The sands of the Kalahari are today one of the diamond industry’s most valuable suppliers of gems; a situation that has developed since the 1970s. Lucara’s Karowe was the latest addition, joining the well-established, Jwaneng, Orapa and Lethlakane mines. And now, GEMD’s Ghaghoo becomes the first underground operation in the Kalahari. It is operated by wholly-owned subsidiary Gem Diamonds Botswana (GDB).

The Kalahari sands do not yield their treasures willingly and establishing Ghaghoo has not been easy. It has required GDB and its contractors to beat the sand and climate – getting in and out of the site, getting equipment in (a triumph of logistics) and driving an 8° decline through sand to access the kimberlite. Shifting sands are a particular problem.

In its first half statement for 2014, GEMD noted that development of Phase 1 of the Ghaghoo mine had been achieved on time and on budget. Development of three production tunnels on Level 1 is underway and the build-up to planned production levels by the end of 2014 is on track.

Optimisation of the treatment plant processes is ongoing during the commissioning phase. The production build-up to 60,000 t/month is still anticipated to be reached by December 2014.

CEO, Clifford Elphick commented that Ghaghoo “will unlock considerable long-term value. The first sale of diamonds is scheduled to take place before the year end. The first diamonds produced during the commissioning of the plant have, as anticipated, been of a significantly higher quality and average size than those mined during the exploration phase. A 20 ct and two 10 ct diamonds have been recovered from the first 2,400 ct recovered [during plant commissioning] as at end of June 2014. This compares to the largest diamond recovered in the exploration sampling of 7 ct. During the development of the production level there has been a greater quantity of water encountered than indicated by the exploration drilling. Steps have been taken to deal with this and it is not anticipated that there will be any impact on the planned production targets for 2014.”

Gope lies 325 km north west of Gaborone and 160 km southwest of Orapa. Earlier in the year, the ride to Ghaghoo was fairly tortuous. Other than a helicopter, the only way in was by road (a loose term for a great deal of the track). There are some 180 km of tarred road between Gaborone and Lephepe, where GDB has established a staging camp where personnel and materials are assembled for the drive into the Central Kalahari Game Reserve (CKGR). There is then a drive of over 100 km along the edge of the CKGR to the ‘gate’, established by GDB but now operated by the government. Here travellers to the mine must have their permits checked before they enter the reserve for the last 45 km west to Ghaghoo.

So, the 145 km (85 miles) from Lephepe are travelled on a sand road that can only be negotiated by multi-traction vehicles. Many of the supplies come in on six-wheel drive, all terrain trucks. Passengers watch for game while being bounced along on their seats. It is a road that can change overnight due to rains, winds and heat. The complete trip from Gaborone takes five to seven hours. As I wrote back in 1980 when visiting the, then De-Beers –owned (now GEMD), Letšeng La Terai mine in Lesotho, “man has always been prepared to go to the ends of the earth in the search for diamonds.” It’s as true of Ghaghoo today as of Letšeng then.

It is a great testament to local Botswana company Camp Construction Botswana (CCB),
the contractor for logistics and camp construction, that delivery of everything the mine needs is accomplished so efficiently. Project Director Ian McAdam explains: “They established our camp (now managed by Servest) very efficiently and brought in all the heavy loads to site, such as the mill, on time. We budgeted for 20 special loads, outside of the logistics contract, but at the end of the day none were required.” CCB continues to deliver explosives, food, new equipment, fuel, mine consumables, etc.

However, a 1.14 km airstrip has recently been completed, making personal travel to the mine a great deal easier, and of course emergency supplies that are not too large can also be flown in.

The project is centred on the Gope 25 kimberlite pipe (GO25). GO136 is another pipe of interest within the GDB mining licence, which will be explored in due course. Operating to the highest environmental standards is of vital importance here and best practices are strictly adhered to, to ensure minimal environmental impact from the mine’s development and operation. Independent advisors, Marsh Environmental Services, undertook an environmental impact assessment which included a stakeholder engagement process. Ghaghoo’s environmental impact assessment report received final approval in October 2008.

The CKGR covers 54,000 km², almost 50% more than the Kingdom of Lesotho (30,355 km²). The Gope mining licence covers an area of 45 km² and the mine footprint will be less than 0.08% of the CKGR.

**History and geology**

GO25 is a primary vertical kimberlite pipe lying beneath some 80m of Kalahari sand (Kalahari Formation). Venmyn reported that “below the pre-Kalahari surface, the wall rocks of the kimberlite consist of Karoo basalt to 391 m and Ntane sandstone from 391 m to an unconfirmed depth. The surface topography is very flat with a maximum elevation difference over the kimberlite of ~5m. The sub-cropping area of the pipe is 10.8 ha. This area decreases to 6.3 ha at a depth of 500 m. The pipe has an almost elliptical shape in plan view. While the orebody has been defined to a depth of 524 m, Venmyn believes that the orebody extends well beneath this depth.”

Sand dilution is a major risk. Country rock dilution is a major control on the diamond grade of the kimberlitic material, in particular that of basalt. “Below the Crater Facies, which caps the Gope Kimberlite and consists of a basalt mega-breccia, is the orebody proper. Five distinct kimberlite facies have been identified in the Gope orebody.

“The three volcaniclastic kimberlite (VK) facies types are distinguished essentially by differences in grade and, to a lesser extent, by density. The BXVK facies represents a VK facies type with a high (average of 44 %) basalt breccia content. The BXVK facies consequently has the lowest diamond grade of the VK facies rocks. The VKSE and VKMain facies appear to contain similar kimberlite components but different quantities and distributions of basalt, and therefore grade. The coherent magmatic kimberlite (CK) facies types are more variable, harder, have a higher density and are more resistant to weathering than the VK facies types. The BXC K facies is differentiated from the CK facies type by its high (average of 48 %) basalt breccia content and consequent lower diamond grade.”

VKSE is the mine’s first target. Thus far this is the highest grade portion of the orebody at 28.45 ct/100 t (cpht).

Falconbridge began prospecting the area in 1979-1980 by heli-borne 12.5 km x 12.5 km reconnaissance sampling and an aeromagnetic survey of 2,300 km². In 1981 the GO25 kimberlite was discovered and evaluation drilling commenced in 1983, yielding 78 ct. That year De Beers entered into a joint venture with Falconbridge. Work continued through the 1980s and in 1988 a shaft was sunk into GO25 to 150 m, 200 m of tunnels with underground bulk sampling at 140 m level for grade evaluation.
By 1993 32,000 samples and, 10.2 km of drilling had been carried out on GO25. Between 1995 and 1996 reverse circulation holes were drilled for modelling of the resource to a depth of 300 m below surface. The underground exploration drifts were lengthened by 1.4 km and additional 18,000 t removed for bulk treatment.

A 1997 prefeasibility study concluded that the GO25 project was not viable based upon a mining depth of 300 m. Between 1997 and 1998 a feasibility study was undertaken to a depth of 400 m. Large Diameter Drilling (LDD) was undertaken between 300 and 400 m. This achieved higher diamond liberation compared to previous programs. Work continued. In March 2007, Venmyn conducted a Due Diligence exercise on the Gope mineral resources ahead of GEMD’s acquisition of the project. Venmyn reports that “no material issues or fatal flaws were identified in the calculation and classification of the Mineral Resources, and the De Beers Resource Statement was deemed fair and reasonable to a depth of 400m, albeit that Venmyn considered it to be conservative.”

Gem Diamonds acquired 100% of Gope Exploration Co (GEC) in 2007, GEC was awarded a Mining Licence in December 2010.

In early 2010, an updated resource statement for Ghhghoo was undertaken by an independent expert. An increase in grade from new statistical modelling, and volume through the reinterpretation of drilling results, led to an uprating of samples during the valuation work: a find of some significance in such a small parcel, given such diamonds’ extreme rarity. The latest resource statement can be found on www.gemdiamons.com

In February this year, GEMD COO Alan Ashworth told IM that by world standards they are “quite excited about the quality of diamonds we are getting.”

In August 2010 GEMD presented the Botswana Government with an updated Ghhghoo study, including the option of an underground mine, which would require significantly less capital to develop. A decline was settled on as the most cost effective access method, and construction of the first phase began in 2011.

Providing power
Being situated in an area with no electricity infrastructure, an independent and highly reliable power source was needed to power the initial camp and construction activities at the site. As the power requirements were scheduled to grow significantly in line with the development to the asset, it was vital that the power capacity could be easily and quickly increased when needed.

Following initial discussions on the possibilities and advantages of rental power, Aggreko supplied a 60 kVA generator to power the first camp on the site before construction to the main camp and the mine began. As the energy demands of the project grew, this was soon increased to 360 kVA.

When construction activities began to ramp up, the power demands of the project increased significantly. At this point the Aggreko solution was increased to a 4.5 MW standalone power plant to act as the sole power supply of the mine. Two additional sets have now been installed, bringing the installed power up to about 6 MW and further increases may be needed, especially if production is increased in the future.

Aggreko has significant experience in providing rental power solutions to mining. The scalable nature of its offering makes it a very attractive solution for mining companies as the power supply can be matched precisely to the fluctuating requirements of a mine over its entire lifecycle. This means that only the required power is supplied and negates the need for the large capital expenditures associated with purchasing permanent power plants.

Aggreko provides regular maintenance including the cost of equipment supplied. This provides peace of mind for the customer knowing it can concentrate on its core activities leaving the power requirements to a specialist power supplier.

Unique sand decline
The first stage in mine development came when GEMD awarded Redpath Mining (South Africa) the first-of-its-kind incline tunnelling contract for the development of a sand tunnel at Ghhghoo. A GEMD technical representative noted at the time that Redpath South Africa’s unique and innovative sand tunnel construction proposal resulted in the company being awarded the contract in May 2011, following a successful tender submission in February 2011.

“During the tender process, GEMD provided each contractor with a specific design for the segmented tunnel; however, the process of clearing the excavated sand was left open. Redpath South Africa was the only contractor that recommended the cost-effective use of conveyor belts for the removal of the sand, as
opposed to articulated dump trucks. Although the initial set-up costs of the conveyor belts are high, the long-term running costs are significantly lower than using trucks, which will ultimately improve the overall efficiency of the project," he explained.

Redpath South Africa's COO Lawrence Shultz managed the project that involved the development of the tunnel to 112 m vertically below the surface at an inclination of 8°. The first phase of the project was the establishment of a box cut 25 m deep and 171 m long into the Kalahari sand to provide safe and secure access to the underground mine." he explains. The concrete-lined segmented sand tunnel extends for 473 m in sand, including the transition zone from sand to basalt.

The project required the acquisition of a 6-m diameter, 94 t open-face tunnel shield (OFTS). The labourers worked within this shield in order to move the tunnel forward segment-by-segment. At the rear, the shield is equipped with 26 hydraulic jacks to push it forward from the installed concrete ring. The shield moved with a 20 mm overlap to ensure no sand filtered into the tunnel. A mini hydraulic excavator cut some of the sand from the face and loaded it onto the conveyor belt for it to be hauled out of the mine. However, mostly the excavator was not a success and a great deal of hand mucking was required – the sand decline was very labour-intensive with the shield providing safe cover for the workers, but no tunnel driving in case any reader should imagine this was tunnel boring.

The width of each segment is 0.61 m. The target advance was to move forward six segment widths or 3.6 m/d. In fact, a best performance of 5.4 m/d was achieved. A 15-man crew on each shift conducted the mining, lining placement and mucking of the material to a dump on surface. Each ring comprises 10 steel-reinforced 7.5 mm thick segments and is designed to withstand a compressive force of 45 MPa. Once in place, the rings were bolted together and then high-pressure grout was pumped through the holes in the segments to form a final seal against the sand and country rock. In total, the decline extends 473 m in sand and a further 480 m in basalt. In total 7,750 segments were used to construct the 775 rings installed in the decline. Each segment weighs 540 kg and each ring has 42 bolts.

Shultz explained that Redpath South Africa faced numerous challenges. “Ghaghoo is extremely remote and isolated, and the majority of the 93 Redpath staff members working on the project [were] located on site. In order to maximise productivity and reduce logistical challenges, staff members [worked] 14-days-on and seven-days-off,” he continues. The weather has caused problems, and continues to do so.

Heavy rains cause flooding with consequent problems at the mine site and on the access road.

Shultz also pointed out an additional challenge in constructing the inclined sand tunnel at the sand and basalt interface – where water could be intersected. At the 2014 Mining Indaba in Cape Town I discussed the project with him and Redpath South Africa Managing Director Ockert Douglas. They noted that there had never before been such a decline – inclined at 8° and transitioning from sand into conglomerate, then calcite. The interfaces between the sand and different rock types were the real challenge with the need to blast the hard material but not to damage the soft material and cause a collapse.

A collapse in an area of unconsolidated sand set the project back some time. Initially efforts were made to grout and consolidate the sand, but this was not successful. The successful method was to load the loose sand and move the shield forward in very small increments of 100 mm. At the same time various objects and material were dropped into the unconsolidated area on top in order to constrict the flow of sand through the aperture.

Drilling of ventilation and escape holes by DeWet Drilling

Once the construction of the shield was completed, Redpath undertook a full risk assessment before putting in place the necessary operating and training procedures. All training was done on site, “in order to equip the workforce with the most practical and hands-on safety skills and knowledge,” Schultz explained.

There were great challenges involved in this decline project. There was a time and cost overrun from the original budget due in main to a fatal accident in which two people died and the sand in-flow mentioned above. Safety procedures and practices were in place but obviously they were fully reviewed and revised after the accident.

Getting into production

The mine design includes three phases of mining. Phase 1 was designed in order to provide valuable information and data with regards to grade and revenue and the planned sub-level caving (SLC) mining method. Phase 1 commenced production in the higher-grade VKSE facies and is intended to go to a depth of 175 m. Ore is being drilled, blasted and loaded in the production tunnels using mechanised drill rigs and LHDs. Dump trucks haul ore to surface via the decline. The subsequent phases of the project development, which includes Phase 2 and Phase 3, will be mined by SLC (and possibly block cave in the future) mining. The current LoM plan just mining the VKSE is for about 10 years but GEMD envisages further extensions once more is known about diamond price and grade.

Kavis Kario, Ghaghoo General Manager
explained to *IM* that the current underground fleet is primarily from Atlas Copco, a Boomer 282 twin-boom jumbo and a new single-boom jumbo, two LHDs – an ST1530 LHD and an ST1030. Truck haulage up the ramp is by two MT42s and an MT2030. There are two AARD utility vehicles (UV80), with cassettes, and a third is one order. Two Fermel units – a scaler and a telehandler – have also been purchased.

Kario previously worked at Botswana's best known underground mine, the BCL nickel/copper mine in Selebi-Phikwe. No other Botswana diamond mine is underground and indeed there is little underground mining generally in the country. Kario’s experience and leadership have been invaluable in assembling an underground mining team for Ghaghoo.

The initial mine is costing some $96 million to develop, about a sixth of the original open-pit plan. It is building up to 60,000 t/month by the end of 2014, which should generate 18,000 ct/month (some 220,000 ct/y). Ashworth believes the most likely ultimate size of the mine will be a 1.6 Mt/y operation, but it could be as high as 3 Mt/y. Feasibility studies will commence in the near future.

In November 2013, first kimberlite ore was intersected in the cross-cut on Level 0, some 134 m below surface. This cross-cut is being used to access the old De Beers sampling tunnels on the 140 m level to allow the area to be dewatered and made safe before ore mining commences on the production levels below. The first production level break-off is at a depth of 154 m below surface.

A decision was taken during 2013 not to sink the originally planned 6-m diameter ventilation shaft and to delay this to 2015. The replanning and a redesign of the ventilation system and escape way to smaller diameter (1,100 mm) drilled holes allowed for this deferment. The drilling of these ventilation and escape holes by DeWet Drilling progressed well and was complete before the end of the first quarter of 2014.

To date, three production tunnels are progressing within kimberlite on the first production level, Level 1 at 154 m below surface, whilst an exploratory tunnel and training stope have been developed in the kimberlite on Level Zero at 130 m below surface. High volumes of water from basalt fissures have recently been encountered in one area and besides contributing to difficult mining conditions have necessitated the procurement of additional pumping capacity and the drilling of additional dewatering bore holes.

**Learning from Letšeng**

Of the $96 million, $71.2 million had been spent out of cashflow by December 31, 2013. So, funding arrangements will only require about $25 million. GEMD’s other producing mine, Letšeng in Lesotho, is, Elphick says, “the world’s foremost source of exceptional large diamonds.” It is certainly a useful bank recovering two +160 ct diamonds at the end of January 2014. These two rough diamonds (a 162.06 ct type II diamond and a 161.74 ct type I diamond) fetched top prices at Letšeng’s February tender.

Both diamonds were recovered in largely undamaged condition, providing further confirmation that the measures which have been implemented to reduce diamond damage at Letšeng are bearing fruit. The mine has put a lot of effort and investment into the goal of not breaking large diamonds.

Letšeng mine last year installed four new Kawasaki Cybas is200 units as secondary and tertiary crushers, which have been specifically configured to the mine’s ore characteristics, to reduce the risk of broken gems. The Kawasaki crushers “have contributed to a significant reduction in damage to the mine’s high-value diamonds and hence an improvement in revenue,” GEMD reports.

Furthermore a feasibility study concluded that the implementation of a new coarse recovery plant would be the appropriate recovery plant to achieve revenue growth by reducing damage in large diamonds. That project commenced in the second quarter of 2014.

At Ghaghoo, however, diamonds are small and not generally type II, therefore breakage will not have the same impact on revenue there as it has at GEMD’s Letšeng. A Ghaghoo innovation is to use autogenous (AG) milling. AG is be used to improve liberation at Ghaghoo, not specifically to limit diamond damage.

**Surface facilities**

Ghaghoo’s project office is provided by VDBB, a project services provider, with its head office in South Africa and offices in Botswana. VDBB provides project controls, and during Phase 1 at Ghaghoo executed the full procurement, expediting, planning, contract administration, cost management, information management and project secretarial services for the project. VDBB’s involvement started in the earlier feasibility studies and it resumed in being an active part of setting up the current project and Ghaghoo Diamond Mines’ commercial processes.

The plant was built and commissioned by Consulmet. The ore starts in a receiving and primary crushing section equipped with a 100 t/h Pilot Crushtec modular jaw crusher (MJ 2436). Fed by a wheel loader, a static grizzly scalps at 500 mm through to a vibrating grizzly and then to the jaw crusher to -150 mm. Material greater than 500 mm reports to the pad for impact breaking and recycling.

Next in the ore flow is the 100 t/h Harcliff AG mill with a grate discharge with 90 mm² maximum, nominal 50mm aperture. The 5.5 m diameter by 2.5 m EGL mill with a 550 kW variable speed drive receives -150 mm feed from the crusher and grinds it to 80% passing 25mm, which is presented to a Vibramech 1,830 mm by 3,660 mm double-deck screen, top deck 32 mm² aperture panel, for sizing. The oversize (-900 to 30 mm) from the top deck is stockpiled. The -30t+1.5 mm fraction from the bottom deck to reports to the 65 t DMS feed bin. The -1.5 mm bottom deck
undersize reports to the degrit cyclone with the – 0.5 mm passing onto the thickener stage before being deposited in the final tailings storage facility or slimes dam.

This use of AG milling is unusual outside of Russia where it is widely used. ALROSA uses AG milling and keeps retention time in wet AG mills to a minimum, as well as optimising the mill drums’ rotating speed. Ashworth explains that Gaghoo ore is particularly amenable to AG milling. It is expected to result in better liberation and reduce diamond breakage. Indeed the grade for Gaghoo’s reserves is higher than that of its resources. The expectation of higher liberation and reduce diamond breakage. Indeed the grade for Gaghoo’s reserves is higher than that of its resources. The expectation of higher liberation means getting more diamonds which will lower the $/ct value but increase the $/t value.

Greater liberation means getting more diamonds which will lower the $/ct value but increase the $/t value.

From the 65 t/h DMS plant with 510 mm diameter Multotec DMS cyclone the -25+1.5 mm concentrate is jet pumped to the recovery room while the -25+1.5 mm tailings together with the grits from the degrit screen (-1.50+0.50 mm) are conveyed to a tailings disposal facility. The DMS effluent (-1.5 mm) is recycled to the mill screen and then to the degrit cyclone.

The final recovery plant can treat approximately 2 t/h. The -25+1.5 mm material reports to two Flowsort TSXR 2/50DE X-ray machines. Tailings from X-ray go to a scavenging grease plant. The final tailings are stockpiled within the Red Area.

There is a 6 m diameter Savanah thickener that treats 250 m³/h of the -0.50 mm material fed to it for the recovery of water. Clear water goes to the 270 m³ Hydrex tank while underflow is pumped to the tailings storage facility.

The MCC (Motor Control Centre) gives indications of the status of all motors, instruments and all equipment in the plant. It enables control of all motors (stopping and starting) and by resetting faults (i.e. trips, fail to start). Instrumentation shows indication of current drawn and speed of motors and thus helps with planned maintenance of the equipment.

**Maximising gem values**

GEMD sells its own diamonds on tender in Antwerp. Some of its diamonds are extracted and either cut and polished by the company itself at its facilities in Antwerp, or are manufactured in partnership arrangements with some of the world’s leading diamantaires. Gem Diamonds’ sales and manufacturing strategy continues to extract additional value from the diamond value chain for the company and it is focused on further developing and enhancing this strategy to ensure increased exposure to the value chain.

“[The] sales, marketing and manufacturing strategy aims to extract additional value further along the diamond chain. During 2013, a number of rough diamonds were extracted from Letšeng tenders and were either cut and polished by the group at its facilities in Antwerp, or were placed into partnership arrangements with some of the world’s leading diamantaires. Of those diamonds extracted from Letšeng tenders for manufacturing, a high-value, 164 ct diamond was placed into a partnership arrangement and manufactured by Baobab. This resulted in 11 large exceptional polished diamonds, all of which received triple ‘excellent’ grading in cut grade, polish and symmetry by the GIA. This business unit continues to deliver planned revenues and profits.”

GEMD established Baobab Technologies in 2012. This is an advanced analytical and manufacturing capability in Antwerp.

Gem Diamonds’ Marketing Services was formed in 2010 and is responsible for implementing the group's sales and marketing strategies. GEMD maximises revenue from its production by actively marketing its rough diamonds through competitive tenders to respected international diamantaires. Gem Diamonds Marketing Services employs an electronic tender platform designed to enhance engagement with customers by allowing continuous access, flexibility and communication, as well as ensuring transparency during the tender process. Although viewings of the diamonds take place in Antwerp over 10 tenders annually, the electronic tender platform allows customers the flexibility to participate in each tender from anywhere in the world. This contributes to the achievement of highest market-driven prices for GEMD’s rough diamond production.

Baobab Technologies’ advanced mapping and analysis of exceptional rough diamonds from Letšeng and Gaghoo allows the company to assess the true polished value of its rough diamonds and thus drives strategic decisions to implement robust reserve prices on its top diamonds at each tender.

In order to access the highest value for its top-quality diamonds, the group also selectively manufactures some of its own high-value rough diamonds through the Baobab operation and places other exceptional diamonds into strategic manufacturing and partnership arrangements with select clients.

In Antwerp in general, leading diamantaires have intensified their focus on the highest-value stones, supported by home-grown research and technology development. Under a new strategic plan unveiled in 2012 (Antwerp Diamond Masterplan: Diamonds Love Antwerp 2020), the Belgian diamond industry is reinforcing Antwerp’s position as a global diamond trading center and knowledge hub.

The Global Diamond Report 2013: Journey through the Value Chain from Bain & Company in association with the Antwerp World Diamond
Centre (AWDC) suggests a bright future for GEMD. Its most significant findings and conclusions include the prospect of “a balanced market over the next four years, with a growing gap between supply and demand longer-term. The rough-diamond market is expected to remain balanced from 2013 through 2017. From 2018 onward, as existing mines get depleted and no major new deposits come online, supply is expected to decline, falling behind expected demand growth that will be driven by China, India and the US. Over the next 10-year period, supply and demand are expected to grow at a compound annual rate of 2.0% and 5.1%, respectively. The supply-demand outlook carries different implications for industry players at different points along the value chain, and it will impact the way they manage their business activities over the next four years and in the longer run.

“With stable market conditions in the next four years, mining companies are likely to focus on maintaining healthy balance sheets, attaining operational excellence and investing in technology to improve productivity.” GEMD is certainly striving for operational excellence and is a leader in investing in technology to help retain the value of large stones.

The report also notes “diamond mining companies have a strong motivation to increase their yields of gem-quality stones, because the price of gem-quality stones has increased faster than that of industrial diamonds, motivating producers to cut and polish stones that were once graded as industrial because they were considered too small for use in jewellery. New sorting and polishing technologies have enabled producers to boost revenues.”

Gem-quality diamonds are sorted by weight, shape, clarity and color. There are up to 12,000 possible combinations of these criteria.