# An Insight Into the Geology, Exploration and Development of Thorium

*a report by*

**Conrad Windham**

*Chief Operations Officer, All Star Minerals, plc*

Thorium owes its discovery to the Swedish chemist Jons Jakob Berzelius, who identified the element as a new mineral in 1828, after Reverend Esmark and his father Professor Esmark had been unsuccessful in identifying the black mineral that the Reverend had found on Lovoy Island, Norway. Berzelius named the new element thorium in honour of Thor, the Norse god of thunder. Thorium is located in the actinide series of the periodic table, having the chemical symbol Th, an atomic number of 90 and an atomic weight of 232.0381.

To date, international knowledge of the world's thorium resources remains limited, intensive exploration for the element not having been justified due to a lack of demand. However, as nuclear power continues to be recognised as the world's only viable long-term source of power generation, interest in thorium as a more environmentally friendly alternative feedstock to uranium is increasing rapidly.

## Sources of Thorium

### *Monazite*

The principal source of thorium is monazite, a reddish-brown mixed phosphate mineral discovered at the start of the 19th century. It derives its name from the Greek mona`zein, meaning 'to be solitary', alluding to the mineral's isolated crystals. Monazite is found in intrusive rocks and pegmatite, as well as in some metamorphic rocks, such as gneiss. However, the richest concentrations of monazite are placer deposits, these being accumulations of sand in rivers and beaches.

Placer deposits of monazite are known to occur in Australia, Brazil, India, Malaysia, Nigeria, Sri Lanka and the US. Lesser quantities of thorium-bearing monazite reserves occur in vein deposits and carbonatites. While monazite is a primary source of thorium and light, rare earth elements, it is also a secondary source of phosphate and uranium.

Historically, until the early 1990s Australia had been the world's major producer of monazite, with regular production having started in the late 1940s. Monazite has been recovered in Australia as a by-product of mining beach sands for ilmenite, rutile and zircon. Throughout the late 1980s and 1990s, monazite production in Australia declined, a result of a decrease in world demand for thorium. Historically, world production of monazite had averaged in the region of 15,000 tonnes per annum. Today, however, annual production is 5,000 tonnes, with the main producers being India and China.

It has been estimated that world monazite reserves are around 12 million tonnes, of which eight million tonnes occur with heavy minerals in the beach sands of India in the states of Kerala, Tamil Nadu, Andhra Pradesh and Orissa.

### *Thorite*

While monazite is the primary ore of thorium, thorite is the most common thorium mineral. Thorite is recognised as an important ore of uranium in the form of uranothorite, which has proved to be a viable ore at Bancroft in Ontario, Canada. Thorite is known to be hosted in igneous pegmatites and volcanic extrusive rocks, hydrothermal veins and contact metamorphic rocks, as well as in small grains found in detrital sands.

### *Thorogummite and Thorianite*

Thorogummite was once deemed to be a variety of thorite, but is, in fact, a product of thorite. The alteration is caused by hydration being facilitated by metamictisation, in which the thorite's crystal lattices are completely destroyed, leaving it amorphous and having no crystal structure. Its association with thorite means that it is a minor ore of thorium. Like thorite, thorogummite is found in igneous pegmatites, volcanic extrusive rocks, hydrothermal veins and contact metamorphic rocks.

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Thorianite, meanwhile, is a mineral containing, on average, 70% thorium, as well as hosting the oxides of uranium, lanthanum, cerium and didymium. Thorianite is usually found in alluvial deposits, beach sands and pegmatites.

## Mining Thorium

The following section is extracted from 'Thorium Fuel Cycle – Potential Benefits and Challenges', International Atomic Energy Agency (IAEA), May 2005.

Monazite deposits are formed by the weathering of parent rocks, followed by the gravity concentration of heavy minerals in sand beds,

Conrad Windham is the Chief Operations Officer of All Star Minerals, plc, a company that explores for thorium and its associated elements, and the founder and Chief Executive Officer of the uranium exploration company U3O8 Energy Ltd. Prior to his directorship of All Star Minerals and U3O8 Energy, Mr Windham worked in financial journalism, focusing specifically on the mining exploration industry. Mr Windham holds a BA from King's College London.

as a result of wind and water in the coastal areas of tropical countries. Separation of the minerals is dependent on physical properties, such as specific gravity, magnetic susceptibility, electrical conductivity and surface properties.

In India, the process begins with separation of the electrically conductive ilmenite and rutile constituents using a high-tension separator. This is followed by the non-magnetic sillimanite, zircon and magnetic garnet being separated from the non-conductive and moderately magnetic monazite through high-intensity magnetic separators and/or wet tables. The resulting concentrate contains 98% monazite.

The monazite is finely ground and, in most countries, dissolved in 50–70% sodium hydroxide at ~140ºC. It is then subjected to a series of chemical operations, including solvent extraction and ion exchange processes to obtain pure thorium nitrate, which is precipitated in the form of thorium oxalate and subjected to controlled calcinations to obtain $ThO_2$ powder.

In India, until recently, the monazite used to be alkali leached, the rare earth separated as mixed chloride and the thorium stored in the form of thorium hydroxide in concrete silos. The hydroxide cake contained around 35% $ThO_2$, 7% rare earth oxide, 0.6% $U_3O_8$ and nearly 28% insolubles and moisture.

Recently, a project entitled Thorium Retrieval, Uranium Recovery and Storage of Thorium Oxalate (THRUST) has been completed for processing monazite in such a manner that all the thorium is separated in pure thorium oxalate form (99% purity), which makes it much easier to handle, store and retrieve to prepare

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mantle-grade thorium nitrate or nuclear-grade thorium oxide as and when required. In addition, the major fraction of uranium present in monazite is also separated in the form of crude uranium concentrate.

### Companies Exploring for Thorium

The past two years in particular have seen a renewed interest in exploration for thorium, a trend that will inevitably increase. Two companies that are already exploring and developing thorium properties are the UK-based company All Star Minerals, plc and the American-based company Thorium Energy, Inc.

#### *All Star Minerals, plc*

All Star Minerals has acquired a portfolio of thorium properties in Western Australia, Sweden and Norway. It has achieved financial

**Table 1: Current Estimated World Thorium Resources**

| Country | Tonnes | % of World |
|---|---|---|
| Australia | 452,000 | 18 |
| US | 400,000 | 16 |
| Turkey | 344,000 | 14 |
| India | 319,000 | 13 |
| Venezuela | 300,000 | 12 |
| Brazil | 221,000 | 9 |
| Norway | 132,000 | 5 |
| Egypt | 100,000 | 4 |
| Russia | 75,000 | 3 |
| Greenland | 54,000 | 2 |
| Canada | 44,000 | 2 |
| South Africa | 18,000 | 1 |
| Other countries | 33,000 | 1 |
| World total | 2,492,000 | |

*Source: Geoscience Australia 2006 and Organisation for Economic Co-operation and Development (OECD)/Nuclear Energy Agency (NEA) Red Book Retrospective, 2006.*

backing from the UK hedge fund RAB Capital, and was listed on the primary exchange of PLUS Markets in April 2006.

All Star Minerals has two adjacent Western Australian properties, Bullbadger and Errabiddy, which cover a combined land mass of 403 square kilometres. The first is focused on a rare earth/carbonatite zone and the second on identifying alluvial deposits.

At Bullbadger, work to date from drainage samples collected by the Geological Survey of Western Australia has identified an anomalous suite of minerals – niobium, cerium, lanthanum, yttrium, titanium, thorium, tellurium and zircon. All Star Minerals believes that this indicates the presence of carbonatites, which are assumed to occur as dykes. Follow-up work by All Star Minerals has confirmed the high prospectivity of Bullbadger for carbonatites, where maximum values returned from sampling have assayed up to 259 parts per million (PPM) thorium, 1% titanium, 928 PPM cerium, 505 PPM lanthanum and 40 PPM niobium.

At Errabiddy, the high monazite levels returned from creek alluvium samples are encouraging for large accumulations of thorium-rich alluvium at the tenement. Two samples assayed have returned grades of 3 and 2% monazite, 1 and 2% zircon and 40 and 44% ilmentite. Grades of 0.12% thorium, 0.46% cerium, 0.25% lanthanum, 1.4% zircon and 9.9% titanium were also returned.

Meanwhile, in Sweden, All Star Minerals has acquired two licences, Samon and Gilpas, which cover 26 square kilometres and 13 square kilometres, respectively.

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The Gilpas licence is situated in the Arjeplog Uranium District, and is prospective for uranium and thorium mineralisation. In 1980 and 1981, two highly radioactive boulders were located in glacial till at Gilpas, with one boulder containing over 29% uranium. At Samon, the target is focused on a pegmatite deposit containing thorium-bearing minerals. A boulder discovered at the surface of Samon in 1970 returned a grade of 3.5% thorium and 0.05% uranium.

### *Thorium Energy, Inc.*

Thorium Energy, Inc. owns 68 separate resource claims in the Lemhi Pass Region of Idaho, US. These resource claims include the mineral rights to the Last Chance thorium vein, located in the Lemhi Pass on the Idaho/Montana border.

A report prepared on behalf of the Idaho Geological Survey has revealed that the Last Chance thorium vein contains the most significant thorium deposit in the Lemhi Pass, and is the richest thorium vein in the US.

> Thorium is likely to represent the future feedstock for nuclear power generation.

The claims owned by Thorium Energy in the Lemhi Pass have confirmed reserves in excess of 600,000 tonnes of thorium, with probable reserves in excess of three million tonnes. The Lemhi Pass vein is reported to contain an average concentration of thorium oxide grading 0.39% $ThO_2$, and 0.33% rare-earth oxide.

It is believed that the thorium reserves at the Lemhi Pass are sufficient to provide the fuel requirements of the US for several centuries. The new published data will ensure that known world thorium resources will have to be updated, and are likely to mean that the US is considered to have the world's largest thorium reserves, moving ahead of Australia.

### Conclusion

Thorium is already understood to be at least three times more abundant in the Earth's surface than uranium. As the technology for thorium-fuelled nuclear reactors moves increasingly closer to commercialisation, there is likely to be significantly more interest in the element from mining companies and investors.

Both All Star Minerals and Thorium Energy will improve our understanding of thorium resources in their chosen countries of operation, but it is clear that there remains a limited understanding of the true extent of the world's thorium resources, as recently published data from the Lemhi Pass reveal.

The fact that it is in three times greater abundance than uranium, and that all mined thorium is able to be used in a reactor, compared with 0.7% of natural uranium, means that thorium is likely to represent the future feedstock for nuclear power generation. ■