AUSTRALIAN ATOMIC ENERGY SYMPOSIUM

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Proceedings of a Symposium on the Peaceful Uses of Atomic Energy in Australia held in Sydney from June 2 to 6, 1958

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ON JULY 25, 1957, the Australian Atomic Energy Commission called a meeting of representatives of universities, professional bodies, industrial firms, power authorities, and Commonwealth and State departments at which it was agreed that a Symposium on the Peaceful Uses of Atomic Energy in Australia should be held during the week June 2 to 6, 1958. The Symposium was intended to bring together members of scientific and technical organisations and industrial firms who were interested in atomic energy, to serve as a focal point for the various activities in these fields, to present the progress already made, and to suggest new lines of investigation and advance. It would also foster public interest in atomic energy, and to this end it was decided that an exhibition be held at the same time as the Symposium, and that public lectures be arranged.

It was thought that the Symposium might be planned on lines similar to the conference held in Geneva in 1955, and that it should include unclassified scientific and technical papers in the many fields of science and technology which relate to atomic energy, with particular reference to scientific and industrial research and applications in Australia and to the part atomic energy might be expected to play in the development of Australia. The University of Sydney generously offered the use of lecture theatres and other facilities for holding the Symposium, and this proved a most satisfactory arrangement.

The response to the invitation to present papers was much greater than expected, and finally 114 papers were selected for presentation at the Symposium to simultaneous sessions throughout the week.

Four hundred and thirty-five people enrolled for the Symposium, including 38 overseas visitors representing Government agencies, universities and industrial firms, from Great Britain, the United States of America, Canada, New Zealand, Pakistan and the International Atomic Energy Agency.

The papers—which covered a wide range of interests in relation to raw materials, nuclear power, nuclear research, the basic sciences, education and the industrial and medical uses of isotopes—were distributed as preprints before the conference. One feature of the conference was the lively discussion that ensued following the presentation of the papers.

Contributions to the discussion are included in this volume, together with these papers.

Visits were arranged during the Symposium week to laboratories undertaking research of interest in nuclear science and technology at the Australian Atomic Energy Commission's Research Establishment at Lucas Heights, at the University of Sydney, and at the New South Wales University of Technology. In addition to the scientific activities, the Deputy Lord Mayor of Sydney welcomed distinguished overseas and interstate visitors at a civic reception. A social was held on the Monday evening, and an official dinner on the Wednesday evening in the Sydney University Union.

In connection with the Symposium, a five-day exhibition was arranged by the Australian Atomic Energy Commission in the Sydney Town Hall. Government and industrial organisations in Australia and overseas participated, and the exhibition covered prospecting and mining of uranium and other raw materials, the development and use of atomic power, the industrial uses of radioactive isotopes and training and research in the broad field of nuclear technology. The exhibition was attended by many thousands of people. A public atomic energy forum was held in the Assembly Hall on the Thursday evening, at which five Australian and overseas scientists answered questions on atomic energy matters put by members of the audience. Several radio and television programs featured atomic energy during this week.

The Symposium, exhibition and associated activities made up an active and interesting week, stimulating interest both among those already engaged in these fields and the general public. They surely mark a milestone in the development of atomic energy in Australia.

J. P. BAXTER

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Instrumentation Problems in Radioactive Prospecting

By J. Daly and D. F. Urquhart*

The paper gives a brief review of problems in the design of equipment for radioactive measurements required in the search for radioactive minerals. The equipment is used for two main purposes, assaying and prospecting. Equipment required for assaying introduces no special problems. However, the use of radiation measuring equipment in moving vehicles, which is of great value in prospecting, involves fundamental difficulties, apart from any practical problems which may arise. As examples, the design of equipment for bore logging and for airborne surveying is discussed. Bore logging involves serious practical problems, and the response of a bore logger is greatly affected by the time constant of the equipment. In airborne prospecting the practical difficulties are not serious, but the response is influenced by the fact that only radiation from the surface can be detected. A simple method is described for calculating the response of moving detectors.

INTRODUCTION

The design of equipment for radioactive measurements is nowadays a fairly well standardised procedure. All that is involved is the selection of a detector capable of giving the information required, and a suitable means of registering this information. The properties of detectors and registering circuits are the subject of a vast literature, in which they are discussed at any desired level of physical and mathematical complexity. A summary at a rather elementary level is given in a publication of the Bureau of Mineral Resources, Geology and Geophysics (Daly, Urquhart and Gibson, 1956); no discussion is given here.

In connection with the search for radioactive minerals, radioactive measuring instruments are required for two purposes, assaying and prospecting.

For the purposes of the present paper the question of instrumentation in connection with assaying may be treated in summary fashion. The measurements required have no unusual features, and the equipment does not differ in design from that used for similar measurements in other fields of nuclear study.

The various methods of assaying may be distinguished as follows:—

(i) Beta or gamma counting, comparing the radiation from the unknown sample with that from a standard. This requires a detector, which may be either a geiger tube or a phosphor and photomultiplier, and counting equipment.

(ii) Simultaneous beta and gamma counting. The equipment is the same as in (i). This method of assaying is fully described by Daly, Urquhart and Gibson (1956).

(iii) Methods involving gamma ray spectroscopy. If a gamma ray spectrum of the radiation from the unknown sample is observed, much more accurate information is obtained on whether the material contains uranium or thorium or both, and its state of radioactive equilibrium. The Bureau has found that there is no advantage in taking a full gamma ray spectrum, but that adequate information is obtained by counting gamma rays of a few selected energies. The standard method now used by the Bureau involves a beta count, taken simultaneously with two gamma counts at selected energies. A scintillation detector must be used for the gamma counts. In addition to the usual counting equipment, pulse amplitude analysers must be provided to select the desired energies. The design of such circuits is standard.

(iv) Delayed Coincidence Methods. These methods have been suggested, but it is not known that they have been used much, presumably because they require a considerable amount of equipment. It is theoretically possible to estimate the amount of any radioactive element which produces a radioactive daughter product of very short half life, by isolating the radiation from each element, and measuring the number of disintegrations of the daughter product which occur within an appropriate time interval after each disintegration of the parent. The equipment required would include gating units, time delays, and coincidence units, in addition to the usual detectors, amplifiers and counting equipment.

(v) Methods involving alpha ray spectroscopy. Such methods are attractive in principle, as both uranium and thorium are alpha emitters. A method of this type has been developed and used in the Bureau, and is described by Howard (1958). The detector is a gridded ionisation chamber, followed by a high gain amplifier and an alpha ray spectrometer. The major drawback to alpha counting methods is the difficulty of preparing the sample in a suitable form.

For prospecting purposes, the information required is a measurement of gamma ray intensity at a chosen point. Consideration of

* Bureau of Mineral Resources, Melbourne. Manuscript received March 13, 1958.

sensitivity, ease of operation, and maintenance restrict the choice of detectors to Geiger tubes, or scintillation detectors, and of registering circuits to ratemeters. The design and construction of portable Geiger or scintillation ratemeters is standard, and such instruments are now well known. The purpose of the present discussion is to consider the problems involved in the extension of these elementary techniques.

Attempts at the extension of geophysical techniques take the following obvious directions:—

(i) Mounting of equipment in moving vehicles, such as aircraft, thus increasing the speed of coverage.

(ii) Construction of continuously recording equipment, which is a necessary consequence of (i).

With ordinary geophysical techniques, the difficulties involved in such extensions are practical ones only. This does not necessarily imply that the difficulties can be easily overcome. Taking some familiar methods as examples, the airborne magnetometer problem has been solved as regards total force instruments. However, notwithstanding continuous research, airborne magnetometers for the measurement of specific components of the earth's field are still in the early experimental stages. In recent years, airborne electromagnetic equipment has been developed successfully. On the other hand, the difficulties in the construction of an airborne gravity meter have so far proved insuperable, and on present indications will remain so for a long time.

The statement that only practical difficulties are involved implies merely that there is no reason in principle why an instrument cannot be devised which will give fundamentally the same information as the instruments at present used on the ground. With radiometric equipment, this is not the case. Apart from practical difficulties, any extension of radioactive prospecting equipment to moving vehicles involves difficulties in principle, as a result of which the information obtained from the modified method is fundamentally different from that obtained by a static measurement of radioactive intensity. These difficulties are due to the following fundamental causes:—

(i) Unlike gravitational, electrical or magnetic fields, radioactive intensity is not a potential field.

(ii) Any radioactive measurement requires the counting of a random process. This necessarily involves a time constant.

As an example of the application of these principles, instruments for two types of radioactive measurements (for radioactive bore-logging and for airborne radiometric prospecting) will be discussed.

RADIOACTIVE BORE LOGGING

Radiometric logging is used for two main purposes.

(i) Stratigraphic logging, used in oil drilling.

(ii) Logging of holes drilled in the exploration of deposits of radioactive minerals.

The problem in stratigraphic logging is generally to record the position of formations of considerable width, with radioactivity which may be very slight. The main purpose of the work is usually to assist in correlation of geological formations from one drill hole to another. High sensitivity is necessary, but the actual nature of radioactive minerals in a formation, or the precise width of the formation, are not matters of prime interest.

Logging of exploratory holes on the other hand, usually involves relatively strongly radioactive formations which may be quite narrow. High sensitivity is not required, but it is of great importance to obtain an estimate as accurate as possible, of the width and grade of the formations. The discussion here is confined to the second type of logging.

The principles of design of a borelogger will be discussed in some detail, because it may be of interest to observe the non-scientific factors which are often of prime importance. The following practical considerations have considerable influence in the design and construction of a bore logger (in Australia at least):—

(i) Shallow exploratory drill holes are kept to as small a diameter as possible for economic reasons. Practically, this means that the probe of a bore-logger for general use must enter an EX hole, and thus its diameter cannot exceed 1⅜in.

(ii) Drill holes commonly pass through crumbling ground, particularly in the weathered zone. The probe of the logger is liable to stick in such ground. This complicates the mechanical design of the logger considerably.

(iii) There are great advantages in using only components which are readily available. The situation in this regard has improved in recent years, but there is still a wide range of components which can be purchased from stock in U.K. or U.S.A. but which are not available in Australia.

(iv) The designer is practically restricted to the use of a standard type of cable, as cable manufacturers could not consider the construction of a special type of cable for which no large market exists.

There is no problem in the design of the detector or registering circuit. The detector is either a Geiger tube, or a phosphor and photomultiplier. Until recently, photomultiplier tubes of small size were not available, and it was impossible to construct a scintillation probe of diameter less than 2in., so that scintillation loggers could not be used in EX holes. Recently, however, a photomultiplier tube of diameter ¾in. has become available, and scintillation probes can now be made which will enter an EX hole.

The registering circuit is a ratemeter of conventional design. The problem for the designer arises from the fact that detector and registering circuit have to be connected by a cable some hundreds of feet long, which introduces a heavy capacitative load. Theoretically, this can be overcome in several ways, which are all considerably hampered by the practical matters listed above. For example, the probe could include impedance matching elements such as cathode followers or pulse transformers, provided it were big enough. Such a probe, however, would have to contain its own power supplies, otherwise a multiconductor cable of special design would be necessary. Such cables are not readily available.

Also, if more components are built into the probe, it is more expensive, and the chance of loss must be minimised. If batteries are included in the probe, they will have to be replaced periodically. The engineering problem of designing a probe which can be easily dismantled to replace batteries, and which will stand up to the water pressure encountered at depths of some hundreds of feet, is considerably more difficult than would at first appear.

These considerations lead to some form of compromise which usually has obvious drawbacks. Two examples may be of interest. The design of loggers specially constructed for the Bureau of Mineral Resources was based on the following primary considerations:—

(i) The loggers were required for use in EX holes at Rum Jungle. There was reason to expect that the ground would be extremely bad.
(ii) Some of the holes were horizontal holes drilled underground. Push rods were necessary in such holes.
(iii) The only Geiger tubes available were glass tubes about ¾in. diameter. As the probe was restricted to 1⅝in. diameter, there was no room in it for other components.

Based on these requirements, equipment was designed in which the push rods were an integral part of the equipment, to be used in all holes. This has the following advantages:—

(i) The push rods provide all the strength necessary, so that a low cost, low capacity cable of low mechanical strength could be used.
(ii) The cable selected was a Pt 11 M coaxial. Because the push rods could be used as an electrical connection, the equivalent of a three conductor cable of very low capacity was available. This was made the basis of an ingenious device for reducing the effect of the cable capacity still further.

The use of the push rods means that the probe must be raised and lowered by hand. The method of reading is to halt the probe at each reading point for a time sufficient for the ratemeter to reach a steady reading. Distances are measured along the push rods, and no errors due to cable stretch are introduced. The probe is relatively inexpensive. However, continuous recording is not easily practicable.

This equipment has been used for several years, and is still in use. Its only serious drawback is that it is slow and cumbersome.

An example of an alternative design is the "Deedle bug" designed by the U.S. Bureau of Mines. The Geiger tube used on this equipment is metal-walled, and is about ¾in. diameter. It requires no protection, and itself forms the probe. The tube is of the high current type, and measurement involves recording the steady current flowing so that the capacity of the cable does not affect the design.

Because the diameter of the probe is considerably smaller than that of the smallest hole, it is not so liable to stick, and the cable provides strength sufficient for retracting the probe. The probe is driven by a winch, which also controls the paper drive of a pen recorder. Continuous recording is therefore possible.

Provided the hole is reasonably clear so that free motion of the probe is not hindered, this type of logger is convenient in use. Its disadvantage is the effect of the time constant on the response. The response may be calculated by a very simple process.

The action of a logger involves feeding a current proportional to the count rate at any instant into a resistance-capacity circuit, and measuring the voltage developed. If R and C are resistance and capacity, and I(t) the current input, the voltage developed is given by:—

$$\frac{C\,dv}{dt} + \frac{v}{R} = I(t)$$

$$\text{or } \frac{RC\,dv}{dt} + v = R.I(t)$$

RC is the time constant of the circuit.

If an analytical expression for I(t) may be written down, the equation can be solved for V immediately. It can also be solved very

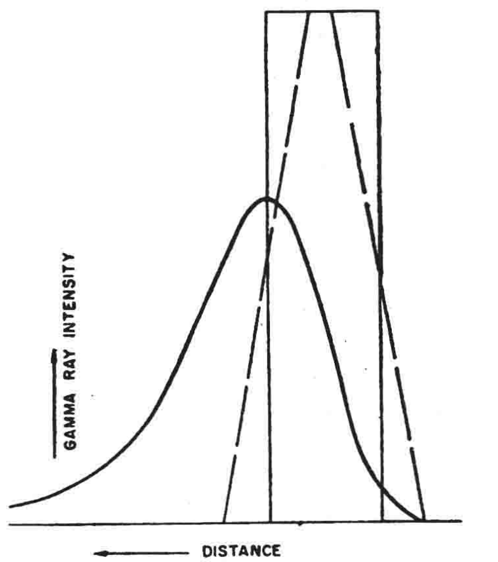

FIGURE 1:—Response of continuously recording borelogging.

conveniently by graphical methods, as discussed, for example, by Bailey and Somerville (1938).

The application of this to the logging problem is shown in Figure 1.

The ideal log which should be obtained when passing a band of uniform radioactivity is shown by the rectangular graph. Due to the finite length of the probe, the actual current input to the ratemeter will have the trapezoidal wave form shown. Graphical integration over the time constant of the equipment gives the response as shown by the curved line, which differs very considerably from the ideal log.

A priori, it would appear doubtful that such a simple theory could provide a realistic basis for the discussion of bore logging problems. However, the theory has been tested by a set of experiments performed by Territory Enterprises Ltd., at Rum Jungle, the results of which were made available to the Bureau of Mineral Resources. The results indicate that the logs calculated by this method fit observations with surprising accuracy, and that this simple treatment can be used with confidence to predict the response of loggers to various conditions.

One significant conclusion from this work is that unless the radioactive formation is considerably wider than the length of the probe, the shape of the log has only an indirect relation to the width and grade of the formation, and it is quite impossible to obtain accurate information on the width and grade of narrow formations from logs of this type. A detailed report on this work will be issued in a Bureau publication.

AIRBORNE RADIOMETRIC PROSPECTING

An obvious method of increasing speed of coverage in prospecting is to use equipment mounted in a motor vehicle or an aircraft. Continuous recording is necessary. Equipment mounted in a motor vehicle has been used successfully by the Bureau of Mineral Resources, but it has been found that the efficiency of this method is limited by topography to a much greater degree than might be expected. The use of aircraft offers greater possibilities. There is no particular problem in the design of equipment for this purpose, nor is the time constant of the equipment an important factor, to a first approximation. However, other problems arise, which are due in principle to the fact that radiation intensity is not a potential field.

The ideal method of prospecting would fulfil the following two requirements:—

(i) It would register radiation coming from any ore body.

(ii) It would register only radiation coming from ore bodies.

Neither of these conditions can be satisfied by any method, because it is possible to record only radiation arising from surface material. Unless an ore body actually outcrops, it may have little or no expression in surface radioactivity. On the other hand, any prospecting instrument will register all surface radioactivity, from whatever source.

Prospecting with a hand instrument involves testing the level of radioactivity at various points, and tracing the source of any anomalous radioactivity (not usually a very easy matter). An improvement in speed of coverage can be obtained by mounting the detecting equipment in a light aircraft. This is flown over the terrain at the lowest possible altitude. The site of any anomalous radioactivity is marked on air photos and the marked sites are later examined on the ground. In principle, this amounts to performing the operation of ground prospecting at the speed of a light aircraft. For the purposes of a mining company wishing to prospect a limited area, this is a very satisfactory method and has been widely and successfully used.

However, it has difficulties where a full routine coverage is required, particularly where information has to be published. The information must be published in some form of map. An inaccurate map is of no value, and an accurate map cannot be prepared from air photos alone, but requires additional control by other surveying methods. The most economical solution is to fly the area, locating the position of the aircraft, not on air photos, but by means of some other surveying method, such as Shoran. An accurate map is prepared separately by the usual methods, and the survey results combined with it.

This involves carrying the necessary positioning equipment in the aircraft. For this reason, a large aircraft is necessary, which must fly at greater heights and speeds than a light one. The disadvantage of the greater height may be minimised by mounting the detector in a "bird," which is trailed below the aircraft in flight. This method has been used successfully by the Bureau, although it introduces difficulties in actual flying which may become serious in areas of rough topography. The extra height and speed mean that the response of the detector averages over a large area, and is affected to some extent by the time constant of the equipment. It is therefore one stage more difficult to relate it directly to conditions on the ground.

A comparison with aeromagnetic methods will help to make the matter clearer. The magnetic field on the ground consists of the effects due to magnetic bodies of geological significance, at various depths, with in many instances a superimposed magnetic "hash" due to detrital material of irregular magnetism, which may obscure the more significant indications completely. In an airborne survey over the same ground the effect of the "hash" disappears, because it is caused by near surface material having random polarity in either sense, and its integrated effect at a distance is zero. The radioactive case is quite different.

Radioactive intensity cannot have a negative value, so that irregularly distributed surface radioactivity will certainly have a positive integrated effect at a distance. Instead of simplifying the picture as in the aeromagnetic case, an airborne radiometric survey is likely to confuse it unless the results are examined with special care.

The effect of time constant on the response can be evaluated by the same theory used for bore logging. However, the problem is rather more difficult, because allowance must be made for the absorption of radiation in the air. The equation:—

$$RC\frac{dV}{dt} + V = R.\ I(t)$$

applies as before, but the expression for I(t) is more complicated.

The effect on the detector of an elementary area of radioactive material at a distance r is proportional to $\frac{e^{-\mu r}}{r^2}$ where μ is the absorption factor for gamma radiation in air. The value of I(t) at any instant is therefore proportional to $\int \frac{e^{-\mu r}}{r^2} dr$, where the integral is taken over the total area of radioactive material observed by the detector at the instant in question. This integration may be performed graphically. Work is in progress to test the application of this theory to actual prospecting problems.

CONCLUSION

The above brief review indicates that the usual principles of the design of radioactive measuring equipment are quite adequate to any of the requirements of radioactive prospecting. There are plenty of difficulties involved in the discovery and exploration of deposits of radioactive minerals, but there is no reason to expect that their solution will be made any easier by improvements in instrumental design.

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The Regional Distribution of Uranium Occurrences, Northern Territory, Australia

By B. P. Walpole*

Uranium deposits in the Northern Territory have been found in Precambrian rocks ranging from Archaean to Upper Proterozoic in age. The important deposits are confined to a particular facies assemblage within the Lower Proterozoic sequence, and to rocks which belong to the lower part of the Upper Proterozoic (Lower Adelaidean) succession. None of the major deposits can be related to granic intrusions and all are Upper Proterozoic in age. Some can be related to Upper Proterozoic volcanic activity, but the remainder, and particularly those at Rum Jungle, are not associated with volcanic rocks.

INTRODUCTION

The first recorded discovery of radioactive mineralization in the Northern Territory was made in 1947, when samarskite was found in the pegmatite of the Butcher Bird mine in the Harts Range. The discovery of the Rum Jungle deposits in 1949 provided an impetus which has since led to the location of more than 70 radioactive prospects in the Territory. Only a few of them have developed to the stage of production. Very few have reserves which allow them to be classed as economic mining propositions, and all these latter occur in the Rum Jungle and South Alligator River districts of the Katherine-Darwin region. All the known prospects occur in Precambrian rocks.

This paper will not describe the different deposits in detail. They will be subdivided into geographical groups and, where necessary, into different types of deposits within any particular area.

GENERAL GEOLOGY

The distribution of the Precambrian rocks of the Northern Territory is shown in Figure 1. It has long been recognised that these rocks can be considered in three major divisions, here referred to as Archaean, Lower Proterozoic and Upper Proterozoic. The divisions were based primarily on degree of metamorphism, the presence or absence of granite intrusions, and the degree of folding, and all data gained in recent years emphasise the correctness of these divisions. Tentative subdivision of the Lower Proterozoic into Lower Proterozoic and Upper/Lower Proterozoic and of the Upper Proterozoic into Lower and Upper Adelaidean is now possible, but it is certain that such subdivision will be modified as more data become available. The salient features of the rocks in these major divisions, and their areal distribution are summarized in Table 1.

* Bureau of Mineral Resources, Geology and Geophysics. Published by permission of the Secretary, Department of National Development. Manuscript received March 25, 1958.

Archaean

Joklik (1955) has described a suite of Archaean rocks from the Harts Ranges of Central Australia. These may be considered as typical. The sediments are very highly metamorphosed, the granite intrusions are gneissic, and granitization and migmatization are common features.

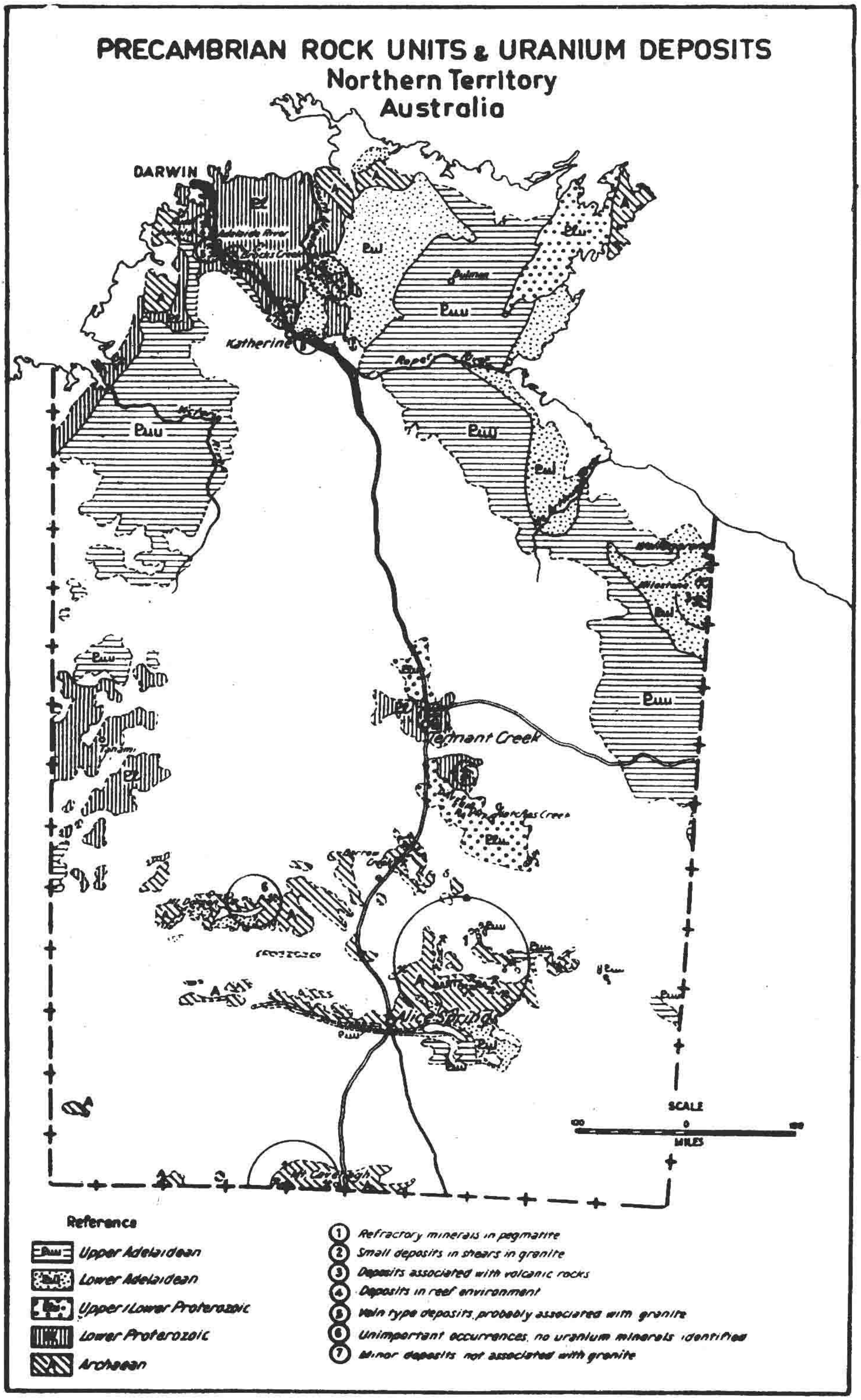
In direct contrast to the intense metamorphism which these rocks have undergone, structural deformation is not severe. This feature has not been widely recognised in the past, but there are very good examples in the Northern Territory which may be noted. One such area is the Harts Range. Here the main structural elements are fairly simple domes and basins, the flanks of which dip at angles averaging only about 40°. Dips of 20° are common. The writer is of the opinion that most of the major faults in the Harts Range area are not Archaean in age, but were developed late in Precambrian time. A second example is the Oenpelli area of the Katherine-Darwin region, where again the structural deformation is not intense, but the degree of regional metamorphism is high.

The Archaean rocks of the Northern Territory are singularly lacking in known economic deposits of base metals in general and of uranium in particular. There are a few minor occurrences of copper, lead and other minerals, but major discoveries of base metals have not yet been made in these rocks.

Uránium discoveries in the Archaean of the Northern Territory are confined to a few occurrences of samarskite in the mica-bearing pegmatites of the Harts Range, and to small veins of pegmatite containing betafite in the Mt. Cavenagh area on the Northern Territory—South Australian border.

Lower Proterozoic

The Lower Proterozoic rocks of the Northern Territory unconformably overlie the Archaean metamorphics, and crop out in the Tennant Creek area, and in the Katherine-Darwin-Victoria River region. The sediments are geosyn-



PRECAMBRIAN ROCK UNITS & URANIUM DEPOSITS
Northern Territory
Australia
DARWIN
Katherine
Tennant Creek
SCALE
100
0
100
MILES
Reference
Upper Adelaidean
Lower Adelaidean
Upper / Lower Proterozoic
Lower Proterozoic
Archaean
1 Refractory minerals in pegmatite
2 Small deposits in shears in granite
3 Deposits associated with volcanic rocks
4 Deposits in reef environment
5 Vein type deposits, probably associated with granite
6 Unimportant occurrences, no uranium minerals identified
7 Minor deposits not associated with granite