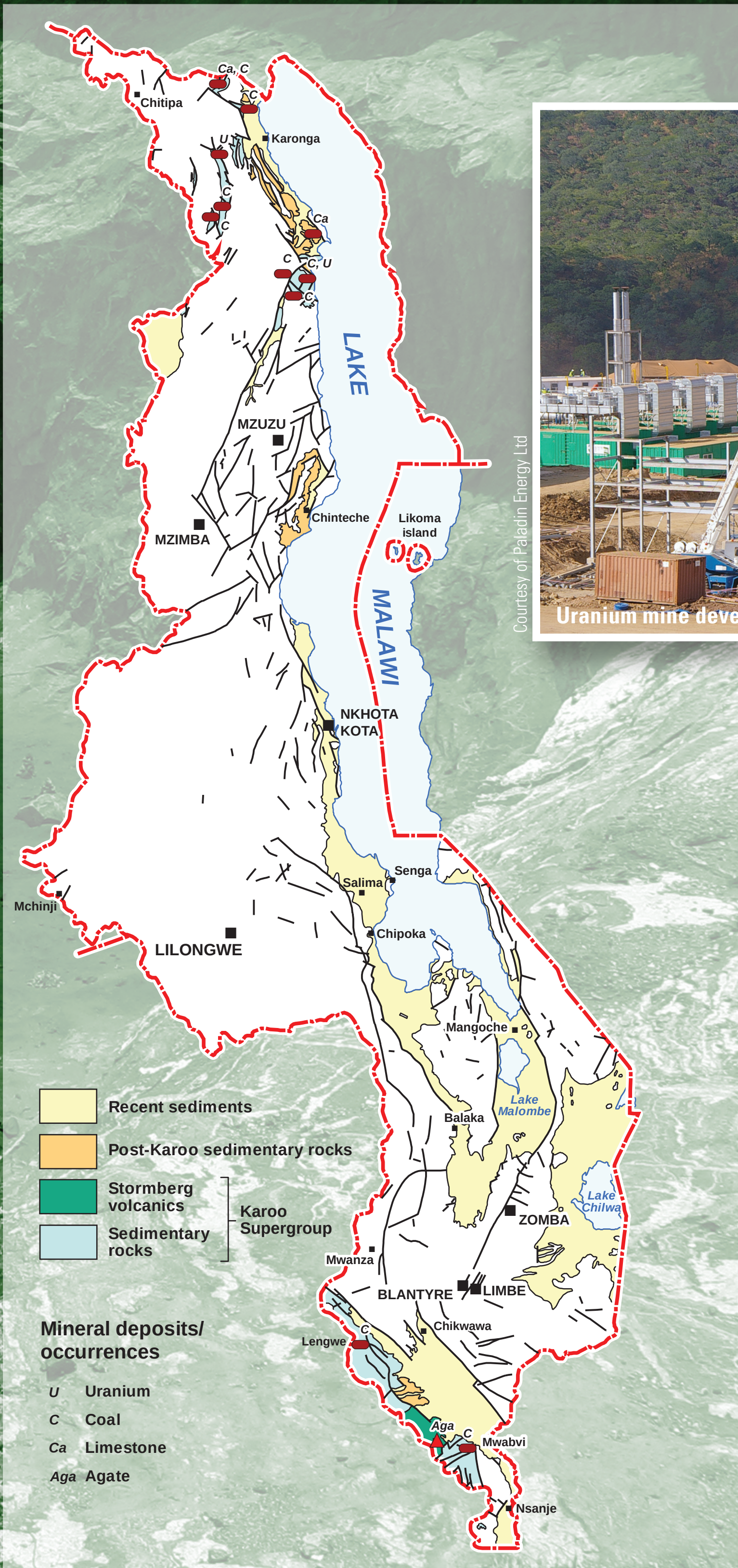
Ministry of Energy and Mines
REPUBLIC OF MALAWI

Mineral potential of Malawi

3 Mineral deposits associated with sedimentary and volcanic cover rocks: Karoo and post-Karoo (coal, uranium, industrial minerals and gemstones)

Produced for the Ministry of Energy and Mines of Malawi by the British Geological Survey under the auspices of the UK Department for International Development.



Uranium mine development at Kayelekera

Courtesy of Paladin Energy Ltd

In Malawi the Permo-Carboniferous to Lower Jurassic sedimentary and volcanic rocks of the Karoo Supergroup and late Cretaceous to Tertiary post-Karoo sedimentary cover overlie an early Precambrian to early Paleozoic Basement Complex. The Karoo Supergroup, along with the Malawi Basement Complex, is cut by Mesozoic alkaline igneous rocks, the mineral potential of which is covered in Brochure 1.

This brochure features the mineral potential of the sedimentary and volcanic rocks of the Karoo and post-Karoo successions respectively.

Ore deposit types range from syngenetic to syn-diagenetic through to late-stage diagenetic and typically include sediment-hosted stratabound deposits of uranium, coal and limestone. The Stormberg volcanics host gem quality blue agate and chalcedony. The Karoo Supergroup also has significant hydrocarbon potential.

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Karoo Supergroup

The Karoo Supergroup rests unconformably upon the Precambrian basement. It comprises Carboniferous to Jurassic sedimentary and subordinate volcanic rocks that are preserved mostly within down-faulted blocks in the north and the south of the country. The Karoo succession begins with the glaciogenic Dwyka Group (K1) followed by the marine and coal-bearing Ecca Group (K2-3), the richly fossiliferous and mainly fluviatile Beaufort Group (K5-6) succeeded by the increasingly eolian Stormberg Group (K7) and culminated by volcanics generated during the rifting of Eastern Gondwana. The coal-bearing members are fluviatile prodelta sediments of localised origin found in a number of disconnected subbasins. The most southerly outcrops of Karoo Supergroup sediments and volcanics in Malawi, referred to as the Chikwawa Group, is a considerably thicker sequence preserved in the Shire-Zambezi fault trough. Deposition in this trough commenced later and continued longer than in the north.

Post-Karoo

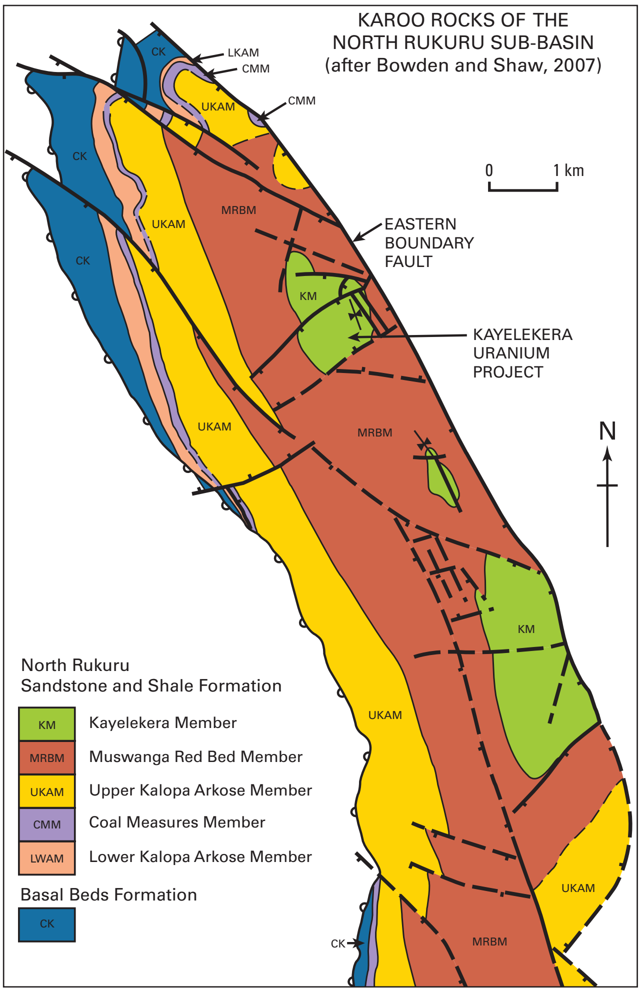
Cretaceous sediments and volcanics of the Lupata Group overlie Karoo volcanics. Karoo volcanics are absent from northern Malawi and none of the Karoo sediments in the north can be conclusively demonstrated to be younger than Permian. The Karoo is overlain by the Cretaceous-age bone-bearing Chiweta Beds and Pliocene hominid-bearing Chiwondo Beds that occur in fault grabens located in close proximity to each other along the structurally complex Rift Valley in the north of the country.

Uranium

Kayelekera Project

The Kayelekera sandstone-hosted uranium deposit lies within Permian Karoo sedimentary rocks of the North Rukuru basin 52 km west of the provincial town of Karonga at the northern end of Lake Malawi and 575 kilometres north of the capital city, Lilongwe. The deposit was discovered and delineated by the Central Electricity Generating Board of Great Britain (CEGB) between 1982 and 1992. In 1998, Paladin Energy Ltd. acquired an interest in Kayelekera through a joint venture with Balmain Resources Pty Ltd. and in 2005 acquired the remaining 10% interest held by Balmain. Paladin Energy Ltd, an Australian publicly-listed company, holds a 100% interest in the Kayelekera Project through its wholly owned subsidiary Paladin (Africa) Ltd, but the Company will transfer a 15 per cent shareholding in PAL to the Government of Malawi under the terms of the Development Agreement signed between PAL and the Government in February 2007. Following environmental approval, Mining Licence ML 152, covering 5,550 hectares was granted in April 2007, valid for a period of 15 years. Construction on the $US200 million development project commenced in June 2007.

The Project is designed to give an annual production of 3.3 Mlbs U_3O_8 from the processing of 1.5 Mtpa of sandstone and associated ores by grinding, acid leaching, resin-in-pulp extraction, precipitation and drying to produce saleable product.



Geological map of the northern part of the North Rukuru basin.

Meanwhile Paladin has commenced exploration on adjacent blocks to the east, west and south of the Kayelekera Mining Lease i.e. Exclusive Prospecting Licences (EPLs) 168,169 and 170 granted in December 2005, and EPL 225, granted in December 2007, with follow-up on radiometric anomalies identified by the previous helicopter radiometric survey with a view to increasing the resource base and mine life. The North Rukuru basin contains a >1500 m thick succession of clastic sediments preserved in a semi-graben. This sequence is divided into two distinctly different formations, namely,

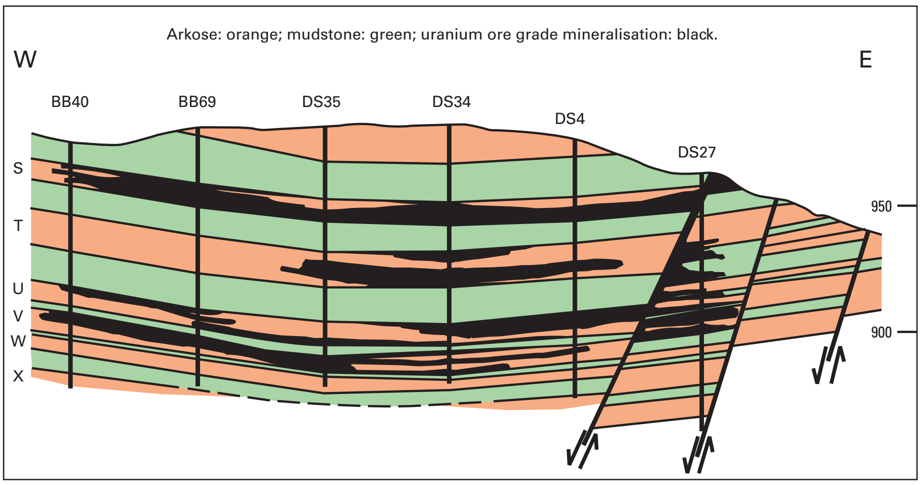
Plant construction at Kayelekera (photo courtesy of Paladin Energy Ltd).

	Proven			Probable			Total		
Type	Tonnes Mt	Grade % U_3O_8	Metal Kt	Tonnes Mt	Grade % U_3O_8	Metal Kt	Tonnes Mt	Grade % U_3O_8	Metal Kt
Arkose	1.60	0.14	2.27	7.80	0.098	7.6	9.40	0.11	9.9
Mudstone	0.18	0.15	0.28	0.91	0.13	1.2	1.10	0.14	1.5
Total	1.78	0.14	2.54	8.70	0.10	8.8	10.50	0.11	11.4

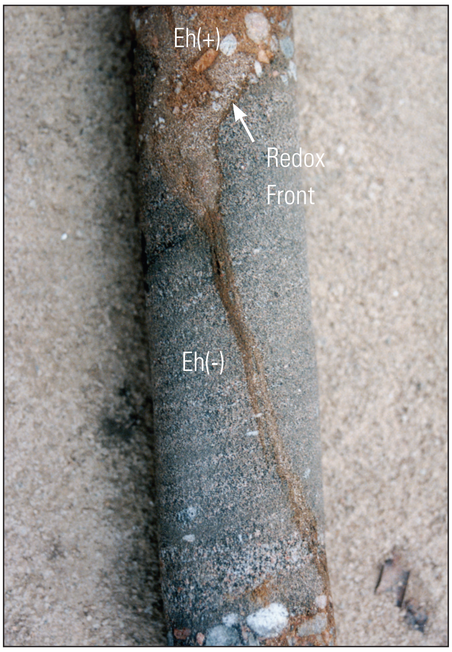
Kayelekera ore reserves, arkose cut-off 400 ppm, mudstone cut-off 600 ppm. These results are based on a blend of 83% arkose and 17% mudstone (Paladin (Africa) Ltd.).

the glacial and glacio-lacustrine Basal Beds Formation comprising a diamictite (tillite) member with an overlying flaggy sandstone and varved shale member followed by a thick series of alternating arkosic sandstones and mudstones of the North Rukuru Sandstone and Shale Formation which is divided into five members. The Kayelekera uranium deposit is developed in the uppermost Kayelekera Member of the preserved succession which, within the deposit area, has a maximum thickness of c.150 m and contains a total of eight separate arkosic units with intervening mudstones in an approximate 1:1 ratio. The base of the Kayelekera Member is dark grey/chocolate brown mudstone which rests upon the Muswanga Red Beds Member. The Kayelekera member succession indicates cyclic sedimentation within a broad shallow intermittently subsiding basin. Each cyclothem generally passes upwards from coarse reduced facies arkose through oxide facies 'red-bed' mudstones into reduced facies carbonaceous silty mudstones locally with thin coaly horizons. Individual arkosic units which may contain several upward-fining sequences, are commonly current bedded and contain carbonaceous debris with associated disseminated pyrite. Lenses of uranium mineralisation occur within the arkose units to a depth of 100 m. These vertically stacked lenses are localised approximately parallel to the synclinal axis of the fault-bounded structure. Mineralisation is offset but is not confined by faults although it is limited by the surface topography which truncates the host lithologies. Most of the mineralisation is contained within six principal lenses in the arkose units although some secondary mineralisation also occurs in the mudstones below the mineralised arkose. Three types of mineralisation are recognised based on the redox state of the host lithology, namely (i) reduced, (ii) oxidised and (iii) mixed oxide and reduced facies. Coffinite is the primary uranium mineral in the reduced facies often associated with organic debris and/or pyrite. The transitional zone includes uraninite and U-Ti minerals whilst the oxide facies contains several yellow-green secondary uranium minerals dominated by meta-autunite and boltwoodite. At a 300 ppm U_3O_8 cut-off, the total measured and indicated resource is 15.3 Mt @ 0.088% U_3O_8 yielding 13.63 Kt of U_3O_8, with a further 3.40 Mt @ 0.06% U_3O_8 yielding 2.04 Kt of U_3O_8 as Inferred Resource under the JORC code. The process plant is currently under construction and due for commissioning during the first quarter of 2009. Open pit mining commenced in June 2008 to develop initial stockpiles, with the first blast occurring on 24 July 2008. It will be a conventional open-pit operation with a seven-year life, but processing will continue for a further four years at a steady state rate of 1.5 million tpa to give an annual output of 1,493 t U_3O_8 in the first seven years and 530 tpa U_3O_8 from stockpiled marginal material grading 0.039% U_3O_8 over the last four years.

Kayelekera is a typical roll-front uranium deposit formed by movement of uranium-enriched oxidising groundwaters down

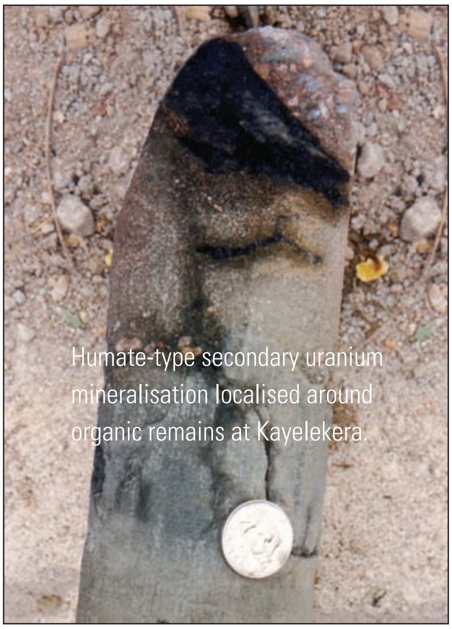


Schematic cross-section through the Kayelekera uranium deposit (after Bowden & Shaw, 2007).



Drill core from Kayelekera showing the oxide-reduced facies interface (Photo by R.P. Shaw).

As a consequence of infill and extension drilling (total 9,955m) carried out during 2008 the JORC and 43-101 compliant proven ore reserve and probable resource estimates have been increased by 17% and 27% respectively at a cut-off grade of 400ppm U_3O_8. This will extend the mine life by 1.5 years to 9 years. The 2008 drilling has also shown that the mineralisation continues towards the northwest and west and thus potential exists to identify additional resources.



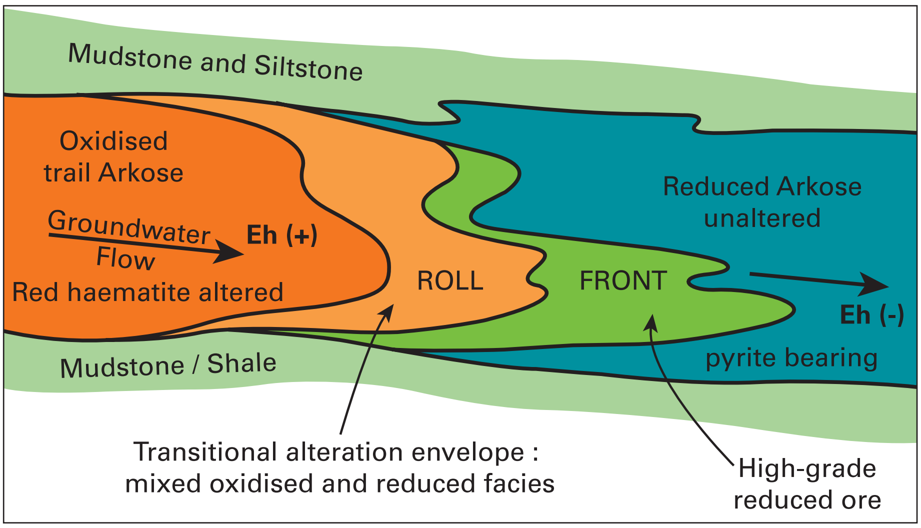
Drill core from Kayelekera showing humate-type uranium precipitation around organic material (Photo by R.P. Shaw).

gradient through permeable arkosic sandstones. The uranium, along with other dissolved metals such as molybdenum, vanadium, selenium and arsenic, precipitates out when the groundwaters encounter the oxidation/reduction interface often forming a crescent-shaped ore body. Uranium, being more mobile under oxidising conditions, tends to be leached from the oxidised parts of the deposit. Over time the reduction front will migrate in the direction of groundwater flow. Disseminated pyrite and organic material act as reductants and organic trash pockets in sandstone can result in the additional formation of rich humate-type orebodies. Tabular blanket deposits also may form at the crescent tips of the front. Whilst some deposits are mined by open pit or underground methods, most future mining may be done by in-situ leaching.

These deposits are normally found with radiation detectors although peak to background ratios may be small and can be easily overlooked. The Kayelekera radiometric anomaly was exceptional in being five times background. Complications can arise where there is secular disequilibrium between uranium and daughter products of the decay chain. Uraninite and coffinite may be so newly formed that radioactive daughter products have yet to develop. Such non-radioactive deposits have to be discovered by geochemical methods.

Recognition of economic concentrations of roll-front uranium within the Karoo basins has encouraged increased exploration activity specifically targeting this style of mineralisation. Globe Metals and Mining is prospecting for roll-front style uranium mineralisation within Karoo sandstones of the Livingstonia sub-basin on the basis of a radiometric anomaly along the eastern escarpment. The first phase of a drilling programme was completed in 2008 at their Chombe, Chiweta and Bunga prospects. *Chombe* is the most advanced and probably the most promising with intersections of 15 m @ 402 ppm U_3O_8 including 4 m @ 864 ppm U_3O_8, 10.6 m @ 373 ppm U_3O_8 including 3.3 m @ 820 ppm U_3O_8 and 8.1 m @ 644 ppm U_3O_8 including 3.1 m @ 806 ppm U_3O_8. It is a roll-front type of uranium deposit but is much more complex than Kayelekera. Primary ore concentrations appear to be associated with numerous channel fillings as in a braided floodplain environment. Secondary remobilisation has occurred in a number of phases with one superimposed or overprinting an earlier depositional front. There is some deposition of secondary uranium associated with carbonaceous lenses. With Livingstonia being that much closer to the Malawi Rift margin faulting has played a greater role in the localisation of the uranium mineralisation although offsets of the mineralised horizon are rarely more than a few metres. Thus the overall geometry is not that of a simple open syncline as at Kayelekera. The main mineralised member is a basal arkosic unit up to 90 metres thick which lies directly above the coal measures sequence. The arkosic sandstones are generally uniform and homogeneous except for a few thin silty interbeds. Proximity to the rift escarpment and other environmental considerations may preclude open pit mining but may be amenable to in situ uranium extraction which has relatively little impact at surface. The natural water table is at a depth of 40 metres but varies somewhat according to the season.

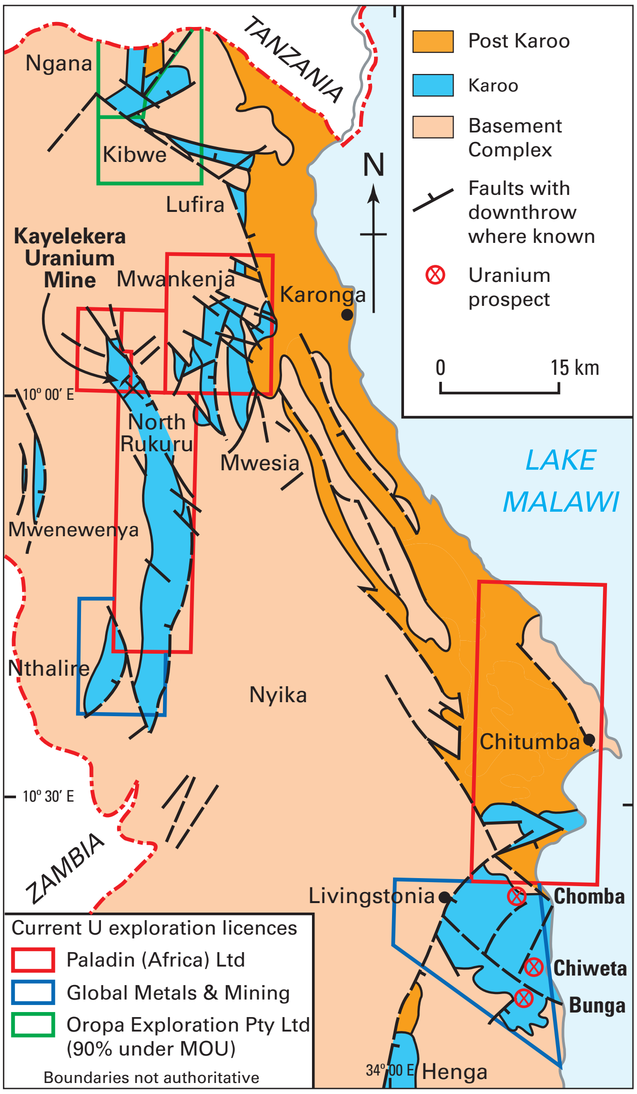
For a roll-front uranium to be amenable to in-situ leaching the uraniferous sandstone must be porous and permeable and confined above and below by impervious mudstone or shale. The beds must be flat-lying or only gently dipping and must be below the water table or in a confined aquifer. In situ leaching enables economic exploitation of uranium from roll front deposits that are too deep for surface mining methods.



Conceptual model of a Uranium roll-front deposit (adapted from Devoto, 1978).

Coal

Coal is an important and underused source of energy in Malawi. It offers a more reliable source of energy than renewable sources such as hydroelectric power generation which is liable to be affected by drought and could be a substitute for fuelwood/wood charcoal which is subject to increasing environmental and population pressures. Small coal basins with potential for only limited reserves of coal have a local economic and strategic value given the high bulk transportation cost.



Distribution of Karoo basins in Northern Malawi: North Nyika and Livingstonia.

Malawian coal is currently used in boilers for raising steam, in cement manufacture, curing tobacco and production of pharmaceuticals.

According to available estimates there are 13 coalfields in the northern region and two in the southern part of the country with speculated reserves totalling as a much as 800 million tonnes. The best known deposits occur in the Ngana, Livingstonia, Lufira, Mwabvi, Lengwe, North Rukuru and Nthalire (sub) basins. Malawian coals are sub-bituminous to bituminous, with a high ash content, high volatile and low sulphur contents. They are bi- and trimaceral humic types rich in inertinite and/or vitrinite and mineral matter, and are typical of other Gondwana coals. The seams so far discovered are mostly <1 metre thick and display rapid vertical and lateral variations. Arkose-related coals appear to be of better quality and more persistent than the coals associated with mudrocks. They offer the greatest potential for economic exploitation in the short to medium term, a point well recognised by the Malawian authorities.

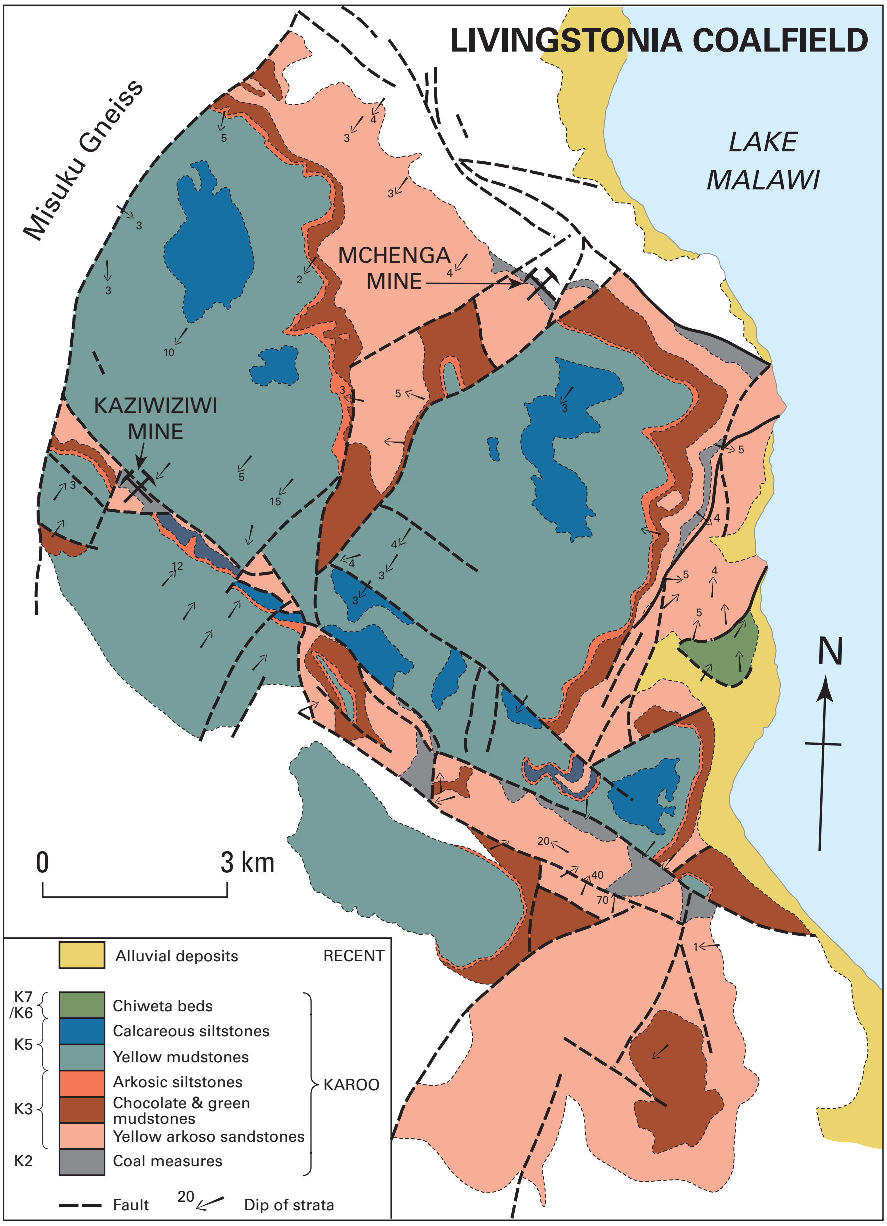
The coal measures vary in thickness up to c.100 m in the north and c. 600 m in the south. They comprise interbedded mudrocks and commonly arkosic sandstones and subordinate conglomerates. The argillaceous beds contain thin multiple coal seams. Sandstone-hosted coals are less common but are notable in the Livingstonia basin where they are presently worked. The northern basins exhibit a regional dip to the east and are mostly half-grabens downfaulted to the west along their eastern boundaries. Only in the basins nearest to Lake Malawi is this polarity reversed and the geometry more compatible with the younger Rift Valley tectonics. A considerable thickness of Karoo-Cretaceous deposits occur beneath the Tertiary to Recent sediments of the northern littoral of Lake Malawi.

The Livingstonia Basin on the southwest side of the Nyika massif represents the southwestern extension of the Ruhuru basin in Tanzania which has been truncated by the Lake Malawi rift. Compared to North Nyika the Livingstonia basin succession was deposited in a deeper water lacustrine environment. It is fault-bounded to the northwest and has a gross geometry consistent with a pull-apart origin in a left lateral transcurrent displacement zone.

Currently there is only one major coal producer, namely **Mchenga Coal Mines**, which is located in the Livingstonia coalfield and extends over 90 km^2 in the Rumphi district.

This coal company operates on a production target of 5000 tons a month and supplies coal to some leading companies in the country as well as supplying 1000 tpm to Mbeya Cement in Tanzania. Mchenga Coal is

Western adit of Kaziwiziwi coal mine, Livingstonia.



Geological map of the Livingstonia basin.

also working on the Chombe coal deposit and the cumulative annual production is likely to touch 96,000 tonnes. Proven reserves in the Mchenga Mine area amount to 1.4 million tonnes. There is another small-scale mining operation at Kaziwiziwi that is managed by the Kaziwiziwi Mining Company.

At Mchenga Mine a prominent seam of interbanded dull and bright coal some 1.5–2.7 m thick that occurs immediately beneath the K3 basal arkose and has considerable lateral extent is currently being worked. The contact between the coals and roof arkoses is sharp, generally flat-lying and remarkably planar.

At their base they rest on carbonaceous micaceous sandstones which show upward fining into the base of the coal. Thinner seams (⩽ 0.5 m thick) occur above the main seam and show similar roof and floor relationships. The mined Kaziwiziwi ‘main seam’, which is sandstone-hosted, is 1.5–2.0 metres thick with the best coal occurring in the uppermost 0.75 m.

The **Ngana coalfield**, which covers an area of 60 km^2 and forms the southern extension of the Songwe-Kiwiri Basin in Tanzania, is being evaluated for its opencast potential. The Ngana coal seam is of the order of 15 m thick and dips eastwards at 30^o. An estimated 50 Mt of in-situ coal is within a depth limit of 200 metres. The stripping ratio of overburden to coal is projected to be ⩾ 10:1. Drill-indicated reserves stand at 18.2 million tonnes with a recovery of 65%. However, a high proportion of waste is recorded and in view of the high ash/low calorific value of the coals it would require extensive washing to produce a saleable product.

The **North Rukuru coalfield** covers 190 km^2 and the coal seams range in thickness between 0.5 m and 3.0 m. The coal resources are inferred at 165 million tonnes with proven reserves of 500,000 tonnes at Kachira in Musisi Forest. The coal may be exploited by open cast or underground mining. The overburden to coal ratio is >15:1.

The **Lufira coalfield** covers an area of 6 km^2 with an estimated coal resource of 1.25 Mt. The coal-bearing sequence dips at 16–25^o to the east and is 20 m thick containing 4–12 seams ranging in thickness from 4 mm to 2.45 m. Drill indicated reserves stand at 600,000 tonnes. The neighbouring

Coalfield	Proven reserves	Resources		Ash	Sulphur	Maceral group composition				Av. Calorific value
		Probable	Possible			Vitrinite	Exinite	Inertinite	Mineral matter	
Ngana	18.2 Mt	50 Mt		27.0%	1.2%	3.0-66%		26-83%	5.0-44%	24.0 MJ/kg
Livingstonia	1.4 Mt	5.0 Mt	20 Mt	17.0%	0.5%	20-25%	1-5%	60-70%	10.0%	30.5 MJ/kg
Lufira	0.6 Mt	50 Mt		27.8%	0.42%	15-46%	0-15%	41-86%	1.0-45%	23.1 MJ/kg
N. Rukuru	0.5 Mt	5.0 Mt	165 Mt	32.1%	0.32%	0-10.5%	0-11%	30-85%	2.5-61%	21.0 MJ/kg
Mwabvi	5.5 Mt		10 Mt	44.1%	0.76%	9.0-18%	0%	34%	48-57%	17.5 MJ/kg
Lengwe		10.0 Mt		59.2%	0.51%					11.5 MJ/kg

Summary and classification of some of Malawi’s coal resources. Maceral estimates for Ngana are taken from Songwe-Kiwiri coalfield in Tanzania (after Semkiwa et al., 2003).

Kibwe coalfield (15 km^2) has estimated coal resources of 2 Mt. The Lufira and Kibwe Basins form part of the concealed Karonga coalfield with a speculated 300 Mt of coal resources.

The coalfields of **Lengwe** and **Mwabvi** in the southern lower Shire valley districts of Chikwawa and Nsanje were subject to detailed investigation by BRGM and the GSD in the period 1987–1991. The Mwabvi coalfield extends over 400 km^2 and coal seams are in places exposed at surface. The BRGM/GSD drilling campaign identified coal reserves of 2.2 million tonnes at 50 m depth and a further 2.5 million tonnes at 100 m depth.

The quality of the coal improved with depth; coal from shallower levels would require washing. Mining at Mwabvi would be by open cast or underground. The Lengwe coalfield covers nearly 350 km^2. 16 drill holes were sunk in a 30 km^2 block around Mkombezi wa Fodya River. The coal occurs within mudrocks and is of limited coalification level compared with Mwabvi coal. Further exploration in the Lengwa and Mwabwi areas need not be inhibited by the restricted size of potential mining blocks due to the heavy faulting, provided that reserves can be located at shallow depths to permit easy exploitation. These areas remain the closest potential coalfields to major local markets and this factor alone offers clear advantages.

Hydrocarbon potential

Coal-bed methane (CBM) is a form of natural gas extracted from coal beds and in recent decades has become an important source of energy in the United States, Australia and other countries. It now accounts for 7% of the natural gas production in the US. The CBM potential of Karoo coals is already being investigated in Botswana and Zimbabwe. Globe Uranium has applied for CBM rights over its Livingstonia and Nthalire tenements and Millenium Mining is also reportedly exploring for coal-bed methane.

Methane can be used for more environment-friendly generation of electrical power, as a feedstock for fertiliser production and other petrochemicals, as a motor fuel in compressed or liquefied form, a household fuel for cooking and heating either in piped or bottled forms. The development of CBM resources would go a long way to address overuse of wood and charcoal in rural areas. It may be especially applicable for gas-fired thermal power generation especially in off-grid rural or remote areas.

Coal-bed methane is adsorbed into the solid matrix (micropore maceral structure) of the coal and may occur in open fractures (or cleats) as free gas or can be saturated with water. Unlike conventional natural gas coal-bed methane contains very little heavier hydrocarbons and no natural gas condensate. It may contain a few percent of carbon dioxide and nitrogen. The gas is extracted via a steel-encased hole drilled into the coal seam (100–1500 metres below ground) similar to a standard gas well. The potential of a particular coalbed as a CBM source depends upon a high cleat density/intensity to impart permeability and a high vitrinite composition. A vitrinite reflectance of 0.8–1.5% has been found to imply higher productivity of the coalbed. However, permeability rather than gas content is the most critical factor. The gas composition also must be considered and if the methane composition is less than 92% it may not be commercially marketable.

The best virgin CBM prospects lie in coal seams thicker than 0.4m at depths of greater than 200 m. Good prospects should typically yield >7m^3 methane per tonne of coal but given the right conditions yields as little as 2m^3/tonne may be economic. Available petrographic data from some of the northern coalfields of Malawi show the coal rank to be appropriate for CBM generation.

Natural Gas

Karoo rift basins of East Africa extend from South Africa to Ethiopia in the Northwest and India in the Northeast. Recently there has been a surge of interest in the hydrocarbon potential in the Permo-Triassic 'East African Rift System' and there is exploration activity in the southern Karoo (Mozambique, Tanzania and Madagascar). Lower Permian sediments and coals and the Upper Permian sediments of the Ruhuhu Basin in Tanzania have been shown to have moderate source rock properties for hydrocarbon generation. They were not subjected to significant subsidence (1500–3000 m depending on basin type) and are moderately mature source rocks. They possibly experienced temperatures in the range 60–110^{o}C and vitrinite reflectance values of 0.5–0.8 were attained, thus placing them within the 'oil window'. Kerogen Type III is typical for all the basins and productivity indices indicate moderate to advanced stages of evolution. No post-Karoo sedimentary cover was deposited in the Ruhuru Basin but the possibility exists of hydrocarbon migration and accumulation in the overlying younger Karoo sediments.

The sequences of Karoo sediments intersects the lake axis and several small faulted Karoo troughs occur on the Malawi side of the lake. Therefore, the possibility also exists of source/reservoir rocks of Karoo age succeeded by post-Karoo Mesozoic reservoir rocks and capped by Miocene to Recent sediments in Lake Malawi. Tectonic activity during the Cenozoic may have adversely affected any pre-existing accumulations in the potential reservoir rocks. See also brochure 4.

Helium

Helium is given off as a by-product of the breakdown of radioactive elements in rocks and minerals. Natural gas deposits contain as much as 7% He and constitute most of the currently extractable helium resources. Helium has a range of unique properties that make it critical for certain science and engineering applications. Worldwide demand is growing rapidly as high tech industries develop new applications dependent on helium. Helium is a finite resource and is inextricably linked with natural gas reserves. The Earth's atmosphere does not retain helium; it dissipates into space. Future potential sources in addition to natural gas are, in order of importance, coal, water soluble gases and gas-absorbent rocks. The Karoo succession contains significant amounts of radiogenic detritus as evidenced from the uranium concentrations and may be considered a potential source of helium as a by-product of natural gas or CBM extraction.

Limestone

Limestone is essential in many chemical and industrial processes for construction industry, agriculture, food products, glass, alumina, paper and steel manufacture. Its primary utilisation in Malawi is for the manufacture of Portland cement, agricultural lime and in sugar refining. Most of the limestone resources in Malawi occur in the Precambrian basement between Blantyre and Lilongwe (see brochure 2).

Sedimentary limestones that occur in the Karoo Supergroup and younger formations at the northern and southern extremities of the country could be exploited for local use. These include the argillaceous limestones of Mpata, Nkana and Mwesia in the Karonga district, and the Pliocene to Pleistocene shelly limestones at Uliwa in the north and Chuzi in the southern region. The argillaceous limestones of the Karonga district, which include marls/marlstones, are of potential use for the production of natural cement, hydraulic lime and as an agricultural additive.

Limestones in the upper Karoo K5 beds of the Nkana area consist of individual units up to 1m thick with 72–82% total carbonate grading 23.8–51.7% CaO, and with a variable MgO content. They are interbedded with mudstones and comprise about 30% of a 30 m section along the Makeye River.

Lenticular beds of limestones and marlstones occur in the Mwesia Beds Formation in the upper Karoo in the Karonga lakeshore area. They are interbedded with mudstones and shales. The thickest bed is a tough, blocky, algal oolitic argillaceous limestone which has been worked for building stone. These calcareous rocks (total carbonate content of 43–55% and MgO is <2%) comprise about one third of a 76 m sequence and represent a resource of many millions of tonnes.

At Chuzi in the Chikwawa area the Red Beds Formation contains limestones interbedded with shales and argillaceous sandstones in lenticular beds up to 1.5 m thick. Dolomitic types (29–30% CaO; 17–20% MgO) predominate although low magnesia types (51–52% CaO; <1% MgO) also occur. This limestone resource is relatively limited but is the only source of sedimentary limestone in the southern region.

Pliocene to Pleistocene platy low magnesia limestones with a total thickness of 1.5–4.0m occur at the top of the Chiwondo beds along the Karonga lakeshore in the Uliwa area. The total carbonate content is 79.5–91.1%, CaO is in the range 42–50% and MgO is typically <2.0%. These limestones could be used as an agricultural additive or for lime-burning.

Karoo-hosted gemstones

Blue agate and **chalcedony** is found in the weathered Stormberg basaltic volcanics to the southwest of Chikwawa and northwest of Nsanje districts. Artisanal mining is currently taking place around Finishi village. The basalts have abundant vesicles and lithophysae lined with pale to deep blue chalcedony-agate. Blue chalcedony occurs in druses in a ‘string of pearls’ arrangement along subhorizontal fissures which in places open up to decimetre size or it infills stockwork fissures a few cm wide. Quartz and calcite crystals incompletely fill the voids in the amygdales after the blue chalcedony precipitation.

The economic potential of the volcanics of the Chikawawa/Stormberg Group may include opal and sapphire. The basalts have notably elevated Cr contents and are rich in hercynite spinels, which may further indicate the possibility of coloured gemstones.

Kimberlites, which are primary source of **diamonds**, are typically hosted by grabens in which Karoo Supergroup sedimentary rocks are preserved. Kimberlitic dykes are known to occur in the Karoo rocks of the Livingstonia subbasin, and in the Mwanza River Valley in the districts of Chikwawa and Mwanza. Targets for diamondiferous kimberlites occur in the west Chirumba diatreme zone in Karonga in northern Malawi. This is discussed further in brochure 1.

Brochures in the series on the Mineral Potential of Malawi

1. Mineral deposits associated with alkaline magmatism.
2. Mineral deposits associated with the Basement metamorphic and igneous rocks.
3. Mineral deposits associated with sedimentary and volcanic cover rocks: Karoo and post-Karoo.
4. Deposits resulting from residual weathering, placer and rift-related sedimentation.

Sources

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