are conscious of that and we are not very likely to make that mistake again. The other point that you made was the shortage of geophysicists. We think that the supply is about 10% of the demand right now in the oil industry. We have started a training program in which we are picking up engineers, mathematicians and others and we are doing the education to make geophysicists of these others. How successful we will be I don't know.

A last comment on Dr. Dash's remarks is perhaps that there is a law called The Law of Supply and Demand and the reason for the brain-drain is because people like money. They come to this side because they are rewarded for endeavour. But it isn't one way, because we send geophysicists and geologists back. Some of us at least are trying some oil and gas in the North Sea, as one example. It is going to help the industry; it is going to help the world.

Dr. Garland. I should like to point out that Dr. Hollister and Mr. Affleck, in commenting on the demand for geophysicists, have used figures from the oil industry, not from the mining industry, and I think this is typical of the situation. The oil industry has been very much more articulate about their needs. They have maintained closer liaison with the universities. We do not even know what the real needs of the mining industry are.

Dr. Parasnis. I don't think I have seen any statistics concerning the needs of the mining industry in the world as a whole, but a few years ago we made statistics at Boliden regarding the needs of mining industry in Sweden. At that time we considered that every major mining company ought to have at least two geophysicists and, on this basis, we have calculated that the needs of Sweden would be satisified by approximately 30 geophysicists.

Dr. Dunham. Is it possible for some organizations to collect this information, for example, the Society of Exploration

Geophysicists? It did seem to me that the AGI did a very useful job as far as it went in finding out what the statistics of employment in geology and geophysics were in general. I am not a member of SEG. I'm just asking anyone who knows about it whether this is possible.

Professor Hollister. Certainly, I think the SEG, particularly through their Mining Committee, of which I believe Ralph Holmer is currently the head, would be not only interested, but willing to help. The Society, I am convinced, will gladly put out any of the funds necessary to make such a survey. Regarding Mr. Affleck's remarks, I was not referring to Gulf's estimate of its needs, but actually Pan American's, and it came out identically. Apparently the oil companies have spent some time doing exactly the job that perhaps the SEG could do for the mining industry. Perhaps some of the larger companies might pool their resources both in Canada and the U.S. to carry forth such a survey. I will be very happy to ask Ralph Holmer if SEG can help.

Dr. Dunham. I don't know, sir, to what extent that covers Europe, and of course it is almost certain that it doesn't cover the Eastern world, but at least this would be an important start. I think perhaps that some of us in Europe might try to do something from that end.

Mr. Jon Baird, Seigel Associates, Toronto. It appears to me that this so-called 'shortage' of geophysicists within the Canadian mining industry can't be too acute, or we would have heard something from some Canadian mining company already. We would have had some of these statistics prepared. However, presuming that there is a shortage, it is not surprising to me that there is one, because I really don't feel that we are gearing ourselves towards producing exploration mining geophysicists. There has been very little cooperation between the companies and the universities. It strikes me that we have one role in this business, and that is to find mines. When I think back to my university career, which ended not too long ago, this was never really impressed upon me. I took geology courses and I took physics courses, and I took some geophysics courses, but when I think back, we should have had a 'beer and bull' session once a week on mines in Canada, or in the world. As has been pointed out, an exploration geophysicist requires certain talents and certain abilities, which can only be brought to the fore by a discussion on a common goal, not learning magnetics or paleontology or anything else. It seems to me that if Canadian youth were presented with the idea of going out and finding mines they would grasp it. I think so many Canadians feel as I do, that our natural resources are a great part of the future, that it can be presented in such a way that people will become interested. But I don't think Canadian mining companies or universities are interested in producing exploration geophysicists.

Dr. Garland. Thank you Mr. Baird. That is a very interesting comment from one who found a mine in spite of his education. But I think that there is a point that Mr. Baird and Dr. Parasnis have emphasized, of the need for people at the Bachelor's level. In the departments of pure science in the university there is tremendous pressure for the good students to go on to graduate work. I think myself that one way of filling the need is to encourage the faculties of engineering to develop their courses in exploration. In engineering you will have students that have a professional interest and a very definite goal, and who do want to go out at the Bachelor level and do this kind of work, yet in Canada we have only one university in which there is considerable emphasis on geophysics in the Engineering faculty.

Professor Hollister. I might comment that we are an engineering school and certainly we will welcome all the young men from Canada to come to the Colorado School of Mines.

Prof. W. Slawson, Dept. of Geophysics, University of British Columbia. We have at our university, five streams through which a student may obtain a Bachelor's degree with some connection with geophysics. Two of these streams are within the Faculty of Applied Science, and three are in the Faculty of Science. Two of the three in the Faculty of Science prepare the students primarily for graduate work. These are what we call our honour programs. These students do go on to graduate work, and they are stimulated to graduate work by the breakthrough Dr. Dunham was talking about. They are interested in the picture of the earth as a whole and these students in the honour program seem to have very little interest in exploration. The students who go through the other streams in the Faculty of Science are in the majors program. It is not equivalent to the majors program as known in the United States, but it does prepare the students for the exploration industry. We have had the programs in existence for only three years, and last year was the first year we turned out very many graduates. In the total five streams I think we had about a dozen students, and there will be about the same this year. In the majors program, which consisted of six to eight students last year, most of these did end up eventually in exploration. Unfortunately for the mining industry, many of them were lured to Calgary by the oil industry. Dr. Mabey suggested summer employment as interesting students into the fields of geophysics. Several years ago, the oil companies came to us on one of their recruiting trips and they very graciously took several of us out to lunch and they asked, "Why aren't we getting our students into geophysics? " We said, "The trouble is that our students come back from the summer jug hustling on the prairies and say that oil geophysics is not for me". The oil companies asked, "What can we do about this? " and we said, "Well, get these students into Calgary, let them see your interpretation offices, let them see what goes on in the inside of the company and not on the fringes." The students have been doing just this, they have been working in the office in Calgary, and come the spring when they graduate they go back to work in Calgary.

The mining industry in British Columbia has gone to almost the other extreme. First of all they don't communicate with us at the university very much. The students that come back from a summer in the field say, "I went to work in June and I was handed ten thousand dollars worth of IP equipment which I had never seen before and I didn't really know anything about, but I was a college student, so therefore I was expected to know everything about it and they said to go forth and use this equipment." And so they were frustrated by being given too much all at once. If they

had, instead of working on their own, been able to work with somebody who had some experience, I think they would have ended up in a much different position.

I have been polling our students that I find around the corridors here, as to how our programs have prepared them with what they need when they get out into industry. The comment which I have received is, "Let's drop some of the geology and put more mathematics into your programs. Not the theoretical mathematics such as they get in the mathematics department of our University, but applied mathematics, useful mathematics such as the kind which involves time series analysis and so on."

Mr. Baird. My question is that if you are trying to recruit somebody to go and find a mine, why don't you teach him in the first year the most practical parts of actual mine-finding? I don't mean how to push buttons on an IP unit, but the fact that IP is used in mineral exploration. The fact that EM is used. I quite agree with the theoretical approach, it is very important, but as you said it is only in fourth year that you really find out that things like IP or EM exist. You may have spent a couple of summers doing mineral exploration using a given machine which has been presented to you and you learn to use on your own, but you don't see the over-all spectrum of how mines are found.

Mr. Brown. May I make a remark here? In discussions with the United Nations teams all over the world involved in exploration there is a general belief that there are very, very few geophysicists capable of deciding answers through geophysics. In the younger techniques there is a lack of philosophy with respect to finding exploitable materials on the part of geophysicists.

Prof. D.H. Hall, Dept. of Geology, University of Manitoba. I would like to make one remark about a very fruitful contact that was made between industry and universities in Canada. Two or three years ago the Society of Exploration Geophysicists held a week-long seminar to which they invited geophysics professors and showed us completely through all phases of their work and invited us into the secret rooms. Everything was opened up beautifully and during that conference we had a discussion about the very problem we are talking about today. One of the results of that was a program that has been carried out by at least one of the companies, of taking students in to work during the summer and providing them with information and material for research. This has been very beneficial for us and very good for the industry too. Perhaps people on the panel can tell us of other examples where something like this might be done again.

I think one of the problems is getting down to the high school students. One of the things we have found is that students come to the university with no feeling that exploration or even study of the earth is an important part of science. They don't come realizing that this is an exciting area of human life. In Denver there is an excellent program in the schools for teaching earth sciences and some parts of the book are almost as good as some of the things we see in the university text books. I would like to ask Dr. Hollister if there has been any appreciable impact on the high school population in the United States from the high schools earth sciences courses.

Dr. Hollister. I think it is a bit too early to judge the full impact. The organization I think you are referring to was commenced by the AGI in Boulder. They produce an excellent volume for the secondary schools, which is broader than exploration geophysics. There is a section on physics, chemistry, applied geophysics and solid earth pure geophysics. I think that in a very few years it will have a large impact on young people and give them the idea of the excitement of the study of the earth. One of the difficulties now is that the secondary school teachers who are involved with this program are having their troubles in getting the program under way.

Dr. Mabey. I would like to raise one question here. A number of the major universities in the United States who have rather large geology departments do not have well qualified teachers in geophysical exploration. I know some of these are very actively recruiting now. Is the shortage of people to teach geophysics at the university level a major problem in increasing the supply of people graduated from the universities who are interested and qualified to work in the field of exploration geophysics? Do you have any ideas on that Professor Hollister?

Dr. Hollister. I would certainly say that the universities and colleges have a difficult time in interesting people in teaching. Often we will find a man who is a first-rate geophysicist in exploration who really feels he is incapable of being a teacher. On the other hand, we are very delighted when we can interest someone from industry to come to the schools. The demand is steady and unfilled for teachers of geophysics in universities. I have letters weekly asking if we don't know of a young man who wants to teach and it is very difficult to find someone.

Dr. Vincenz. There are psychological factors which we should take into account. I think sometimes we are forgetting there is a problem of temperament and a problem of fashion. Some students are temperamentally suited to be explorationists, and the right moment to catch them is when they have just got their B.S. and they are not married to any particular field. But the moment they have passed that temperamental period of their lives they settle and don't want to leave. It was mentioned here that students complain that they haven't had enough applied mathematics. This is absolutely true. I have a student who is proceeding to a Ph.D. degree who hasn't yet decided what he wants to do. I suggested to him to go into the field of instrumentation. He said that he would like to do some theoretical work.

Dr. H. Rychborst, Dept. of Energy, Mines and Resources, Ottawa. I would like to point out the situation in the Netherlands. I have been here for about 6 months. We have four universities producing about 14 or 15 geologists or engineers a year, 70% of them going to foreign countries. The government does not see this as a brain-drain, they see it as a healthy feature. We have dropped geology in all of our courses and added mathematics and physics. The situation is that as long as we cannot see what the industry demands will be for the next ten years, since it takes at least ten years to educate a Ph.D., we can't solve the problem of shortages in geologists or geophysicists or engineers.

Dr. Parasnis. I should like to make a

comment concerning the extent of mathematics that exploration geophysicists should have in their training. Professor Hollister has sketched a course in which the students are to learn up to differential and integral calculus. This knowledge is indispensable. However, concerning subjects such as information theory, filter theory, Fourier transforms, etc., I would say that in routine interpretations in mining exploration we do not as a rule require this high level of mathematics, because most routine decisions we make concern the placing of drill holes on the basis of clearly defined anomalies. On the other hand, I think that the mathematics and physics training of geologists who are handling geophysical data is far behind the times. In the first place, they have no idea about how to manipulate physical ideas and physical magnitudes and secondly, they are usually incompetent to treat the data quantitatively because their mathematics are insufficient. Geologists ought to be definitely more conversant with physics and mathematics than they are.

Subjects such as information theory, Fourier transforms, etc., have their place in advanced interpretation, also in mining geophysics, but I believe that the type of mathematical training needed for making routine decisions by exploration geophysicists is the sort of training necessary, say, for solving problems such as those in the book by Eve and Keys.

Dr. J.M. Harrison, Dept. of Energy, Mines and Resources, Ottawa. There are two points I would like to make, one of which is an emphasis of what has been said earlier by Professor Hollister and Professor Vincenz that exploration geophysics, or geology, or exploration earth science is a state of mind as much as anything else. Mr. Baird is extremely fortunate that he has that particular state of mind that he enjoys mine-finding. I know lots of earth scientists who are making substantial contributions who couldn't care less about finding mines, nevertheless the work they do is important towards that end and can't be discouraged.

The second point is the shortage. Although we are all worried about the shortage, I wonder how real or how acute it is. If there are 100 jobs available and 95 people applying, each applicant is going to get about five or six offers. If there are 100 jobs available and 105 applying, the student is going to have to make the applications. It may be a fairly small difference in numbers that will make an extremely large apparent difference in the situation. The other aspect of this is the making of silk purses out of sows' ears: that is, people trained in other disciplines can become geophysicists. I was at a meeting two weeks ago at which the astronomers were complaining they couldn't get enough astronomers, the mathematicians were in a terrible state, physicists couldn't get enough of the right kind of people. My friends in the social science field made precisely the same complaints. Obviously there are just not enough trained people available to do the work we want done, no matter what field you wish to go into. At the moment at least, it is a matter of competition. Earth sciences has an opportunity, as Professor Dunham mentioned, to make the picture extremely attractive to the student. We have to sell the idea through the exciting new ideas, techniques, the Holy Grail concept, for these imaginative and very idealistic young students of today. We must provide the proper image, and one way *not* to do this is to turn a good, excitable and exciting young student onto routine survey work. I support the point made by Professor Slawson about getting a lad into the interpretative field, where he can use his brains and see what all this is for. This is how we attract these men; not by sending them in the bush fighting flies and making monotonous readings day after day.

Mr. Affleck. I would like to speak on the point that Professors Hollister and Hall discussed, encouraging high school students into earth sciences. Some years ago, we in Pittsburgh tried a little experiment, through the Pittsburgh Geological Society, by making a series of five television tapes, half hour each, on earth sciences. They were directed at high school teachers, hoping to get them interested in earth sciences. After these tapes were used three times, they were converted to 16 millimetre film with sound track by the Pennsylvania Geological Survey. These films are available through the Pennsylvania Geological Survey to anyone that wants them.

Dr. McNatt. I would just like to second this idea that the real place to start is in the high schools. I will start with Professor Hollister's remark that people come to engineering schools because they want to be engineers. But I suspect that very few people, very few youngsters in the world are even aware of what exploration is all about, either in the mining or the petroleum industry. I was struck the other day by a movie my company made. It wasn't about geophysics, it was about oil in general as a source of energy, but the professional people who made this picked up a good deal of geophysics along the way and it made a pretty interesting and glamorous film.

It seems to me it would be an excellent idea for the mining industry and the petroleum industry to put out more than one professional film which would talk about exploration.

Professor Hollister. I believe there is a film that is being put together now covering the exploration end of mining. The film that was made by SEG a number of years ago, called, I believe, *The Earthquake Makers,* dealt primarily with the petroleum aspect of exploration, although it did indicate a wide use of airborne magnetics and airborne EM. I think it was quite a successful film. We have used it a good many times to show our own freshmen who are undecided what particular discipline of engineering they wish to enter.

Mr. Joe Anzman, U.S. Bureau of Reclamation, Denver. I just recently joined the Bureau; the seven years previous I was with a mining company, so I'll speak from the mining standpoint. Much has been said about getting people into exploration. This is important. No one seems to say anything about keeping them there once you get them. Dr. Harrison and Mr. Baird made comments which most closely agreed with my own feelings. Exploration is very obviously a point of view. A sound explorationist is by nature, in mining at least, an individual, a cantankerous type who can take data and numbers which are the results of his surveys and can relate these to geology, and then can relate this geology to the geologist in terms that he can understand. It's a man who can think independently about what he sees and he is also a man who can stand up on his hind

legs when necessary and argue loud and clear for his beliefs as far as the exploration end of things go. I think perhaps, in mining at least, that a great deal has been lost because we don't take these attributes and consider them as attributes.

It is the research geophysicist who is looked on as the leader. Perhaps it should be the field geophysicist, who is going to find the orebodies. Otherwise, he will go into nuclear physics, or some other field where he can use his discipline where he can be regarded as an individual, and as a person who is doing effective work.

Dr. Garland. Are there any other comments? The remarks made here this morning will of course appear in the *Proceedings,* and if we haven't come to any very definite conclusions, perhaps it is because we had an impossible task. However, we have agreed to ask the Mining Committee of SEG to produce figures on precisely what the needs in exploration as applied to the mining industry, are. Once we see those figures presumably we can take more action on the question.

Mr. Mabey. In closing I would like to thank the members of the panel and all of you in the audience who contributed to the discussion this morning.