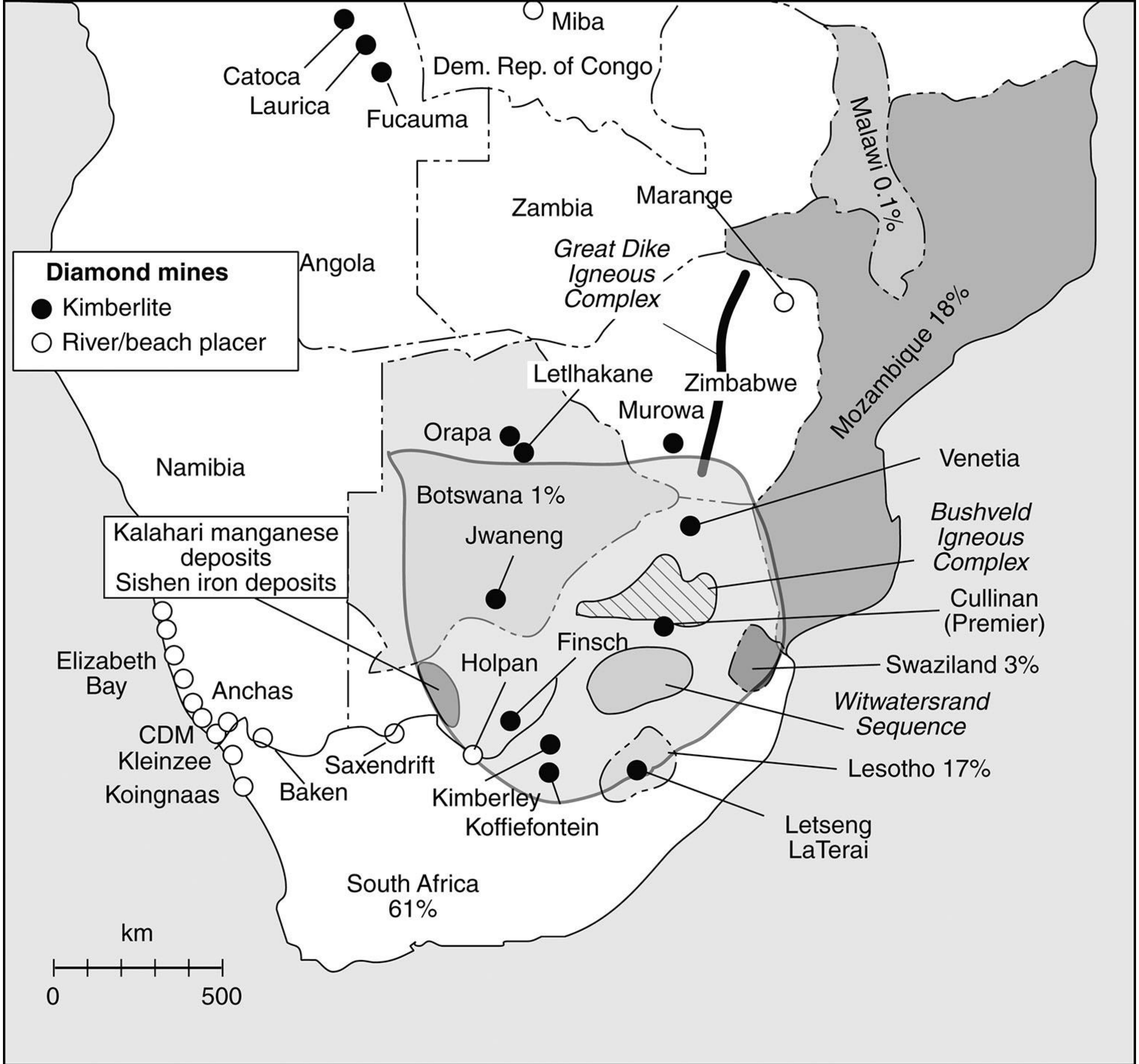
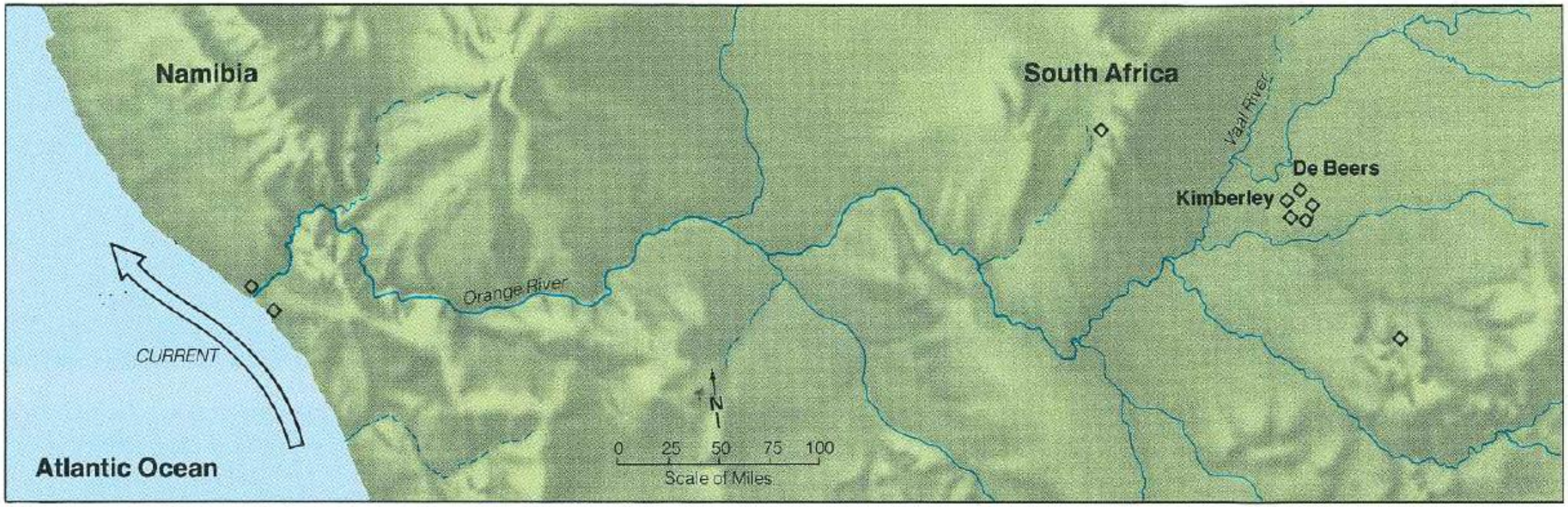
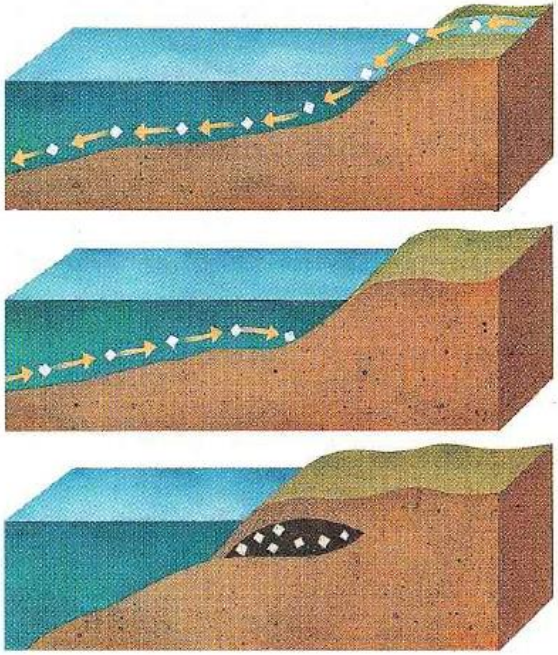
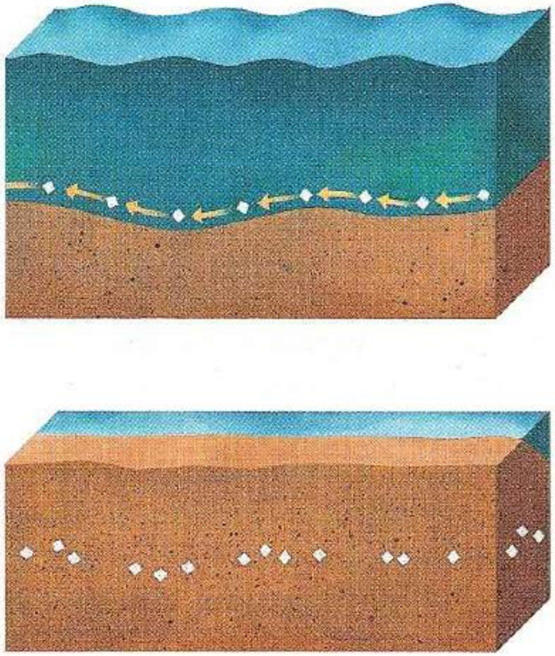


Miba
Catoca
Laurica
Fucauma
Dem. Rep. of Congo
Malawi 0.1%
Zambia
Marange
Great Dike Igneous Complex
Angola
Diamond mines
Kimberlite
River/beach placer
Mozambique 18%
Letlhakane
Zimbabwe
Murowa
Orapa
Namibia
Venetia
Botswana 1%
Bushveld Igneous Complex
Jwaneng
Kalahari manganese deposits
Sishen iron deposits
Cullinan (Premier)
Finsch
Elizabeth Bay
Holpan
Swaziland 3%
Anchas
Witwatersrand Sequence
CDM
Kleinzee
Saxendrift
Lesotho 17%
Koingnaas
Baken
Kimberley
Koffiefontein
Letseng
LaTerai
South Africa 61%
km
0
500

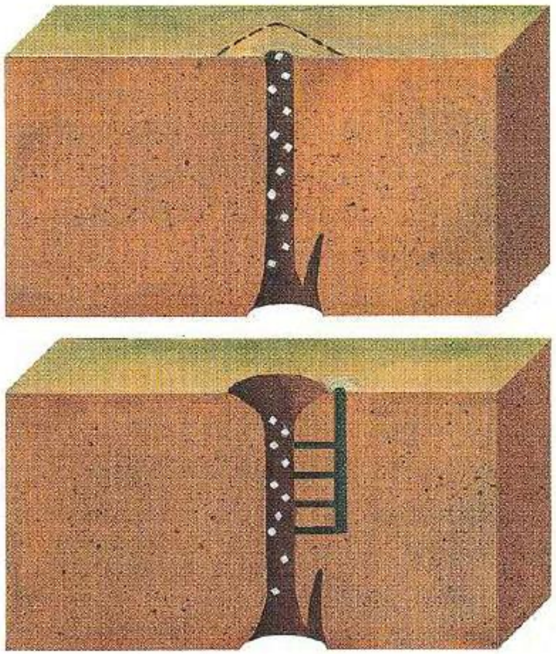




OCEAN BEACH
From the river's mouth *(top)*, diamonds were swept into the open sea. Coastal currents and wind returned some of them to the shore *(center)*, where in time they were buried under deep layers of sand *(bottom)*.

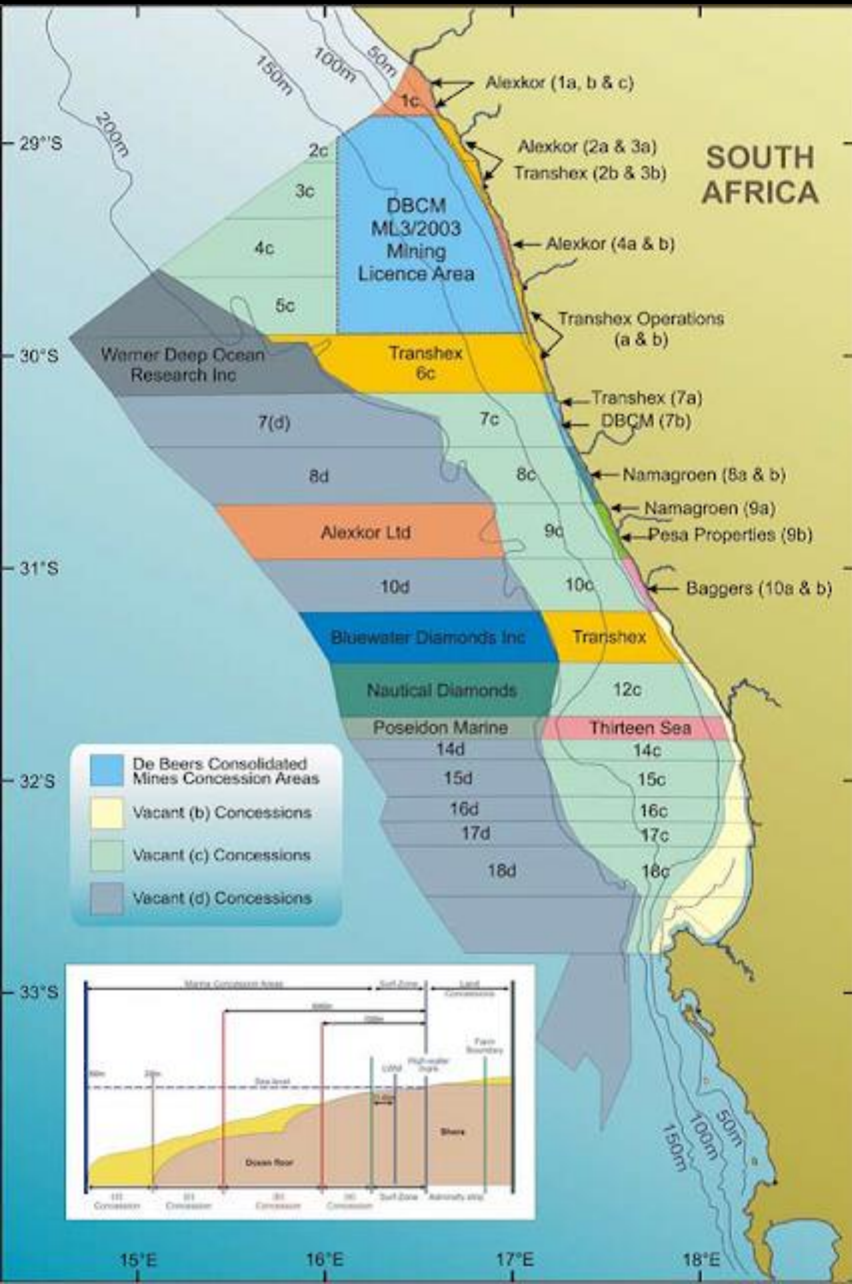


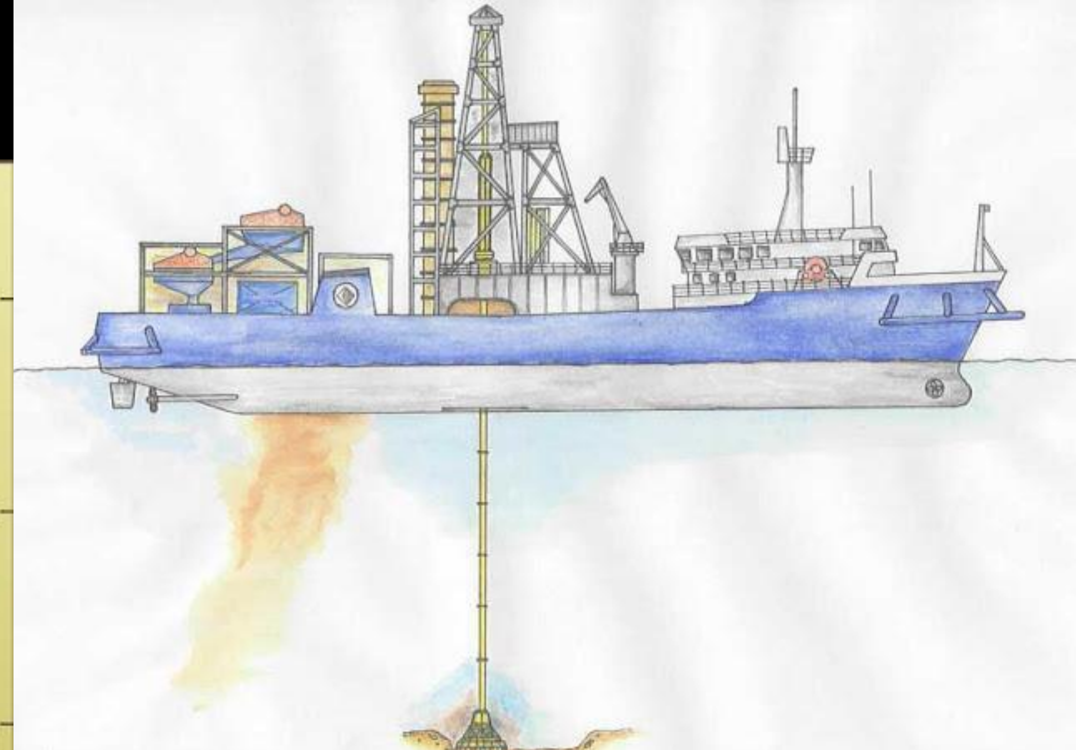
ALLUVIAL DEPOSITS
Freed from their matrix by erosion, diamond crystals were washed to the river *(top)*, where many of the crystals were deposited along with other alluviums and covered by centuries of silt *(bottom)*.

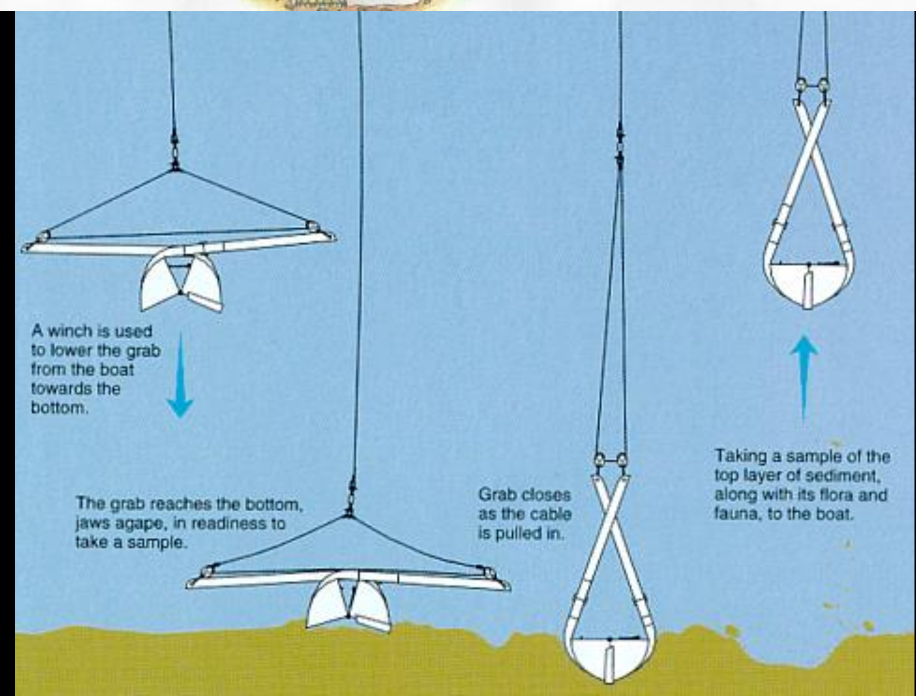


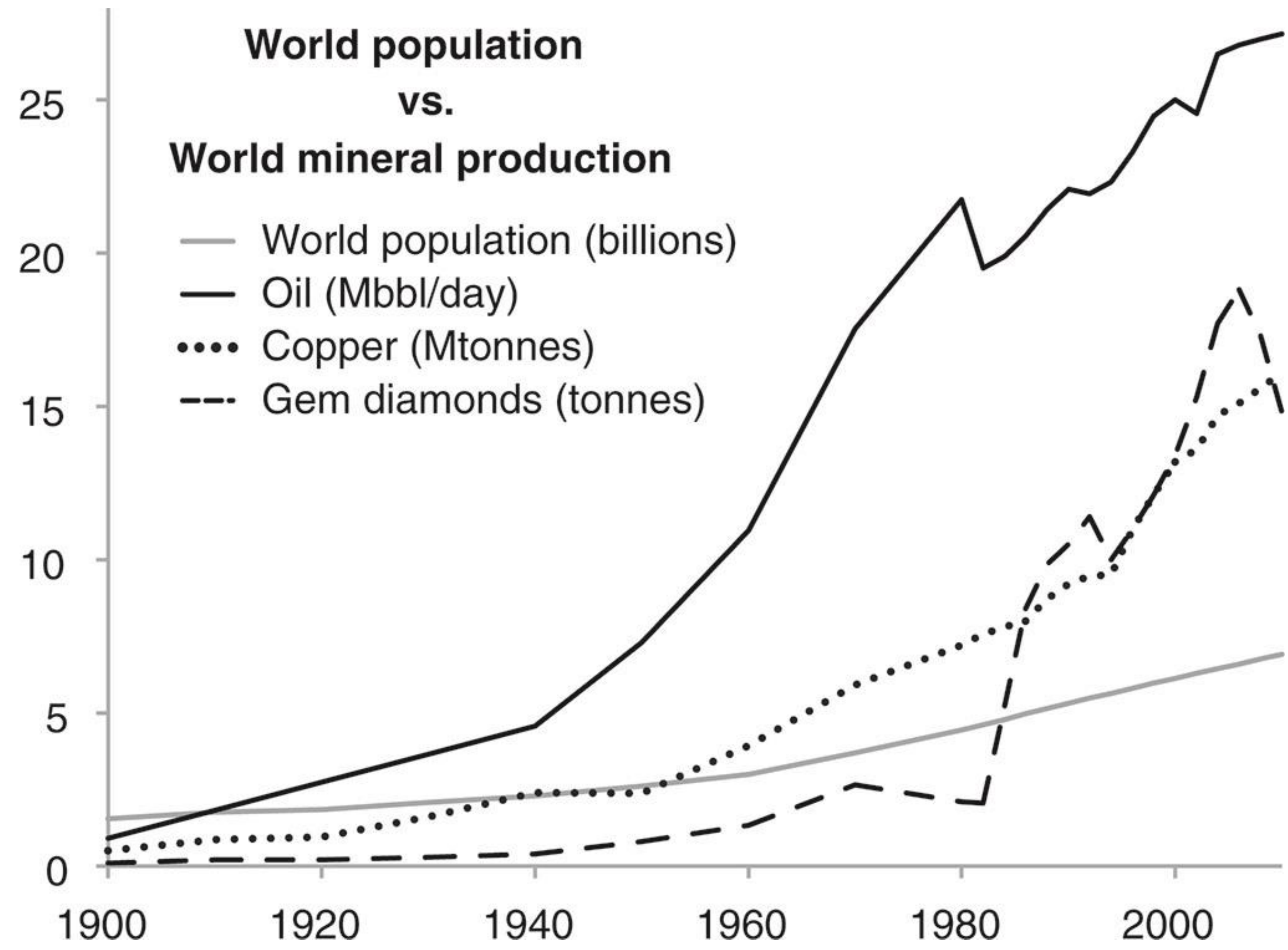
VOLCANIC PIPE
About 20 per cent of the world's diamonds originate in South Africa's remarkable array of ancient kimberlite pipes *(top)*. A pipe is usually mined first as an open pit and then by tunneling from a parallel shaft *(bottom)*.

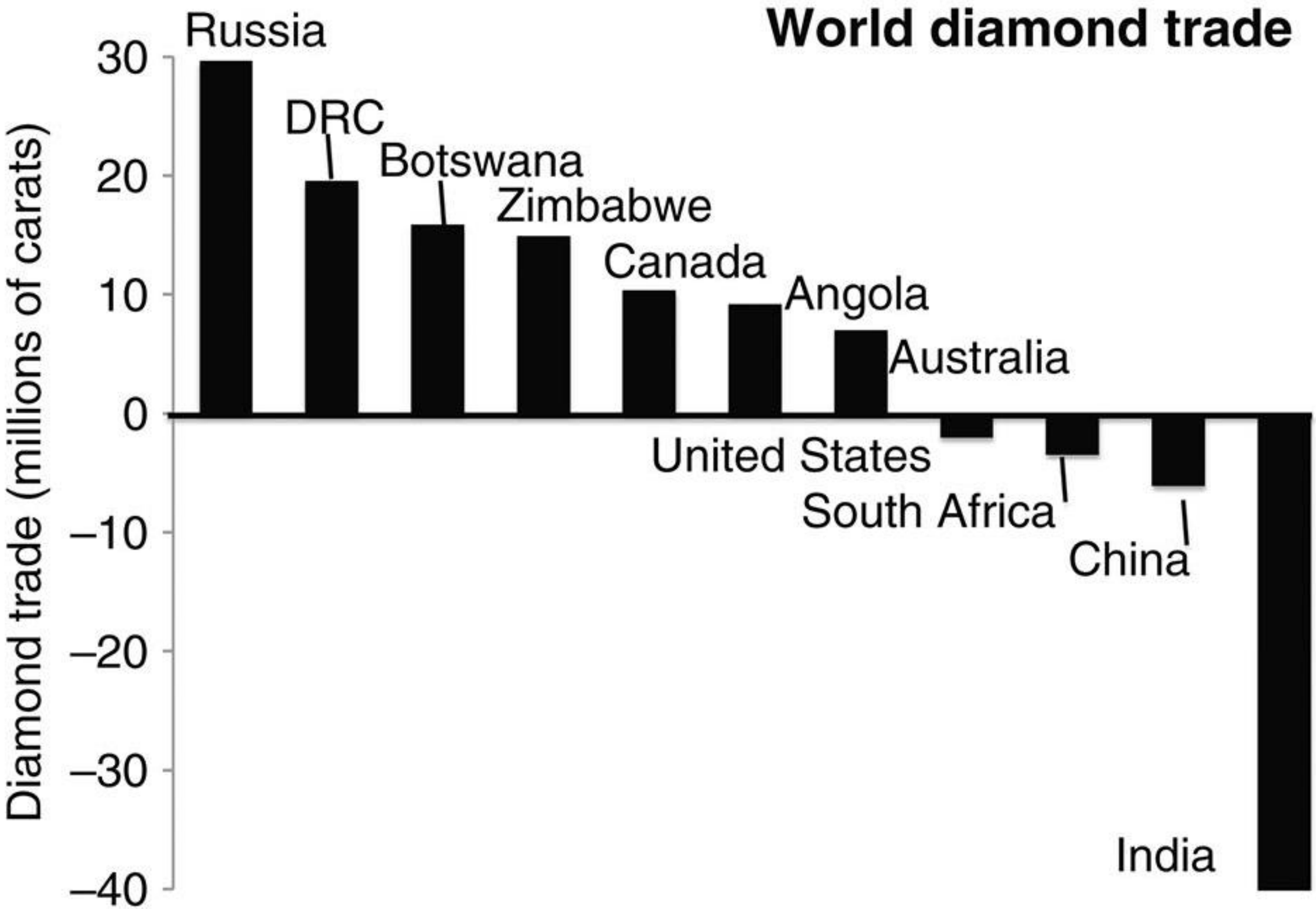
(b)


SOUTH AFRICA
Alexkor (1a, b & c)
1c
Alexkor (2a & 3a)
Transhex (2b & 3b)
2c
3c
4c
5c
DBCM ML3/2003 Mining Licence Area
Alexkor (4a & b)
Transhex Operations (a & b)
Werner Deep Ocean Research Inc
Transhex 6c
Transhex (7a)
DBCM (7b)
7(d)
7c
8d
8c
Namagroen (8a & b)
Namagroen (9a)
Pesa Properties (9b)
Alexkor Ltd
9c
10d
10c
Baggers (10a & b)
Bluewater Diamonds Inc
Transhex
Nautical Diamonds
12c
Poseidon Marine
Thirteen Sea
14d
14c
15d
15c
16d
16c
17d
17c
18d
18c
De Beers Consolidated Mines Concession Areas
Vacant (b) Concessions
Vacant (c) Concessions
Vacant (d) Concessions
29°S
30°S
31°S
32°S
33°S
15°E
16°E
17°E
18°E
50m
100m
150m
200m

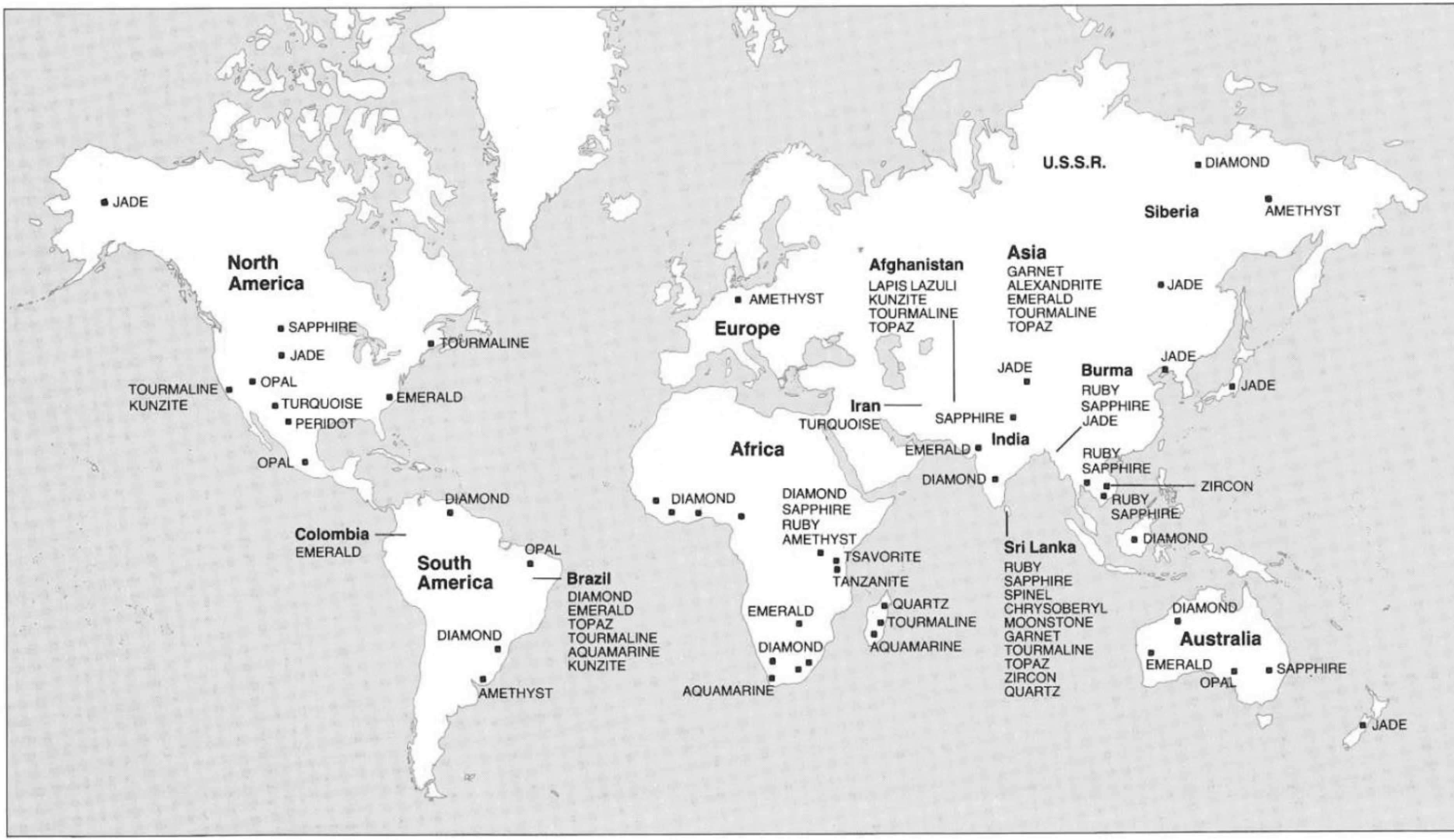


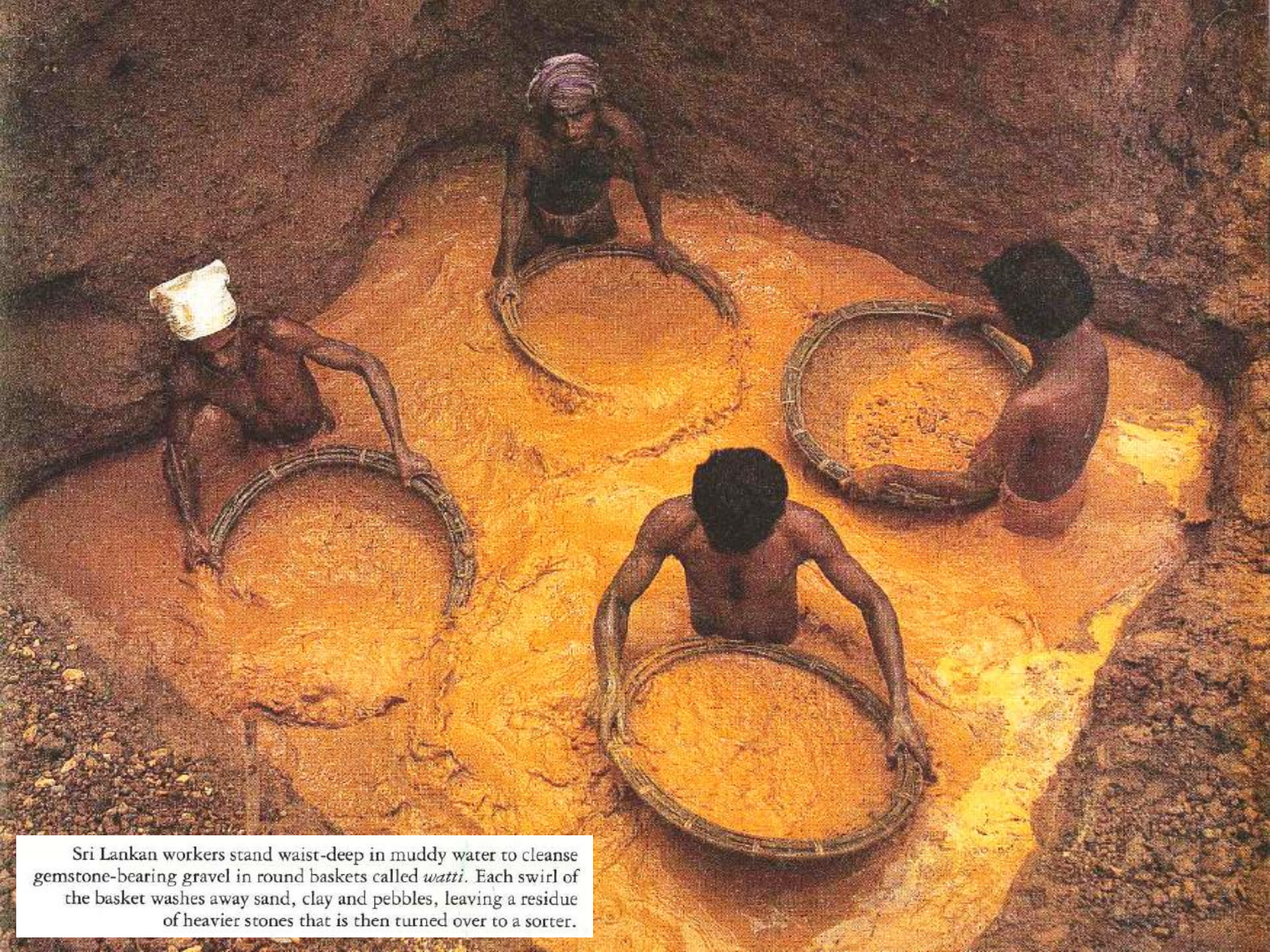

A winch is used to lower the grab from the boat towards the bottom.
The grab reaches the bottom, jaws agape, in readiness to take a sample.
Grab closes as the cable is pulled in.
Taking a sample of the top layer of sediment, along with its flora and fauna, to the boat.


World population
vs.
World mineral production
World population (billions)
Oil (Mbbl/day)
Copper (Mtonnes)
Gem diamonds (tonnes)
0
5
10
15
20
25
1900
1920
1940
1960
1980
2000


World diamond trade
Diamond trade (millions of carats)
30
20
10
0
–10
–20
–30
–40
Russia
DRC
Botswana
Zimbabwe
Canada
Angola
Australia
United States
South Africa
China
India

A map of the world's major deposits of gemstones shows them dispersed unevenly across six continents. Whether there are substantial finds to be made in Antarctica is still unknown.





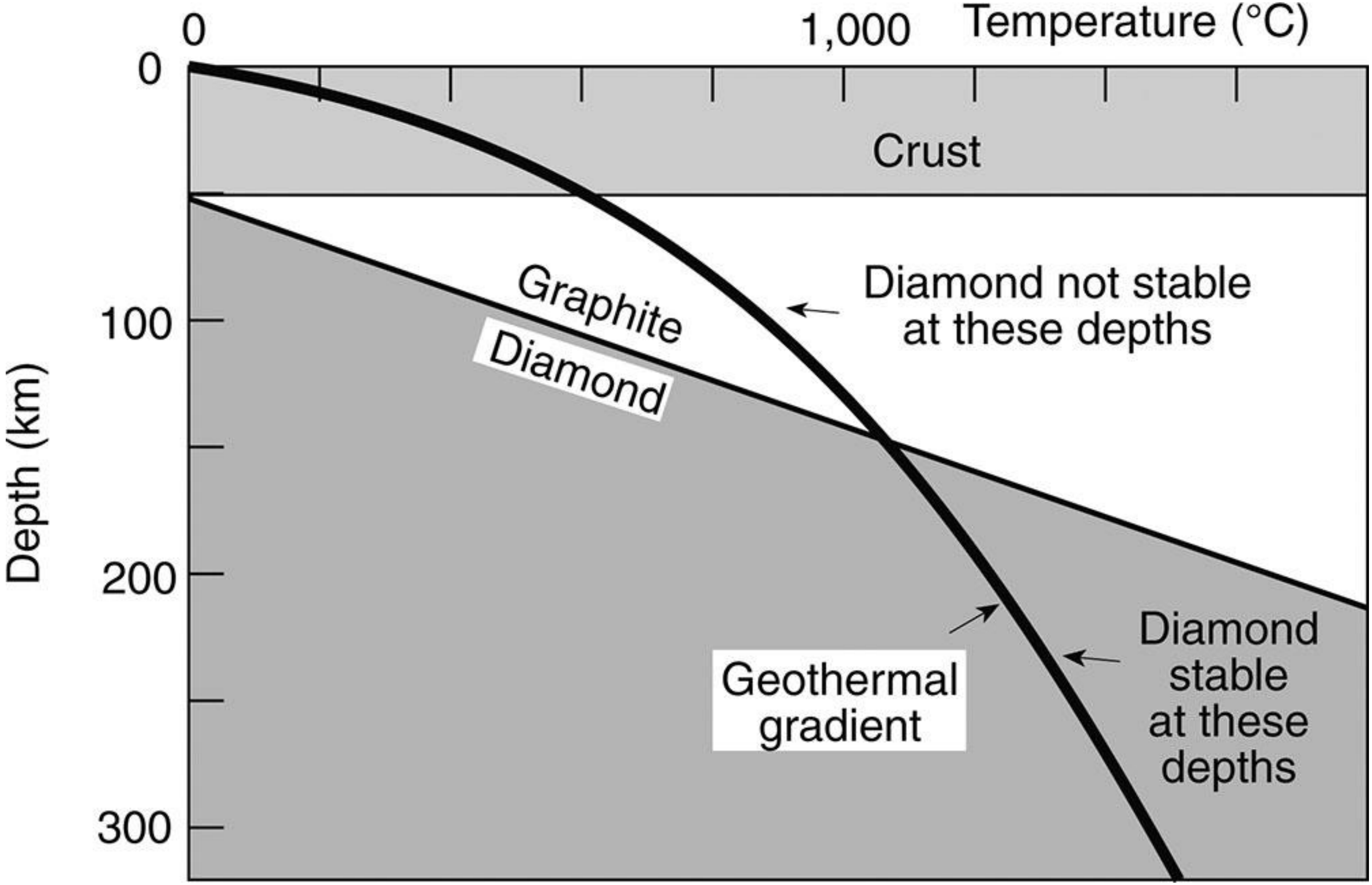
Sri Lankan workers stand waist-deep in muddy water to cleanse gemstone-bearing gravel in round baskets called *watti.* Each swirl of the basket washes away sand, clay and pebbles, leaving a residue of heavier stones that is then turned over to a sorter.

Diamonds

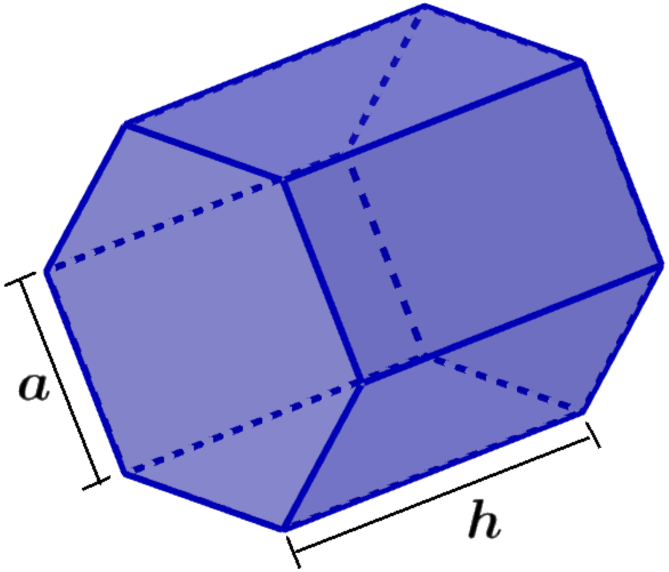
- Placer deposits produce ~1 carat / tonne ore, Kimberlites produce ~0.3 carats / tonne ore. Why?
- 1 carat = 0.2 grams
- Canada produced 10.5 billion carats worth $2 billion in 2012
- Australia produced ~9 billion carats worth ~$270 million
- In USA, 97% of industrial diamonds are synthetic
- De Beers held 90% of diamond market in 1987, but only 35% in 2015
- Diamonds may be made from human ashes!

Rough diamonds

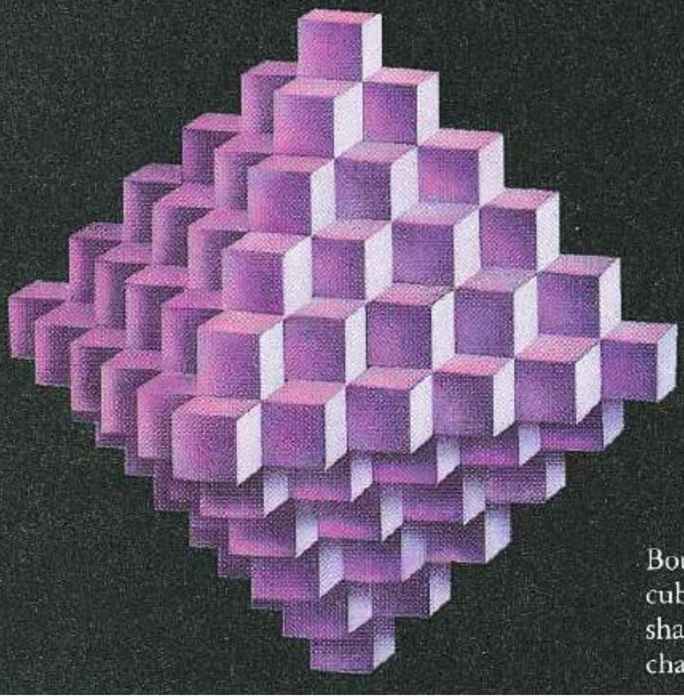
Carbonado

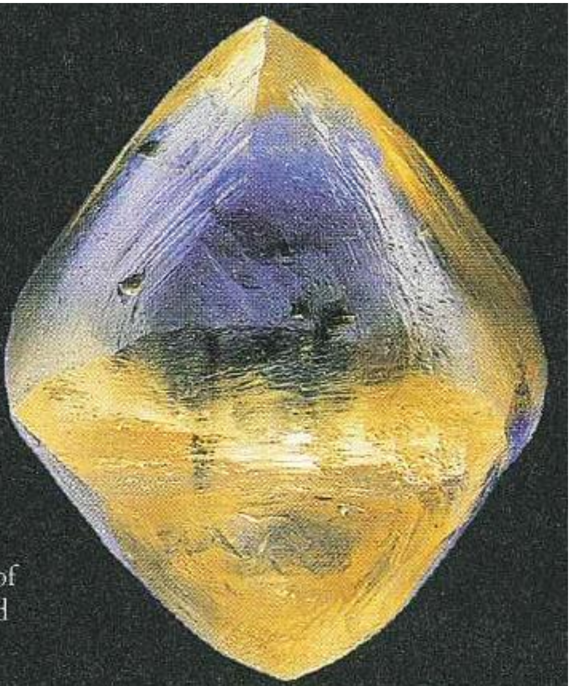

0
1,000
Temperature (°C)
0
100
200
300
Depth (km)
Crust
Graphite
Diamond
Diamond not stable
at these depths
Geothermal
gradient
Diamond
stable
at these
depths

Graphite

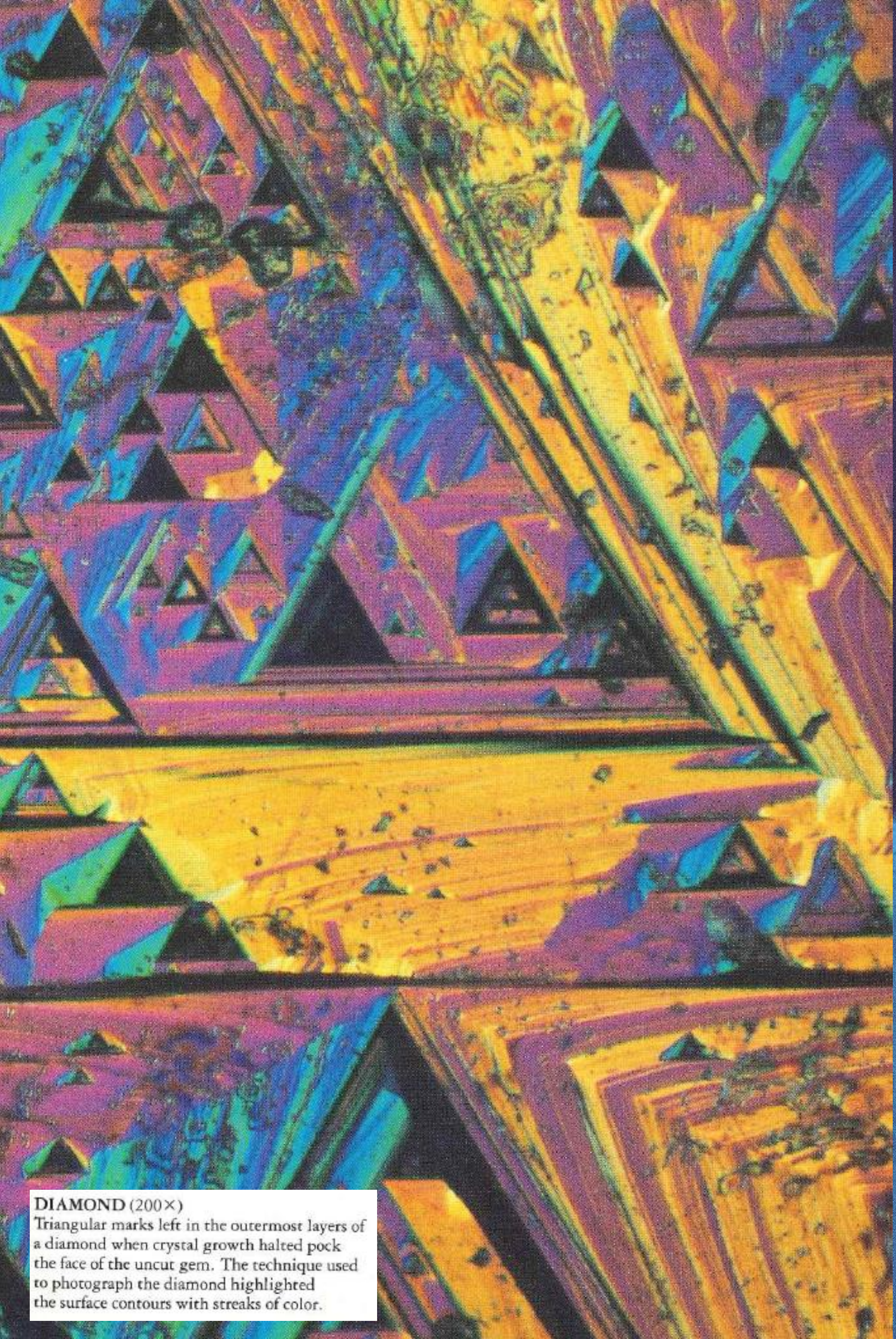


Diamond

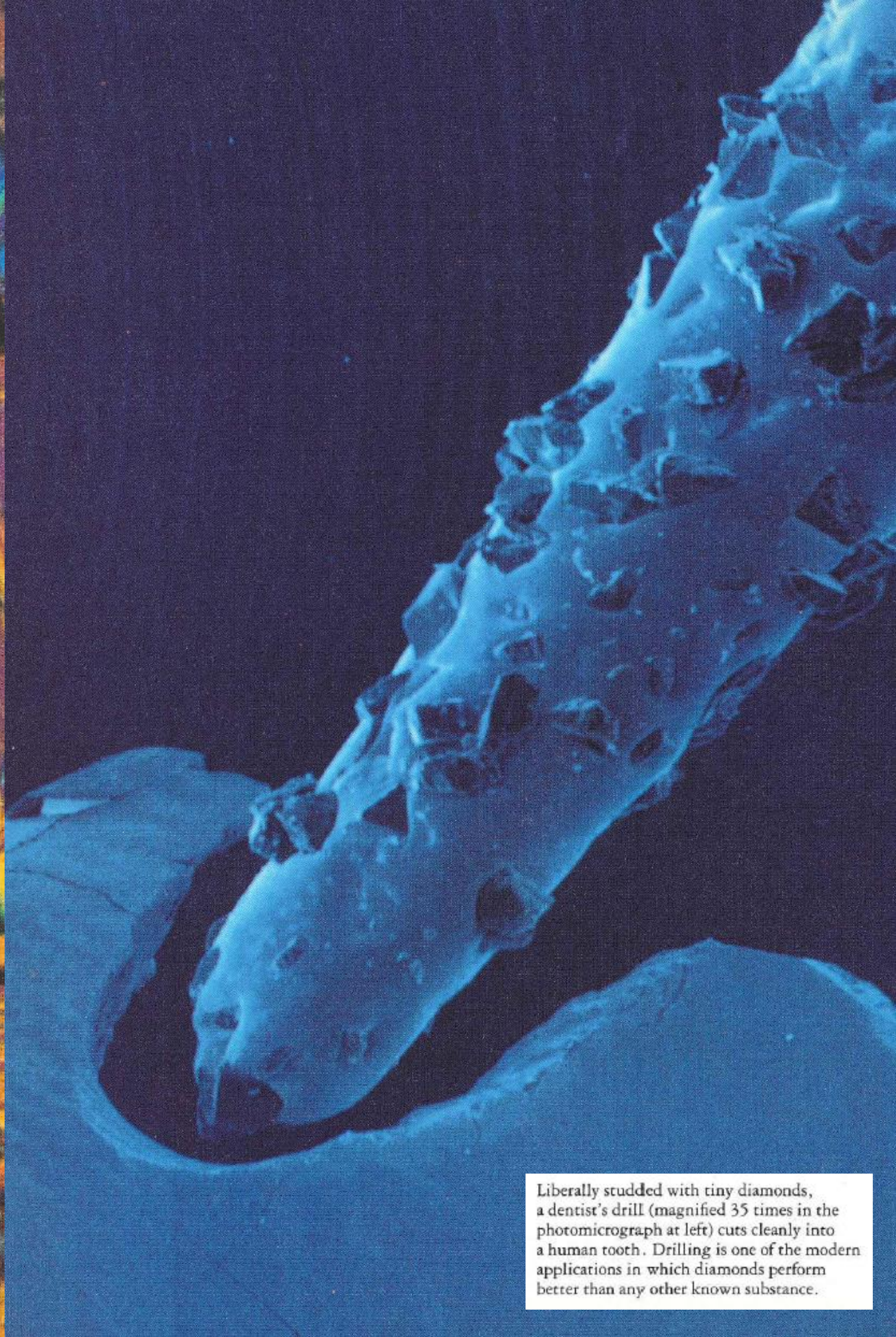




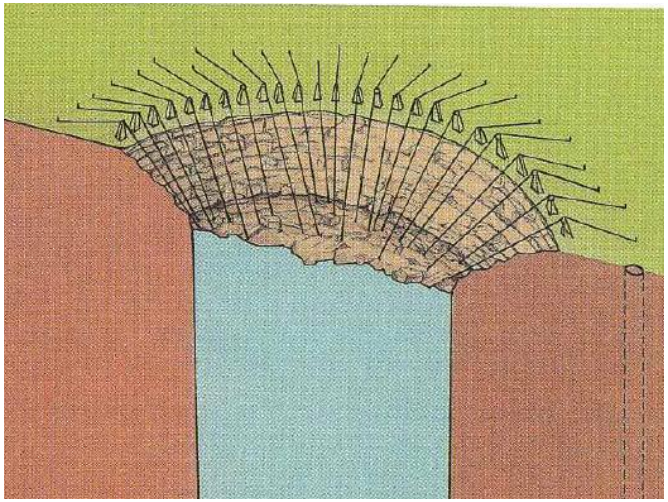
Bounded on all sides by stepped faces, an array of cube-shaped isometric cells forms an eight-sided shape called an octahedron (*left*) — a characteristic crystal shape of diamond (*right*).



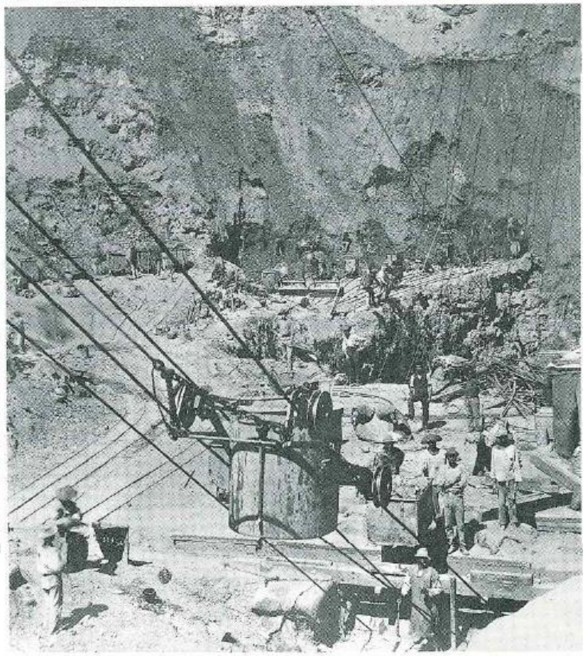
DIAMOND (200×)
Triangular marks left in the outermost layers of a diamond when crystal growth halted pock the face of the uncut gem. The technique used to photograph the diamond highlighted the surface contours with streaks of color.



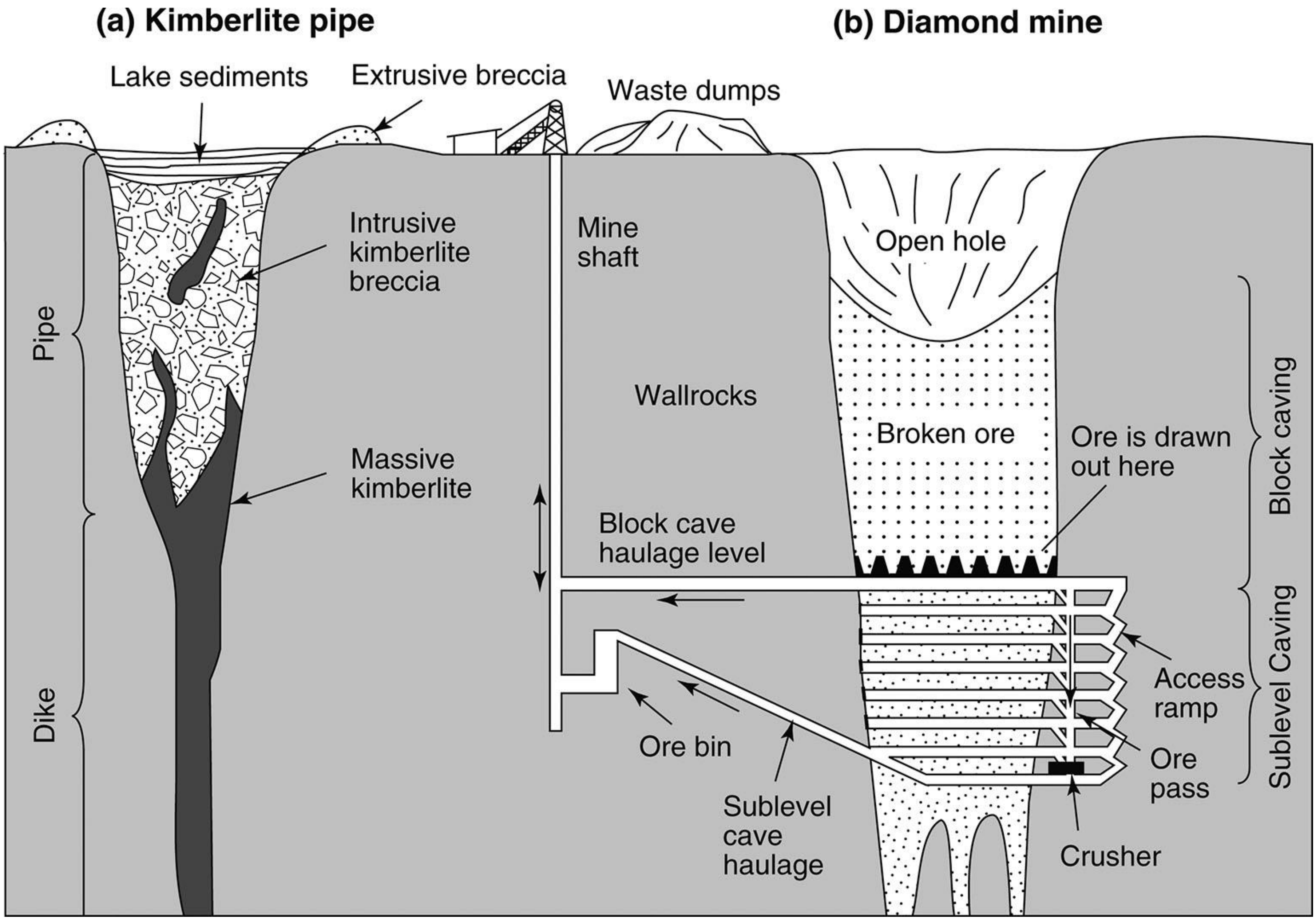
Liberally studded with tiny diamonds, a dentist's drill (magnified 35 times in the photomicrograph at left) cuts cleanly into a human tooth. Drilling is one of the modern applications in which diamonds perform better than any other known substance.

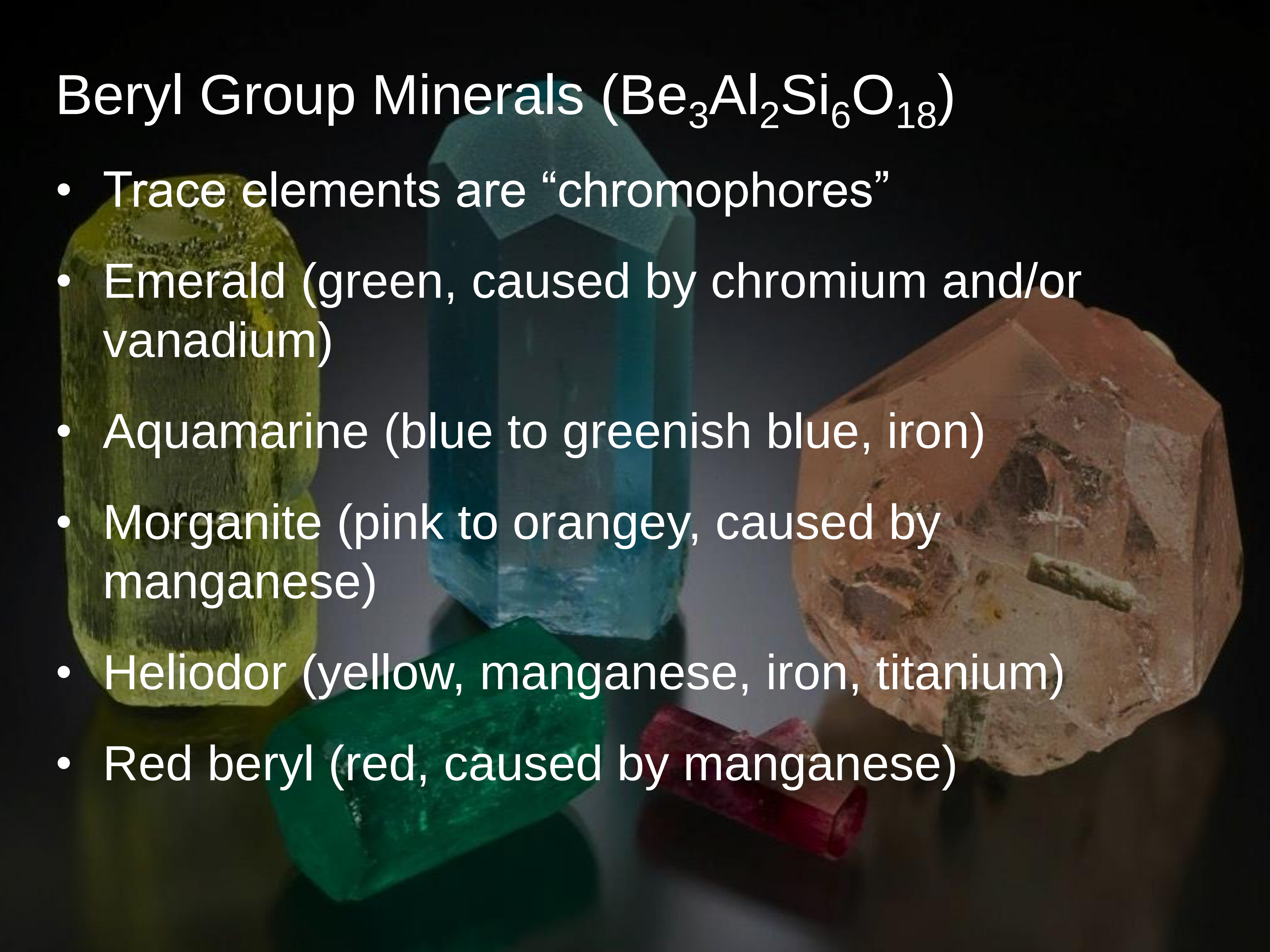


At one Kimberley mine, where water is scarce, diamond seekers in the 1870s employ a process called dry digging. African workers sifted the earth dug from the claims through rough sieves; sorters *(seated at center)* then carefully picked through it by hand to find the gems.



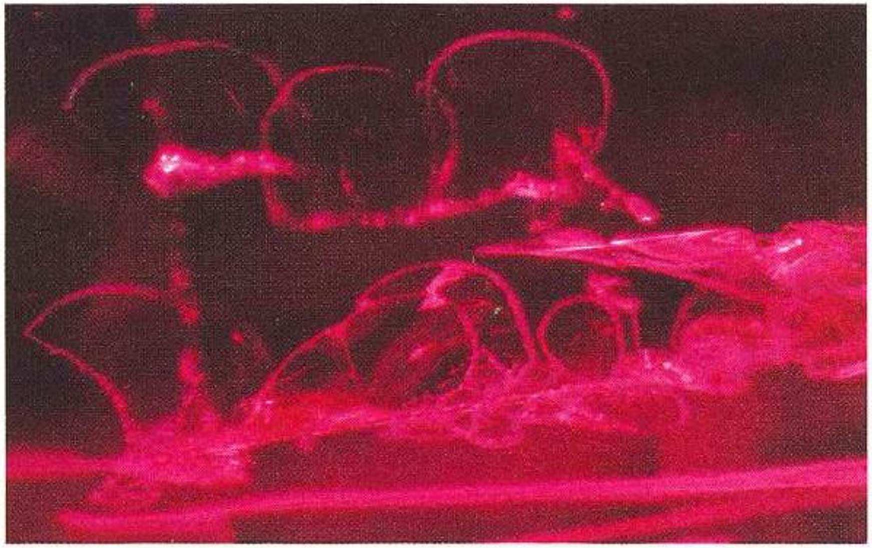
The honeycombed chasm at Kimberley *(above)* is crisscrossed by a skein of cables, the primary means of moving men and ore to and from the floor of the mine *(right)*.


(a) Kimberlite pipe
(b) Diamond mine
Lake sediments
Extrusive breccia
Waste dumps
Intrusive kimberlite breccia
Massive kimberlite
Pipe
Dike
Mine shaft
Wallrocks
Open hole
Broken ore
Ore is drawn out here
Block caving
Block cave haulage level
Access ramp
Sublevel Caving
Ore bin
Sublevel cave haulage
Ore pass
Crusher

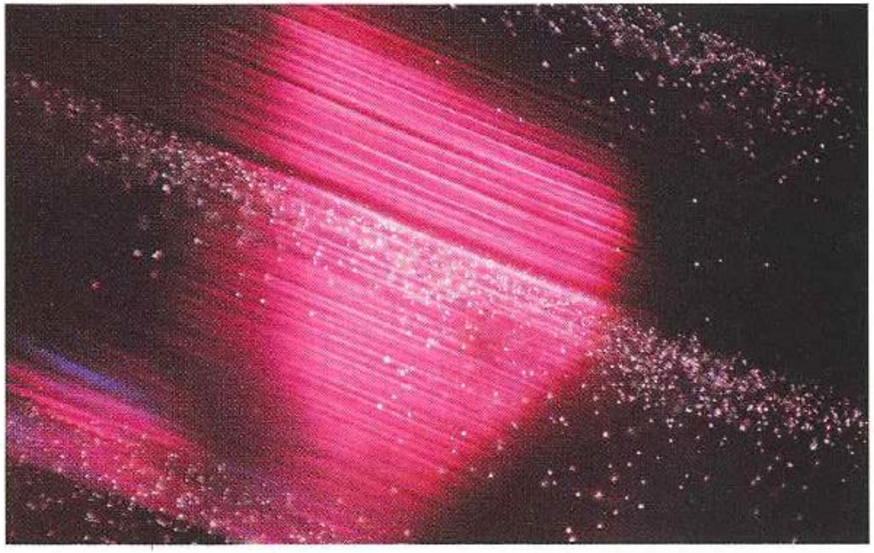


Beryl Group Minerals ($Be_3Al_2Si_6O_{18}$)

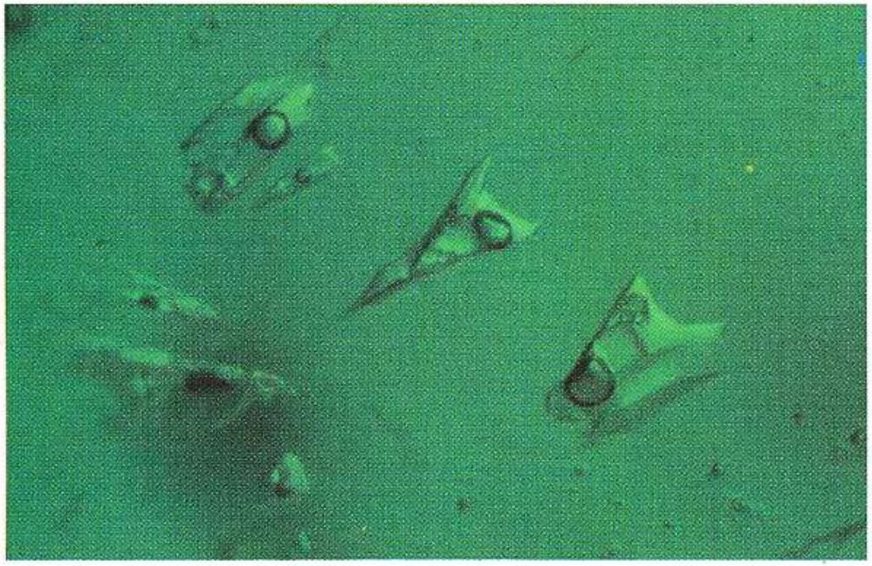
- Trace elements are “chromophores”
- Emerald (green, caused by chromium and/or vanadium)
- Aquamarine (blue to greenish blue, iron)
- Morganite (pink to orangey, caused by manganese)
- Heliodor (yellow, manganese, iron, titanium)
- Red beryl (red, caused by manganese)



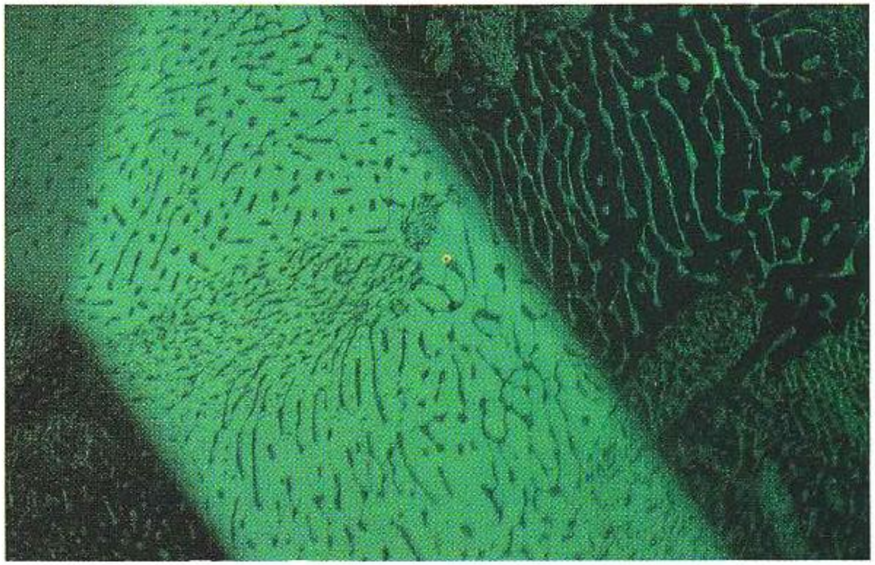
NATURAL RUBY (60×)
In the interior of a natural ruby, wing-shaped fractures mark the boundaries between separate, interlayered crystals, which are joined at common crystal planes to form a single gemstone.



SYNTHETIC RUBY (45×)
The laboratory origin of this ruby is evidenced by bands of differing color — the result of varying amounts of pigment in the molten gem material as it accreted — and by galaxies of trapped gas bubbles.

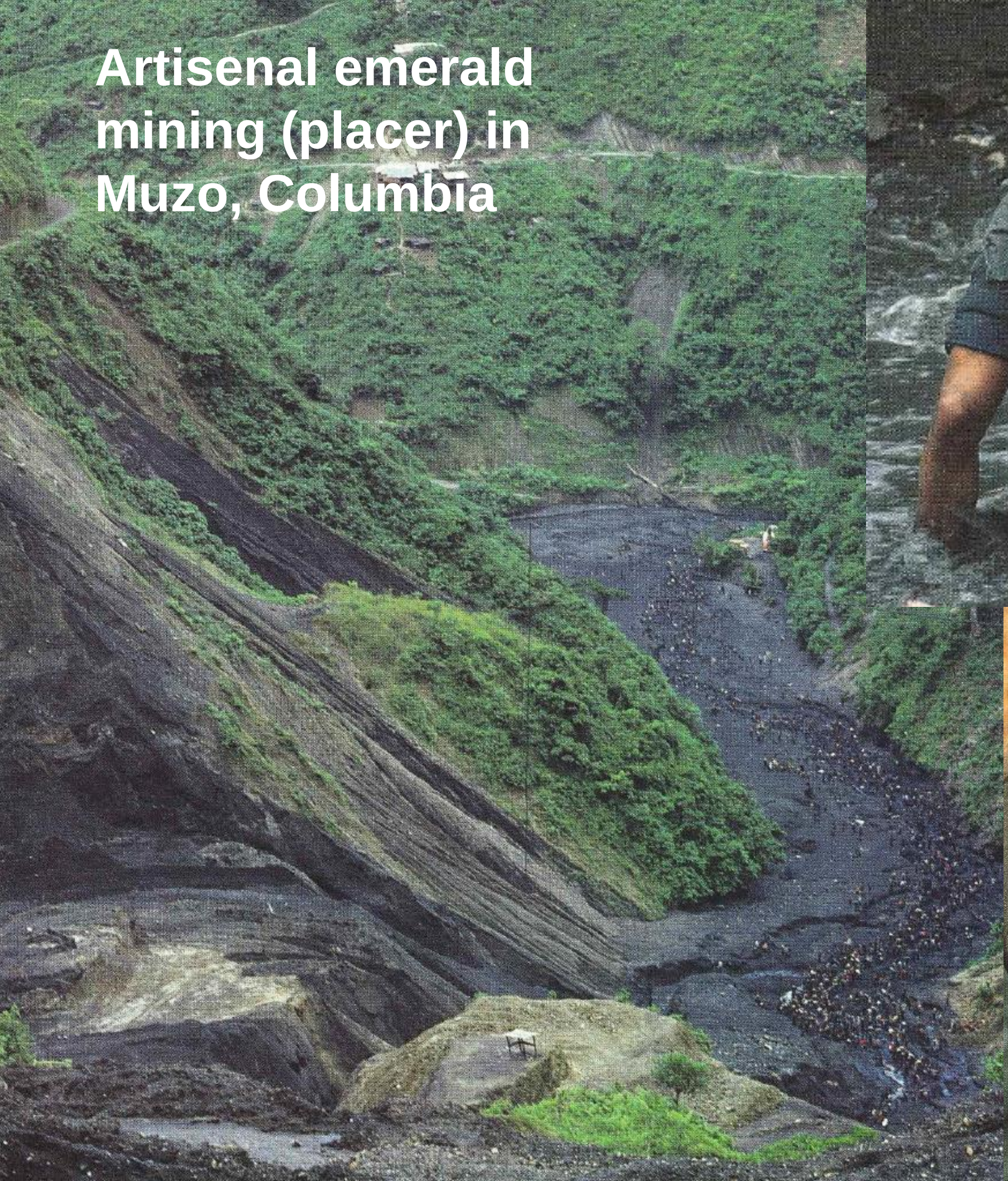


NATURAL EMERALD (100×)
The interior of a natural emerald is pocked with cavities containing liquid, gas bubbles and particles of solid — indications of the chaotic geologic environment in which the emerald took shape.



SYNTHETIC EMERALD (40×)
A "flux fingerprint," typical of flux-grown emeralds, marks the site of a crack that opened during crystal formation, then filled with new emerald deposits that trapped threadlike veins of unmelted flux.

Artisenal emerald mining (placer) in Muzo, Columbia



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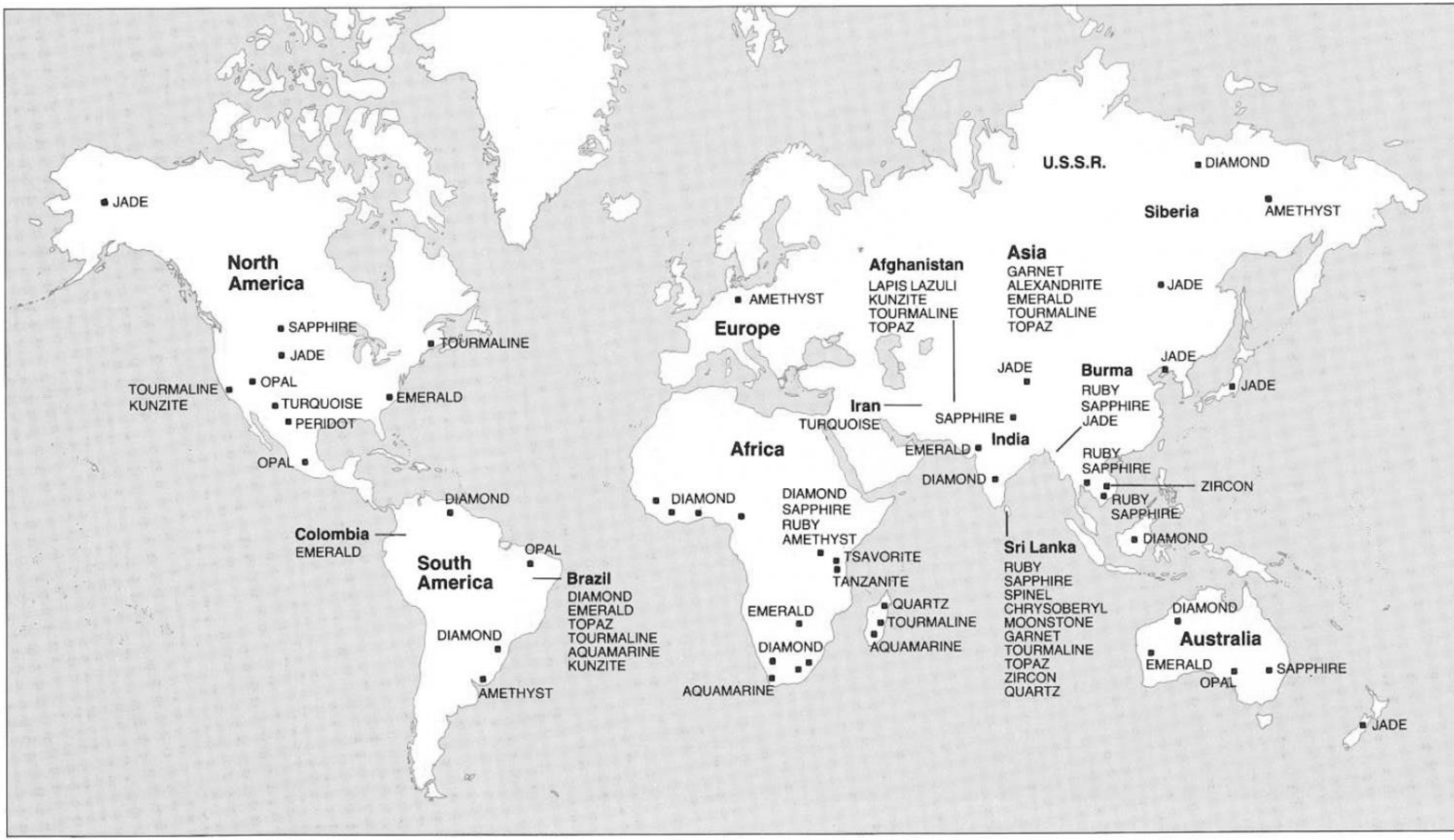

AMETHYST
Intergrown crystals of amethyst *(below)*, the most valuable of the many forms of quartz, may derive their color from minute traces of iron. Quartz is abundant, but large, evenly colored amethysts of gem quality *(above)* are scarce.

Amethyst crystals glint from the muck moments after the stone overlying the gemstones was shattered and removed. The pit is located in the gem-rich state of Rio Grande do Sul, Brazil.

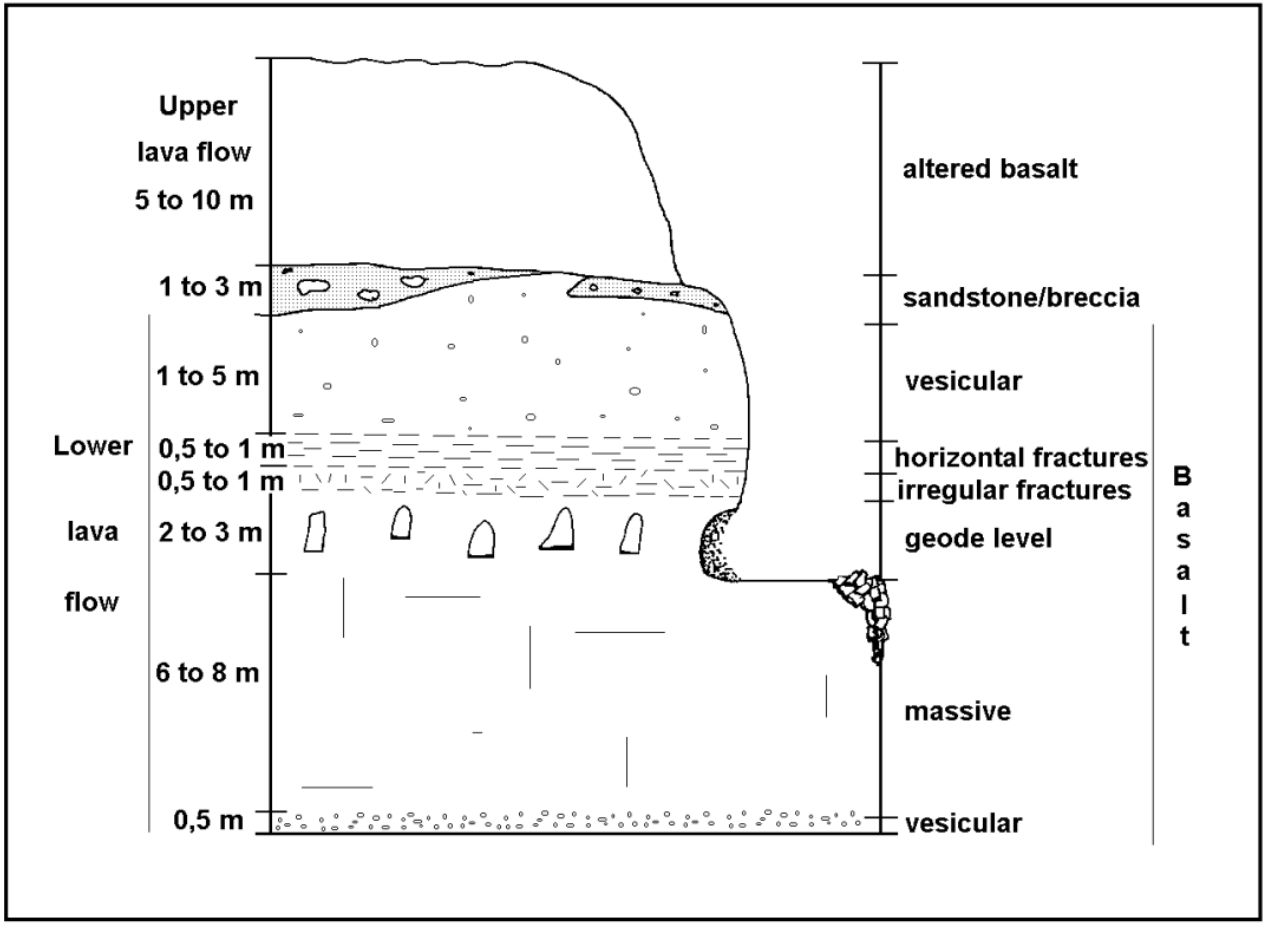

Figure 6 – Schematic rock section from Ametista do Sul Mining District, showing the different zones in the mineralized lava flow.

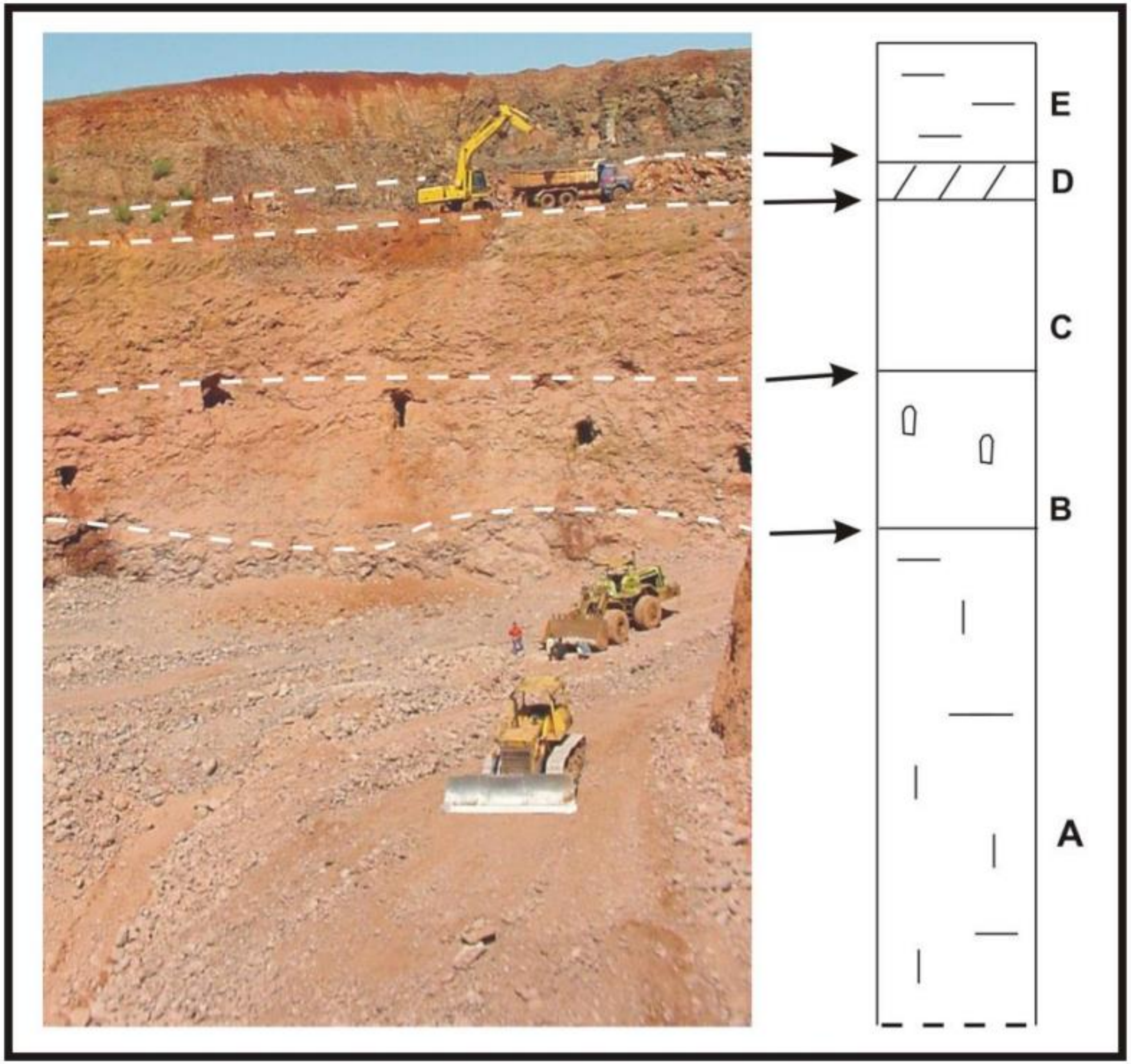

Figure 3 – Surface agate mine in Salto do Jacui Mining District, showing a typical lithological profile. **A** – Ground rock below the mineralized lava flow. **B** and **C** – mineralized flow of basaltic/andesitic composition (A) with a zone of dacitic composition. **D** – Upper glassy (?) zone of the lava flow, strongly weathered, with yellowish to grayish yellow color. **E** – The upper unit - a weakly altered dacitic flow.

Figure 4 – Surface agate mining in Salto do Jacuí Mining District. **A** and **B** – open pits and underground adits opened in the weathered volcanic rock. **C** – miners collecting agate geodes in the removal regolith. **D** – agate geodes to be commercially classified; in the back, the surface mine.

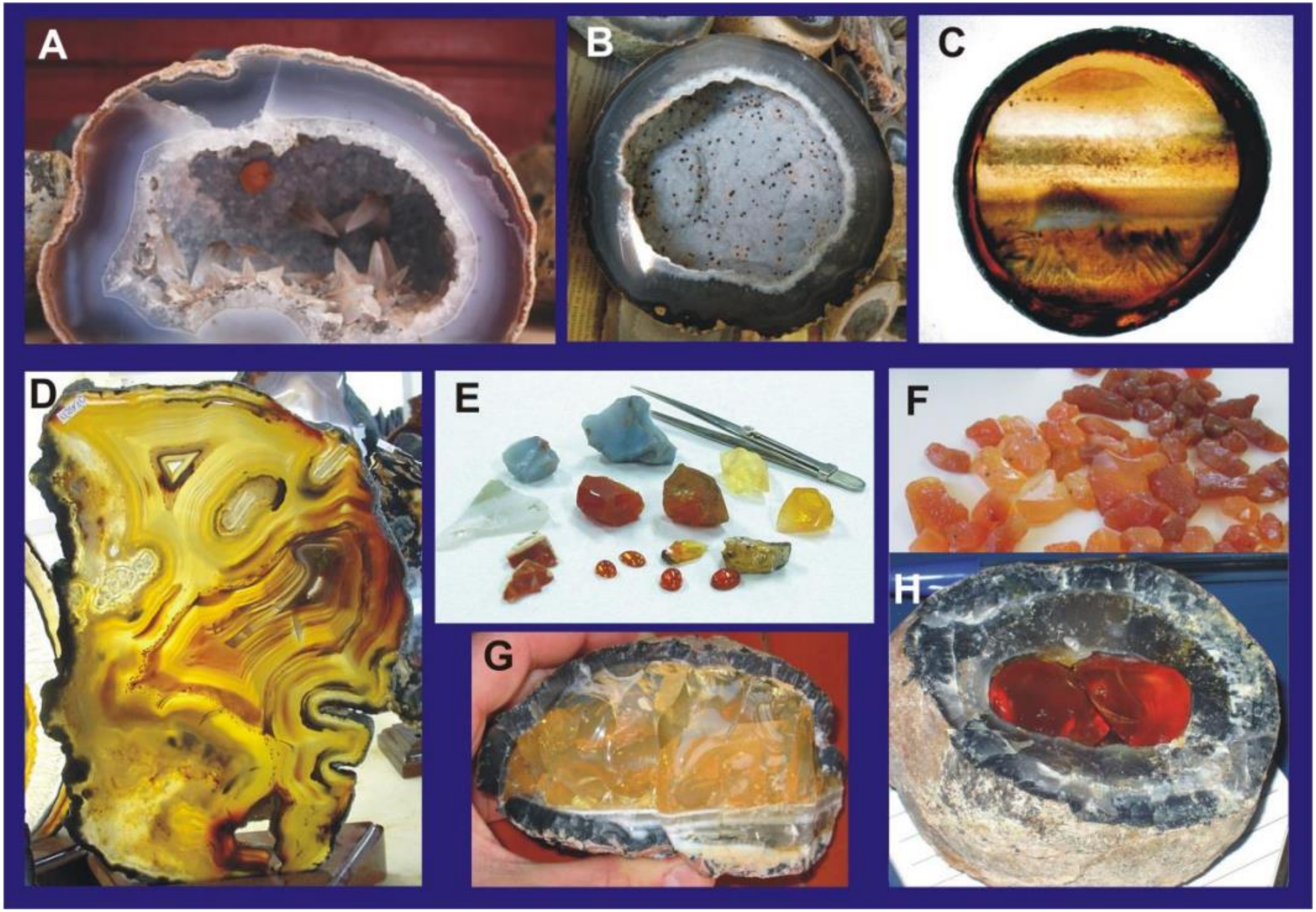

Figure 5 – Agate and opal in Salto do Jacuí region. **A** – the halve of a geode filled with agate, quartz and well formed calcite crystals. **B** – the halve of a geode filled with agate and spherical Fe and Mn oxides. **C** – a polished scenic agate plate; **D** – a polished agate plate showing a complex pattern of banding. **E** – opal samples of different colors. **F** – fire opal samples. **G** – a geode piece filled with agate and yellow to orange opal; **H** – a geode piece filled with agate and two "balls" of fire opal.

Figure 11 - Gem processing and gemstones workshop in Soledade **A** – Polishing agate geodes and agate plates. **B** – Dying agate geodes and plates. **C** – Exposition of polished agate plates. **D** – Geode pieces filled with amethyst, citrine (heat treated amethyst) and calcite crystals.

Corundum Group Minerals (Al_2O_3)

- Generally forms in low silica, high aluminum rocks like peridotite (mantle rock) or altered limestone
- Ruby (red from chromium)
  - 1 carat ~$4,000 – $10,000
- Sapphires (blue from iron and titanium)
  - 1 carat ~$4,500 – $7,500