IUREP ORIENTATION PHASE MISSION

Summary Report

MADAGASCAR

A summary report prepared on behalf of the Executive Group for the IUREP Orientation Phase
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The OECD Nuclear Energy Agency (NEA) was established on 20th April 1972, replacing the OECD’s European Nuclear Agency (ENEA).

NEA now groups all the European Member countries of OECD with Australia, Canada, Japan and the United States. The Commission of the European Communities and the International Atomic Energy Agency take part in the Agency’s work.

The main aims of the NEA are to promote cooperation between Member governments in the safety and regulatory aspects of nuclear power and in the development of nuclear energy as a contributor to economic progress.

This is achieved by:
- encouraging the harmonisation of governments’ regulatory policies and practices;
- reviewing technical and economic aspects of the nuclear fuel cycle;
- assessing demand and supply, and forecasting the potential contribution of nuclear power to energy demand;
- exchanging scientific and technical information; and
- coordinating and supporting research and development programmes, notably through the setting up of joint projects.

The International Atomic Energy Agency (IAEA) came into being in Vienna, Austria, on 29 July 1957. Its main objectives are to “seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world” and to “ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose”.

The IAEA is an intergovernmental organization like the United Nations, the World Health Organization and other specialized agencies of the United Nations. It is directed by a Board of Governors, which is composed of representatives from 34 Member States, and a General Conference of the entire membership of 112 States. The IAEA has its own programme, approved by the Board of Governors and the General Conference, and its own budget, currently at 107 million dollars (1985), financed by contributions from its Member States.

Although autonomous, the IAEA is a member of the United Nations system and sends reports on its work to the General Assembly and to other United Nations organs.
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SUMMARY

A report has recently been made public which describes the findings of the International Uranium Resources Evaluation Project (IUREP) Mission to Madagascar.

The IUREP Orientation Phase Mission to Madagascar estimates the Speculative Resources of that country to be within the wide range of 4 000 to 38 000 tonnes uranium. Such resources could lie in areas with known occurrences (uranotherianite, Ft. Dauphin up to 5 000 t U, i.e. "pegmatoids"; uranocircite, Antsirabe up to 3 000 t U in Neogene sediments; carnotite-autonite, Karoo area up to 30 000 t U in sandstones and in areas with as yet untested environments (e.g. related to unconformities and calcretes).

Modifications to existing uranium exploration programmes are suggested and policy alternatives reviewed. No specific budget is proposed.

INTRODUCTION

During the bibliographic study, which formed the first phase of the International Uranium Resources Evaluation Project (IUREP), Madagascar was identified as one of the countries with good potential for uranium resources in addition to those reported on in "Uranium Resources, Production and Demand", December 1977 [OECD(NEA)/IAEA]. Following a meeting at which the IUREP Orientation Phase was discussed in some detail with a number of representatives of selected countries, the Malagasy authorities requested an Orientation Phase Mission. This Mission was undertaken by two consultants, Mr. J.H. Meyer and J.W. Brinck in September/October 1981.

The full report on this mission (126 pages, 20 figures, 6 tables, 4 appendices) has been released and is available for study at the locations listed in the Annex of this report.

The Executive Group for the Orientation Phase wishes to acknowledge the excellent cooperation given to the Mission by the Malagasy authorities and all staff assigned to assist the mission. Particular thanks are expressed to Dr. M.D. Rakato-Andriantsilavo, Director Industries/OMNIS; Mr. G. Teunissen, UNDP Resident Representative; Prof. A.H. Razafiniparany of the University of Madagascar and to Dr. D. Searle, Project Manager IAEA/UNDP for their help, information and geological discussions.

GEOGRAPHY

The Democratic Republic of Madagascar (Republika Demokratika Malagasy) comprises the island of Madagascar and minor adjacent islands in the Indian Ocean. The main island has an area of 595 309 km². Situated in the southern hemisphere, it extends over a maximum length of 1 580 km and width of 600 km and is located between latitudes of 11°57' and 25°38' South and longitudes 43°12' and 50°17' East and is almost entirely within the tropics. Its coastline extends over a total length of more than 5 000 km. To the West it is separated from the African coast by the Mozambique channel, the latter being 400 km wide at its narrowest part. The 1977 population was 9.1 millions.
Along its longitudinal axis there are three parallel geographical zones: the central elevated plateau, formed from ancient systems, a narrow littoral strip to the East and a zone of sedimentary formations, consisting of low plateaus and extensive plains to the West.

Most of the island is savannah-steppe and much of the interior is covered with laterite. Except for the drought-ridden South, rivers are numerous and flow generally westward. These are generally not navigable.

The island has essentially been denuded of its original forest, which once covered the entire land surface. Over large parts of the island, lateritic soil is covered only with a thatching of bozaka, a stout, stumpy grass. Forest areas represent only ten per cent of the surface.

The eastern region, is the most humid of the entire island; rainfall persists throughout the year. During the summer season, November to April, the sometimes catastrophic cyclones occur mainly in February and March. Temperatures range between 17°C in the winter and 31°C in the summer. The climate of the region is of the equatorial type.

The central plateau has a tropical, mountain climate, with well differentiated thermal seasons. About 1.40 to 2.00 metres of rainfall occur annually, of which only 0.10 metres fall during the winter months (May to September). Temperatures of the plateau have an average range of 12 to 21°C, during the winter months. Despite this relatively moderate climate, rainfalls are sometimes heavy, particularly during the summer, causing flooding and road washouts.

The climate of the western region is relatively dry and hot. Temperatures are higher; Mahajanga has a mean temperature of 27°C. Towards the south, the climate becomes increasingly drier.

While it is, in theory, possible to carry out most types of exploration activities on the high plateau throughout the entire year, the rainfall occurring in the eastern region during the wet season generally restricts exploration work there to the drier season (May to September).

GOVERNMENT

Madagascar became an independent republic in 1960 and is a member country of the United Nations. The institutions comprise the following:

- The Supreme Council of the Revolution;
- The National Popular Assembly;
- The Government;
- The Military Committee for Development;
- The Constitutional High Court.
The State regulates and controls investments in the economy. More than 60% of the economy is now under direct State control. The Government has declared that it will not offer compensation to nationalized firms, except in a few extraordinary cases.

Investment plans, published by the Government (Ministère auprès de la Présidence, 1977), show that current emphasis in investments is in industry, mines and energy and in buildings and public works, with these being the main growth sectors planned.

MINING INDUSTRY

For the year 1976, the value of mined products is reported as follows (in Millions of FMG*):

<table>
<thead>
<tr>
<th>Product</th>
<th>Value (in Millions of FMG*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromite</td>
<td>4 935</td>
</tr>
<tr>
<td>Graphite</td>
<td>1 079</td>
</tr>
<tr>
<td>Mica</td>
<td>165</td>
</tr>
<tr>
<td>Precious and ornamental stones</td>
<td>290</td>
</tr>
<tr>
<td>Industrial minerals</td>
<td>30</td>
</tr>
</tbody>
</table>


The mining industry contributes just over 1% to the GNP. At present the industry mines three products of economic importance; these are: chromite (120 000 tonnes annually), graphite and mica (Phlogopite). Of much less importance, significant only to the local employment pattern, is the limited exploitation of deposits of garnet, quartz, celestite and semiprecious stones.

Chromite reserves have been estimated as sufficient for 20 years of production at current levels. Additional reserves are estimated to be 3 million tonnes (at Andriamena) and 250 to 500 thousand tonnes (at Kanomena).

MAPS AND REPORTS

Topographic maps of the whole island to scales of 1: 100 000, 1: 200 000, 1: 500 000, 1: 1 000 000 and 1: 2 000 000 are available.

* FMG: Malagasy Franc
1 US$ = 250 FMG in 1976
These maps can be obtained from the Institut Cartographique de Madagasikara (FTM - Foiben-Taosarintan' i Madagasikara), B.P. 323, Antananarivo.

Aerial photographs to the scale of 1: 48 000 can also be procured from FTM.

Geological maps at the same scales as the topographic maps and covering the whole island are available from the Service Géologique d'Ampandrianomby, Direction de l'Industrie et des Mines, B.P. 322, Antananarivo.

Geological maps to scales of 1: 100 000 and 1: 200 000 of the whole country were completed in the early 1970s.

A composite map at the scale 1: 500 000 was prepared by Besairie (1969/70).

The Service Géologique has kept records of all mineral indications, which are shown on the "Cartes minières et des indices" to the scale of 1: 500 000.

MINING LAW

At the time of writing, a mining law, specifically covering the industry is in preparation. Pending the final publication of a new mining law, all mineral developments, except for the designated strategic minerals, remain subject to the old law.

A similar law covering the petroleum industry has been promulgated (Code Pétrolier, 1980). An English version is attached to the IUREP full report.

It is anticipated that the principles of the forthcoming mining law will basically parallel those of the "Code pétrolier", where they pertain to prospection, exploration, production, extraction research and taxation. Under the terms of the Code, the State is the sole proprietor of natural resources and has the monopoly on operations associated with any such activities throughout the territories (and off-shore zones) under Malagasy sovereignty. The State may subscribe the entire capital stock of a national enterprise, but must hold at least 51% of the shares.

TECHNICAL, ADMINISTRATIVE AND REGULATORY AGENCIES

For strategic mineral resources, including uranium, OMNIS is the only technical, administrative and regulatory Agency. OMNIS was founded with the specific purpose to prospect for, to explore and to exploit the strategic mineral resources of Madagascar, in particular, uranium and radioactive minerals. Conditions and terms for commercial participation in these activities have not been specified and will be negotiable. Exploitation of a mineral deposit requires an exploitation permit and a mining concession, which will be given to the bearer of the title to an exploration permit, upon proof of discovery within the perimeter of the exploration permit.
Igneous and metamorphic Precambrian basement rocks make up two thirds of the island, the remainder consisting of Mesozoic and Tertiary formations, all of which are covered in places by younger volcanics and sediments. A sketch map of the regional geology is shown in Figure 1.

Madagascar formed part of the Gondwana pre-drift land mass; its position explains the similarity in tectonics and geology with East Africa and India.

There were three major tectonic periods:

- Before 2 600 MY: Early cratonization
- Between 2 600 and 300 MY: Intercratonic orogenies and great magmatic re-activations;
- After 300 MY: Platform cover and major tectonic rifts.

As indicated above, Madagascar separated from Africa and thereafter from India at about 300 MY.

There were four orogenic periods: Kavirondian (2 500 - 2 400 MY), Eburnean (2 150 - 2 050 MY), Kibarian (1 250 - 1 150 MY) and Panafircan (550 - 450 MY), the last being the cause of abundant pegmatization and associated mineral deposits (beryl, mica, monazite, etc.) in several areas of the island. There is some indication that this orogeny also caused the total remobilization of all the uranium.

Following separation from Africa, the deposition of the Karoo facies sediments began in western Madagascar in the intercratonic channel. These sediments, which attain considerable thickness, are termed the Karoo ("Karoo malgache") because they are somewhat similar to equivalent formations in East Africa. The Karoo is overlain partly by younger mainly marine sediments.

Several major faults control the general structure of the island, striking N 20° E and N 20° W, the former is represented in the east coast of the island. With the separation from India, a tilt of the land mass to the east is considered to have taken place; this is reflected in the shallow dip of the western sedimentary sequence and in the transgressive and regressive cycles on the east coast. Faulting during the Tertiary era has not affected the sediments markedly, but has re-sealed some of the faults in the basement and created new ones there.

Faulting is also considered the cause of the major unconformities between the Archean and the Middle Proterozoic in the south-east of the island and the Middle Proterozoic and Karoo sediments of Middle Jurassic to Carboniferous age in the south-west. In addition, there are several disconformities in the Karoo.
The Precambrian

Important progress has been made recently in unravelling the complex geology of the Precambrian by absolute age dating, using radiometric methods. A synthesis of the Precambrian is shown in Table 1. It differs in some rather important aspects from earlier interpretations, in particular from the geological maps at scales of 1: 000 000 (Besairie, 1964); 1: 500 000 (1969-1970) and of 1: 2 000 000 (Besairie, 1973).

Taking these geochronological results into account, the following geological units are distinguished:

The Antongil system forming the original continental nuclei and consisting of granites and migmatites with intercalated quartzites, micaschists, gneiss and amphibolites (epidote-bearing granite of Antongil - migmatites of Mananara and granitic, orthogneissic and silicoaluminous ectinitic formations of the Masora group).

The group of migmatites and granitoid migmatites (the core of anticlinal ridges).

The Andriamena-Manampotsy system: an ectinitic assemblage limited to synclinal or furrows with numerous metamorphic basic - and ultrabasic intrusions (gabbros, norites, anorthosites, amphibolopyroxenites, pyroxenites, peridotites) and containing at the base: migmatites and silicoaluminous ectinites with graphite (Manampotsy-Ambatolampy groups) and above: calcium ferro-magnesian series (Beforona-Alaotra-Andriamena-Maevatanana).

The Androyen system: an ultrametamorphic assemblage of muscovite granite-gneiss (fr. leptynites granulitique) and pyroxenitic-werneritic formations (Fort-Dauphin-Tranomaro-Bevinda groups).

The Amborompotsy assemblage - a series of schists, quartzites and limestones (SQC) in the central region and comprising the littoral and lagoonal SQC-series with its lateral equivalents of epicontinental to geosynclinal facies (Amborompotsy-Ikalamavony series).

The Ampanihy group: an assemblage of gneiss and leptynite with garnet, silimanite and graphite and intercalated quartzites, amphibolites, limestones and manganiferous gondites.

The Vohibory and Ambohipato-Daraina-Milanoa groups, which form two geographically separated assemblages, one in the extreme South (Vohibory), the other in the extreme North (Ambohipato-Daraina-Milanoa) and both characterized by a similar copper mineralization. The Vohibory consists of a volcano-sedimentary rock assemblage (abundant amphibolites, amphibolopyroxenites, leptynites and limestones) overlying the graphite series of Ampanihy.

The Ambohipato-Daraina-Milanoa group consists of the more or less metamorphic, volcano-sedimentary Dairanan-Milanoa series (tuffs, breccias, flows, volcano-sedimentary conglomerates) associated with truly metamorphic rocks (amphibole-schists and epidote bearing amphibolites), overlying the granodioritic complex of Ambohipato-Vohemar (amphibole-epidote and pyroxene-bearing migmatites with residual pyroxenites and gabbros).
## Table 1
STRATIGRAPHY OF THE PRECAMBRIAN (after RAZAFINIPARANY, 1978)

<table>
<thead>
<tr>
<th>Absolute Age and duration of orogenic cycles in MY</th>
<th>Stratigraphic Scale</th>
<th>Deposits Formed</th>
<th>Principal Orogenies and Magmatic Reactivations</th>
</tr>
</thead>
<tbody>
<tr>
<td>550 - 100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>550</td>
<td>Cambrian</td>
<td>No known deposits</td>
<td>Pan-African Orogeny: Local reactivation of migmatites, granitisation by anatexis. Pegmatites (U, Th, Be, Nb, Ta)</td>
</tr>
<tr>
<td>550 + 100</td>
<td></td>
<td></td>
<td>General rejuvenation of biotites</td>
</tr>
<tr>
<td>1 200 - 200</td>
<td>Upper Proterozoic</td>
<td>No known deposits</td>
<td>Kibarian Orogeny: Metamorphism in amphibolite (facies of the foregoing series and reactivation of the oldest ones. Formation of migmatites, granites and charnockites.</td>
</tr>
<tr>
<td>1 200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 200 + 200</td>
<td>Middle Proterozoic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 300</td>
<td>Lower Proterozoic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 600 - 200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 600 + 200</td>
<td>Archean</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 000 - 200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 000 + 200</td>
<td>Natachean</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Phanerozoic is sub-divided into transcratonic and intercratonic cover rocks. The transcratonic platform cover is of little importance for uranium, consisting mainly of marine post-Karoo sediments and Oligocene and Plio-Pleistocene volcanics associated with tensional stresses in the interior.

The intercratonic rocks of the Karoo consist of a succession of sedimentary formations in the Western part, largely with very moderate dips to the West. There are two major subsidence basins, the Morondava in the South and the Mahajanga in the North. A complete section of the Karoo is given in Table 2.

Total length of exposure of the Karoo is over 1 450 km, maximum development is in the southern part of the Morondava basin, where it is rich in monazite derived from the ultrametamorphic Androyen system. In the centre of this basin, the sequence commences with the upper part of the Sakoa group; the latter is completely absent in the northern part. In the Mahajanga basin neither the Sakoa nor the Sakamena group is exposed.

Of importance in the Morondava basin is the occurrence of the Tsimiroro horst of the Precambrian. West of this horst, sediments are more continental in character.

### The Phanerozoic sedimentary cover:

- **The Karoo:** a lower continental sequence dating from the Upper Carboniferous to the Middle Jurassic.

- **The marine Upper Jurassic** with alternating glauconitic marls and fossiliferous limestones (Ammonites).

- **The Cretaceous:** alternating marine deposits (clays, marls and fossiliferous limestones (Ammonites, Gastropodes and Lamellibranchiates) and continental sandstones with dinosaurs and important volcanic intercalations during the Turonian.

- **The marine Tertiary:** Eocene limestone with abundant foraminifera.

- **Younger Tertiary deposits:** Miocene-Pliocene and Quaternary continental deposits.

- **The younger volcanics:**

  Cretaceous intrusions and volcanism of the Androy massif, the basaltic and rhyolitic flows of the eastern coast, basic, differentiated intrusions of Ambatovory-Analamy, Valozoro (?), Manama (?) and the Tertiary and Quaternary volcanic massifs (Montagne d'Ambre, Ankaizina, Itasy, Ankaratra).

### PAST PROSPECTION, EXPLORATION AND MINING

Prospection and exploration activities for uranium in Madagascar consist of two phases.
<table>
<thead>
<tr>
<th>AGE</th>
<th>GROUP</th>
<th>THICKNESS</th>
<th>FORMATION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle Jurassic</td>
<td>Isalo</td>
<td>900 m (S)</td>
<td>Isalo III</td>
<td>Different facies with marine episodes</td>
</tr>
<tr>
<td>to</td>
<td>Group</td>
<td>400-2 300 m(S)</td>
<td></td>
<td>Sandy facies with intercalated clays (Makay sands)-deltaic environment</td>
</tr>
<tr>
<td>Triassic</td>
<td>(1 000 - 4 000 m)</td>
<td>0 - 5 000 m(N)</td>
<td>Isalo IIa</td>
<td>Alternating sands and clays-deltaic-fluvialite deposits</td>
</tr>
<tr>
<td>Triassic</td>
<td>Sakamena</td>
<td>200/300 m</td>
<td>Upper</td>
<td>Mostly coarse, conglomeratic sands - deltaic-fluvialite deposits</td>
</tr>
<tr>
<td>to</td>
<td>Group</td>
<td>400 m</td>
<td>Middle</td>
<td>Slates and micaceous sands (at base), sands with alternating clays and sands (on top) lagoonal - paralic environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>very regular</td>
<td>(II)</td>
<td>Basal conglomerate and feldspatic coarse sands; alternating thic zones of sandy/schists and thin zone of inequigranular sands. Continental shelf-marine</td>
</tr>
<tr>
<td>Permian</td>
<td>Sakoa</td>
<td>150/2 500 m(S)</td>
<td>Lower</td>
<td>Limestone series of Vihitalia: reefal Is.</td>
</tr>
<tr>
<td>to</td>
<td>Group</td>
<td>60/300 m(N)</td>
<td>(I)</td>
<td>Lower red series: alternating sands and red schists</td>
</tr>
<tr>
<td>Carboniferous</td>
<td></td>
<td></td>
<td></td>
<td>Coal seam series: arkosic sands with intercalated black schists and coal seams: continental</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Basal series: tillites, schists, sandy schists with small intercalations of dolomitic limestone</td>
</tr>
</tbody>
</table>

PRECAMBRIAN BASEMENT
The first phase is marked by the predominant activities of the CEA during the period 1946 to 1965, the second by those of the newly formed OMNIS (Office Militaire National pour les Industries Stratégiques) organisation of Madagascar from 1976 to the present and assisted by concurrent IAEA and UNDP programmes. In conjunction with a multi-mineral survey, the UNDP carried out a gamma-ray airborne survey in 1966 over two small test areas in south-eastern Madagascar, apparently with negative results.

The CEA Program

The first targets of the CEA were the uraniferous pegmatites in the Itasy area and secondary occurrences in the area of Antsirabe (Figure 2) in a Neogene basin. These programs were terminated by 1954 because in neither case were results sufficiently encouraging to justify their continuation. Activities were then diverted to the area of Ft. Dauphin in southern Madagascar (Figure 2), where earlier prospection had identified the occurrence of uranothorianite in phlogopite and the eluvial cover of pyroxenite deposits. Subsequently, significant resources of uranothorianite were located in place, by G.M. and heavy mineral stream sediment surveys south of the Mandaré river and many of these deposits were brought into production. Simultaneously, heavy mineral beach placer deposits were evaluated for their monazite content.

The search for uranium was then diverted to other areas, particularly for sedimentary sandstone-type deposits in the Karoo of western Madagascar. After an extensive airborne scintillometric survey and ground follow-up work, more than 400 radiometric anomalies, with and without mineral indications (carnotite and autunite) were located in the Folakara (Figure 2) and Makay areas. Extensive but shallow (less than 100 m) drilling, totalling 57 000 m, located less than 300 tonnes of uranium, contained in eight different lenses. The exploration programme in this area was abandoned in 1965, probably because of its limited success and the important deposits discovered elsewhere in the world.

The OMNIS and IAEA/UNDP programme

In 1977, OMNIS contracted Hunting Ltd. of the United Kingdom to carry out an airborne gamma-ray and magnetometric survey of part of the Fort Dauphin area, which identified "several dozen" anomalies, many of which appear to be unrelated to the past CEA mining operations. Follow-up work in the area, currently still in progress, includes radiometrics, emanometry, magnetometry, geological mapping, trenching and drilling of anomalous zones.

The IAEA/UNDP programme includes training in drilling techniques, assessment of the known uranium occurrences in general (in 1976), the supply of exploration equipment, including analytical facilities and geological and geophysical investigations, including drilling in the revived projects at Antsirabe and Folakara (MAG77/012: 1977-1982). This work is being carried out in cooperation with OMNIS personnel and equipment.

Pending the issue of a final report at the end of 1982, an assessment of the results of this work is premature, but at the time of the Mission no additional significant uranium resources had been located.
Figure 2  PRINCIPAL URANIUM DISTRICTS AND URANIFEROUS PROVINCES
(after Carrie, 1980)

Legend:
- Recent Formations
- Neogene and Quaternary Volcanism
- Marine Miocene
- Marine Eocene and Oligocene
- Cretaceous Lavas
- Marine Cretaceous
- Marine Jurassic
- Cretaceous Intrusions
- Continental Cretaceous
- Continental Jurassic
- Marine Perno-Trias

Undifferentiated Basement
Fault

Scale:
0 50 100 150 200 km

Legend:
- Recent Formations
- Neogene and Quaternary Volcanism
- Marine Miocene
- Marine Eocene and Oligocene
- Cretaceous Lavas
- Marine Cretaceous
- Marine Jurassic
- Cretaceous Intrusions
- Continental Cretaceous
- Continental Jurassic
- Marine Perno-Trias

Undifferentiated Basement
Fault

Scale:
0 50 100 150 200 km
Known uranium occurrences

Using the categories of uranium deposits of the NEA/IAEA classification system, the following types have been identified in Madagascar:

Disseminated, magmatic deposits:

Uranium mineralization at Itremo and Ampasindava appears to be related to mafic alkaline intrusive differentiates, enriched in residual elements (Zr, Ti, Nb, REE, V, Th, U, P, F). Uranium occurs with Ta and Nb in alkaline granosyenite intrusives.

Pegmatitic deposits:

The occurrence of uranium tends to be concentrated in the potassium-rich pegmatites, almost exclusively in niobotantalates, rarely as uraninite.

The richest pegmatite fields are in the Itasy-Antsirabe-Mandoto area but the average grade does not exceed 100 g U/m³.

The CEA explored some of the more important deposits, e.g. at Ambatofotsy, including drilling and exploration adits.

Sandstone-type deposits:

The Karoo

The more important uraniferous zones discovered by the CEA are in the area of Folakara (latitudes 835-885; longitudes 240-265).

Detailed sedimentological and geochemical studies indicate that the occurrences may be of two different types: in zones with sudden resumption of sedimentation and in paleostream channels, MOREAU, 1963.

Analytical results show that three different samples had uranium contents ranging between 230 and 1 750 ppm U and were out of equilibrium.

CARRIE, 1980, reports a CEA estimate of 300 tonnes U of contained resources.

The Antsirabe basin

Mineralization occurs in near-horizontal lenses of argillite and sandstone and consists of uranocircite (barium-autunite) and other secondary oxides in this Neogene Plio-Pleistocene basin.

Maximum grade (at Vininkarena) is reported as more than 4 000 ppm U, (although the average grade is much less), occurring in lenses up to 85 cm thick.
This superficial mineralization is described as very mobile, disappearing and reappearing as a function of rainy seasons. Known mineralization is not confined to any particular lithological or stratigraphic horizon, but appears to follow stream channels, close to the Acean basement. There is an apparent relationship to paleosoils ("tourbe"). An attempt at relating mineralization to structural controls was not definitive.

Reconnaissance drilling at 250 m centres, followed by local, detailed drilling by the CEA indicated 120 tonnes of uranium contained in the basin.

CAKRIE, 1980, estimated the average grade of mineralized zones as 480 ppm U at a cut-off grade of 100 ppm U and 1 000 ppm U at a cut-off of 420 ppm U.

Other types of deposits:

Uranothorianite deposits in the Fort-Dauphin area

The deposits consist of numerous lenticular mineralized zones ("nuages") within larger lenses and bands of pyroxenite, occurring over an area of about 80 by 30 km in southern Madagascar. The age of the uranothorianite has been dated at 485 MY and therefore it appears to be related to the Panafrican orogeny.

The content of uranothorianite in the ore ranges from 0.1 - 1.0%, averaging 0.3%. The uranium content in the mineral in different deposits ranges from 5 to 25%.

One of the largest deposits worked by the CEA was Ambindrakemba. It is a large sub-vertical (75°W) lens of nearly 500 m outcrop length, with a width of 30-70 m. The mineralization consists of several longitudinal ore shoots of finely disseminated uranothorianite, with a uranium content of 22% (unusually high). The uranothorianite content averaged 0.4%, indicating an average grade of 880 ppm U.

In the deposits, the uranothorianite mineralization occurs as disseminations, sometimes forming ore shoots, in pyroxenite, as inclusions in anorthite, as large cubic crystals in calcite-filled vugs in pyroxenite and in accompanying calcite lenses (cipolins) and werneritites. It is an accessory mineral in most or all of the phlogopite deposits, occasionally of sufficient grade to be a co-product. The pyroxenite hosting the phlogopite and uranothorianite is described as interstratified, sometimes intrusive and cross-cutting lenses in ultra-metamorphic schists of the Androyen system (NO1ZET, 1953, 1959; BEZAIRIE, 1966).

The paragenesis of uranothorianite remains subject to dispute. A first attempt to explain phlogopite mineralization, by LACROIIX, 1941, who proposed that the pyroxenites did not belong to any known igneous suites and should be considered as metamorphic sedimentary rocks.

However, the pegmatoidal character of many of the rock suites, intrusive features of the cipolins, occurrence of wernerite as a contact mineral in endomorphosed igneous rock and particularly the total absence of any trace of the regional metamorphism forming the Androyen system remain to be explained.
VON BACKSTROM (1974) has advanced the hypothesis of an orthomagmatic origin of the pyroxenites. If this is accepted, these rock suites would become a member of a carbonatitic igneous suite, of which geochemically similar examples are known in African shield areas (e.g. Palabora).

It should be noted that several mineralized and unmineralized samples, collected by the Mission, were subsequently examined by electron microprobe and that preliminary results appear to confirm that a sedimentary origin of the host rock is not indicated. All elements indicative of a carbonatite are present. Further investigations are continuing.

Monazite occurrences

Monazite occurs as an accessory mineral in pegmatites and granites. It also occurs in detrital concentrations. The latter are the only accumulations of potential economic interest. The most important resources of this type and which have been exploited on a modest scale, are found in beach placer deposits along the south and south-east coast and are considered to have been derived by erosional processes from the Chaines anosyennes.

The monazite, a component (up to 30%) of heavy mineral concentrations forms 2 to 3% of the beach sands, the uranium content of the monazite being of the order of 0.3%.

Mining and Production of Uranium

The annual production of uranothorianite averaged about 500 tonnes during the years 1958-1963, amounting to a total of 3 990 tonnes. Apart from uranothorianite, a few tonnes of monazite were recovered from placer deposits, but this production is insignificant.

The average thorium content of the total concentrates produced was 60%, the uranium content 12%. Recovery of uranothorianite from ore was 80-85%; the concentrates would have contained 75% uranothorianite, which was processed in gravity concentrating plants. Two of these were located near the Beticky river, about two km from the village of Tranomaro, one for eluvial and alluvial material and the other for mined ore. At the nearby (5 km) Ambindandarakeamba pit the U+Th/U ratio was about 3.2. An interpretation of published data indicates that the CEA produced 5 900 tonnes of concentrate containing some 1 200 tonnes of uranium from ore grading an average 0.3% uranothorianite and corresponding to a uranium concentration of 600 ppm in the ore. Production was from a total of 96 known deposits and occurrences.

Apparently, the rate of production diminished after 1963 and appears to have stopped around 1966. In 1968, the CEA reportedly left Madagascar completely.

NATIONAL PROGRAMMES

The OMNIS Uranium Project

A partial organigramme of OMNIS, supplied by the organization, is attached in the Appendix to the full report. The objectives of the OMNIS uranium activity are:
- to resume uranium mining in the Fort-Dauphin area;
- to explore any area in the national territory for the discovery of new resources.

A planned uranium production of 400 tonnes U$_3$O$_8$ per year within four years was given as a first target (verbal communication, OMNIS).

The Head Office of the OMNIS organisation is located at:

21, rue Razanakombana  
B.P. 1 bis Antananarivo  
Tel: 242-83  
Telex: OMNIS 2370

Personnel

The uranium section, being young, is still at the development stage. It is staffed by professional and technical personnel trained in a wide variety of disciplines and with varying levels of experience. Such personnel includes geologists, mining engineers, geophysicists, analytical chemists, economists and technicians, among others.

Airborne Surveys

The French CEA carried out an airborne scintillometric survey of almost the entire area underlain by Karoo sedimentary formation. The results were not available to the Missions. Flight lines were East-West, i.e. across the regional bedding, spaced at 500 m apart. Extra flights were made to obtain closure and to verify anomalous zones. Flight altitude was 75 m.

A number of significant anomalies were obtained, notably between latitudes 835 to 885 and longitudes 240 to 265 (Folakara).

These proved to be due to uranium mineralization (mainly carnotite and autunite) located at the base of the Isalo II formation.

In March 1977, the Fort Dauphin area was flown (by Hunting Geology and Geophysics Ltd.) by gamma spectrometer and magnetometer. The survey, carried out on contract to OMNIS, covered 2 700 km$^2$, by flight lines totalling 7 310 line-km. (Survey costs are reported by OMNIS to be US$25 to 30 per line km, including data reduction and interpretation.

It is the Mission's opinion that, because of the chemically-weathered surface of the entire island, airborne surveys should not be given any high priority.

Bilateral and International Technical Assistance

From 1976 onward, the International Atomic Energy Agency (IAEA) has given assistance to the Government to carry out uranium prospection, under its regular programme. The assistance rendered to date has been partly in supplying a drilling engineer to train Malagasy nationals in drilling techniques (at Fort-Dauphin).
Current IAEA expenditures run at approximately US$50 000 annually for its regular programme.

In August 1979, a Project of the United Nations Development Programme (UNDP) was initiated, in conjunction with the IAEA and the Malagasy Government, to explore for and evaluate uranium resources, mainly in the Antsirabe and Folakara regions for the period 1979-1982.

The Government contribution to the project is FMG 686 000, the UNDP contribution totals US$1.48 million. Logistic support is supplied by the UNDP's local office in Antananarivo.

FAVOURABLE AREAS FOR SPECULATIVE RESOURCES

Introduction

All known primary uranium mineralization in the crystalline basement of Madagascar is reported to be 500 MY or younger, possibly due to a total remobilization of the uranium at the time of the last (Panafrican) orogeny. To this orogeny is attributed the abundant pegmatization of several areas in Madagascar (PREMOLI, 1977).

Review of Areas and Environment favorable for Speculative Resources and their Assessment

In view of the results obtained from past exploration and production of uranium, the interpretation of known uranium occurrences in Madagascar, of the geochemical reconnaissance stream sediment survey carried out by the Mission and its own geological observations, as well as current developments on the understanding of uranium ore genesis, the mission considers the existence of a moderate uranium potential in speculative resources likely, which are estimated to total from 4 000 to 38 000 tonnes U.

Using the six different categories of deposit types established by the NEA/IAEA and described previously, the favourability for the occurrence of speculative resources and estimate of their extent is as follows:

Quartz-pebble conglomerate deposits

No occurrences of uraniferous basal Lower Proterozoic conglomerates are known in Madagascar. Elsewhere in the world, such deposits are restricted in geological time.

Proterozoic unconformity-related deposits

There are no mineral indications for the occurrences of these deposits. In Madagascar, the presence of two major unconformities, one between the Middle Proterozoic SQC series and Archean migmatite granites, the other between the base of the Karoo and Lower Proterozoic may be favourable environments of the type described. It is conceivable that the uranium may have been remobilized, as it evidently was in the case of the surficial showings in the Karoo.
Although it is by no means definitive, it should also be mentioned that a further favourable aspect is that stream sediment sampling by the Mission showed several moderately anomalous concentrations in terms of total uranium along several locations of the western (Karoo) unconformity.

Disseminated, magmatic, pegmatitic and contract deposits

Occurrences of radio-active minerals are known in the area of Itremo (Ambatofinandrahana), 230 km south of Antananarivo, where more than forty localities with bastnaesite mineralization, extending over a total distance of 15 km are associated with alkaline differentiates in a sub-circular intrusive gabbroic complex.

In other alkaline intrusions in the Ampasindava region, extending over 200 km from the Peninsula to Antogil Bay, as well as in the west at Ambohitrosy and in the Manama area in the south, the presence of nepheline syenite indicates favourability for uranium occurrence and of pyrochlore as refractory minerals.

In general, the uranium content in this type of deposit is low (up to 200 - 300 ppm U) and the uranium may normally only be recoverable as a co- or by-product along with niobium, zirconium and lithium. None of the known deposits and occurrences appear to have any similarity with the pegmatic-alaskites of Roessing in Namibia, nor to the alkaline syenite rocks of Illimaussaq, Greenland or Pocos de Caldas, Brazil. No speculative resources tonnages can be assigned to this type. The Precambrian basement of Madagascar is rich in pegmatites, either in groups or isolated. Radioactive minerals of Th and U are usually associated with niobotantalates in potassium-rich pegmatites. The largest and most well known pegmatite is located at Ambatofotsy. Other pegmatites of this type are in the Antsirabe-Mandoto region (Romboarive, Ambatofotsikely, Samaha, Fiaolanana, etc.) Mineralization consists of betaflite, euxenite, etc. About one quarter of the hundred pegmatites examined by the CEA contained some radioactive minerals, invariably at low grades and not exceeding 100 g of mineral/m$^3$. Because the uranium would normally not be recoverable as a sole product at this grade, resources of this type cannot be included in the category of speculative resources.

Sandstone deposits

(a) Neogene basins

There are three similar Neogene basins of lacunstrine sediments between Antsirabe and Ambatolampy, totalling 1 000 km$^2$ in area, favourable to uranium mineralization. Only the southern basin contains known mineralization (at Vininkarema). Despite the fact that these occurrences have been known for a very long time and that considerable work has been expended by the CEA in exploring these basins at the reconnaissance level, the information available to evaluate these is at present inadequate. An estimate of the size and grade of the Vininkarema occurrences has already been cited. If similar occurrences are assumed for the other two basins, the total uranium contained in them would be less than 400 tonnes U.
Additionally, there are other areas, where recent fault-controlled troughs, associated with volcanism, which may represent favourable environments of similar type, but which may have little or no surface expression. Total speculative resources for Neogene basin sediments are estimated to be 1,000 tonnes to 3,000 tonnes U.

(b) The Karoo

The sedimentary, predominantly continental formations of the Karoo system are exposed for over 1,450 km along the western edge of the Precambrian basement, occurring as two major basins with considerable subsidence. The exposed widths vary from 20 km in the northern Mahajanga basin to more than 100 km in the Morondava basin. The northern part of the Morondava is considered to be of enhanced favourability, because of the more continental character of the formations and because of structural conditions. Mineralization by uranium vanadates and secondary minerals has been traced intermittently (in irregular, discontinuous lenses) over several tens of kilometers. Two different types of controls for uranium mineralization have been recognized.

- A sudden resumption of sedimentation after a prolonged period of diastrophism (mineralization near edges of subsidence zones).
- Stream channels at the boundary between homogeneous and compact basal sands and subjacent mudstones.

Based on present information, the most favourable areas of the Karoo are considered to be those with the Isalo Group I and Group II formations, particularly the base of the Isalo Ila (deltaic to fluviatile), lying unconformably over Isalo I. The unconformity has been traced for over 800 km, roughly paralleling the western coast line and 150 km inland.

The more obvious target area is that east of the Tsimiroro horst (more continental character of the Karoo).

Practically the entire area of Karoo outcrop was flown by the CEA in the 1950's, using total count scintillometric equipment and a large number of anomalies were interpreted. Two areas, i.e. the vicinity of Folakara and to a lesser extent the Makay area were examined by ground follow-up work, at the reconnaissance, systematic and detailed levels, including shallow drilling. Only minor resources of uranium (300 tonnes U, estimated by CARRIE, 1980) spread over eight separate lenses were located during the course of this work.

Despite this somewhat discouraging result, a number of experts who had the privilege of examining areas of the Karoo (which was closed at the time of the mission's stay), including PREMOL and CARRIE, state that the potential of the Karroo has not been examined fully.

It is concluded that the Karoo system of Madagascar remains a large favourable setting with possible economic potential. Areas with enhanced favourability include:

- the Folakara area (known mineral indications);
- the Makay area (radiometric anomalies);
- the area of the Sakao (complete sequence of the Karoo, presence of coal beds);
- the area east of the Tsimiroro horst;
- the northern section of the Morondava basin;

It is estimated that these more favourable areas encompass a total of more than 23,000 km².

The Karoo system of Madagascar is considered to have the potential for several moderately sized sedimentary sandstone type uranium deposits (i.e. 5,000 to 10,000 tonnes each). In addition, there are possibilities for the occurrence of other type of deposits, although little is known so far of the favourability for these.

Because of the lack of information on structural and geological conditions at depth and the incomplete coverage of the area during the earlier prospection phase, the estimate of speculative resources must cover a wide range.

Speculative resources of the Karoo are estimated to range from 1,000 to 30,000 tonnes U.

Other type of deposits

Uranothorianite of the Fort-Dauphin area

Present evidence indicates that known uranothorianite mineralization is confined to an area of 100 km (length) by 30-40 (width) in southern Madagascar. Over one hundred occurrences and deposits of uranothorianite are known in this area, which is bordered to the south by alluvial formations, to the west by the Androy massif, the east by the Anosyenne granite. To the north, mineralization appears to be restricted to the inside area of the loop of the Mandrare river, although geological reasons for this limitation remain obscure. Inside this polygonal area, mineralization is associated with zones enriched in wernerites and pyroxenites of the Tranomaro group.

The results of the (1977) airborne gamma spectrometric survey by the Hunting group suggests the presence of a number of significant anomalies outside of known deposits, but until the present mostly of unknown origin. Additional uranium resources may occur there. However, unfortunately ground follow-up, verification and evaluation of these anomalies remains to be completed. Anomalies may be due to a number of other extraneous causes, including man-made causes (e.g. road material).

The deposits have in places been eroded to colluvial and alluvial placer concentrations. The possibility of larger placers occurring under extensive cover and of in-situ deposits under calcareous weathered surface capping should not be excluded.

Known deposits have generally excellent radiometric expression and the Mission considers the chances for significant new discoveries may be limited. Because of the lack of supportive data and large variations in Th/U ratios and...
grades, speculative resources come in a wide range, i.e. 2 000 to 5 000 tonnes U. The lower end of the range relates to earlier estimates of 2 000 tonnes U in the EAR category.

Speculative potential for uraniferous calcretes

An area with a calcareous crust of Eocene age, in close proximity with Precambrian basement, in southern and southeastern Madagascar has previously been pointed out as a possibly favourable environment for uraniferous calcretes (PREMOLI, 1977, IUREP Phase I, 1978).

The area roughly parallels the present coast line, north and south of Tuliara ("plateau Calcaire Mahafaly"). It is not known if any prospection activities have taken place there in the past or whether there are any indications of uranium mineralization.

RECOMMENDATIONS FOR FUTURE EXPLORATION

General

In general the extent to which exploration can be carried out will be constrained by the availability of trained manpower and equipment which is at present limited and projects should be assigned different priorities.

The Fort-Dauphin and Antsirabe areas

It is recommended that the exploration activities in both these project areas should be maintained at the present level. The potential for uranium resources in both is considered to be relatively limited (as is also reflected in the low estimates of speculative resources). The reasons are as follows:

Both areas were subject to prolonged and intense exploration by a highly competent organization (i.e. the CEA) in the 1950s and 1960s. The Fort-Dauphin uranothorianite appears now to be a less desirable target than at that time. In the first place, most of the higher grade, larger tonnage deposits have probably already been exploited (by open pitting); secondly, thorium is now virtually of no value as a co-product; thirdly, known deposits are characteristically small and low in grade.

The Neogene basins of the Antsirabe area also do not have the potential for large scale resources on the basis of the known nature of the mineralization and the small area over which these basins extend.

The programme proposed by CARRIE (1980) for the Antsirabe area is endorsed, and includes the following:

- Photogeology for structural analysis and sedimentological studies; carbone spectrometry; emanometry (springs); soil and water geochemistry.
- Topographic mapping (1:20 000 or 1:40 000) where required.
- Foot-borne radiometry, geological reconnaissance, geochemical surveys, roughly east-west, spacing to vary between 500 m to 1 km.

- Phased approach to exploration-large scale (i.e. reconnaissance) grid, e.g. for radiometry and soil geochemistry, followed by smaller grids to define drilling targets.

- Drilling should be core drilling because of disequilibrium problem.

The Karoo

Little is known of the geology and setting of the uranium occurrences in the Karroo. Ore control and genesis remain to be evaluated. It appears important before carrying out any further activities to improve this understanding and to develop an exploration model. There is agreement with the recommendations of CARRIE, 1980, who proposes a two-phased programme for the Karroo:

- In Phase I, it is the objective to arrive at a better understanding through: "Geologic studies on sedimentology and paleostructures, to develop a structural pattern and evaluate its influence on the various physico-chemical parameters controlling remobilization of uranium (notably variations in oxidation/reduction)."

- The area selected for phase I could be east of the axis of the Tsimiroro horst, because of its enhanced favourability and better accessibility.

- Such studies should include compilation of previous (mainly CEA, also OMNIS petroleum logs) results, Landsat imagery and photogeology, to prepare a base map for later detailed geological mapping in the field (scale 1:50 000 and 1:100 000) in selected areas.

- Where necessary, core drilling for stratigraphic information should be carried out.

- Regional geochemical (stream sediments) and geophysical surveys (including seismic).

Phase II: The programme will be mainly subsurface exploration to verify and define potential targets interpreted from the data derived in phase I, to be carried out by diamond drilling (grid and/or profile).

Areas having speculative potential for Proterozoic unconformity-related deposits

A first, reconnaissance phase of a prospection programme to test the areas in which the unconformities are located might be carried out by local prospectors under the supervision of a geologist with field experience in these types of deposits and their geological environments. It is suggested that the programme include:
- reconnaissance radiometric surveys along widely-spaced profiles (400-500 m) across the unconformities, accompanied by prospecting and geochemical (stream sediment, water and soil) sampling;
- reconnaissance geological mapping;
- limited core drilling for stratigraphic and structural information.

Relating general criteria to the area of the unconformity between the Karoo and Lower Proterozoic in Madagascar, it appears that the environment merits some investigations and prospection. As in other types of deposits it would be highly desirable to develop a preliminary understanding of the host rock environment and to devise an exploration technique accordingly.

**Areas with speculative potential for uraniferous calcrete deposits**

All or part of the following methodology is applicable in the prospection and exploration for uraniferous calcretes:

- mapping of calcretes, including radiometric surveys of areas with surface expressions of anomalous radioactivity;
- LANDSAT and/or photo interpretation, including a search for paleodrainages to interpret ground water convergence or flow contribution;
- preparation of base maps, including the location of all wells;
- ground follow-up: sampling for all accessible wells and analysis (U, TDS, pH) and well yield and total depth. If uranium is above back ground, analysis for V, HCO₃, K, F, Cl, B, may be advisable;
- drilling.

**AVAILABLE POLICY OPTIONS**

The IUREP mission believes that in order to evaluate favourable areas fully within a reasonably short time (of the order of five to ten years), considerable commitments both in fully qualified and trained personnel and in financial expenditures would be required. However, without knowing fully the extent, nature quality and results of previous work, an exact estimation of such requirements would be difficult.

To meet these requirements the Government has several alternative options:

(a) **Exclusive National Development**

This option would not only require significant financial commitment by the Government, but also extensive training of Malagasy nationals in all disciplines relevant to uranium exploration and development and at all levels. The last requirement would, even if funds are available and committed, delay the program significantly.
(b) National Development in Cooperation with International and/or Bi-Lateral Financial and Technical Assistance

It is unlikely that aid available from any of the international organisations (UNDP/UN or IAEA, UN Revolving Fund for Mineral Resources, World Bank, IMF, CEC) could satisfy the requirements. The present UNDP/IAEA assistance is operating at a modest level. Bilateral assistance would be an alternative. Such assistance provides a useful means of training of personnel.

(c) Foreign Commercial Participation by Uranium Mining Companies in Exploration and Development

Serious consideration is already being given by the Government to this alternative, which would have the marked advantage of making the foreign expertise readily available to the uranium project. In order to attract foreign investment, conditions must be sufficiently attractive, particularly in view of the current over-supply of uranium and the recession in the world's economies.
Those wishing to consult the full report on which this summary is based should write to one of the following:

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