



Salomon Kroonenberg Why Hell Stinks of Sulphur

Mythology and geology of the underworld

Salomon Kroonenberg is emeritus professor of geology at the Technical University of Delft. He is the author of *The Human Scale* (2006), which won him the Eureka Prize and has been translated into German, Chinese and Turkish.

An erudite combination of personal and literary travel writing, advocacy of depth-ecology and globe-consciousness, and geological popular science. A terrific, beautifully illustrated book.
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An entertaining book...
Delightfully enthusiastic.
Vrij Nederland

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We know almost everything about the exterior of the earth, but for most people its interior is completely unknown. Beneath us, stretching for a distance comparable to that between Paris and New York, lies an underground realm associated with darkness and death. It has inspired writers and artists since time immemorial; when trying to imagine hell, they have usually located it under the ground.

Subterranean mythology is geologist Salomon Kroonenberg's point of departure. With Dante's *Inferno* to hand, he takes the reader on a journey in the footsteps of Homer, Virgil,

Da Vinci, Descartes and Jules Verne. Along the way he turns a scientific spotlight on the background to myths of the underworld. At a small lake near Naples he searches for the gates of hell, as described in Virgil's *Aeneid*. Kroonenberg's vast reserves of knowledge and his expressive prose allow him to transform even inconspicuous features of the landscape into fascinating sites.

Kroonenberg has the gift of being able to explain complicated matters. He compares the inside of the earth to a gobstopper, ready to expose one gorgeous colour after another. Gasses, ores, liquids and metals add to its immense variety, and there are underground rivers and lakes that have never seen the light of day. The mineworkers of the past, who were often terrified by the strange noises, the darkness, the sudden gushing of water, had their own patron saint, St. Barbara. Even today she is asked to bless tunnelling projects before the drill sets to work.

Kroonenberg is not, however, concerned only with myths, or with the beauty of natural phenomena. He sees the earth beneath our feet as a source of information about the unimaginably ancient planet on which we humans live out our brief lives. We have never penetrated beyond a depth of twelve kilometres, but if this book makes one thing clear, then it is that we should not see the world as a supermarket for raw materials, or simply as rock to be tunnelled through, but as a unique archive, a living ecosystem whose riches we can still barely guess at.

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A fascinating search for the geological foundations of hell.

An appeal to find ways to ensure a good life for mankind that will not exhaust the earth.

Kroonenberg keeps up the suspense on all levels, so that his book reads like a voyage of discovery.

Sample translation

Waarom de hel naar zwavel stinkt by Salomon Kroonenberg
(Amsterdam: Atlas, 2011)

Translated by Liz Waters

For additional information on Salomon Kroonenberg and other Dutch writers, please also visit:
- The non-fiction pages at the foundation website: www.nlpvf.nl/nf/

Why hell stinks of sulphur

[pp. 177-198]

The city of Dis

For there among the tombs were scattered flames
That made them glow all over with more heat
Than any craftsman requires for his iron.

All of their open lids were lifted up,
And from inside such harsh laments escaped
As would come from the wretched and the injured.

Dante Alighieri, *The Divine Comedy*, 9, 118-123
(tr. James Finn Cotter)

Our fear of the underworld involves a curious paradox. Caves are not simply frightening; throughout man's existence they have provided him with shelter against the cold and the rain. Our distant ancestors were happy to live in caves. The Grotte du Vallonnet in the French Alps, made of calcite from the Jurassic period, was inhabited by humans 900,000 years ago. Sima de los Huesos, or the Pit of Bones, is a dried up underground karst river in the Cretaceous limestone of the Atapuerca Mountains in northern Spain in which human remains at least 850,000 years old have been found. Peking Man lived in a karst cave of Ordovician limestone at Zhoukoudian from 500,000 years ago until it collapsed 270,000 years later. The first Neanderthal to be found, in the nineteenth century, was in a karst cave of Devonian limestone near Düsseldorf. The famous paintings in the karst caves of Lascaux and Chauvet in southwestern France and Altamira in Spain are 35,000 to 10,000 years old, and the 38,000-year-old Venus of Hohle Fels was found in a cave of Jurassic limestone. The forefathers of the ancient Greeks lived in caves as well, in the Pindus Mountains, and as recently as 1985 two hundred Greek families still inhabited cave dwellings, according to Anna Petrochilou.

Not all ancient peoples were blessed with a karst landscape, but camping out in the rain was unpleasant. Some built turf huts, like the Dutch, made wooden cabins or dwellings with dry-stone walls or, in the absence of trees as in the northern Siberian tundra, erected bearskin tents with poles made of mammoth tusks. Others made their

homes under overhanging cliff faces along clefts in the rock, like the Anasazi in the southwestern United States, but there were some who saw that it was possible to create your own cave. True, caves can't be hacked out of every kind of rock, but some soft types suit the purpose excellently, especially loess and tufa, as in the Neapolitan tufa deposits around Lake Averno. Both have the additional advantage of not being stratified and therefore staying nice and dry, since rainwater becomes trapped in the fine pores instead of dripping through cracks onto the cave floor.

Perhaps the most famous cave dwellings excavated by man are those of Cappadocia, in the middle of the high plains of Anatolia. The region has been prone to volcanic activity for over twenty-five million years and it still has ten active volcanoes, including Mount Ercyes and Mount Hasan. Between eleven and five million years ago awe-inspiring eruptions took place, comparable to those of the Phlegraean Fields near Naples. At least two ancient calderas, super-craters over twenty kilometres across, remain as evidence, although they are now hard to make out from ground level. They're known as the Derinkuyu caldera and the Acigol caldera. When they were created, huge glowing clouds blanketed the landscape for miles around with thick layers of hot volcanic glass particles, the ignimbrites we encountered earlier in this book. Most ignimbrites are white, soft and easily quarried, but sometimes, when the glass particles melted together, they became hard. In many places further flows of lava poured out over the ignimbrites. Erosion then undermined the solid lava on top of the soft ignimbrites, carving out a fairy-tale landscape of steep white cone-shaped ignimbrite mounds, some still topped with plugs of dark lava. They are known as fairy chimneys and whole plains are full of them, like beds of nails for cyclopes. Sometimes they look like melting glaciers, sometimes like a procession of robust ladies-in-waiting in hooped skirts, sometimes like giant chess pieces at stalemate. Those who prefer to see them as erotic symbols can have their fun. They're world famous, and not just because they make such an enchanting landscape but because entire underground cities have been dug out of them, with thousands of dwellings, churches, monasteries, hermits' cells, crypts, storerooms and wine cellars. The underground city of Derinkuyu is twenty storeys deep, reaching forty metres below ground. It was large enough to house ten thousand people, all connected by an astonishing labyrinth of narrow passageways that could be closed off if necessary by rolling millstones across them. There was also an ingenious ventilation system that made fresh air available even at the deepest levels.

What drives people to live below ground in such a magnificent landscape? Not nostalgia for limestone caves, at any rate. Intriguingly, the most ancient Stone Age inhabitants didn't live underground here at all. The area is part of the fertile crescent where ten thousand years ago, when the climate improved after the last ice age, agriculture was invented. Excavations have shown that whenever possible people here chose to live on

fluvial terraces, close to the water but still on dry land. The Hittites of the late Bronze Age, the Persians from the sixth century BC onwards, and later the Greeks and Romans lived above ground as well. It was not until the Byzantine period that the digging began. In reality it was a survival strategy.

In the sixth century AD the Byzantine Christians found themselves wedged between the Arabs advancing from the south and the Persians to the east. In the ninth century the Seljuks (Turks) conquered the region, but in inaccessible Cappadocia, underground cities offered protection for centuries. It was principally the monks who encouraged people to move underground. Is that why there are so many underground churches and monasteries? Or did people feel menaced by creatures of the underworld?

It wasn't difficult, in any case. Making a cave dwelling would have taken no more than a few months and minimal building expertise. The shapes of the vaulting and pillars were borrowed from Byzantine architecture, but there was no compulsion to use them. If you wanted a round ceiling you made a round ceiling, if you preferred a rectangular one, that was fine too, and if you made a mistake you could always start again somewhere else. The Christians were able to cling on here until the tenth or eleventh century. No one lives in the caves any longer, they are used only for storing fruit, wine and grain, but you can still spend the night in a cave hotel.

Of course there are other options, as we saw in Jerusalem, a city built of limestone won from the stone quarries of Salomo, directly below the city. In Naples, with its famous yellow tufa, this approach worked for over twenty-five centuries.

A summery Sunday morning. The luxurious Caffè Gambinus is already open, extravagant pastries duplicating themselves in the gold-framed mirrors to draw visitors in. But that's not the reason we've come. This is simply the gathering point for inquisitive people who want to see underground Naples: several Italian couples, a Danish family and me. Our guide Salvatore Quaranta hurries us off to the Quartieri Spagnuoli or Spanish district, the most disreputable neighbourhood of the old city centre, a maze of steep narrow streets paved with *piperno*, as the lava of the Vesuvius area is called. There's nothing to indicate that another city lies beneath us.

At a small public square, Salvatore suddenly disappears into a house, urging us to follow him. We find ourselves in a dark little office with a dilapidated desk and one wall covered in cuttings in various languages about La Napoli Sotterranea and an organization set up by Salvatore along with his brother Michele called Libera Associazione Escursionisti Sottosuolo. We're given only a little time to look before being led through an inside door to a spiral staircase of two hundred steps that will take us forty metres down. We immediately leave behind the noise of those endless streams of Vespas and Cinquecentos.

We find ourselves under a high vaulted roof cut out of the *tufi gialli*. The patterns hatched into the tufa are typical of Roman excavation work, but even they weren't the

first. In the fifth century BC the Greeks who founded Cumae built a new city, Neapolis, at a place where they encountered the yellow tufa familiar to them from Cumae. They quarried it to build their temples and homes. Until the Second World War the only building stone used in Naples was tufa from its own bowels. Salvatore shows us how they did it. Blocks of stone were hacked out underground, then hauled up in a lift through a shaft no more than a metre wide. A house left a small hole down below, a palazzo a large hole, as was precisely the intention, since the resulting space functioned as a cistern, a reservoir of drinking water for the house: small for a small house, large for a sizeable palazzo. The Negative of Naples, they call it. It's a remarkably refined system. The larger the building the larger the hole it left. The water came from streams flowing in from the hills nearby. It was channelled through underground aqueducts, so the cisterns are connected by narrow passageways that the more corpulent of visitors can barely squeeze along. They dug no more than forty metres down, since otherwise they would have been excavating below sea level, allowing salt water to seep into the cisterns.

The area shown to visitors is only a small part of the underground city, which is almost as large as above-ground Naples. Geologist Mario Tozzi, the great researcher into all things subterranean, describes his visit to the catacombs of Fontanelle in his book *Italia segreta* (Secret Italy). The Negative of Naples was not only its quarry and reservoir but its graveyard, storeroom, cess pit, sewer, refuge for criminals and the persecuted, place of healing for those who believed in the beneficial effects of speleotherapies, church and place of pilgrimage.

If you died of the plague that ravaged the city in 1656, Tozzi writes, you most likely expired on the street. Someone would put you into one of the tufa holes, since the churches and crypts were already filled with corpses. You were placed in a niche in a seated position until all the noxious fluids had drained from your body. Only after everything had leaked out was your dried corpse hung up in its underground resting place. When you enter Fontanelle Cemetery, the first sight to greet you out of the half-darkness is of breathtaking rows of skulls leaning against a metres-thick wall of tibias, ulnas, femurs and other long bones. Here lie the corpses of at least forty thousand people, some say several million men, women and children. Researchers have excavated another fifteen metres down and found only bones, bones and more bones, the remains of poor people who couldn't afford funerals as well as those who died from disease, poverty or an eruption of Vesuvius. By 1837 the Fontanelle catacombs were so full that nothing more could be added.

It's now a place of pilgrimage. Aside from bones, there are innumerable burial chapels, and reliquaries in marble or wood holding one or more skulls. Anyone who sees the ghost of a deceased loved one in a dream will adopt a skull in Fontanelle Cemetery, put messages in it, or flowers, photographs or drawings, and make it privy to his deepest

desires. Mario Tozzi was shameless enough to read one of the notes: 'Dear soul, come into my dream, tell me your name, and please let my number win the state lottery.'

In the section that Salvatore showed us there was none of that, but we did see traces of a different horror: the Second World War. Because of its harbour, railways and factories, Naples was the most bombed city in Italy, first by the British, then by the Americans and then, after the allies took it, by the Germans. Twenty-eight thousand bombs landed on the city, killing twenty thousand people and reducing large areas to rubble.

Thousands of the city's residents survived by turning one of the narrow lift shafts into a spiral staircase and taking shelter in the depths – the steps by which we entered. At least four thousand people lived down there for months on end, in five hundred or more underground rooms. Salvatore shows us the rusting remains of water pipes and electricity cables, and redundant insulators. I can see graffiti scratched onto the walls (tautology to an Italian, since *graffiti* means 'little scratches'), including caricatures of Hitler, Mussolini and Hirohito, and planes dropping bombs. In a niche it says '*Riservato al signor Campagna*', no doubt an unpleasant person, and next to it '*Anna e Renzo si sposarono il 20 Settembre 1943*': Anna and Renzo were married on 20 September 1943, when wartime bombing was at its height. They were safe underground; the roof proved strong enough to withstand aerial bombardment. Hell was above, in the city.

Much of the underground city is inaccessible now, since after the war all the rubble was shovelled into its subterranean passageways. Only in recent years have pioneers like Salvatore and Michele Quaranta recognized the value of the Negative of Naples.

It's also possible to dig an excellent house out of loess, a fine-grained sediment deposited by the wind, rather like the Sahara dust you'll sometimes find in a thin red layer on your car after a strong southerly wind. On our first-year field trip in South Limburg our university teacher, Hans Wensink, a big man in every sense, taught us how to identify loess in an Edelman auger. 'Loess feels just like a young girl's thighs,' he said with a broad grin. I was nineteen and green. I'd never felt a girl's thighs, so I learnt it the other way around: the thighs of a young girl feel just like loess.

The loess layer in Limburg is thin, in most places no more than a few decimetres, a couple of metres at most, but on the loess plateau in the central and upper reaches of the Yellow River in China, the loess is some three hundred metres thick. During the ice ages it was blown away across the notoriously arid Gobi desert as a fine dust that travelled great distances. Every ice age has left behind a layer of loess, demarcated by soil horizons from the warm periods between one ice age and the next. It's possible to trace some thirty ice ages this way. The Chinese loess plateau is about the same size as Spain and an estimated forty million people still live in caves cut into it. Forty million. The same as the population of Spain.

Ideally they like to carve their caves out of steep, south-facing hillsides, to get as much sun as possible. Sometimes you'll see dozens of cave dwellings in a row, all at the same level in a particularly thick layer of loess, identical with their round ceilings and a flat entrances, like a dovecote. It's not unusual to find an entrance neatly closed off with a semi-circular window and a door. In flat areas with no steep hillsides people will dig a square hole in the loessial ground, as if making a swimming pool. This creates a courtyard. In the four walls of the hole they then dig out separate dwellings, all with their entrances facing onto the courtyard. Entire extended families live down there. If you look out across the plain you'll see no sign of human habitation, since nothing sticks up above the ground. At most you might spot a tree that seems to have no trunk, since it's been planted in the middle of an excavated courtyard. The underground dwellings are cool in summer and warm in winter, and of course they are cheap to build. The only disadvantage is that they collapse during earthquakes, which destroy the cohesion between the grains of sediment. In an earthquake in 1920 more than 15,000 cave dwellings were destroyed and a thousand people killed, although they were safer there than in the mud huts above ground in the same region, every one of which collapsed. The system has existed for at least four thousand years, making it one of man's first underground ventures. It was not an original idea, of course, since badgers, foxes and rabbits had set the example.

But what brought people here? American architect Gideon S. Golany claims one of the driving forces behind the huge proliferation of cave dwellings in the Ming and Qing dynasties from the fourteenth century onwards was that in earlier times so much wood had been used for homebuilding and as fuel that the region was totally deforested. Here too, then, the decision was made not just on grounds of comfort but from bitter necessity.

Nowhere do cave dwellers live closer to hell than here in Xinjiang, a region in the far northwest of China. The miserable houses are dug out of a thin layer of loess that covers grey, yellow and red pleated sandstone and shale. Some have roofs of corrugated iron, others are just deep enough to require no additional roofing. What has brought people to this dry, desolate landscape? Only down in the valley is it possible to grow crops, since the rivers that carry water from melting snow on the peaks of the Tien Shan mountains flow northwards, eventually running dry in the vast expanses of the Dzungarian desert. There is vegetation in the valley, where the better villages are found, but nothing grows on the slopes of the mountains. Anyone who lives here must be a mineworker, mining coal.

China lives on coal. Its antediluvian steam trains run on it and in the waiting rooms at railway stations you'll see great heaps of the stuff. In car parks, bus stations and courtyards, at the side of the road: coal is everywhere. Brick factories, lime kilns and steelworks all rely on coal, and the residents of towns and villages burn coal briquettes. The whole country stinks of coal. In the east you find impressively modern mines, but here in Xinjiang they are still extraordinarily primitive.

The coal seams, the carbonized remains of the vast peat bogs of the Jurassic period, are trapped between sandstone and shale. The folding of the seams, a distant echo of the collision of India with the Eurasian continent, has brought them to the surface here and there, while elsewhere it has buried them deep beneath more recent layers. Surface seams are sawn into large cubic chunks that are then wrenched loose and loaded upright onto open carts on bicycle wheels. Coal seams at greater depth have primitive tunnels hacked into them along which the coal is brought out in wagons on narrow-gauge railways, sometimes powered only by human muscle. I saw women pulling rail wagons full of coal out of the mine: convicted prostitutes from Shanghai, I was told. This was in 1995. Perhaps conditions have improved since then.

That's only one aspect of the problem. If you look out across the coalfields from high ground you'll see plumes of smoke rising everywhere. The coal is burning – sometimes spontaneously, sometimes because of mining activity. It's one of China's biggest problems. Not only is a valuable raw commodity being lost, the fires release so much CO₂ that according to estimates for the year I visited, it accounts for two to three per cent of the annual rise in CO₂ in the atmosphere. Later the figures were adjusted downwards significantly.

Zhang Xiangmin, a slender young Chinese geologist, is investigating ways of using satellite images to detect coal fires. It's a major project based at the international educational institute ITC in Enschede, the Netherlands, working together with a number of Chinese institutions. I'm supervising him as part of a team of Chinese and ITC geologists.

It's a longstanding problem. Back in 1958 a special fire brigade was set up, deputy director Zhang Lun tells me in his office in Ürümqi, capital of Xinjiang, a city of millions where the elegant buildings of the original Uyghur Muslim population are gradually being supplanted by the traditional architecture of the Han Chinese. The city is still bilingual; the signs in the building that houses the special fire brigade are in both Chinese and Uyghur, a Turkic language written in Arabic script.

Xinjiang has nine major coalfields, Zhang Lun tells me, and there are at least forty-four active fires in them. The ITC team has discovered more than a hundred and fifty with its thermal images taken by satellite. Seventy million tons of coal goes up in smoke every year, three times the annual production of the Xinjiang mines. On display at the institute is a large model of the area, with flashing red lights to mark the location of fires.

There is no easy solution. Using his radiometer, Zhang Xiangmin has confirmed that seams of low-grade coal on south-facing slopes exposed to the fierce desert sun all day can easily reach 75°C: the temperature at which coal spontaneously combusts. Unless it's stopped, the fire will eat its way in along the seam. The layers of rock above it are

undermined until the whole lot collapses. Entire villages have disappeared that way. To make matters worse, such subsidence can allow air to penetrate deep into the rock, creating a chimney effect that enables the fire to move further underground. In some places coal is burning two hundred metres below the surface, reaching temperatures of up to 2000°C. Small streams of lava, molten sandstone, drip from the cliffs. Where these natural chimneys come to the surface, the hot fumes leave deposits of pitch, sulphur and ammonium chloride. They almost look like volcanoes. Zhang Xiangmin's research has revealed that some of these natural coal fires may have been burning for up to a million years.

Mining only makes the problem worse, since spontaneous combustion can occur in the fine coal dust it releases. During the Japanese occupation there were efforts to solve the problem by bricking up passageways in the hope of stopping the air getting in. If there happened to be miners left deep in the mines, too bad. After all, they were only Chinese, wrote the English-language newspaper the *China Daily*. Nowadays attempts are made to close up the air vents with loess, to smother smouldering surfaces with a blanket of loess, or to douse the burning coal with water drawn from the rivers, but the fires are often so deep that such measures do little good.

For the period of our research we're housed in a village appropriately named Liuhuangou, or Sulphur Valley. The accommodation is basic, and above ground. Its elderly supervisor was banished here in the 1940s for being a supporter of the Kwomintang. There's no running water; supplies are brought to us from the dam every few days in a barrel atop a cart. At night we walk to one of the coal fires to see the mountain glowing inside. Sometimes flames burst from it.

Mining continues even where the coal is on fire. After all, the steelworks in the village needs feeding: old bicycles, cracked woks, everything that can be melted down is thrown into the furnace, and a constant supply of coal is required to keep it burning.

A mineworker descends the twenty-metre vertical shaft in an empty barrel. He has to fill the barrel with shovelfuls of coal, then stand on top of the load and signal that he's ready to be winched back up. We stand and watch. The miner emerges dripping with sweat, and not only from his hard labour. Then Zhang Xiangmin climbs into the barrel and measures the heat at a depth of twenty metres with his radiometer: 70°C. Under normal circumstances such temperatures are not reached until over two kilometres down into the earth's crust. A pump blows fresh air into the shaft, but it has hardly any cooling effect. The heat is so intense because the coal a little further down is burning. This is as hellish as it comes.

The Uyghur miner goes home to his cave dwelling, with no running water. At least if his house hasn't collapsed because of the coal fire underneath. How does he get himself clean? In the 'steam spring', a kind of sauna built on top of the coal fires. It's a simple concrete building, with long narrow strips of cloth hanging in the doorway by way of appeals to the prophet. Inside the sulphur fumes rise freely to the surface through large square holes in the ground. An hour in there and you feel reborn, as you do in the Solfatara, except that here there's no undressing, nor any chairs or benches. You simply lie on the cement floor. Now I understand why in Chinese Taoist mythology there are at least eighteen hells.

Since prehistory, then, no one has voluntarily lived below ground. The monks in Cappadocia moved underground as they fled Arab and Persian invaders, the Neapolitans sheltered from bombing during the Second World War, the Chinese of the loess plateau had run out of building materials and the Uyghurs of Xinjiang dug caves to live in so that they could work as miners. In all sorts of ways hell was outside, on the earth's surface, and life below ground was safer.

So what kind of earthly hell could have persuaded modern architects to design underground dwellings?

In the village of Vals in Graubünden, Switzerland, Bjarne Mastenbroek and Christian Müller of architecture bureaus SeArch and CMA created a luxury bunker, dug into a steep slope, because local people said the beautiful unspoilt landscape was increasingly being made unsightly by, well, architects with their innovative designs. The valley is famous for its thermal baths, and rules introduced to protect the surrounding countryside state that a wooden replica of every new house must be built on the intended spot to prove it won't look out of place. On this occasion hell was the villagers, local officials and draconian building codes. It's impossible to make a replica of an underground structure, so the architects were given permission to go ahead and build. The house is full of Dutch design and affords a beautiful view of the mountains.

There's no view of the inside of the earth, however, even though that too is undeniably beautiful. Beneath the moraine left by the last ice age, out of which the house has been dug, lie the Bündner schists, splendidly shiny layers of slate, and above it, higher up the slope, are layers of greenstone and limestone, compressed and displaced remains from the depths of the Tethys Ocean, which was once four hundred kilometres wide at this point. From inside you can see none of that. The architects wanted people to look outwards, not inwards. And the irony is that no one lives in the house. You can only rent it, as a holiday home. Even with such luxury on offer, no one would opt for permanent residence under the ground.