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ENGINEERING GEOLOGY IN AUSTRALIA, 1966.

by

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SUMMARY

About 75 engineering geologists and 10 engineering geophysicists are employed in Australia. Their activities cover a wide range: most are employed, at all stages of investigation and construction, on major engineering projects; others investigate materials resources, drainage problems and aspects of city planning. The reliance of engineers on engineering geologists varies greatly with the organization and with the type of engineering activity involved.

Divergent views are held in Australia on two important aspects of the practice of engineering geology: the training of engineering geologists and whether they should be employed mainly in engineering organizations or in geological organizations. The views on these subjects are summarized. The author believes that an engineering geologist should be a well-trained, competent, and preferably experienced, geologist who has had "on-job" or post-graduate training in engineering geology. Engineering geologists can operate very efficiently in an engineering organization provided the organization is large enough to employ several geologists; otherwise, despite certain inherent dangers, engineering geologists, he believes, are best provided by geological organizations.

Few novel techniques of investigation are being used by engineering geologists in Australia; the emphasis has been on refinement of existing techniques, rigorous control of investigating procedures and improved methods of analysis and presentation of results.

Engineering geophysics is possibly used more extensively in Australia than is usual elsewhere, and has proved a valuable adjunct to geological work.

The paper concludes with eight suggestions of contributions that E.C.A.F.E. could make to engineering geology in South-east Asia.

INTRODUCTION

At the 1960 meeting of the Senior Geologists' Working Party of E.C.A.F.E. a paper by Mr. L.C. Noakes was presented giving the scope of engineering geology activities in Australia at that time, the role of the engineering geologist and training needed, and notes on selected techniques of investigation. The paper that follows is intended to bring Mr. Noakes' report up to date and to suggest matters that the meeting might recommend to the Secretariat for further study.

In February 1966 a symposium on undergraduate geological training was held at the Australian National University, Canberra; it was attended by senior representatives of geology departments of most Australian universities, State and Commonwealth geological survey organizations and industry. At the symposium a paper, titled "Engineering Geology", was presented by Mr. D.G. Moye, Head, Engineering Geology Branch of the Snowy Mountains Hydro-Electric Authority. I have drawn heavily from Mr. Moye's paper and have discussed various other matters with him. I am greatly indebted to him for his assistance.

SCOPE OF ENGINEERING GEOLOGY

One tends, when considering engineering geology, to think largely in terms of geology as applied to major engineering projects - dams, hydro-electric schemes, and bridge and building foundations - and it is in these activities that most engineering geologists are employed and in which an engineering geologist most nearly becomes a geological engineer. However it is, I think, proper to recognise five other broad categories of engineering geology, all of which may be involved in the investigation of major projects, but are not necessarily so connected. They are:

1. Investigation of roads, airfields and canals
2. Investigation of construction materials
3. Drainage problems, including slope stability
4. Engineering geological mapping, especially of urban, or proposed urban, areas
5. Miscellaneous, including coastal engineering geology, military engineering geology and permafrost investigations. No, or little, work is being done in Australia in these fields.

Groundwater, as a resource, does not fall within the field of engineering geology but groundwater is, of course, a critical element in most engineering geology investigations. The study of soil and soil mechanics, because of the specialized techniques and methods of analysis, has largely passed from the hands of geologists into the hands of engineers, except in so far as the soils can be mapped as a geological unit or units. There is, however, greater scope for a useful contribution by geologists in this field than may be commonly recognised.

ENGINEERING GEOLOGY IN AUSTRALIA

The use which engineers in Australia make of engineering geologists on major construction projects varies greatly with the type of project and the organization involved. As is common in America, in particular, the engineering geologist is usually intimately associated with major dam or hydro-electric projects from the first conception of the scheme until, or even after, completion. This practice differs from that in some parts of Europe, where engineering geology services are not so widely used at the construction stage.

Many major bridges and buildings are built without geological advice, but on others geologists have contributed substantially to an evaluation of foundation conditions and have also assisted during construction. In the Adelaide area, South Australia, many financial institutions will not approve building loans (including those for private houses) until foundation conditions have been investigated, and the type of footing prescribed, by a competent geologist or engineer. Much of this work is done by engineering geologists of the Mines Department. (This precaution is necessary because of the widespread occurrence of swelling clays in the soil).

In airfield and road construction little use is generally made of engineering geologists except in the selection of construction materials. There is, however, an increasing awareness in the Territory of Papua-New Guinea, of the usefulness of engineering geologists in selecting road locations for new roads and prescribing remedial treatment on existing roads. Owing to the steep terrain, relatively young and soft sediments, high rainfall and high seismicity, serious slope and pavement stability problems arise in the Territory.

Marine structures, beach erosion control, canals and military engineering projects are generally investigated and built with little geological assistance. Some studies are being made of the movement of beach sands in Victoria and elsewhere.

Availability and suitability of construction materials are investigated by Survey and industry geologists. The work is generally, but not always, carried out by engineering geologists. Materials investigated include sand, gravel, road and concrete aggregate, road base and base course material, brick clay and shale, bentonitic clay, cement-making and ceramic materials, pozzolans, earth-core materials for dam embankments, rock-fill, rip-rap and building stones. For some of these, field investigations only are carried out and laboratory testing is performed by engineers, chemists or physicists. The Australian Government's Bureau of Mineral Resources is undertaking a study of the properties of building stones, including the development of standard tests and accumulation of data on which to evaluate the significance of the tests in terms of "on job" performance. The group is also engaged in the search for useful building stones for major buildings in the national capital. The work is at an early stage.

Many drainage problem areas are very small and are dealt with by engineers on an ad hoc basis, but from time to time engineering geologists are asked to advise on specific problems (see below regarding services provided in the Australian Capital Territory). Reference has already been made to the problem of slope stability in connection with road works in the highlands of Papua-New Guinea; geologists have also carried out slope stability investigations in Australia but conditions there are generally much less severe than in P.N.G.

No engineering geology maps, of the type published by the United States Geological Survey, are produced in Australia. These maps and notes present the geology of a quadrangle in terms of foundation conditions, materials resources and groundwater conditions. Maps have been produced showing, both on the detailed and regional scale, the occurrence of a particular resource, such as brick shale and clay. Systematic mapping is also carried out in new and proposed development areas around Canberra, A.C.T. The purpose of the investigation is to advise planning authorities on excavation and foundation conditions for location of services and buildings, the distribution of possible construction materials and any other useful mineral deposit, and the distribution of areas of poor drainage. Drainage problems in developed areas are also investigated as the need arises. It is hoped, as staff shortages are overcome, that these, and similar surveys, will lead to the publication of general-purpose engineering geology maps.

The earthquake hazard in Australia is generally low but the Territory of New Guinea has wide areas with extremely high risk. A committee in Port Moresby, of which an engineering geologist and a geophysicist are members, is at present engaged in producing a code to govern the siting and design of engineering structures, particularly buildings, in earthquake-prone areas.

EMPLOYMENT OF ENGINEERING GEOLOGISTS

The following table is adapted from one compiled by Mr. D.G. Moye, based on a canvass of engineering and geological organizations, universities, and industry. The figures refer to geologists who are employed either full-time or a substantial part of their time on engineering geology. The figures are probably not complete for industry; in addition Surveys and industry may use geologists normally employed on other aspects of geology on engineering investigations as the occasion demands. None of the University and Institution of Technology staff are engaged full-time on engineering geology; some of them undertake consulting work.

Employment of Engineering Geologists by Organizations

State and Commonwealth (of Australia) Geological Survey Organizations	30
Electricity Authorities (geologists mainly employed on hydro-electric projects, but some on thermal projects)	17
State Public Works Departments	2
State Water Conservation and Irrigation Departments (or Authorities)	5
Municipal Water Supply and Sewerage Authorities	2
Roads and Highways Departments and Authorities (State & Municipal)	6
Other State Departments (e.g. Railways Departments)	1
Teaching (University and Institution of Technology)	9
Industry	2
Consultants (Self-employed or employed by consulting companies)	2
Total	76

In addition to the engineering geology services provided in Australia and its Territories, the Snowy Mountains Hydro-Electric Authority, under the Colombo Plan, has carried out the investigation of elements of the Mekong Basin project, under the auspices of E.C.A.F.E. They are Pa Mong dam site in Thailand-Laos, Sambor dam site in Cambodia, and the Prek Thnot project in Cambodia.

A noteworthy feature of the pattern of employment in Australia is the small number of private consultants and consulting organizations that employ engineering geologists. There are several consulting geophysical companies that undertake investigations in engineering geophysics, but only one employs a geologist to supplement and interpret its work. The scarcity of privately-employed engineering geologists appears to be due to three factors: 1. Major public works are generally investigated, and supervised during construction, by public authorities which either employ their own, or call on government-employed, engineering geologists.

2. Government-employed engineering geologists are generally available to give advice and conduct limited investigations on public works being designed and supervised by consultants or on major works being investigated by and built for private organizations.

3. The lack of awareness of the usefulness of engineering geologists on the part of some government, municipal and private organizations.

Several large organizations retain, or engage from time to time for specific purposes, high-level overseas consultants. Senior engineering geologists in some governmental authorities also act as consultants for other organizations.

This pattern, of the dominance of governmental activity in developmental fields - particularly the provision of specialist skills, reflects a stage through which most developing free-enterprise societies pass. The pattern will doubtless continue for some time but with private enterprise assuming an increasingly important role.

ORGANIZATION OF ENGINEERING GEOLOGY SERVICES

The manner in which engineering geology services are provided falls into four broad categories:

1. Geologists employed by the engineering organization (governmental or private) requiring the services. This is the system used by such organizations as the Snowy Mountains Hydro-Electric Authority, the Tasmanian Hydro-Electric Commission, some State and municipal water supply and irrigation authorities, at least one highway and one railway department, and one major quarrying company.

With this arrangement it is possible to establish a very close and well-integrated teamwork between engineers or production managers and geologists. Because the administrators of the organization know both the staff available and the likely calls on their services, investigations and construction services can be planned well in advance. The geologists can keep themselves well informed on all aspects of projects in hand, can quickly learn to think in engineering terms, and can call on all the laboratory (including soil and materials-testing laboratories) and other facilities of the organization. Being in the organization the geologists' position can be formalized, arrangements made for their views or instructions to be considered or implemented promptly as required, and formal reports kept to a minimum. The disadvantages of the arrangement include the danger (except where there are a number of engineering geologists in the organization) that the geologist, being in an engineering organization, lacks the supervision, guidance and stimulus of other geologists, does not have access to an adequate geological literature or to specialist geological services (e.g. palaeontology), gains experience in a very narrow geological environment, and lacks the opportunity - and hence incentive - for promotion. Should he find senior engineers unreceptive to his recommendations he may find it difficult to press his view.

In the field of major construction projects by large, permanent, engineering organizations, engineers are generally well served by a cadre of geologists in the engineering authority.

2. <u>Geologists employed by a geological survey, or similar government scientific organization, which provides engineering geology services for other organizations.</u> With this arrangement it should be possible to ensure that geological services of a high standard are provided because of the opportunity for wide experience and discussion, and the availability of more adequate geological laboratories than an engineering organization would normally have; facilities for physical testing of materials may, however, be inadequate, as provision of these is commonly regarded as an engineering function. Many of the other disadvantages listed in the preceding paragraph should also not apply. Survey geologists should be able to make a broader approach to engineering geology problems than those within an engineering organization who are commonly committed to providing a service, often in a narrow context, to engineers. Further, it is necessary to make periodic formal reports to the organization for which the work is being done (e.g. preliminary, feasibility, design and completion reports) and this has the salutary effect of making the geologist concerned critically examine his ideas on the problems with which he is confronted in a manner which may not be done if such formal reports are not required.

On the reverse side, there is considerable danger of geologists not adequately versed in engineering concepts or industry requirements being asked to make engineering judgments or advise on the suitability of construction materials. Organizational difficulties may also arise if co-operation between the two organizations is inadequate e.g. provision of engineering geology services requires adequate advance notice of needs, on-site services for the geologist need to be planned, the geological organization must be prepared once it accepts a commitment, to maintain the service asked for even if it imposes strains or appears to run counter to its own order of priorities. The geologists involved must also realize that they must meet quite rigorous deadlines in the submission of reports.

The Bureau of Mineral Resources, which provides extensive engineering geology services, mainly for the Commonwealth Department of Works, believes that by advance planning and close and continuing personal contact between engineers and geologists, it has overcome most of the difficulties referred to above. In present practice the Bureau carries out preliminary, detailed and design investigations and provides construction services. At the construction stage of major projects, an engineering geologist is recruited for the project; he becomes the resident project geologist and works as a member of the supervising engineering team, subject to the project engineer for discipline, etc. Technical supervision of his work and support facilities, such as petrographic work, are provided by the Bureau.

3. Engineering geologists employed in industry. As the table on page 4 shows, very few geologists are employed in this way. Undoubtedly the numbers will increase in the future. Where the geologist is employed full-time as an engineering geologist the remarks under (1) above apply. However, there is probably a great deal of incidental engineering geology done by company geologists whose experience lies in other directions e.g. a geologist employed by an exploration company may be required to advise on the suitability of road-making materials or stability of slopes, or even carry out a mine dam investigation. In such cases lack of experience may result in inadequate or unsound advice to the company's engineers.

4. Provision of consulting engineering geology services by University or other teaching staff can be of benefit both to the client and to the consultant, provided the consultant concerned is a fully trained and experienced engineering geologist and the work undertaken is essentially of an advisory nature. Academic duties are likely to prevent a lecturer from undertaking full-scale site or resources investigations, involving extensive mapping or supervision of drilling.

Private consultants (other than University staff) - either individuals or companies - have a very real role to play in the solution of engineering problems and it is to be hoped that their present scarcity in the Australian scene will not continue for much longer.

In overseas practice there are many kinds of consultant services, ranging from engineering organizations (with their own engineering geologists) with the resources to carry out the complete investigation, design and supervision of construction of major projects, to individuals who advise on aspects of investigations. It is therefore difficult to generalize in a brief paper about the advantages and disadvantages of the use of private consultants. Consultants who review the investigations, recommendations and designs of others (commonly the client of the consultant), if of a high calibre, are of the utmost value to clients and are widely used throughout the world. There are drawbacks in some circumstances to the use of consultants to carry out investigations. Those operating on a small scale are apt to lack the necessary facilities to give the client all the services he may need; further a consultant generally has to give an estimated cost of his investigation. This estimate may be a firm quotation or merely an indication of order of cost; where a quotation is given there will always be the risk that the amount of investigation carried out will be based on the quotation rather than the needs of the project.

TECHNIQUES IN USE

No attempt is made here to list all the techniques in use in Australia, or even to mention all new developments. There are few new techniques in use; most original work consists of refinements of established methods in efforts to improve, and express in quantitative terms, all forms of geological data.

Approaches adopted include:

Extensive use of bulldozers and sluicing to determine bedrock geology, even at the feasibility stage of investigation.

Use of stationary split inner tube core barrels for diamond drilling. A third, plastic, tube can be inserted, and a retractable leading piece can be used, to recover soft unconsolidated material. This equipment permits 100 percent core recovery under a great range of conditions. The split tube also permits relatively undisturbed core to be obtained and examined. The undisturbed core in the barrel is commonly photographed to provide a permanent record.

The South Australian Mines Department has adapted equipment to permit undisturbed samples of soft material to be taken from diamond drill holes with a stainless steel push tube sampler, and to conduct standard percussive penetration tests at the bottom of diamond drill holes.

Carefully-controlled pressure testing of drill holes to determine the permeability to water of the ground drilled, to ensure that results obtained have a more than qualitative significance.

Detailed study of joint, fault and bedding orientations to select the best locations and orientations of underground openings and ensure stability of foundations. A bore-hole camera has been used by one authority to examine the in situ condition of ground and the orientation of geological structures, and a borehole periscope has been developed to permit inspection of drill holes to a depth of 20 feet.

Determination of elastic properties by mechanical and seismic tests.

On one hydro-electric project in New Guinea grouting experiments are planned at the feasibility stage of investigation because of the possibility of high leakage through a ridge 3,000 to 4,000 feet long. The practicality and economics of the scheme may depend on the development of an effective and economical seal over the length of the ridge.

Reference is made elsewhere to plans for a study of foundation response to earthquakes at the sites of proposed hydro-electric schemes in New Guinea. It is proposed to use the existing regional seismological network, together with a seismograph or accelerometer in the project area, and a number of smoked watch-glass seismoscopes at the project site located on a variety of possible foundation materials.

Transistorized borehole temperature loggers have been developed to record, at design stage, rock temperatures in the vicinity of proposed underground power stations.

At the construction stage increasing use is being made of stress and strain meters of various types to determine excavation-induced stress concentrations and primary stresses around underground openings. A major need exists for a device which could be placed at depth in a drill hole at design stage to give designers information on the primary stress field, so that the most efficient shape for excavations can be determined at the planning stage, and a record can be made of stress changes as excavation proceeds.

The engineering geologist is also playing a large part in effecting economics and improving safety in openings by proper positioning of rockbolts; this may involve a study of the depth of the envelope of fractured rock around openings. He is also assisting similarly in the design of grouting.

The use of refraction hammer seismographs by geologists is proving a valuable aid to the delineation of shallow sub-surface conditions on major projects, investigation of deposits of construction materials and in the planning of urban engineering services. With many types of instruments small explosive charges may be used to increase the depth from which information can be obtained.

TRAINING OF ENGINEERING GEOLOGISTS

At the symposium referred to in the Introduction it was apparent that there were two divergent views on the training of engineering geologists. One view is that, for those wishing to become engineering geologists, courses should provide at undergraduate level, probably by inter-Faculty arrangements, for those subjects of value to the engineering geologist which are not normally included in the geology course - subjects such as rock mechanics, soil physics and chemistry, soil mechanics, groundwater hydrology, and various civil engineering subjects such as strength of materials. In view of the study load in existing courses some support subjects now commonly taken would have to be omitted and aspects of geology would need to be condensed or omitted. The opposing view was that the first requirement of a university course is that it produce a competent, well-equipped geologist and that special knowledge and skills should be added at the post-graduate level or by "on-job" training.

As engineering geologists provide services for engineers who presumably are competent to check the validity of deductions of an engineering nature, made by a geologist, provided the latter presents the facts in terms which are meaningful to an engineer, it seems to the author that the first requirement for an engineering geologist is that he be a competent geologist. Geological observations and inferences can not be so readily checked by an engineer. The engineering geologist should therefore have had a sound academic geological training (though the course may contain but brief tuition in some aspects of the science, e.g. palaeontology) and, if possible, some general geological experience. Because of the volume of work in most undergraduate geology courses most specialized engineering geology tuition must inevitably be left to the fourth, or later, years. The most important aspects of geology for the engineering geologist are possibly petrology, sedimentation, structural geology, hydro-geology, geomorphology and the weathering of rock.

For most aspects of engineering geology some further training is needed to express geological data in engineering terms. A great deal of the necessary experience can be obtained by "on-job" training by competent instructors but, increasingly, advanced engineering geology practice, such as the use of rock mechanics, particularly at the design and construction stages for engineering structures, requires some formal post-graduate training.

Applied geology courses, at undergraduate level, are given at most Australian universities and these include a greater or lesser component of relevance to the practice of engineering geology. However, there are no adequate courses, at undergraduate or graduate level, designed to meet the specific needs of the prospective or practising engineering geologist. Theses on engineering geology topics are being accepted for honours and masters degrees at some universities and would doubtless be accepted for higher degrees.

ENGINEERING GEOPHYSICS IN AUSTRALIA

Geophysics has been used in Australia in the investigation of foundations and materials resources more extensively than appears to be the general rule elsewhere. The deep weathering which is such a feature of much of Australia led to the early development of interest in geophysics as a prospecting tool for minerals, and in the 1950's the Bureau of Mineral Resources built up a strong team of prospecting geophysicists. Inevitably their services were sought to solve problems of depth of weathering and overburden, physical properties of bedrock, and the occurrence and properties of potential construction materials, for major engineering structures, particularly dams.

At present the Bureau of Mineral Resources employs seven engineering geophysicists, and governmental engineering authorities employ another three or four. In addition, there are several consulting geophysical groups which are prepared to undertake engineering geophysics investigations. Engineering geologists in several governmental organizations also use geophysical techniques from time to time.

Fairly standard geophysical techniques are used: refraction seismic traverses, supplemented by surface resistivity surveys and, in suitable situations, magnetic work are the main techniques used. Reflection seismic techniques also have been used. Seismic equipment ranges from sophisticated 24-channel instruments with a variety of energy sources to hammer-actuated seismic timers. Electrical logging of holes has been undertaken and experiments have been carried out, or are planned, with nucleonic down-hole methods measuring rock density and water content. Systematic study of foundation response to earthquakes for various earth materials on the sites of planned hydro-electric schemes in New Guinea is also to be undertaken. In the laboratory, measurements of the physical properties of specimens of rock from engineering projects are undertaken to facilitate engineering design and the interpretation of field measurements.

The Bureau's Engineering Geophysics group also undertake investigations into the occurrence and quality of groundwater and into the incidence of vibration in buildings produced by such sources as blasting, traffic and machinery. It has a number of interesting research projects in hand including the detection of caverns and pinnacles in buried limestone, the relationship of size of explosive charge to amplitude of ground vibration, a study of the flow of water through porous media, determination of the rippability of rock by geophysical methods, and a study of the effect of grouting on the seismic properties of rock.

POSSIBLE CONTRIBUTIONS TO ENGINEERING GEOLOGY BY E.C.A.F.E.

Agenda item IX, under which this paper is presented, calls for recommendations by the meeting to the Secretariat "in regard to further action to be undertaken by the Secretariat in engineering geology". The author is not aware of what action has already been taken by the Secretariat in this matter, of the present status of the proposal to set up a Geological Centre, nor of the present availability of engineering services and training facilities in the region, consequently some of the remarks that follow may be inappropriate.

The following suggestions are offered:

1. As can be seen from this paper there remains, even in well-developed countries, a lack of awareness of the role that engineering geologists and geophysicists can play in the efficient investigation, design and construction of a great range of engineering projects and in the exploitation of construction materials. Publicity about the role and availability of engineering geology and geophysics would therefore appear to be a task of prime concern to E.C.A.F.E. This publicity should be directed not only to governmental and international planning agencies working in the region but also to engineering organizations engaged on all manner of tasks.

2. The Secretariat might take active steps to enlist further assistance from governments contributing to aid programmes, by lending or seconding experienced engineering geologists (and geophysicists) to assist in development schemes, as has been done on the Mekong Basin project.

3. Representations could be made to those universities of the region which presently do not have courses for engineering geologists, as to the desirability of providing both undergraduate and post-graduate training courses to help in the development of the region. Provision of fellowships and scholarships for graduate geologists in countries other than their own could also be considered as a means of providing "on-job" training in engineering geology techniques.

4. If the proposal to establish a regional Geological Centre is proceeded with, consideration could be given to the employment of an experienced engineering geologist to act as a consultant and to the provision of laboratory facilities to enable tests of relevance to the investigation and design of engineering projects, etc., to be carried out. Facilities could include petrography, unconfined and confined strength tests, photo-elastic studies, equipment and qualified experts for the in situ measurement and interpretation of stress and strain in underground openings, standard equipment for determining properties and suitability of potential construction materials such as aggregate, sand and gravel, brick clay and shale, and pozzalans. Some of these facilities may be more appropriately provided as an adjunct to an engineering laboratory.

5. Experts could examine and recommend standard test procedures for site and laboratory investigations, and standard methods of presentation of data, e.g. in different countries and organizations the results of water pressure tests to determine the permeability of foundation materials are presented in a variety of ways - in darcies, gallons (imperial or American) per minute per foot of drillhole, litres per minute per metre of drillhole, feet per year, metres per year, and lugeons* - and doubtless others.

6. For those countries which are subject to earthquakes and for which a service does not already exist, a body could be set up to collect data and advise on regional earthquake hazard, on likely foundation response to earthquakes and on aseismic design of structures, including buildings.

7. In conjunction with the Geological Centre, a sound engineering geology reference library could be provided.

8. Facilities or funds could be provided for research, either at a selected university or at the Geological Centre, into specific problems, related to the engineering geology of particular projects, as they arise.

Presumably E.C.A.F.E.'s role in many of the points suggested above would be to investigate the need for and feasibility of the proposal and, if adopted, approach an international body, such as U.N.T.A.B., or a national government, for assistance in the matter.

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* One lugeon is defined as a rate of water loss of 1 litre per minute per metre of drillhole (of diameter 46 to 76 mm) at a pressure of 10 bars. Foundations or walls of pressure shafts are widely accepted as watertight if loss does not exceed 1 lugeon.