Field Course on the Rare Element Pegmatites of Madagascar

Technical Program
And
Field Trip Guidebook

June 11 - 22, 2001
Antananarivo, Madagascar

Organized by

Museum of Natural History, Milan (Italy),
University of New Orleans, Dept. of Geology & Geophysics (LA – USA)
Direction of the Geological Survey, Ministry of Energy and Mines, Antananarivo (Madagascar)

With the collaboration of

ATPEM (Assistance Technique aux Petits Exploitants Miniers), Direction des Mines et de la Géologie, Antananarivo (Madagascar)
Gondwana Gems, Antananarivo (Madagascar)

Organizing Co-Sponsors:

S.N.T.P. International, Group CFE, Antananarivo (Madagascar)

UNESCO-IUGS-IGCP

Editors:
F. Pezzotta and Wm. B. Simmons

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Field Course on the Rare Element Pegmatites of Madagascar

Program

Monday, June 11		
	11.00-12.00	Participants registration at “La Résidence” hotel, Ankerana, Antananarivo
	12.00-13.30	Lunch at “La Résidence” hotel
	13.30-14.00	Transportation by minibus to “Service des Mines”, Ampandrianomby, Antananarivo
	14.00-14.20	Opening ceremony at “Service des Mines”
	14.20-18.00	Scientific presentation at “Service des Mines”
	18.00-18.30	Transportation by minibus to “La Résidence” hotel
	19.30	Dinner and night at “La Résidence” hotel
Tuesday, June 12		[STOP 1]
	06.30	Wake-up
	07.00-08.00	Breakfast at “La Résidence” hotel
	08.00-11.30	Drive Antananarivo - Antsirabe
	12.00-13.30	Lunch at “Imperial” hotel, Antsirabe
	13.30-19.00	Round trip by car Antsirabe - Tritriva lake, visit to the outcrops of the Tritriva area
	19.00-20.00	Return to Antsirabe and deposit luggage at “Imperial” and “Diamant” hotels
	20.00	Dinner at “Imperial” hotel and night at “Imperial” and “Diamant” hotels
Wednesday, June 13		[STOP 2]
	06.30	Wake-up
	07.30-08.30	Breakfast at “Imperial” Hotel
	08.30-18.30	Round trip by car Antsirabe - Mahaiza. Sandwiches for lunch
	19.30	Dinner at “Imperial” hotel and night at “Imperial” and “Diamant” hotels
Thursday, June 14		[STOP 3]
	06.30	Wake-up
	07.30-08.30	Breakfast at “Imperial” hotel
	08.30-18.30	Round trip by car Antsirabe - Sahatany valley, sandwiches for lunch
	19.30	Dinner at “Imperial” hotel and night at “Imperial” and “Diamant” hotels
Friday, June 15		[STOP 4]
	05.30	Wake-up
	06.30-07.30	Breakfast at “Imperial” Hotel
	07.30-09.00	Drive Antsirabe-Ambositra
	09.00-13.30	Drive Ambositra-Ambalamahatsara. Sandwiches for lunch
	13.30-18.00	Visit to the pegmatites of the Ambalamahatsara area
	18.30	Malagasy dinner at Ambalamahatsara village and camping in Ambalamahatsara
Saturday, June 16		[STOP 4]
	06.00	Wake-up
	06.30-07.30	Malagasy breakfast at Ambalamahatsara
	07.30-10.00	Continuation of the visit of the local pegmatites
	10.00-13.30	Drive Ambalamahatsara-Ambositra
	13.30-15.00	Lunch at “Grand Hotel” restaurant in Ambositra
	15.00-18.00	Drive Ambositra-Fianarantsoa
	18.00-19.00	Deposit luggage at “Plaza Inn” hotel, Fianarantsoa
	19.30	Dinner and night at “Plaza Inn” Hotel

Sunday, June 17		[STOP 5a-b-c]
	06.30	Wake-up
	07.00-08.00	Breakfast at "Plaza Inn" Hotel
	08.00-11.00	Drive Fianarantsoa-Ihosy
	11.00-17.00	Drive Ihosy-Betroka. Sandwiches for lunch
	17.00-18.00	Preparation of the camping in Betroka
	18.00	Malagasy dinner and night in Betroka
Monday, June 18		[STOP 6]
	06.30	Wake up
	07.30-08.30	Malagasy breakfast in Betroka
	08.30-12.00	Drive Betroka-Benono (Tanandava area)
	12.00-18.00	Visit of the gemstone deposits of yellow K-feldspar. Sandwiches for lunch
	18.30	Return to Betroka, dinner and camping at Betroka
Tuesday, June 19		[STOP 6]
	06.30	Wake-up
	07.30-08.30	Breakfast in Betroka
	13.30-20.30	Drive Betroka-Ihosy, sandwiches for lunch
	20.30	Dinner and night at "Chez Farjou" hotel, Ihosy (camping in the hotel)
Wednesday, June 20		[STOP 7]
	06.30	Wake-up
	07.30	Breakfast at the "Chez Farjou" hotel, Ihosy
	08.30	Trip to Ilakaka, sandwiches for lunch
	18.00	Return to Ihosy
	19.00	Dinner at "Chez Farjou" hotel, Ihosy (camping in the hotel)
Thursday, June 21		[TOTAL ECLIPSE OF SUN]
	07.30	Wake up
	08.00-09.00	Breakfast at "Chez Farjou" hotel
	09.00-10.30	Visit to the outcrops nearby Ihosy (cordierite-bearing migmatites)
	10.30-11.30	Drive Ihosy-Ranohira
	11.30-14.30	Visit to the fossil-bearing sediments (Barasaurus) nearby Ranohira
	15.00-17.30	Observation of the Total eclipse of sun at the Orombe plateau (h. 16.28)
	17.30-22.00	Drive to Fianarantsoa and dinner at "Plaza Inn" hotel, in Fianarantsoa
	23.30	Night at "Plaza Inn" hotel
Friday, June 22		
	07.00	Wake-up
	08.00-09.00	Breakfast at "Plaza Inn" Hotel
	09.00-13.30	Drive Fianarantsoa-Antsirabe
	13.30-15.00	Lunch at "Imperial" hotel in Antsirabe
	15.00-19.30	Drive Antsirabe-Antananarivo
	20.00	Closing ceremony and dinner at "La Résidence" hotel, Ankerana, Antananarivo

[STOP 1] Tritriva Lake

"Migmatites" and gneiss hosting a pink-granite stock, part of the large "*Granite du Vavavato*" pluton, outcropping north of Betafo. A large number of pegmatites of the Betafo region are hosted inside or close to the Vavavato granite. Along the road close to the Tritriva Lake we will visit a large outcrop with a sub-horizontal large "barren" pegmatite. A number of recent volcanoes with mainly explosive activity are visible in the area.

[STOP 2] Mahaiza area

The Tsaramanga ("good-blue" in the Malagasy language, because of the great blue color of gemmy beryl) pegmatite, hosted in coarse grained gabbro stock ("Gabbro de l'Itsindro", intrusive complex of Ambatofinandrahana), the "Itongafeno" pegmatite, as reported in the old literature, is a primitive pegmatite with large quartz core of good rose color. Deep blue ("santamaria" in gemology), and exceptionally emerald green, large beryl crystals occur together with columbite, euxenite and pyrochlore-group minerals. Southeast of this pegmatite, extensive outcropping of giant masses of rose quartz and extensive tourmalinization of the hosting quartzites occur.

[STOP 3] Sahatany Valley

The pegmatite field of the Sahatany valley is hosted in a tectonic unit mainly composed of schists, quartzites and marbles (Série Schisto-Quartzo-Calcaire). First stop of our visit to the Sahatany valley: leucogranitic-pegmatitic stock hosted in marbles outcropping close to the cement factory of Ibity. Beautiful landscape of the Ibity quartzite massif (antiform structure), schists and marbles forming gentle hills, and synkinematic granites forming long sub-vertical lenses in morphologic evidence. Second part of the day spent in the middle-lower part of the Sahatany; historic pegmatite of Manjaka (the type locality of behierite) and a number of other dikes outcropping in the nearby area. Pegmatites of the elbaite subtype and of the "danburite subtype" (see below, text II). Typical accessories: "rubellite", morganite and other varieties of beryl, danburite, spodumene, rhodizite, Nb-Ta oxides, behierite, et cetera.

The Sahatany

This area lies S of the town of Antsirabé and develops along the valley of the Sahatany river. It is limited east by the quartzitic massif of Mount Ibity and south comprises the area of the confluence of the Sahatany with the Manandona River. The crystalline basement of the area comprises calcic and dolomitic marbles, quartzites, schists, orthogneiss, leucogranitic stocks and a gabbroic pluton. A large number of pegmatites of the Lepidolite, Elbaite and Danburite Subtypes occur, mainly distributed in the marbles. Minor pegmatites of the Beryl-Columbite Subtype occur in the northwestern portion of the district. The dikes are intruded either concordant or discordant with the schistosity of the rock, and are from sub-vertical to nearly horizontal. Since the beginning of this century, the mining for gemstones of polychrome tourmaline, pink, green, blue and polychrome beryl, danburite, scapolite and kunzite, continued to the present. At the beginning of this century a number of pegmatites, including Tsarafara, Ilapa, Ampatsikaitra, Manjaka, Maharitra and Antandrokomby, produced from large miarolitic cavities spectacular specimens with polychrome or red crystals of tourmaline, and in some cases vivid pink gemmy beryl. The pegmatites of Manjaka and Maharitra are largely exhausted while the others still are productive. Since the early 1970's, a part of the deposit was donated to the rural community, with the result that the production drastically decreased. Most of the deposit, mainly in the largest kaolinized dikes, is worked with hundreds of dangerous pits, and the deposits are completely covered by dumps. Nevertheless, some discoveries always occur and some good specimens are produced. The rarest and best-known minerals that Manjaka produced are the yellow rhodizite crystals and the very rare behierite crystals. Maharitra is the type locality for bityite (named by A. Lacroix after Mount Bity, the present Ibity massif); this mineral was recently recovered in good samples at Ilapa. Hambergite was found at Maharitra. At Tsilaizina, large tabular crystals of pink beryl, with a yellow-green core, were found in the early 1990's in a kaolinized pegmatite just as described by A. Lacroix. In the same locality, hosted in massive quartz, and rarely in small miarolitic cavities, the yellow Mn-rich variety of tourmaline "tsilaisite" occurs.

Among the most important pegmatites, is the Antandrokomby dike, the type locality for Manandonite and londonite. This pegmatite is an example of the Danburite Subtype. Micas are absent, and danburite occurs either in the border zone of the dike, as centimeter size pale yellow crystals hosted in medium grained feldspars, or in the coarse-grained central pocket-zone, in crystals together with polychrome and red tourmaline and pink to green spodumene.

[STOP 4] Ambalamahatsara area

Zoned pegmatite field; primitive dikes close to a synkinematic granite (Granite of the intrusive complex of Ambatofinandrahana) and medium evolved to high evolved pegmatites in schists and marbles. Association of green amazonite together with deep-red tourmaline. Spectacular example of "line rock" with magmatic slumpings and other complex structures.

[STOP 5a-b-c] The road Fianarantsoa-Betroka

Landscapes with large domes of synkinematic granites ("migmatitic granites", as reported in the old geologic maps).

NW-SE trending megastructures related with the Ranotsara-Bongolava Shear Zone (see below).

The Precambrian crystalline basement of Madagascar can be divided into two principal areas by the Bongolava-Ranotsara Shear Zone (BRSZ). The geology and mineralogy of the rocks outcropping north and south of this large ductile fault are significantly different. In particular the well-known phlogopite ore bodies, orthoclase gem deposits and U-Th, sapphire and zircon-skarns are typical of the large area of crystalline basement outcropping in the south.

The BRSZ is evident in most large scale geological maps of Madagascar, and is located between the southern end of the east coast near Manambondro, passing through the type locality Ranotsara, towards the Ihosy region, in the south central part of Madagascar. It crosscuts the island in a roughly NW-SE direction and appears as a topographically well-expressed lineament, for over 200 km. The BRSZ represents the lithological boundary between the southern Fort Dauphin Series of the Androyen system, with high Pan-African metamorphic grade, and the northern Ikalamavony series of the Vohibory system and the Ranomena Charnockites of the Graphite system with lower Pan-African metamorphic grade. Archean terrains, and in particular greenstone belts, occur only north of the fault. The BRSZ formed during the latest stages of the Pan-African event over a period of 20 Ma, from 540 to 520 Ma, and represent the result of the final Pan-African continent-continent collision between West Gondwana and East Gondwana.

The crystalline basement south of the BRSZ is characterized by a series of other important shear zones, large scale ductile folds, more or less deformed anorthositic and gabbroic plutons and slightly to non deformed alkaline granitoids. In the old literature, the southeastern portion of this basement, close to Fort Douphin has been called the "Anosyennes Belts", and is characterized by large outcrops of "Anosyen Granites" and charnockites, with a "Malagasy facies".

[STOP 6] Tanandava area (Benono village)

Phlogopite orebodies, "alkaline skarns" and gemmy yellow K-feldspar deposits. Granulite-facies gneiss, pyroxenites and marbles. Miarolitic NYF pegmatites and interaction phenomena between pegmatites and marbles (see below, text III).

[STOP 7] Isahalo and Ilakaka

The occurrence of gemstone deposits of alluvial origin in the region of Tulear has been known long time. In recent years, production of sapphires, garnets and others gemstones, frequently of high quality, occurred in various localities mainly in the area of Betioky. The origin and the potential of these deposits were unclear and no specific study was made. No one could predict what would happen after the summer of 1998. Indeed, along the road Ioshy-Tulear, immediately after the fascinating rocks of the Isahalo National Park, some locals discovered the first sapphires in a small river at a small village named Ilakaka. Quickly the news spread to the nearby villages and towns, and to Antananarivo, and many Malagasy people arrived and organized into small groups to wash the gravel for sapphires. Even though valuable gemstone material was always rare, sapphires and a number of other gemstones were found everywhere the soil was washed, not only along the Ilakaka River, but also in the nearby region. Many of the Malagasy people who knew, or supposedly knew, how to mine gemstones came from all over Madagascar to Ilakaka. This rapid influx of people resulted in the abandonment of mining for gemstones in other areas of the country. Gemstones dealers from Madagascar, India, China, Korea, Thailand, South Africa, Europe and the USA, started to visit Ilakaka to buy the production. In November 1998, a few months after the first discovery, Ilakaka was transformed from a desert to a town of about 10 thousand people. People quickly, arrived and built up small hotels, organized taxi services, food transportation, car repairs, etc. The Malagasy government immediately understood that the situation was developing without any control, so the Service des Mines organized a first office for its police and the Government extended the limits of the Isahalo National Park, to protect many areas.

Some areas close to the Ilakaka River were officially reserved for Malagasy people to work. The rest of the region, for many hundreds of square kilometers was assigned to a restricted number of private companies. Indeed, a very large area of about 200 kilometers extending north south between the Isahalo mountains to the east and the town of Sakaraha to the west, was more or less productive. To control the illegal trading, the national Service des Mines organized and built a place in which gemstones can officially be marketed. Outside this place all trade is officially forbidden. Security is guaranteed by a large number of armed soldiers. In the large area reserved for locals, the mining is organized in groups where three or four men operations excavate the soil, and make pits and tunnels inside a sequence of sand and gravel lenses. The sand is put on the dumps and the gravel is placed inside sacks, which two or three people carry to be washed at the river. Three or four other people wash the gravel and select the gemstones. At the end of each day, the people who transport the sacks are given a sack of gravel in payment for their work. Anything they find they can keep. The other workers will divide the proceeds earned from selling the gemstones found by the group.

The gemstones present in the deposit are numerous, and the most important include: corundum, colorless, sky blue to deep blue, green, purple-violet, vivid yellow, vivid pink and, rarely, red; topaz, colorless to sky-blue; tourmaline of all colors; zircon, mainly red, brown and violet; spinel, pink, violet, green, bluish and red; garnet with a wide range of reddish and purple colors; chrysoberyl, vivid yellow-green and of the cat-eye variety; chrysoberyl of the alexandrite variety, in some cases with a very good metameric effect; beryl, colorless, pale blue and pale pink; kyanite, pale to deep blue; andalusite, reddish-brownish. In addition to these minerals, transparent pebbles of colorless, amethyst and rose quartz are abundant.

Geological observations indicate that the gemstones of the Ilakaka region, are hosted in coarse-grained lenses of graywacke of the Permian-Mesozoic sedimentary sequence. The sequence ranges from Permian to middle Cretaceous in age, and consists mainly of sediments of continental origin. Sediments of mostly marine origin cap the sequence. From the Permian to the middle Cretaceous, a time span of over 150 millions year, the crystalline basement of Madagascar underwent deep erosion. The erosional products of this process were transported by the rivers to west where they were deposited in a sedimentary basin formed by the opening of the Mozambique channel. Because of the sub-tropical climate, the weathering was extensive and only the most resistant minerals were preserved. In particular, only quartz, corundum, garnets, and a few other resistant minerals survived the erosion and transportation to accumulate in the river gravels. This process occurred during the erosion of enormous volumes of rock of the crystalline basement that covered the ones now exposed to the east. The concentration of the more resistant minerals in the beds of the rivers, allowed the mingling of numerous different gemstones derived from deposits of different origin (e.g. pegmatitic, metamorphic, pneumatolytic). These sands and gravels were eventually lithified into sandstones and graywacke by diagenetic processes. The uplift of these sediments, due to tectonic movements, allowed a new erosive process which re-transformed sandstones and greywackes into sands and gravel, liberating the more resistant precious stones in the process. The local occurrence of small, unrounded colorless quartz or amethyst crystals is due to the presence of narrow quartz veins of hydrothermal origin, probably related to Cretaceous volcanism.

(I) SHORT NOTE ON THE HISTORY OF MALAGASY MINERALOGY

Federico Pezzotta

Although it lays a relatively short sail from the African mainland, Madagascar apparently remained uninhabited until around 1500 to 2000 years ago. The first settlers came not from the nearby continent of Africa, but from the distant shores of Indonesia and Malaysia, 6400 km away. Over the centuries, after a series of wars and confederation, the population evolved into 18 ethnic groups. In what became the ruling tribe, the Merina of the central highlands, Asian features predominate, as they do in the neighboring Betsileo tribe. The largest coastal tribes, the Sakalava of the west coast and the Bara of the southern central region, appear to have more African origins.

The first Europeans, a Portuguese fleet under the command of Diego Dias, arrived on the island in 1500. In the following centuries, the Portuguese, Dutch and British attempted to establish permanent bases on the island. For several decades, from the end of the 17th century onwards, bands of pirates established their Indian Ocean bases in Madagascar, especially on and around Nosy Boraha (the actual island of Sainte Marie). They made significant genetic, as well as financial, contributions to local communities. In the early 18th century, the island of Nosy Boraha, headquarters of pirates in the Indian Ocean, attracted buccaneers and ruffians from such diverse places as France, Holland, the USA, Portugal and Britain.

According to information reported by A. Lacroix (Un Voyage au Pays des Bérils, 1912), the second group of French people that visited the island in 1547 with Captain J. Fonteneau reported the presence of precious stones. In 1658, Mr. Flancourt reported the presence of topaz, blue-beryl, emerald, ruby and sapphire, and published a map indicating the area of occurrence of rock crystals. However, by this time, rock crystal from Madagascar had been arriving in Europe via India for some time. By the mid 18th century naturalists, impressed by the extraordinary clarity of the Malagasy quartz crystals, began to debate the origin of the deposits (e.g. Romé de l'Isle, Cristallographie. T. I, 1783). Even though there were numerous reports of gemstones coming from visitors to Madagascar, the efforts of mining exploration by the "Compagnie Française des Indes" during 17th and 18th century were unsuccessful.

By the mid 19th century, only a few additional reports were available about the mineralogy of the Island, and these include the presence of "Venus hair" (rutile) and black tourmaline in quartz crystals. New interest in exploration ensued when the presence of fossil coal deposits along the Northwest coast was reported. A. Grandidier, during six years (1865-1870), made a naturalistic exploration of Madagascar collecting true zoological and botanical treasures but, unfortunately, he couldn't collect minerals (he brought with him only a few small fragments) because of the protectionist law imposed by the local government, by which foreigners involved in mining ventures would be punished severely (with death!). In 1883, R. Baron conducted additional research, but little was reported about mineralogy.

In 1890, France and Britain signed a treaty that outlined their respective spheres of influence. In 1895, 15,000 French soldiers coming from Mahajunga on the west coast marched on Antananarivo to overthrow the Malagasy Queen Ranavalona III and her government. When they arrived in the capital on 30 September 1895, 11,000 soldiers had perished of various diseases. Nevertheless, the remaining soldiers easily overcame the Malagasy (Merina) defenses. After the invasion, the French set up a colonial administration with General Joseph Galliéni as the first Governor General. In that period, foreign settlers and companies expropriated land.

On the occasion of the military expedition to conquer Madagascar, a naturalistic exhibition about the island was organized in 1892 at the Muséum National d'Histoire Naturelle in Paris, but only a few specimens (about one hundred fragments of minerals and rocks) were available in the collections.

Consequently, A. Milne Eduards, Director of the Museum, asked A. Lacroix, Professor at the Museum, to organize a scientific expedition to Madagascar to make a first compilation of the natural products present in the Island. The French Government didn't provide for the financial support for the expedition and A. Lacroix wrote "in spite of the scientific method and also good sense, they decided to reverse the problem, by trying to exploit before studying". Nevertheless, some specimens from that period arrived at the Museum from Madagascar and it was in 1894 that the first Li-rich tourmaline was sent by M.E.F. Gautier to A. Lacroix.

When the General J. Gallieni became Governor of the colony, A. Lacroix succeeded in interesting him in his project, suggesting that he send to all the administrators of the island a detailed questionnaire about the rocks and minerals and that they be requested to assemble and expedite to the Museum collections of minerals and rocks for study. The initiative was successful and A. Lacroix found a good collaboration in the Captain Mouneyres, chief of the Service des Mines (Mining Survey) in Antananarivo. Thanks to Mouneyres and to many other collaborators, including M. Villiaume, R. Baron, M. Guillaume Grandidier, M. Allaud, M.P. Lemoine, many samples of rocks and minerals were shipped from the island to the Museum over a period of ten years. In 1911 A. Lacroix obtained financial support for a field trip to Madagascar from the Ministry of Colonies and the Public Education. He spent much of that year on the expedition, taking about two months to go by ship from France to Madagascar and two months to return. He used much of the time in transit to write and organize his trip and his report. On the island he concentrated his activity in visiting the most important mineral deposit in the highlands, between Antsirabé and Fianarantsoa, where most of the samples he studied in the laboratories of the Museum came from. During the tour, Lacroix collected a large amount of information and many samples and established collaboration with local administrators, engineers and geologists, of public and private companies. In the Museum Laboratories, A. Lacroix performed additional mineralogical and petrographic research over ten more years, until in 1922 he published his "Minéralogie de Madagascar", the result of over 25 year of work. This publication represented the basis for all the future mineralogical and petrographic research on the island.

Reading Lacroix's book and the other reports of that period, it is evident that a great development of private and public activities in prospecting and mining gemstones and ore minerals occurred during the first two decades of the 20th century. The first regular shipment of gemstones began in 1904, and controls over the trade were established in 1907. The total weights, undivided, of exports during 1908-1922 inclusive, ranged from a low of 46 kg in 1915 to a high of 1,029 kg in 1920, the annual average being 282 kg. Most was shipped to France and the remainder to Germany and Switzerland.

Madagascar remained a French colony until 1960 and the French government promoted great investment for the geological and mineralogical research up to that year. H. Besairie, director for many decades of the Malagasy Service Géologique (Geological Survey), in his book "La Recherche Géologique a Madagascar" (The Geological Research in Madagascar) in 1960 wrote that the evolution of the geological research in the island belongs to three periods. The first one is that of the naturalists and finished with the publication in 1922 of the "Minéralogie de Madagascar" of A. Lacroix. The second period started in 1925 when the Malagasy Service Géologique was created. Two or three geologists, together with some collaborators, started mapping the geology of the island at 1:200,000. In 1939, 41 geological maps had been published. The work was suspended during the Second World War and in 1946 a summary containing a description of the results obtained during these year was published. The third period, started in 1948 and finished in 1958, was characterized by a great financial effort to promote the geological research. In ten years, one billion and two hundred million French Francs were employed for the activity of the geological survey. In the field and in the laboratories, including geologists, analysts and collaborators, 32 people were active during 1948, and the number increased to 187 in 1956. As a result of this work, a very large amount of information was generated and published. Among the main results of these years were the maps: the geologic maps 1:1,000,000 and 1:500,000 of Madagascar; the maps of the distribution of ore deposits 1:500,000 of Madagascar, supplied with explanatory notes; geologic maps 1:200,000 and 1:100,000 of much of the country; and the map of the mines and of the substances 1:1,000,000. The studies of general geology were supported by geochronology, allowing a better understanding of the evolution of the Malagasy crystalline basement. In 1960 H. Behier, mineralogist since 1953 at the Service Géologique, produced the second main-work (after that of A. Lacroix) on the mineralogy of the island, the "Contribution a la Minéralogie de Madagascar". This author, collaborating with laboratories of analyses in Madagascar, France and Washington, discovered about 70 new mineral species for Madagascar and the new mineral hibonite. H. Behier, up to his death in 1963, worked at the organization and at the improvement of the Musée National de Géologie (National Museum of Geology) and of the Laboratory of Mineralogy of the Service Géologique. He was responsible of the compilation of the list of minerals forbidden for the exportation, listed in the Mining Law. This list was officially compiled to "protect" the rare minerals of Madagascar, but in reality H. Behier probably intended to protect his own business, remaining the only person who, after the law was enacted, was able to export minerals to museums and mineral collectors.

During the 40s and 50s significant additional research was performed by the French "Commisariat à l'Energie Atomique" (C.E.A.) which concentrated its activity on uranium and beryllium. Unfortunately most of the results of that scientific research and the mining activity are not accessible. Also during the 40s and 50s, reports were made on ore-deposits and the mining activity of: graphite; phlogopite; industrial kyanite, sillimanite, garnet and corundum; piezoelectric quartz; Nb-Ta oxides, feldspars and micas in pegmatites; copper minerals; lead minerals; chromite; manganese minerals; nickel minerals; gold; barite; monazite, ilmenite and zircon in sands; coal; gypsum; bauxite; and iron in nodules in the soil. Unfortunately, even if the mining activity was very intense, very little was preserved in mineral collections. Oral communications of some geologist and engineers, who worked in the mines at that time, report the existence of enormous crystals and wonderful natural cavities, found mainly in mining pegmatites, that were destroyed to produce industrial minerals. In these years some exceptional specimens were donated or bought by the Museum of the Ecole des Mines, in Paris. The Musée National de Géologie, at the Service des Mines, was organized and improved by H. Behier during the same decades. Unfortunately not a lot actually remains in the museum.

Madagascar made a peaceful transition to independence in 1960 and in that year P. Tsiranana was elected as the first president. Up to 1972, the French were permitted to retain control over trade and financial institutions and maintain military bases on the island. Little information is available concerning the mining activities during these years. Nevertheless, it is known that many mines continued working on ore minerals and gemstones, but no significant financial support was devoted to scientific research. H. Besairie remained as the director of the Service Géologique and much of his activity was to reorganize the data obtained in the previous years. On January 1, 1964, he published the geologic map of Madagascar 1:1,000,000, including the results of the previous studies on geochronology, and in 1966 he published the book "Les Gites Mineraux de Madagascar", a review of all the mineralogy of Madagascar, including many maps reporting much of the more interesting localities.

In September 1972, after massive antigovernment demonstrations, Tsiranana resigned and the power passed to General G. Ramantsoa. The French military bases were then closed down and there was a return to the collective system that had been practiced in rural areas prior to the colonial era. After 1972, and in particular during the first D. Ratsiraka government (1975-1993), Madagascar turned to the USSR to supply its armed forces with military hardware, and private companies were nationalized. During the 70s and 80s much of the previous mining activities stopped and many gemstones deposits, such as the world famous Sahatany valley, were officially turned over to rural communities. Because of the lack of organization and knowledge of mining techniques, in a few years many of the deposits were rather completely destroyed at the surface with thousands of small and dangerous tunnels and pits covered by dumps. Much of the marketing of gemstones became illegal. H. Besairie remained on the island up to 1978, the year of his death, trying to go on with his studies, helped by some of the Malagasy geologists. In these years, the government created the OMNIS (Office Militaire National pour les Industries Stratégiques), which concentrated its activity in mining chromite and graphite, and in researching, in collaboration with some foreign companies, coal and oil. In the 80s, only a few Malagasy-French and Malagasy-German companies were allowed to organize mining activities for gemstones. In these years, some scientific research on pegmatites and mineralogy was made and published by Russian geologists. In addition, the "Carte Minière" (map of mines) of Madagascar 1:2,500,000 was published by the Service Géologique in 1977. In 1984 in France, the French National Institute of Research B.R.G.M. published the 4 volume summary of economic geology "Plan directeur d'actions pour la mise en valeur des ressources du sol et du sous-sol de Madagascar".

During the 90s, at the end of the first political period of D. Ratsiraka, during the political period of A. Zafy, and actually again with D. Ratsiraka, Madagascar abandoned communism and turned to democracy. New opportunities were provided for foreign investors and in the last few years, many dealers of gemstone and mining companies came to the island. Unfortunately, Madagascar is a country in which many deep contrasts coexist. Indeed, enormous limitations to the scientific and economic development of mineralogy in the island still exist. Among the largest difficulties are: the difficulty of the government in many areas of the country to ensure the respect of the national law; the presence in the old Mining Law of the list compiled by H. Behier of "forbidden substances" which includes rather all the minerals interesting for scientific research; the widespread illegal market of gemstones and gold; the high cost of airplane and ship transportation; the bureaucratic difficulties and the high taxes for the importation of equipment; the lack of professional competence of much of the local and foreigner operators; the lack of understanding of locals of the importance of not damaging mineral specimens during recovery and transportation; the difficulties in accessing many areas mainly because of the lack of roads; the lack of security in many of the remote areas because of the presence of brigands; the traditions of local people living in remote areas which must be respected; the lack of enough information in the international community. Nevertheless, the rapid economical, political and social development of Madagascar during the last few years indicates the possibility of great scientific and economic development in the next few years. Moreover, the creation of many international research groups on geology, petrology, geochronology, mineralogy and paleontology have resulted in a number of publications and expositions (e.g. the "International Symposium on the Geology and the Mineral Resources of Madagascar" in August 1997) have served to spark new scientific interest in this country.

(II) SHORT NOTE ON THE CLASSIFICATION OF MALAGASY PEGMATITES

Federico Pezzotta

Rather all the pegmatites of Madagascar formed during the Pan-African event, but many different mechanisms were responsible for generating the magmatic liquids. These different mechanism lead to the formation of a wide variety of different types of pegmatites. A. Lacroix classified Malagasy pegmatites in two main groups, the Potassic Group and the Sodalithic Group. The Potassic Group is characterized by pegmatites frequently of large size, rich in K-feldspar with blue beryl, black tourmaline, muscovite and many accessories such as U-P-REE-Ta-Nb bearing minerals. The Sodalithic Group is characterized by pegmatites rich in albite, together with Li-bearing phases, such as Li-tourmaline, spodumene, amblygonite and lepidolite, and with pink Cs-bearing beryl. This classification was particularly useful in the past to prospect for industrial minerals, and in particular industrial beryl, characteristic of the Potassic Group.

H. Besairie used the classification of A. Lacroix but divided the beryl-bearing pegmatites of the Potassic Group into three different types: the Three-Zones Type, the Two-Zone Type and the Unzoned Type. The Three-Zone Type constitutes large, generally discordant, dykes, 100 to 300 meters long and 20 to 40 meters thick. The Zone I is characterized by giant crystals of quartz and perthite. Quartz may form very large masses (the pegmatite core) of white, pink or, rarely, smoky color. The Zone II is generally thin, and consists of quartz masses from a decimeter to a meter, with perthite, radial muscovite aggregates or muscovite books, and columbite. The large beryl crystals occur at the contact between the Zones I and II. Rare U-REE-Nb-Ta minerals are commonly associated with beryl. The Zone III is medium grained, with dominant of graphic textures, muscovite in books, garnet, magnetite, columbite, small beryl and Nb-Ta minerals. Black tourmaline may or may not be present and sometimes forms significant concentrations at the walls of the dikes (tourmalinization). Exceptionally, between the Zones I and II, Li-tourmaline together with lepidolite and amblygonite occur. The pegmatites of the Two-Zones Type are normally of smaller in size, with an inner zone similar to the Zone I described above, and a large rim zone similar to Zone III described above. The Unzoned-Type dikes are composed by a single unit similar to the Zone III described above.

Starting from the Petr Cerny's classification and proposing some new subtypes*, the Malagasy pegmatites can be classified as indicated here below:

(I)	LCT and NYF RARE ELEMENT PEGMATITES	
	1) Beryl Type (LCT)	1a) Beryl-Columbite Subtype
		1b) Beryl-Columbite-U Subtype*
		1c) Beryl-Columbite-Phosphate Subtype
		1d) Chrysoberyl Subtype* (mainly miarolitic)
		1e) Emerald Subtype*
	2) Complex Type (LCT)	2a) Lepidolite Subtype (miarolitic or massive)
		2b) Amblygonite Subtype
		2c) Elbaite-Subtype (miarolitic or massive)
		2d) Danburite-Subtype* (mainly miarolitic)
	3) Rare Earth Type (NYF)	3a) Allanite-Monazite Subtype
		3b) Monazite-Thortveitite Subtype*
		3c) REE-Carbonates Subtype*
(II)	NYF MIAROLITIC PEGMATITES	

Most of the pegmatites of the Beryl Type, the Rare Earth Type, and of the Rare Element Class, correspond to the Potassic Group of the classification of A. Lacroix. All the Complex Type (LCT) pegmatites correspond to the Sodalithic Group. The pegmatites of the Rare Element and the Miarolitic Classes constitute a large number of pegmatite districts, all along the island. Each district may contain many different types and subtypes of pegmatite, sometimes with a well-developed zoned distribution. Some short notes on the main characters of each type of Malagasy pegmatite of the Rare-Element and the NYF-Miarolitic classes are reported here.

LCT and NYF RARE ELEMENT PEGMATITES

The ***Beryl Type (LCT)*** presents in Madagascar five subtypes; the Beryl-Columbite Subtype, the Beryl-Columbite-U Subtype, the Beryl-Columbite-Phosphate Subtype, the Chrysoberyl Subtype and the Emerald Subtype. The pegmatites of the **Beryl-Columbite Subtype** are the most common in Madagascar. They correspond to the Three Zones, Two Zones and Unzoned types described by H. Besairie. K-feldspar is much more abundant than plagioclase, and muscovite is abundant in many of the pegmatites. Except for beryl and columbite-tantalite, the other accessories are rare, even though many different mineral species may occur locally, including phosphates and U-Th minerals. In some dikes K-feldspar is of the amazonitic variety (unusual for pegmatites of the LCT family). The pegmatites of the **Beryl-Columbite-U Subtype** are similar to the previous described but are rarest and of smaller size. These pegmatites are characterized by exceptional concentrations of U-Th minerals, and in particular oxides, together with their alteration minerals. Such concentrations can produce in Malagasy pegmatites modest ore deposits. The pegmatites of the **Beryl-Columbite-Phosphate Subtype** contain significant concentrations of phosphate minerals such as triplite and triphylite, together with a large number of primary and alteration minerals. The pegmatites of the **Chrysoberyl Subtype** contain beryl and rare columbite-tantalite minerals, but mainly chrysoberyl crystals, included in the quartz of the pegmatite core, or inside miarolitic cavities. Other accessories are rare except black tourmaline, which can occur either in pockets or included in quartz. Almandine-rich garnet can also occur in well-formed and large crystals hosted in quartz. Biotite largely dominates over muscovite. These pegmatites have been included in the Beryl Type, but their classification is problematic because of the presence of characteristics, such as, for example, the abundance of biotite and the dominance Nb over Ta, typical of the pegmatites of the NYF Family. The pegmatites of the **Emerald Subtype** are pegmatites rich in beryllium hosted in metamorphic basic rocks which underwent a intense reaction along the margins generating in the endo- and exo-contacts green crystals of Cr-rich beryl, emeralds.

The pegmatites of the ***Complex Type (LCT)*** frequently form a zoned pegmatite field around the granitic plutons from which originated. These pegmatites occur in four subtypes in Madagascar: the Lepidolite Subtype, the Amblygonite Subtype, the Elbaite Subtype, and the Danburite Subtype. In the same pegmatite field two or more subtypes can occur, frequently associated with one or more subtypes of the Beryl Type. In addition, in some large concentrically and laterally zoned dikes a transition from one subtype to another can occur. Albitic fine-grained masses of late-stage formation, associated with rare accessory minerals, are typical of this type of pegmatites. Characterizing minerals are polychrome to red tourmaline, pink beryl and rather pure spessartine. The pegmatites of the **Lepidolite Subtype** are zoned to homogeneous dikes, up to many meters thick and up to two hundred meters long. Some large sub-horizontal dikes have a stratified structure with chemically highly evolved portions alternating with less-evolved portions. Stratified aplite (line-rock) can occur inside some dikes. Miarolitic cavities are rare if not absent, but exceptionally can be of enormous size, allowing to the formation of large polychrome crystals of tourmaline. These largest cavities occur at the core margin of the pegmatite with giant grain size. Among the accessories, spodumene can be abundant and lepidolite can constitute rather large monomineralic fine-grained masses. Topaz can be locally present in cavities. The pegmatites of the **Amblygonite Subtype** are rare in Madagascar and are similar to the ones of the Lepidolite Subtype, but contain large masses of massive amblygonite, together with other phosphates. The pegmatites of the **Elbaite Subtype** constitute dikes from small size (few centimeters across and few meters long) to rather large size (many meters thick and some hundred meters long). The largest dikes in some cases laterally change to the Danburite Subtype or to the Lepidolite subtype. Li-rich tourmaline is the only significant Li-bearing mineral and micas and spodumene are rare or absent. The pegmatites of the **Danburite Subtype** are characterized by the presence of early-formed danburite (locally abundant). Associated minerals include spessartine and abundant tourmaline and spodumene. In some dikes, vivid blue apatite is present. The pegmatites of this Type occur in marbles or in metamorphic sequences composed by marbles, quartzites and schists. Micas are always absent or are present in very limited amount only in cavities. The size of the dikes ranges from few decimeters thick to, in some very rare cases, many meters thick, for 50 meters to some hundred meters in length. Miarolitic cavities are rare but locally may concentrate in columns ("chimneys") along the dip of the dikes. Some Elbaite Subtype and many Danburite Subtype dikes contain among the accessories rhodizite and londonite.

The pegmatites of the ***Rare Earth Type (NYF)***, contain silicates, phosphates and carbonates of Rare Earth elements. Depending on the abundance of the different accessories these pegmatites are classified in: Allanite-Monazite Subtype, Monazite-Thortveitite Subtype and REE-Carbonates Subtype. All these pegmatites have biotite as the only mica, or normally largely dominating over muscovite. The pegmatites of the **Allanite-Monazite Subtype** are characterized by the abundance of these two accessories, together with a number of other rare minerals, including strüverite, fergusonite and others. Beryl can be locally present in subordinate quantities. The pegmatites of the **Monazite-Thortveitite Subtype** are similar to the Allanite-Monazite ones, but contain thortveitite among the accessories. These beryls may contain up to several wt% Sc. Among the accessories, in addition to thortveitite, beryl and large crystals of monazite, there are strüverite, fergusonite, xenotime and zircon. The pegmatites of the **REE-carbonates Subtype**, contain a significant amount of "bastnaesite" and others REE-carbonates, concentrated in large crystals at the core of the dikes, together with well-formed hematite crystals. Monazite is present in the border zones of the pegmatites, together with biotite and magnetite. Aegirine is locally present as an accessory mineral.

NYF-MIAROLITIC CLASS

Malagasy pegmatites of the NYF-Miarolitic Class constitute medium to large-size dikes and swarm of dikes hosted in metamorphic rocks. They are typically characterized by abundant miarolitic cavities with simple mineralogy, including smoky, citrine and amethyst quartz, corroded K-feldspar, colorless, yellow and blue topaz and colorless, green, yellow and blue beryl. Locally, some black tourmaline may occur, and in some dikes very abundant magnetite in large crystals can be present hosted in the mass of the rock. Other accessories are very rare. The Malagasy pegmatites of this Class strongly differ in the structure from those reported from other localities in the world, being the latest mainly hosted inside the parent granite, forming typical pods and veins. It would probably be necessary to divide the NYF-Miarolitic Class into two subtypes, one for the pegmatites hosted inside the parent granitoid and one for those hosted in the metamorphic rocks.

(III) SHORT NOTE ON ALKALINE SKARNS AND URANO-THORIANITE MINERALIZATION IN SOUTHERN MADAGASCAR

Federico Pezzotta

All along the shear zones of the granulite-facies crystalline basement outcropping south the Ranotsara-Bongolava Shear Zone, locally in association or in contact with undeformed alkaline magmatic intrusions, and in association with carbonatic and pyroxenitic metamorphic rocks whose protholiths were sedimentary rocks, an exceptionally high alkaline fluid activity, of probable deep origin, occurred. This phenomenon, with a not yet well understood mechanism, produced veins and masses of "alkaline skarns"; rocks frequently of pegmatitic grain size, with exceptional concentrations of large crystals of many minerals such as phlogopite, diopside, scapolite, titanite, andradite, thorianite, zircon, apatite, spinel, and many others, including locally corundum varieties, hibonite, sapphirine, kornerupine, grandidierite, etc.

Similar rocks are present also in other localities in the world, such as in Canada and the Kola Peninsula, and their origin is still under debate. Different theories consider the effect of metamorphic fluids, of magmatic fluids, of magmatic pegmatitic or carbonatitic liquids. Recent hypothesis for the case of the southwestern Greenville Province, in Canada, consider a pegmatite-related pneumatolytic model linked to marble melting.

Phlogopite orebodies

The famous phlogopite mineralization of southern Madagascar occurs within a 350 km N-S trending zone of isoclinally folded and intensely sheared granulite-grade supracrustal rocks and orthogneisses, the Betroka-Beraketa shear belt. The rocks present along this tectonic structure include plagioclase gneisses with two-pyroxenes, leptinitic gneiss with garnet, sillimanite and cordierite, quartzites, metapelites with cordierite-orthopyroxene-garnet-plagioclase, with spinel and sapphirine, calc silicate rocks and marbles, veins of syenite and pegmatite. Petrologic studies demonstrated that these mineral assemblages were formed during metamorphism at temperatures over 850 °C and pressures of 7-8 kbar (about 20 km deep in the crust).

Rakotondrazafy et al. (1997) demonstrated that the phlogopite mineralizations were formed after high-grade metamorphism and deformation in the shear belt, during the latest stages of the Pan-African uplift and cooling (about 490 Ma). The mineralization is confined to the basic pyroxene plagioclase bands and their arrangement, shape and paragenetic zonation indicates formation through channelized fluid flow along a system of late shear fractures. An extremely coarse-grained aggregate of anhydrite, calcite, giant euhedral phlogopite and apatite forms the central part of the mineralization. It is surrounded by a monomineralic diopside zone from which large euhedral crystals grew into the "pegmatitic" aggregate. The size of these masses is from few decimeters up to 30 meters, and around them the host pyroxene-plagioclase gneisses have been subjected to metasomatic alteration. The largest mineralization, includes outwards the monomineralic diopside zone, subsequent zones respectively with (1) phlogopite and diopside, (2) diopside, amphibole and spinel, (3) amphibole-rich, pyroxene and plagioclase gneiss.

The industrial exploitation of the ore deposit of phlogopite started in 1927 (before this year, only small prospects were made by locals) with the company "Société des Minerais de la Grande Ile" and the company “Société d’Ampandrandava”. In 1928 the production was 800 tons. The production decreased during the Second World War and resumed after 1948. In 1949 it was 959 tons and was exported mainly to the USA. In 1950, 26 companies were working a total of 102 ore deposits, but about the 60% of the whole production came from 12 deposits. In 1952 the production was over 1000 tons but after that year a crisis of the marked limited the development of the activities. Moreover, many of the deposits were exhausted at the surface and needed more expensive work underground below the water table. For these reasons only a few well-organized companies continued mining phlogopite during the sixties and rather all the activities finished in the seventies. Actually, rather all the mines were abandoned because of the replacement of natural mica uses by synthetic products. Only a few mines are still operated by locals for collectibles and ornamental stones.

Orthoclase

The presence of unusual and exceptional crystals of orthoclase close of the village of Itrongay, between the towns of Betroka and Benenitra, was reported by A. Lacroix (1922). This author reported of a pegmatite characterized by crystals of colorless to yellow gemmy orthoclase together with gemmy crystals of diopside and zircon. Single crystals, 2 to 5 cm across, were found at the locality in the ground, without any matrix, sometimes partially covered by kaolin or amorphous silica. Chemical analyses indicate abundant Fe_2O_3, up to 2.88%. Further mineralogical investigations characterized chemically and structurally this world unique feldspar, indicating a significant substitution of Fe^{3+} for Al in the Y site of the crystallochemical formula. All these studies refer generically to crystals coming from Itrongay, and in one case from Ampandrandava (E-NE of Bekily).

The production of gemmy orthoclase from the region continued more or less over the decades, since the time of Lacroix. The crystals that reached the market were usually highly damaged and were normally considered only for gemological purposes. Nevertheless these orthoclase crystals are the world’s best crystals, with respect to their color, complex shape and the transparency, but unfortunately rather all of them, when discovered by locals, are immediately broken to check for the presence of gemmy portions.

Itrongay is an old and small village, which was probably the place, where, at the time of Lacroix, the minerals found in the area were brought and offered to buyers. This name was reported in the geological maps of the fifties, but not in the topographic maps. Indeed, for a long time rather nothing remained of the village, and other villages developed in the nearby region. The yellow gemmy orthoclase is actually found over a rather large area, from the classic Itrongay region to the south-east for at least 40 km. Along the same direction, other sporadic finds occur up to the region of Ampandrandrava. The gemmy orthoclase is concentrated in some large outcrops of medium to coarse-grained marble. The outcrops are carbonatic lenses, pinching and swelling over distances of many kilometers, morphologically constituting very gentle hills of white color. The white color of the ground is due to a crust of decomposed carbonates at the surface.

The observation inside the pits shows that the marble, constituted by rather pure fine to medium grained calcite, with minor small grains of phlogopite and diopside, is penetrated by a network of coarse grained veins of granular, colorless to pale yellow or pale green, orthoclase, locally associated with spinel, diopside, phlogopite, apatite and zircon. The thickness of the veins varies from a centimeter to many decimeters. The grain size of the calcite increases considerably adjacent to the veins. Locally, the granular orthoclase is present in masses at the intersection of veins constituted by coarse-grained calcite, together with spinel, diopside and other accessories. Abundant open cavities, normally a few centimeters across, but in some cases up to many decimeters, occur inside the masses of coarse-grained orthoclase. Inside these cavities only orthoclase is present; it forms well-shaped gemmy crystals isolated from the matrix, and enclosed in a grayish to white clay. Most of the crystals originally grew on the orthoclase of the walls of the cavities but further fracturing occurred, probably due to the increase of volume of the host rock during the superficial alteration processes. In addition, many of the crystals display slight corrosion on all the surfaces. Perfectly doubly terminated crystals grown floating in the pockets are rare.

Field observations show that the gemmy orthoclase-bearing veins, inside the marbles, are concentrated at the intersection between the marble lenses and pegmatitic dikes. Indeed, undeformed discordant granitic pegmatites, few decimeters to some meters thick, are widespread in the area hosted in the paragneiss and pyroxenites. These pegmatites have a primitive composition with biotite and abundant magnetite. Blue beryl is locally present together with zircon and other accessories. K-feldspar is of pinkish-reddish color, is perthitic and graphically intergrown with white to smoky quartz. Plagioclase is scarce. Some rare miarolitic cavities are present, some up to a few decimeters across. In these cavities well-formed smoky quartz crystals and corroded K-feldspar are present. In one of these pockets, abundant well-formed, gemmy, pale yellow scapolite crystals, up to 5 cm, were found. These pegmatites, intersecting the marble lenses, underwent deep reaction processes. Normally the size of the pegmatites, in the first few meters in the marble, sharply increases. Continuing in the marble, the dike degenerates into a series of minor apophyses, and then into a network of small, fracture filling, veins. The pockets with the gemmy orthoclase occur in the apophyses and in the veins. Within the marble, the pegmatitic dikes change to a rather monomineralic coarse-grained rock, a K-feldspar unit. K-feldspar becomes rather vitreous, of milky, pale yellow to pale green, appearance due to abundant fluid inclusions. Exceptionally, inside this unit some pegmatitic masses with coarse-grained graphic K-feldspar-quartz intergrowth may occur. At the contact of this unit with the marble, and along the aphophyses and the smaller veins penetrating the marble, some accessories, including spinel, diopside, titanite, apatite, phlogopite and zircon, can be abundant. Calcite as accessory inside the veins and locally as the main component of the veins characterizes the more distal volumes.

More studies are necessary to formulate a genetic hypothesis but these observations seem to indicate that the gemmy orthoclase is the result of intense interaction of magmatic-pegmatitic liquids and fluids with marble. The undeformed style of the pegmatites, the presence in the pegmatites with miarolitic cavities and the presence of abundant cavities in the veins in the marble indicate a process of formation at the latest stages of the Pan-African event, during the uplift process.

U-T, Sapphire and zircon skarns

The world famous urano-thorianite deposits, as well as the sapphire deposits of southeast Madagascar are distributed in an area between the southern part of the Betroka-Bekily shear zone, and the Anosyan Mountains. These deposits seem to be related to the same genetic processes, which produced the phlogopite deposits previously described. In the area, the Tranomaro Group granulites include abundant marble and pyroxene-scapolite gneiss in contact with the Anosyan granitic (mainly charnokites) plutons. Granitic and pegmatitic apophyses and dikes are locally abundant in the area.

H. Besairie reported the first occurrence of thorianite in the phlogopite deposit in 1947. Some years later, in 1953, the mineral was discovered in rather large quantity in the alluvial deposits of the pyroxenites of Andriandampo. At the end of 1953 the total production of urano-thorianite was of 50 tons. The alluvial deposits, which at the beginning provided for much of the production, exhausted quickly. Subsequent works were made in the primary deposits in the pyroxenitic skarns. Much of the production was made from 1958 to 1962, with a total of over 3000 tons of Urano-thorianite. Among the more famous localities are Ambindandrakemba, Androtsabo, Anjahamaronono, Marosohihy, Belafo, Amboasarikely, Ambandaniro, Andoloabo and Betanimena.

Urano-thorianite (up to 50 mol% of UO_2 component) occurs in diopside-rich exoskarns (the so called pyroxenites) either located at the contact between marbles and granitic bodies or distal. Moine et al (1997) recognized two main stages of metasomatism and crystallization. Aluminous diopside, CO_3-scapolite, titanite or spinel and urano-thorianite are characteristic of stage 1, dated at 565 Ma. During stage 2, diopside was altered to fluor-pargasite and the most calcic scapolites (meionite) were transformed into anorthite+calcite. Fluor-phlogopite as well as newly formed urano-thorianite and hibonite are also typical of this stage. Hibonite crystallized at the expense of corundum or spinel in leucocratic segregations made up of meionite and anorthite. The granitic bodies, clinopyroxene-bearing potassic granites or syenites, were altered into scapolite-wollastonite rocks (endoskarns). Finally, large irregular shaped veins of REE-rich calcite with zircon (dated at about 515 Ma), titanite, diopside, scapolite and urano-thorianite crosscut the skarns. The calculated temperature and pressure conditions of metamorphism and metasomatism are: T ≈ 850 °C and P ≈ 5 kb for regional metamorphism and stage 1 metasomatism; T ≈ 800 °C and P ≈ 3 kb for stage 2 metasomatism. The fluorine presence in the fluids, associated with the formation of the skarns of the Tranomaro group, allowed the transportation of Th, Zr, REE and Al and the formation of minerals such as urano-thorianite, hibonite, baddeleite, zircon and zirconolite. The lack of fluorine in the fluids prevented the formation of these minerals in the phlogopite-skarns occurring in the western part of the granulite province.

In these skarns, the leucocratic segregations in marble, made up of meionite and anorthite, together with hibonite, locally generate some significant gemmy corundum (sapphire) deposits. The most famous is Andranondambo, approximately 100 km northwest of Fort Dauphin. A complete description of the deposit was recently (1997) reported by the Swiss gemologists E.J. Gübelin and A. Peretti. These researchers discovered in the sapphires a large variety of mineral inclusions, and in particular: calcite, F-bearing minerals (F-apatite, F-phlogopite, fluorite), zirconium-bearing minerals (baddeleite, zircon, zirconolite), Ti-bearing minerals (zirconolite, rutile, F-phlogopite), calc-alkali silicate minerals (K-feldspar, plagioclase, scapolite), thorium and uranium phases (thorianite and zirconolite), hydrous minerals (Mg-hornblende, diaspore), apatite, and various spinels in the system Mg-Al-Fe-Zn-O. In this deposit, sapphire probably formed during both phases of metasomatism (see previous description). Other minor localities, with pale to deep blue, and locally red, purple and green corundum, normally opaque and of poor gemmy quality but with good crystalline shape, are distributed in some places in the region. Many of these crystals are found in the altered rock at the surface and are loose from the matrix. Probably not all of these crystals are associated with the same rocks. Indeed, some corundum, similar to some occurrences north of the Ranomafana-Bongolava Shear Zone, are found in feldspathic veins in migmatites at the contact with granitic-syenitic masses. Other corundums have been found in amphibole-rich veins, of probable metasomatic origin, and in granulitic pyroxenites.

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