PROPOSAL 19-95

PHD PROGRAM IN GEOLOGICAL ENGINEERING

The requirements to initiate the proposed PhD program are described in the attached pages from the Department of Geological Engineering and Sciences.

I. EXECUTIVE SUMMARY

The Department of Geological Engineering and Sciences at Michigan Technological University proposes to establish a Ph. D. program in Geological Engineering. This new Ph.D. program will build on the existing Ph. D. program in Geology (established 1965), and will simultaneously take advantage of growth in research in Geological Engineering and fill a nationwide demand for graduates at the Ph.D. level in this area.

The new Ph.D. will be the only Geological Engineering program in the State of Michigan. The existing B.S. and M.S. programs in Geological Engineering at MTU are well known and highly competitive programs on a nationwide basis, and the B.S program is currently among the largest program in the country. A new Ph.D. program in Geological Engineering will have a significant national impact, as only 7 Ph.D. granting programs in this research area exist in the United States and Canada. The program will have a particularly strong impact in the upper Midwest, where a Ph.D. program in Geological Engineering now exist only at the University of Minnesota.

The research programs in the department, as reflected in both graduate enrollment and research funding, have grown significantly in the past 5 years. Total graduate enrollment is now 34 students. This includes 14 Ph.D. students in Geology, which represents an increase of 55% over the last five years, and an increase of 180% over the last ten years. Of those 14 Ph.D. students, 3 would immediately qualify for a Ph.D. in Geological Engineering. Inquiries regarding a Ph.D. in Geological Engineering have also increased.

Research expenditures have grown approximately 250% in the last 5 years, to a 1993-94 level of more than $1 million, 39% of which can be attributed directly to Geological Engineering. On a per faculty basis this currently averages to >$100,000/faculty member. In addition, three Department of Energy research grants totalling about $4 million in the area of enhanced oil recovery techniques have been awarded during the current year to this department.

The development of a Ph.D. in Geological Engineering will strengthen both the engineering program and overall research strength at MTU, and will form a critical component in the rapidly expanding area of the engineering and science of the environment.

II. INTRODUCTION

Michigan Technological University was founded in 1885 as the Michigan School of Mines with a mandate to provide knowledgeable graduates to serve the expanding mining industry in Michigan. The lineage of the Department of Geological Engineering and Sciences can be traced directly back to that original mandate. The department came into existence in 1927, and the Geological Engineering B.S and M.S. degrees were established in 1942. The Geological Engineering undergraduate program at MTU has consistently been among the top four in the country over the last 15 years, and currently has an enrollment of 139 students.

The Michigan School of Mines has expanded into a full-fledged university with nationally recognized programs in engineering and science. In 1984, the university was designated one of Michigan's four research universities, and the engineering college is now the 12th largest in the country. The Geological Engineering program is a viable part of that research effort with this years research budget expected to be over 1.2 million dollars, 10 faculty members, and 34 graduate students. A Ph.D. program in Geological engineering is needed to fulfill a high demand for Ph.D. graduates in both industry and academia. Such a program will strengthen Michigan Tech's overall engineering program, and in particular will provide impetus to the university's long range focus on engineering and science in both the environmental and materials areas.

The current geological engineering program is particularly strong in the areas of hydrogeology, groundwater contaminant hydrology and remediation of groundwater systems, geoenvironmental aspects of resource recovery, and rock engineering. Supporting areas include aqueous geochemistry, applied and engineering geophysics, minerals engineering, remote sensing, natural hazard mitigation, and global engineering/atmospheric physics and chemistry. The department collaborates closely with active research programs in Civil & Environmental, Electrical and Mining engineering, and many current Ph.D. students are in interdepartmental areas shared with these three departments.

III. OBJECTIVES OF A PH.D. PROGRAM IN GEOLOGICAL ENGINEERING

[1] To create a Ph.D. program in an area of high national need in industry, government, and academia.

[2] To build on the rapid growth in research funding and interest in geoenvironmentally related engineering problems, resource engineering and global engineering.

[3] To provide a critical degree program in the growing environmental area at MTU that will interact closely with a large number of existing and new research and graduate programs.

[4] To aid in the recruitment and retention of exceptional faculty and graduate students.

[5] To contribute to MTU's ongoing program to strengthen both research and doctoral programs.

IV. JUSTIFICATION FOR THE PH.D. PROGRAM

Geological Engineers are engineers with a strong geology background who are competent to deal with engineering problems of earth materials. As such, the field draws from traditional engineering disciplines, and applies these engineering concepts in a unique way to geological materials. It overlaps and interacts with traditional fields such as civil, mechanical, and mining engineering as well as newer fields such as minerals engineering, environmental engineering, hydrogeology, and global engineering.

Geological Engineers have a major impact in both the minerals and petroleum industry, and have always been involved in groundwater investigations, slope and rock stability engineering, foundation investigations and dam siting, and large scale tunnelling projects. More recently, Geological Engineers are in very high demand in the areas of environmental remediation, prediction of groundwater flow and contaminant migration, and site assessment. The rapid growth of these latter areas is the major immediate impetus for the development of a new Geological engineering Ph.D. program at MTU. In dealing with problems such as groundwater contamination and migration, geological engineers are the most competent to deal with predicting where the fluids will migrate, how fast they will move, how the fluids will interact with the rocks through which they flow, and how the system might be remediated. This represents a merging of the traditional subdisciplines within geological engineering of hydrogeology and reservoir engineering, with modern concepts of organic and inorganic chemistry and geochemistry taken from chemistry and geology, and the application of geophysical techniques widely used in the petroleum industry. It combines a rigorous understand of engineering principles with an equally rigorous understanding of the distribution of rock units and structures below ground, and the important physical properties of the materials through which fluids must flow.

The demand for Geological Engineers is reflected in a report by A. Keith Turner (1991), who conducted a survey that ranked the demand for 28 specialty skills required for site cleanup, based on case histories of 22 EPA hazardous waste sites. The highest demand was for groundwater hydrologists, the core area in the proposed Ph.D. program. Other skills ranked by this survey that are included in MTU's geological engineering program were engineering geologist (7th), geochemist (14th), geophysicist (15th), and remote sensing expert (28th). Ground-water hydrologists were also in highest demand in both the site assessment and surface/subsurface cleanup stages of hazardous waste site remediation. Projected demands for ground-water hydrogeologists, engineering geologists, and geochemists were expected to double in the next 5 years. In addition, there is a growing recognition that, in order to both understand the problem and create an effective remediation plan, professionals must have research skills considerably beyond the M.S. level. Each major waste site is, in effect, a unique research project involving investigative abilities at the Ph.D. level and beyond. Solution of these problems requires a team approach that centers on the ability to understand and communicate with a wide variety of research specialists.

The development of a Geological Engineering Ph.D. program at Michigan Tech will have a significant impact on the State of Michigan given the states location relative to the Great Lakes and the importance of energy and mineral resources to the states economy. The recent DOE-funded research program in the development of enhanced hydrocarbon recovery techniques in Michigan oil fields will directly enhance the state's energy base. In addition, the nature of the oil and gas industry in Michigan provides unique challenges of its own. In Michigan, the industry consists of many small companies with minimal financial and technical resources available for waste cleanup. The technical expertise needed to remediate contaminated sites and to prevent future contamination generally comes from outside the industry. This places very strong demands on the state's professional engineering community. The general area of resource engineering, with its emphasis on hydrocarbon recovery, mineral and petrophysical engineering, and the environmental aspects of resource recovery, are of critical interest to the State.

Only 7 Ph.D. programs in Geological Engineering exist in the United States and Canada. This has resulted in an extreme scarcity of qualified Geological Engineering Ph.D.'s to fill faculty positions because of the high demand for these Ph.D.'s in industry. Many Geological Engineering departments have been forced to hire faculty with other degrees such as Civil, Mining, or Environmental Engineering. While competent from an engineering point of view, many of these faculty do not have a sufficient background in geology, with the result that the unique aspects characteristic of Geological Engineers are diminished or lost to the profession. At a time when the expertise of a well trained Geological Engineer is in great demand, such a dilution will have serious consequences in the solution of engineering problems that deal with earth materials.

Both the number of Geology Ph.D. students, the number of Geological Engineering M.S. students, and the externally funded research program in the present department have grown significantly in the past 5 years. Research finding has increased to 2.5 times what is was 5 years ago, and major block-grant and DOE funding within the last year has raised the total annual research budget to over 1.2 million dollars. The research emphasis of the faculty has also dramatically shifted in the past 5 years from a traditional geology emphasis to a strongly engineering-oriented program in the areas of hydrogeology and resource engineering. The department now has 6 of 10 full time faculty working in some area of Geological Engineering, including hydrogeology/environmental engineering (2), resource engineering (3), and geophysical engineering (1), as well as adjunct faculty in geological engineering (2) and resource engineering (2). The complexity of research projects in engineering has exceeded that of the currently available M.S. program in Geological Engineering, and more and more students require a Ph.D. level program. Some students have opted to do an engineering thesis under the umbrella of the Geology Ph.D. program, others have enrolled in the Environmental Engineering Ph.D. program in the Civil Engineering Department, and still others have gone elsewhere for Ph.D. work. Research funding, the type of research being carried out, and student demand and needs all justify the development of a new Ph.D. program in Geological Engineering.

A New View of Geological Engineering

A characteristic of the current climate in the engineering profession is one of almost constant change. Interactions among engineering disciplines, and between engineers and scientists, is becoming commonplace as the problems to be solved grow in complexity. New engineering fields are being developed and growing, and traditional boundaries between disciplines are becoming blurred. One area of future growth is that which deals with the engineering of large scale natural systems. Loosely referred to as "global engineering", it includes:

Geoenvironmental Engineering:

Hydrogeology, groundwater engineering, geotechnics, geomechanics, reclamation engineering, resource engineering, shoreline engineering, remote sensing

applications in terrestrial and oceanic systems, and earth system engineering.

Natural Hazard Mitigation:

Volcanic hazards, seismic hazards and earthquake prediction, and remote sensing

Atmospheric Engineering:

Atmospheric remote sensing, natural and industrial pollution, global climate change prediction, climate and atmospheric modelling, and atmospheric hazards to aircraft.

The present department is uniquely poised to expand into the areas of global engineering under the umbrella of the Geological Engineering program. It has a strong existing program in Geoenvironmental Engineering, equally strong geology programs in natural hazards prediction, volcanic-atmospheric interactions, and remote sensing, and is in the process of developing an interdisciplinary graduate program in Atmospheric Remote Sensing. It is also closely allied with the interdisciplinary research group in fluid dynamics at MTU. The situation is ripe on this campus to develop a significant program in "global engineering" within the proposed geological engineering Ph.D. program.

V. OTHER GEOLOGICAL ENGINEERING PH.D. PROGRAMS IN THE STATE OF MICHIGAN

The new Geological Engineering Ph.D. program at Michigan Tech will be the only such Ph.D. program in the State of Michigan. With its emphasis on the engineering applications of geology, hydrogeology, geochemistry, and geophysics, it will be unique in the Midwest. The only competing programs in the Midwest include the program in the Department of Civil and Minerals Engineering at U. Minnesota, one in the Department of Geological and Petroleum Engineering of the School of Mines and Metallurgy at the University of Missouri at Rolla, and one in the School of Petroleum and Geological Engineering at the University of Oklahoma. The Michigan Tech program will be the only program in the Midwest in which geological engineering, geology, and geophysics are so closely integrated.

VI. ADDITIONAL RESOURCES NEEDED FOR THE GEOLOGICAL ENGINEERING PROGRAM

No significant new resources are needed within the current Department of Geological Engineering and Sciences. The faculty already have significant experience with the Geology Ph.D. program, and all full time faculty have Ph.D. degrees. The recent new additions to the faculty, and the shift in research emphasis of the faculty as a whole to engineering topics, means that both the expertise and personnel are available to develop a viable Geological Engineering Ph.D. program. Current levels of research funding are high and expanding. Finally, strong cooperative research programs have been developed with a variety of other engineering and science departments at Michigan Tech, ensuring a constant inflow of new ideas and approaches to the complex engineering problems that must be solved.

VII. ACADEMIC FIELDS OF STUDY

The Geological Engineering Ph.D. program will have four focus areas:

Hydrogeology and geoenvironmental engineering

Natural Hazards: Global Impact and Mitigation

Resource Engineering

Geophysical Engineering

All of these areas are actively growing in both research and teaching terms. Of 14 Ph.D. students advised by the Department, 10 are involved in one or more of these 4 focus areas. Almost all of the current research funds are concentrated in these areas.

Hydrogeology and Geoenvironmental Engineering

The faculty in the Department of Geological Engineering and Sciences whose primary functions are to teach and conduct research in the areas of hydrogeology and geoenvironmental engineering are Drs. John Gierke and Alex Mayer. Adjunct faculty include Dr. Allan Johnson (Mining Engineering) and Dr. William Griffin (U.P. Engineering and Architectural Associates). Furthermore, faculty in other Departments who either conduct or cooperate on research in these areas and/or contribute to groundwater-related courses include Drs. Neil Hutzler, Sheryl Marlor, and Jim Mihelcic (Civil and Environmental Engineering), Drs. Charles Kerfoot and Don Lueking (Biological Sciences), Dr. Gary McGinnis (Institute of Wood Research), Dr. David Shonnard (Chemical Engineering), and Dr. Carl Nesbitt (Metallurgical Engineering).

The research and teaching activities involve physical hydrogeology (water supply and development), chemical hydrogeology (contaminant fate and transport), and subsurface remediation (soil and groundwater treatment processes). The focus of most studies is on experimental and modeling techniques for enhancing the level of understanding of mechanisms that contribute to the movement of subsurface fluids and pollutants. Especially important are studies that lead to protection of groundwater supplies, either with engineered systems or through management practices, or remediation of contamination.

Ongoing research in this area includes studies of volatile organic chemical removal from clay soils by *in situ* mixing coupled with thermally enhanced extraction, solute movement with transient, unsaturated flow, pesticide leaching under finger-flow conditions, immiscible organic liquid movement in reactive clay soils, and three-dimensional visualization of groundwater model input and output. Federal agencies that are funding these studies include the National Science Foundation, Department of Energy, and U.S. Department of Agriculture. Some of the research is performed in cooperation with faculty from the Department of Civil and Environmental Engineering. In addition, faculty in the Geological Engineering and Sciences Department cooperate with other faculty on studies of air sparging of groundwater and *in situ* metal precipitation for controlling acid mine drainage.

Global Impacts and Natural Hazard Mitigation

The primary faculty involved in the study of global impacts and natural hazards are Dr. William Rose and Gregg Bluth (Department of Geological Engineering and Sciences), Dr. Alex Kostinski (Physics and Department of Geological Engineering and Sciences), Dr. Ann Maclean (Forestry) and Drs. Richard Honrath and Kurt Patterson (Department of Civil and Environmental Engineering). The contributions of geology faculty are primarily focused towards interpreting the records of past climates and natural disasters (volcanic eruptions, floods, and earthquakes) that have been recorded in geologic materials and the impacts of current volcanic eruptions on weather. The combined efforts of all the faculty from these

different departments covers all aspects of global studies, from ancient geologic records through modern engineering approaches for minimizing human impact on the environment.

Engineering approaches to solving problems associated with global change and natural hazards requires a broad-based understanding of geology, meteorology, and chemistry. The Department of Geological Engineering and Sciences has already demonstrated the unique ability to integrate engineering and scientific approaches in solving global problems. Michigan Tech has recently been awarded four NASA Global Change Ph.D. Fellows, two of which are in the Geology Ph.D. program, one is in Physics and the other is in Biology. These highly competitive awards are evidence in the growth of global studies at MTU. The recent (last five years) addition of two engineering (Honrath and Patterson) and a physics (Kostinski) faculty with expertise in atmospheric modeling is providing opportunities for the Geological Engineering program to use their geologic expertise in developing engineering solutions to global climate change and natural hazard mitigation.

Resource Engineering

Resource engineering involves analysis of resource production potential and design of systems for extracting resources. Ongoing projects involve research in oil and gas fields in Michigan, California, Louisiana/Texas Gulf Coast, and the North Sea. Petroleum related research at MTU includes reservoir characterization, horizontal drilling development, well logging, basin analysis, seismic interpretation and geochemical modeling. Especially important is consideration of the environment in resource development and how environmental protection can be incorporated in the design of resource recovery systems. Resource engineering is a growing program area and includes Drs. Bill Gregg, Jackie Huntoon, Charles Salotti, and Jim Wood (Department of Geological Engineering and Sciences), Dr. Jim Hwang (Institute of Mineral Processing), Drs. Al Johnson and Francis Otuonye (Mining Engineering), Dr. Carl Nesbitt (Metallurgical Engineering), and Dr. Steve Shetron (Forestry).

Currently, the Department of Energy is funding two large research projects at MTU: subsurface visualization (California) and enhanced oil recovery (Michigan Basin). Funding from NSF and the Global Basins Research Network are supporting other research in petroleum development and exploration.

Geophysical Engineering

The Department has three Geophysics faculty: Drs. Sue Beske-Diehl and Jimmy Diehl, who share a single faculty position, Dr. Wayne Pennington, and Dr. Charles Young. These faculty work in conjunction with faculty in Electrical Engineering (instrumentation development and signal processing), Forestry (field soil moisture and physical property determination), and Chemical engineering, Physics, Metallurgical and Materials Engineering (determination of material physical properties).

The MTU geological engineering curricula is unique in that there is a strong geophysics component; most Geoscience and Geological Engineering programs have very limited course offerings in geophysics, usually in the general area of solid earth geophysics. This strong geophysics background has been one of the main reasons our undergraduate and graduate students have been so successful in industry and so competitive in a rapidly changing job market. In addition, it has provided them with more options for future advancement in the engineering consulting area. There is a growing awareness among consulting firms that geophysical tools provide valuable information for site characterization and monitoring, and are exceedingly cost competitive in comparison to extensive drilling programs. Near surface geophysical methods are rapidly becoming one of the most extensively used techniques in geotechnical and groundwater engineering investigations. This is clearly an area of high and growing demand that the department of Geological Engineering at Michigan Tech is uniquely qualified to contribute to.

VIII. COURSES OF STUDY

The Department of Geological Engineering and Sciences offers a wide variety of courses at the 400, 500, and 600 levels, course descriptions for which are listed in **Appendix A**. The existing courses will meet

the needs of students in the new Ph.D. program in Geological Engineering, and new courses will be added when the currently advertised position in geophysics is filled. The course numbering system is set up to give as much flexibility as possible in the course offerings for Ph.D. level students. Many Ph.D. level courses are taken by small numbers of students, and have course contents that vary from year to year depending on the interests of the students and the research topics under discussion. Such courses are given in the GE 505-507 and GE 606-608 series, and add considerable flexibility to the program.

The degree schedule of each Ph.D. student is worked out individually by that students advisor and thesis committee. This typically involves a mixture of courses taken from a variety of departments in the university at various levels of instruction, in a deliberate attempt to utilize the excellent course offerings that exist in science and engineering at Michigan Tech. Typically, Ph.D. students take more than 50 credits beyond the M.S. degree. The degree schedules of three recent Ph.D. students who have or will shortly receive a Ph.D. with an engineering emphasis are attached in **Appendix B**.

IX. SUPPORTING AREAS

Soils Engineering and Hydrology

This is an especially active research area, with significant joint activity between the Departments of Geological Engineering and Civil and Environmental Engineering(CE). Three faculty, six M.S. students, and three Ph.D students in the Geological Engineering Department are conducting research on contaminant fate, transport and remediation in soil and near surface systems. In addition, strong ties exist with faculty in the Departments of Metallurgical & Materials Engineering (MY), Mining Engineering (MI), and the School of Forestry and Wood Products (FW). These ties include collaborative research projects, co-advising of M.S. and Ph.D. students, and offerings of relevant graduate courses. Laboratories and analytical equipment are shared among these departments. The faculty external to the Geological Engineering Department have expertise in the physical, chemical, and biological aspects of contaminant fate. These faculty also are involved in developing remediation techniques for industrial operations such as mineral, wood, and metals processing. Many of these external faculty recently participated in a National Science Foundation proposal for obtaining Ph.D. research traineeships in the area of hydrogeology.

The Geological Engineering Department also has strong ties with groundwater and soil remediation professionals in industry. The department includes an adjunct faculty from a local engineering consulting firm. In addition, department faculty participate in consulting projects and consulting training. These activities enhance the graduate program by allowing faculty and students access to real-world, field-scale problems. Geological Engineering faculty also are collaborating with researchers at national laboratories (Oak Ridge). These efforts expand the scope of research due to the excellent facilities offered by national laboratories and graduate fellowship opportunities available through the labs.

Faculty members in this area are Drs. Gierke (GE), Griffin (GE), Hutzler (CE), Johnson (MI), Mayer (GE), McGinnis (FW), Mihelcic (CE), Nesbitt (MY), and Shetron (FW).

Atmospheric Sciences and Engineering

Atmospheric sciences and engineering involves the study of the physical and chemical aspects of natural and human impacts on the atmospheric environment. Research in this area is currently being conducted in the Geological, Electrical, and Civil Engineering departments and the Department of Physics (PH). The research topics include the transport, fate, and measurement of anthropogenic and natural chemical components in the atmosphere. Air pollutants such as greenhouse gases and photochemical compounds are being studied in the Civil Engineering department, while volcanic cloud phases such as particulates, aerosols, and gases, are the subject of research in the Geological Engineering and Physics departments.

Remote sensing of the atmospheric environment also is an especially strong research area at MTU: a graduate curriculum in atmospheric remote sensing was initiated last year, the Geological Engineering

department houses the Laboratory for Atmospheric Remote Sensing, and a Center of Remote Sensing and Image Analysis was proposed this year. Activities related to the Clean Air Act and an emphasis on global atmospheric problems will result in increased research efforts in atmospheric engineering. The urgency and complexity of these problems will produce a need for Ph.D. graduates with interdisciplinary backgrounds.

Faculty members active in this area include Drs. Bluth (GE), Honrath (CE), Kostinski (PH), Patterson (CE), Rose (GE), and Schulz (EE). In addition, there are eight other faculty (from Electrical Engineering, Forestry, Geological Engineering, and Mathematical Sciences) in the curriculum in atmospheric remote sensing.

Resource Engineering

Traditional and remedial studies of resource recovery are conducted in the Geological Engineering, Mining engineering, and Metallurgy Departments, the School of Forestry and Wood Products, and the Institute of Materials Processing (IMP). A major research program in petroleum recovery is underway in the Geological Engineering Department. The current search for a new faculty member in geophysics is designed to strengthen the geophysical and reservoir engineering components of this research program, and enhance the petroleum engineering aspects of the Geological Engineering curriculum. This program is critical given the general move of the North American oil/gas industry from exploration to production and enhanced recovery of existing reserves. In addition, mineral recovery also is a traditionally strong research area within the Geological and Mining Engineering departments and in the Institute for Materials Processing.

The remediation of earth systems impacted by resource recovery efforts is a major research focus at MTU. Faculty and graduate students in the Geological, Mining, and Metallurgical Engineering departments and in the Institute for Materials Processing are conducting interdisciplinary studies of waste production from the petroleum and mining industries. These efforts include the development of remedial techniques for surface and subsurface materials impacted by mining and petroleum wastes. In addition, the current regulatory focus on pollution prevention is expected to generate additional research activity by encouraging the development of extractive technologies which minimize the production of associated waste products.

The faculty in this area are Drs. Gregg (GE), Huang (IMP), Huntoon (GE), Johnson (MI), Nesbitt (MY), Otuonye (MI), Salotti (GE), Shetron (FW) and Wood (GE).

Earth Systems Interactions

This area includes studies of interconnections of physical, chemical, and biological processes occurring between environmental media. Faculty in the GE department are conducting research in collaboration with faculty in the Departments of Biological Sciences and Civil & Environmental Engineering and the School of Forestry and Wood Products. The ties between GE faculty and other departments are strengthened through service on Ph.D. committees for students in these departments. Graduate level classes are offered in this area within the GE department, the Departments of Biological Sciences and Civil & Environmental Engineering, and the School of Forestry and Wood Products.

Collaborative research in this area will increase significantly in the near future, due to (1) the addition of new faculty in the GE and other departments who are interested in this area of study and (2) the emphasis of funding research on global change by governmental agencies. The curriculum in atmospheric remote sensing and proposed laboratory of atmospheric remote sensing will enhance interdisciplinary research efforts in earth system interactions.

Faculty participating in this area of study include Drs. Bagley (BL), Glime (BL), Huntoon (GE), Kerfoot (BL), MacLean (FW), Mihelcic (CE), Patterson (CE), and Wood (GE).

X. ADMINISTRATION OF PROGRAM

Recruitment

The department has multiple methods to recruit students. The new Ph.D. in Geological Engineering Program will be advertised in the departmental graduate brochure, which has descriptions of the degree programs and research interests of each faculty. We will also recruit outstanding students from the B.S. and M.S. Geological Engineering programs and from other quantitative programs within the university. Of course, the program will be advertised by word-of-mouth by our colleagues at other schools and by ourselves at a professional meetings. These types of recruitment efforts work effectively for the Geology Ph.D. program giving it a good mix of international and U.S. students from a variety of colleges and universities.

Students from our own B.S. and M.S. Geological Engineering Programs have already expressed an interest in receiving a Ph.D. in Geological Engineering. In addition, several students recruited from outside of MTU wished to enter a Ph.D. in Geological Engineering program, but have had to choose an alternative such as the Ph.D. programs in Environmental Engineering or Geology. The hydrogeological portion of the Geological Engineering M.S. program has been growing the last several years and a natural consequence of this growth is the development of a Ph.D. program in Geological Engineering. Many of the current M.S. students come from diverse educational backgrounds with many having degrees in other disciplines such as Mechanical Engineering and Environmental Engineering.

Admissions

The Geological Engineering and Sciences Graduate Committee oversees the admissions process. Departmental faculty carefully review each candidate's file and recommend approval or rejection of the applicant, make comments, indicate whether they are interested in advising the student, and whether they have funds to support the student. A major effort is made to match prospective graduate students to those faculty most interested in working with that particular student. The faculty whose interests most closely resemble those of the candidate review the file first. The Graduate Committee then makes a recommendation to the Departmental Chair based on the responses from the faculty. The Department Chair forwards the decision to the Graduate School. In addition to meeting the graduate school requirements for admission, the department requires three letters of recommendation attesting to the applicants potential for success as a graduate student, as well as the results of the Graduate Record Examination General Test. A minimum score of 550 in the Test for English as a Foreign Language (TOEFL) is required for admission into the program. A B.S. degree from an ABET accredited engineering program is not required for admission into the Ph.D. program, as the Ph.D. in Geological Engineering is a research degree.

Research Advisor and Advisory Committee

The experience of the department shows that many Ph.D. students choose their advisor upon entering the program. The decision is based on mutual interests and the availability of funding. The student is free to change advisors later, if desired. Those who have not chosen an advisor upon entering the program interview faculty with similar interests and select an advisor within nine months. Departmental funds are sometimes used to support students who have not chosen an advisor or whose advisor cannot support the student. Students are strongly encouraged to write research proposals to support their Ph.D. research.

Qualifying Examinations

Candidates for the Ph.D. degree in Geological Engineering will demonstrate their preparation for original doctoral research by passing a written comprehensive exam. They must demonstrate knowledge of fundamental geological engineering principles, in addition to knowledge in the areas of Earth Science pertinent to their Geological Engineering field. The student should meet with his or her advisor in order to devise a carefully planned reading program to prepare for this exam.

The comprehensive exam will take place within four academic quarters of entrance for Ph.D. students who possess an M.S. degree in Geological Engineering, or its equivalent, and seven quarters for those who possess a B.S., or its equivalent. Students possessing an M.S. degree in another field will be allowed to postpone the exam until their seventh academic quarter of residence. The committee will determine at the conclusion of the exam whether the student has demonstrated reasonable ability in geological engineering and supporting areas of the geosciences. Students who do not pass the exam on their first attempt may, at the discretion of the committee, be allowed to retake the exam once. Students failing the examination a second time must withdraw from the program. Based on the exam results, the committee may also specify additional courses that the student must take.

Students will be required to orally defend a written thesis proposal within six (6) months of passage of the written comprehensive examination. The written portion of the thesis proposal defense will be a high quality proposal for doctoral research prepared by the student in a form suitable for submission to a funding agency. The student will submit copies of the proposal to the committee at least one week prior to the exam. During the oral exam, the student will defend the proposal and answer questions formulated by the committee members.

The written comprehensive examination and oral proposition defense will be administered by a committee of at least four faculty, at least three of which must hold appointments in the Department of Geological Engineering and Sciences. Other members of the faculty of MTU are invited to attend the exams as non-voting participants.

Graduate Forms

The student must fulfill the residency requirement as stipulated by the Graduate School and is responsible for completion of Forms D-1 through D-8 and obtaining the required signatures. The forms should be filed in the

following sequence:

D-1 Acceptance into the Doctoral Program

This form is typed and signed by the Department Chair as soon as the student arrives.

D-2 Recommended Advisory Committee

The student and the advisor selects two additional faculty to be members of his/her advisory committee. The Department Chair reviews the selection and recommends any necessary changes.

D-3 Preliminary Program of Study

The student and advisor, in consultation with the advisory committee, determine a preliminary plan of study. The committee members and the Department Chair must approve the plan before it is forwarded to the Graduate Dean.

D-4 Report on the Comprehensive Examination

This form is completed when the student passes the Comprehensive Examination. The form requires the signature of the committee members and the Department Chair before it is forwarded to the Graduate School.

D-5 Degree Schedule

This form is submitted to the Graduate School after all course work and the Comprehensive Exam have been completed. It must be completed prior to the scheduling of the final oral examination.

D-6 Approval of Dissertation Proposal

This form approves the student's dissertation proposal. Each member of the examination committee must sign this form.

D-7 Scheduling of Dissertation Defense

This form serves as notification to the examining committee members and the Graduate School of the time of the oral examination/dissertation defense. The form not only sets the time and place of the Defense, but also names the dissertation committee. This committee will probably consist of the three original dissertation advisors and at least one additional examiner. One of the members must be from a cognate department or from outside the University.

D-8 Report of Dissertation Defense

This form notifies the Graduate of the results of the Dissertation Defense.

The advisory committee is responsible for monitoring the progress of the student ensuring that the Graduate School forms are completed on schedule.

The department administrative aide is responsible for handling routine inquiries, application and file maintenance.

XI. STUDENT INTEREST IN THE PROGRAM

A Ph.D. in Geological Engineering program will readily attract graduate students. Several Ph.D. students, who are presently enrolled in programs in Geology, Environmental Engineering, Geotechnical Engineering, or Sensing and Signal Processing, would have entered the Geological Engineering program if a Ph.D. had been available. The research projects of these students. (R. Dai, J. Graf, C. Huang, and C. Wang, are summarized in Appendix D. Students inquiring into graduate school have also expressed an interest in a Ph.D. in Geological Engineering even without a program being advertised. For Fall, 1993 admission into the graduate program, 17 students from schools other than Michigan Tech identified themselves as interested in a Ph.D. program in Geological Engineering.

The M.S. programs in Geological Engineering and Civil Engineering will also provide a source of applicants for the Geological Engineering Ph.D. program. Several current M.S. students in those programs have expressed an interest in continuing on in an engineering Ph.D. program. **Appendices C and D** summarize currently enrolled students, and recent graduates, respectively, in the graduate programs offered by the Department of Geological Engineering and Sciences, and interdisciplinary Engineering Ph.D. programs in Environmental Engineering, Geotechnical Engineering, and Sensing and Signal Processing.

XII. FINANCIAL AID TO STUDENTS

Faculty Research support, from a wide variety of sources, is clearly sufficient to support Ph.D. students. Funds are from the Department of Energy, the Environmental Protection Agency, National Aeronautic and Space Administration, the National Science Foundation, and private companies. Faculty research support in the Department is currently $100,000 per faculty member for this year and is growing. This level ranks the department quite high both nationally and within Michigan Technological University.

The Departmental faculty are currently advising 34 graduate students enrolled. Of the 19 Masters candidates, ten are in the Geology program, 3 in the Geophysics Program, 4 in the Geological Engineering Program and 2 in the Civil Engineering Program. Of the 15 Ph.D. candidates, 14 are in the Geology Program and one is in the college Environmental Engineering Program.

The Department supports these students in a variety of ways. Fourteen of the students are receiving Graduate Research Assistantships (GRA), four have Graduate Teaching Assistantships (GTA), three are supported by Ph.D. Challenge Grants in which half the funding comes from the Graduate School and half from a research grant. Seven Graduate Students receive fellowships from diverse sources. Four students are working at full-time jobs related to their degree and will soon finish their Ph.D. theses. Two are using personal funds for their education.

Upon entering the department, graduate students, especially Ph.D. students, are encouraged to write or help write proposals which provide funding for fellowships or research assistantships. Although, the success rate is variable, one or two successes in a year can help release funds for the support of other graduate students. Three Graduate Students have recently successfully competed for resources from funding agencies. They were the primary writers of their proposals with modest help from their advisors. Two students, Drew Pilant and Dave Schneider, have won prestigious NASA Global Change Fellowships and one, Catherine McKissock, secured a fellowship from Amoco.

Two faculty of the Department are part of a cooperative research program with the Finnish Geological Survey. Three Ph.D. students, one completed, one nearing completion and one just accepted as a new student, are taking part in this program. Support for this program is split between Michigan Technological University in the form of a Challenge Grant Fellowship and support from the Finnish Geological Survey.

XIII. FACULTY

The faculty of the Department of Geological Engineering and Sciences have the expertise and breadth of experience to support a Ph.D. in Geological Engineering. The faculty is thoroughly familiar with the requirements necessary to run a high quality Ph.D. program through experience with the existing Ph.D. program in Geology, which was established in 1965. Departmental faculty are already advising Ph.D. level students in engineering research areas through the existing Ph.D. program in Geology as well as Interdisciplinary Ph.D. programs in Environmental engineering, Geotechnical Engineering, and Sensing and Signal Processing. In addition, all faculty have participated as members of Ph.D. thesis committees in almost every existing Ph.D. program at Michigan Tech.

A brief summary of the experience of the faculty in the Department is summarized below:

Industry Experience

* James R. Wood, Senior Research Geochemist, Chevron Oil

* William Gregg, Engineering Geologist, Cyprus Industrial Minerals Company; and Winsor Minerals; Consulting Geologist, Noranda Exploration, Johnson and Johnson, Cliffs Engineering.

* Theodore Bornhorst, ARCO Exploration and Technology Group, Amselco Exploration Hanna Mining Company.

* Douglas McDowell, Humble Oil Company, Appalachian Exploration division

* Alex Mayer, Civil Engineer for Water Resources Projects Section East Bay Municipal Utility District, Oakland, CA.

Government

* John Gierke, Oak Ridge National Laboratory, U.S. Air Force Laboratory Graduate Fellow.

* Bill Gregg and Theodore Bornhorst, Geological Survey of Finland.

* Theodore Bornhorst, Michigan Low Level Radioactive Waste Authority, Michigan Geological Survey, Los Alamos Scientific Laboratory.

* Douglas McDowell, Pennsylvania Geological Survey, U.S. Geological Survey (Alaska)

Awards

* Jim Wood, Clarke Medal, Geochemical Society

* John Gierke, U.S. Department of Energy Environmental Restoration and Waste Management Distinguished Junior Faculty Award

Teaching Awards

* Bill Gregg, Distinguished Teaching Award, MTU; Excellence in Teaching Award

* Jim Wood, Jimmy Diehl, Bill Gregg - Teaching Honor Roll

* Bill Gregg, Advised winners of best student papers at Institute on Lake Superior Geology, K. Sikkila and D. Saja.

Adjunct Professor

* Charlie Salotti, Program Director, Geochemistry, NSF, NAS-NRC Committee Member; Standard oil, Gulf Oil, Chevron - USA; Chevron - Overseas; Consultant-Electrical Power Research Institute, NYSE Industrial.

* Jiann-Yang Hwang conducted more than 60 industrial and governmental research projects as members of the Institute of Mineral Processing.

The department consists of 6 Professors (two of which share a single position), 2 Associate Professors, 3 untenured Assistant Professors (one of which is partly shared with Environmental Engineering), 1 Administrative Aide, and one Clerical Position.

FACILITIES

The Department of Geological Engineering and Sciences has approximately 14,000 square feet of office, classroom, and laboratory space available, mainly in Dillman Building (former Civil-Geology Building) but with a small amount of research space available in the new Metallurgy and Materials Building. The department, along with the Civil and Environmental Engineering Department, and the Biology Department, are well along in the planning process for a new building in Environmental Sciences and Engineering. The Department of Geological Engineering and Sciences, based on current (April, 1994) design plans, has 21,074 square feet of space allotted to it in the new building, with construction slated to start in 1996-7, in addition to 5,014 square feet of undergraduate teaching laboratory space in Dillman. This increase in space, the first significant increase in space for the department since 1957, will allow significant expansion of the existing Ph.D. research program in Geology and the proposed Ph.D. in Geological Engineering.

The department is well equipped with a networked system of Sun and PC workstations and computers, with fiber optic access to the university system and international computer networks (MERIT, BITNET, INTERNET). A variety of small, fast computers are available for computational needs. In addition, a special research laboratory for 3-Dimensional visualization in petroleum exploration and production, and a second laboratory with extensive image processing and remote sensing capabilities and high performance graphics workstations, have recently been developed, with state-of-the-art software (Terascan, ERDAS Imagine, IDL) and hardware. Images can be accessed from a range of sources ranging in scale from satellite imagery to optical microscope and scanning or transmission electron microscope. Software is available for groundwater flow and contaminant transport modelling (MODFLOW, SEFTRAN, MT3D, ModPath), geochemical modelling (SUPCRT, CHILLER, PTA/PTX, GEOTHERM,

WATEQ3), graphics and 3-dimensional visualization (Ideas, SpyGlass, Surfer, PVWave, Landmark), and a wide variety of other, specialized software is available.

Engineering Research laboratories include facilities for materials testing, physical properties determination, microscopy, X-ray diffraction, and sample preparation. Engineering laboratories include facilities for routine geotechnical measurements, chemical analytical equipment including portable gas chromatograph, pressure cells for moisture content determination, flexible-wall permeaters and flow-through column cells for hydraulic conductivity and solute transport measurements, sonic velocity bench, and mechanical deformation cells. A number of field spectrometers for infrared, visible, and ultraviolet remote sensing ground truth measurements are available.

The department is very well equipped with geophysics equipment, including a fully instrumented paleomagnetics laboratory with computer-interfaced equipment for directional and material magnetic analysis, and a PAR vibrating sample magnetometer for hysteresis and Curie temperature measurements of materials. State-of-the-art field and laboratory Phoenix Geophysics magnetotelluric equipment is available, as well as field seismology, gravity, magnetic, and resistivity equipment, including ground penetrating radar.

The department also has access to a fully equipped underground mine drift for both teaching and research purposes, complete with underground classroom, mining and ventilation equipment, and research facilities.

XV. LIBRARY HOLDINGS IN GEOLOGICAL ENGINEERING

Library materials are housed in the J.R. Van Pelt Library, a centrally located, four story building, constructed in 1967. Library holdings consist of 329,679 print volumes, 4,977 journal subscriptions, and access to a variety of information in electronic format. The library is also designated as a selective depository for U.S. government documents. Because of Michigan Tech's concentration in engineering and sciences, the library is particularly well equipped in those fields. Additional materials are available through the library's computerized interlibrary loan service.

The library collection in Geological Engineering and Sciences consists of 6,100 print volumes and 13,876 serial volumes, with an additional 38,895 print volumes and 57,287 serial volumes in closely related fields such as civil, sanitary, chemical, and mining engineering, as well as dynamics and mathematics, and numerous other fields. All major and most minor journals in the research areas of interest to the current faculty and graduate students are directly available in the library. Other materials can be obtained through interlibrary loan or direct computer access to journals. The fact that the library spends approximately 90% of its acquisitions budget on serials is a direct result of the library's effort to keep researchers up-to-date on the latest developments in their respective fields. An excellent map collection exists, including topographic maps at various scales for all of the United States and Canada, as well as an extensive collection of hydrologic, geologic, geophysical topographic, and geologic maps for North America and the rest of the world.

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