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Nuclear Power
Two Billion
Years Ago

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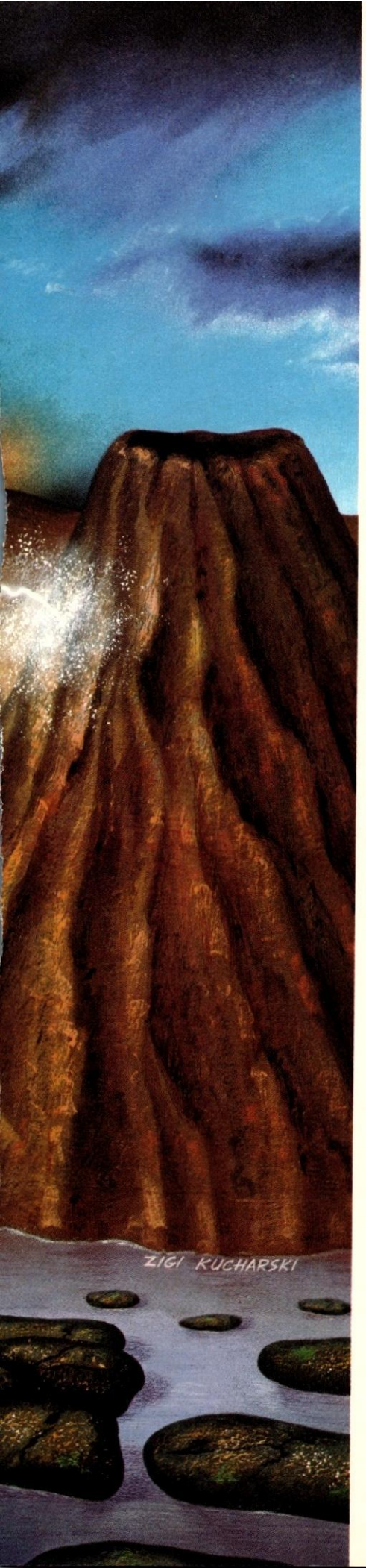
ZIGI KUCHARSKI



THE NAKED REACTOR

by Dr. R.M. Pearce

Two billion years ago, a nuclear chain reaction started in a uranium-rich vein of ore in West Africa. This unlicensed reactor ran for at least the next 200 000 years. No containment was built nor was any environmental impact statement ever submitted, for man had yet to appear on Earth.

When the French Commissariat à l'Énergie Atomique (CEA) announced in 1972 that the remains of a fission reactor had been discovered at Oklo, in what is now the Gabon Republic in West Africa, the news was greeted with some skepticism. Perhaps there was some reluctance to admit that modern man's technological prowess in nuclear engineering had been preempted by nature two billion years ago. Two years of intense research at the ancient reactor sites confirmed the CEA's interpretation and the scientific findings were summarized and shared when the International Atomic Energy Agency sponsored a conference in 1975 on the Oklo phenomenon. The conference, attended by 74 scientists of various chemical, physical, engineering and geological disciplines from 20 countries, was convened at a dramatic site on the floor of the open cut mine in Gabon alongside the remains of the reactor.

Although research on some of the more detailed aspects of the Oklo phenomenon is still underway, the unanimously accepted general picture of what happened is as follows: About two billion years ago, the uranium from an entire water shed was concentrated at the delta of a river system. By way of explanation as to why the uranium was there, it is necessary to know a bit about the geological aspects of the period.

Surveys have shown that nearly all of the world's known uranium deposits are located in or very near Precambrian formations. The richest and most extensive deposits date back to the Precambrian period. Why? One of the more acceptable views is that three major modes of uranium concentration existed in geological times. One of these modes existed prior to two billion years ago, the others later.

The first mode was mechanical. Grains and pieces of insoluble uraninite (partially oxidized uranium) were eroded from crystalline rocks and washed downstream. Because of their high density (similar to lead) they accumulated in stream sediments. Oxygen was responsible for the second mode of concentration which has continued to mobilize uranium. Two billion years ago, blue-green algae began to proliferate, producing free oxygen for the first time in Earth's history. Uranium grains exposed to this new environment became oxidized and changed to soluble compounds. Whenever uranium in stream sediments was exposed to oxygen, it became dissolved in water and washed downstream. In the earliest part of the period, this led to large deposits of highly concentrated ore.

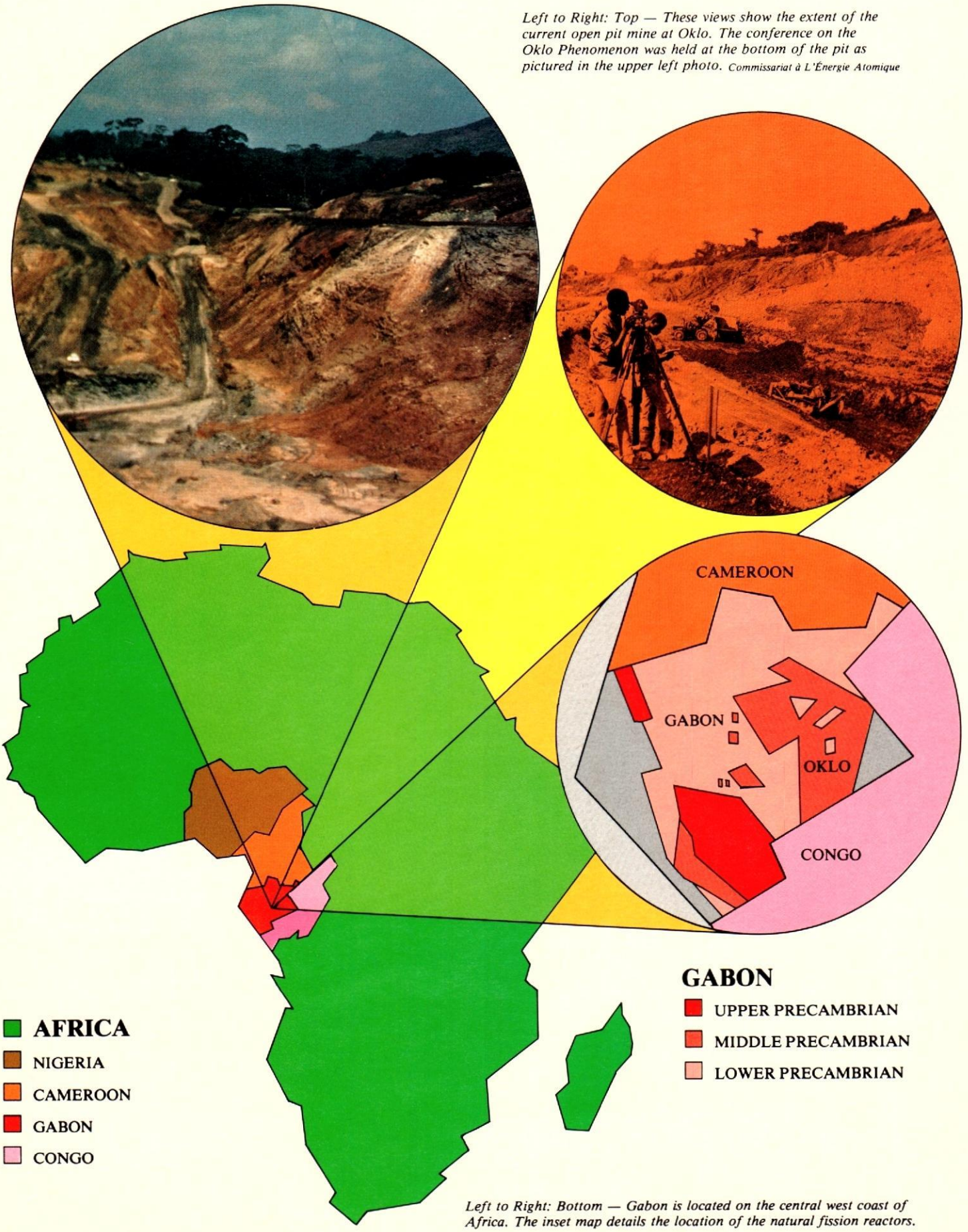
Until the unstable reservoirs of placer deposits were exhausted, a one time surge of mobilized uranium moved into new resting places, such as the swampy river delta at Oklo, where decaying organic ooze produced a reducing environment[1] and caused the uranium to be redeposited in the sediments.

These rich pockets of uranium, capable of supporting neutron chain reactions, were trapped by the tilting of sedimentary ore formations during the upheavals of the Earth's crust in the first oxidation-reducing cycle. All evidence shows that the major rich ore forming period ended at least one billion years ago.

Contemporary nuclear engineers know that a nuclear chain reaction cannot be sustained in natural uranium when surrounded by ordinary water. Natural uranium is a mixture of 99.3% U238 and 0.7% U235, the fissionable isotope. The U238 and the ordinary (light) water absorb too many neutrons for the reaction to proceed. (*Ascent* readers are familiar with the Canadian solution to this problem — the CANDU reactor which uses only heavy water, a relatively weak absorber of neutrons.)

Left: In this view, on what would have been a clear day in the Precambrian era, the blue-green algae which produced the first free oxygen for uranium oxidation is visible in the foreground. Zigi Kucharski

Left to Right: Top — These views show the extent of the current open pit mine at Oklo. The conference on the Oklo Phenomenon was held at the bottom of the pit as pictured in the upper left photo. Commissariat à L'Énergie Atomique



Left to Right: Bottom — Gabon is located on the central west coast of Africa. The inset map details the location of the natural fission reactors.

But back in the Precambrian era, natural uranium did not have this shortcoming: the half-life[2] of U238 (4-1/2 billion years) is about 6-1/2 times longer than the half-life of U235 (about 700 million years).

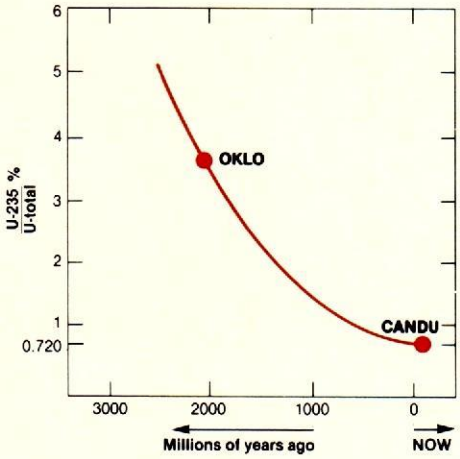


FIGURE 1

A time comparison (fig. 1) indicates that the percentage of U235 in uranium ore was higher than it is now and could have accounted for 3.5% of the total uranium at Oklo. Based on this comparison, we can state positively that a chain reaction in uranium and light water could have been sustained two billion years ago. Thus, in Precambrian times, it would not have been necessary to manufacture enriched uranium (increase the ratio of U235 to U238) to operate ordinary water reactors, such as those found in the United States and Japan.

With the uranium deep underground at Oklo, a chain reaction began in several different places and continued for 200 000 - 600 000 years until the U235 had been significantly depleted and the chain reaction stopped. The system was not explosive and appears to have run at the modest level of 10-25 kilowatts or the equivalent of 30 horsepower. The reactors were at a depth of about 4 km beneath the ground at the time when they were operating.

Erosion of the land surface during the past two billion years has left them only 2-300 metres below the surface today. The power of the reactors was controlled by the density of the water. As water heats up, it becomes less dense. So, as the reactor zone heated up, the water expanded out of the reactor and the reaction slowed down. AECL's SLOWPOKE reactors, supplied to universities for research, are also self-regulated by the expansion of water.

A total of at least six natural reactors has been found at Oklo in a series of uranium deposits approximately one metre thick and 10 metres wide.

It is interesting that the periods of time involved since the Oklo reactor shut down are so long that the residual radioactivities at the site are now too weak to provide any useful data to help reconstruct the parameters of the two billion year old reactor. The most useful analytical tool has been mass spectrometry which has allowed researchers to measure the distribution through the site of the isotopes of uranium and plutonium and the now inactive fission products. In fact, it was during a routine mass spectroscopic analysis of some Oklo ore samples by the CEA that some anomalously low U235 abundances were measured giving the first suggestions that some U235 missing from the sample had been fissioned by neutrons. Each reactor site was subsequently identified after considerable detective work by the CEA and some samples were found which contained only .44% of U235, as compared to the value .72% which is expected throughout the world.

Confirming evidence that a chain reaction had taken place at Oklo came from mass spectroscopic analysis of (now stable) fission product neodymium: figure 2 shows

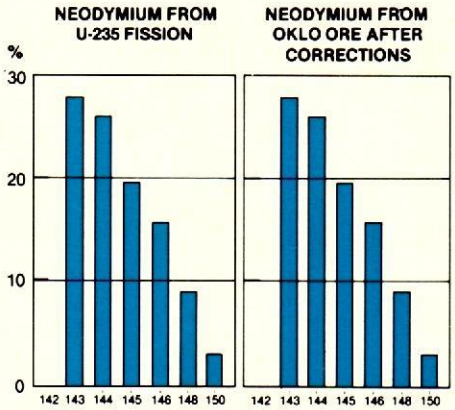


FIGURE 2

the distribution of relative abundances in the various neodymium isotopes. The characteristic distribution from fission is seen to be very different from the distribution found in a normal sample. The distribution found in the Oklo site (after corrections for the amount of neodymium originally present and for the neutron burnup of certain neodymium isotopes) is in excellent agreement with the distribution from reactor products. Similar confirming evidence has come from other families of isotopes.

Clearly, the Oklo phenomenon affords workers in waste disposal technology a unique opportunity to study migration of fission products with a time scale which cannot be equalled in an experiment. During the lifetime of the reactors, approximately six tonnes of U235 were consumed at Oklo, and a corresponding six tonnes of fission products were generated. The total energy release of 15 000 megawatt years was equivalent to running a Pickering type CANDU reactor for 10 years.

R. D. Walton of the Division of Waste Management and Transportation USAEC, and G. A. Cowan of the Los Alamos Scientific Laboratory have concluded that the "escape of radioactive products from the Oklo reactor zone was quite limited." The heavy elements have remained fixed but there have been some displacements in the intervening two billion years of elements such as xenon, rubidium, barium, molybdenum and iodine. The study of migration of the now stable fission products at the Oklo site is continuing.

The search is on in several countries for other fossil reactors and some experts feel that the prospects of finding additional reactors are good. One can speculate that some fossil reactors have been unknowingly mined in the last few decades. But one thing remains certain. Fission is not an invention of man.

Dr. R. M. Pearce is Chairman of the Department of Physics of the University of Victoria, British Columbia. Extra research material was provided by M. Tomlinson of Atomic Energy of Canada Limited, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba.

1. *An environment which is conducive to the removal of oxygen from the sediments.*
2. *Half-life: The rate of decay of radioisotopes according to the time it takes them to lose half their strength (intensity). Half-lives range from fractions of seconds to billions of years.*