0 PREFACE

This document is part of the "**Hârn-Guild-Team**"-project (**HGT**), initiated and coordinated by the **European Hârnmaster Guild** (**EHG**). The goal of the **HGT** is to elaborate all the guilds and societies forming the Hârnic Mangai.

"**Mining**" is a gaming resource for the fantasy world of Kethira, as published by Columbia Games in its HârnWorld/Encyclopaedia Hârnica series. This document focuses on Lythian mining and is based upon Terran history as was in the late medieval period. The main source for this text is:

> *[Agricola 1557] Georgius Agricola: De Re Metallica Libri XII; Basel 1556 (latin), Basel 1557 (german by P. Bech).*

The information found in Agricola's compendium has been translated to the Lythian situation at 720 TR, as described by the official HârnWorld publications. This article describes the most advanced technologies applied by miners throughout all Lythia. While Trierzon and Azerya are the technically most advanced regions of the continent, even there not all machines and methods are known or even applied at the same time (e.g., rope drilling is restricted to eastern Lythia). The application and selection of different technologies strongly depends and reflects the social environment: “Primitive” civilizations don't allow for the support of a highly specialized division of labour. The costs of manpower have a strong impact on the development of mechanisation: If slaves are cheap (as in a militaristic civilisation), there will be no need to develop or apply complicated and expensive machines. The same is true in sparsely populated areas, where the low demand does not justify for advanced mining machinery. The last argument can be fairly applied to Hârn, which has a small population whose low degree of demand only allows for small scale mining.

This article should be accompanied by three other documents "**Mines in Lythia**", "**Metallurgy**", and "**Miners' Guild**". While the first lists details on all known mines of Lythia and the second gives an overview on metallurgy, the third presents detailed information on the powerful Lythian Miners' Guild.

References are marked in **bold capitals**. Important phrases are typed in *italic capitals* where they are explained. Citations are printed in *italic*

Credits

WRITER

Christian Düntgen (xris@xris.de)

MAPS & GRAPHICS

Christian Düntgen

EDITORS

Philip Calkins
Dirk R. Festus Festerling
Bruce A. Hunt
Michael Jung
Neil Milne

COPYRIGHT NOTICE

REFERENCES

Please visit the websites at
www.johalla.de/EHG
www.columbiagames.com
www.kelestia.org

and enclosed by quotation marks, followed by a reference to the source.

1 GEOLOGY

The principles of mining technology, almost all the realted problems and dangers are based on geology. We therefore start with a short overview on the most important geologic terms and concepts. Most of Kethira's geologic knowledge was a byproduct of mining, but by now, only parts of the following concepts have been developed by kethirans. Nonetheless, for a gamemaster, is is always good to know, what principles stand behind “reality”.

1.1 CLASSIFICATION OF ROCKS

There are many kinds of rock, with all kind of different properties. These properties strongly rely on the rocks' origins:

1.1.1 INGENIOUS ROCKS

INGENIOUS rock is formed by molten magma, and is further divided into plutonic and volcanic rocks. Both classes of rock tend to be rather hard to work.

PLUTONIC rocks originate from volcanic underground processes. Cracks and fissures allow magma to ascend into the earth's crust. There is cools down and solidifies. Special cases are rocks, that are molten by nearby magma and resolidifies later on. Intrusive rocks exist in a wide range of forms, including:

- BATHOLITH: large irregular intrusions.
- STOCK: smaller irregular disordant intrusions.
- DIKE: a relatively narrow tabular discordant body with near vertical attitude.
- SILL: a relatively thin tabular concordant body intruded along bedding planes, horizontal attitude.
- PIPE or VOLCANIC NECK: circular or tube shaped nearly vertical body which may have been a feeder vent for a volcano.
- LACCOLITH: concorant body with essentially flat base and dome shaped upper surface, usually has a feeder pipe below.

Examples for plutonic rocks are granite, diorite, gabbro, and peridotite.

VOLCANIC (or ERUPTIVE) rocks emerge from volcanic activities at the surface. Thus, cooling and solidification takes less time than with ingenious rocks. Typical volcanic rocks are rhyolite, andesite, basalt.

1.1.2 SEDIMENTARY ROCKS

This class of rocks originate from alluvial (clay, sand, gravel), volcanic (ash) or limnetic/maritime (chalk, turf, salt) sediments. As sediment deposition builds up, the overburden (or lithostatic) pressure squeezes the sediment into layered solids in a process known as LITHIFICATION. By pressure and heat, the sedimentary strata may be compressed, conglomerated and chemically processed. The term DIAGENESIS is used to describe all the chemical, physical, and biological changes undergone by a sediment after its initial deposition and during and after its lithification, exclusive of surface alteration (weathering). Thus, clay becomes slate, sand becomes sandstone, ash becomes sinter, chalk becomes limestone or even marble, turf becomes coal, tar, mineral oil or gas.

Sedimental rock is easier to work than ingenious or eruptive rock.

Typical rocks of this class are: sandstone, graywacke, sandy slate, clay schist, marl, conglomerate; sand, gravel, clay; mineral salt, gypsum, limestone, calc-spar, quartz, baryte, ore; coal, brown coal, chalk; ash, sinter.

1.1.3 METAMORPHIC ROCKS

METAMORPHIC ROCKS are formed by subjecting any rock type to different temperature and pressure conditions than those in which the original rock was formed. These conditions change the original mineralogy to either other minerals or to other forms of the same minerals (e.g. by recrystallisation).

CONTACT METAMORPHISM is caused by magma that is injected into the surrounding solid rock (country rock). Around the igneous rock that forms from the cooling magma is a metamorphosed zone called a *contact metamorphism aureole*. The formation of important ore minerals may occur by the process of metasomatism at or near the contact zone.

Regional metamorphism is the name given to changes in great masses of rock over a wide area. The high temperatures and pressures in the depths of the Earth are the cause of the changes, and if the metamorphosed rocks are uplifted and exposed by erosion, they may occur over vast areas at the surface.

Typical rock types are: slate and phyllite; schist; gneiss; granulite, some marbles and quartzite; hornfels and skarn.

1.2 Folding/Bending of Stratified Rocks

Native rock will be bended by the tectonic forces within the earth. Thus, the strata may get bend or even folded. This is best illustrated by stratified rocks, as are most sedimentary rocks.

1.3 Faults

Tensions within the earth's crust may result in cracks, breaks and faults within the strata. Such cracks become interesting for miners, as mineralized ground water will circulate through the faults and sedimentate valuable ores (see "veins" below).

From faults may also arise harm to a mine, as natural clefts may are a major source of water inflow into a mine. If a water bearing cleft is accidentally cut, a sudden inflow may flood the adjacent tunnels.

1.4 Deposits

Deposits are areas, where interesting minerals somehow have been concentrated to a degree that makes exploitation considerable to miners. Deposits have varying size, forms and richness, depending on their geologic genesis and history.

1.4.1 Beds/Strata

Bed or *stratum* is a term for a kind of deposit, that usually originates from sedimentary processes. Coal is usually found in beds, rock salt and various other minerals precipitate on the ocean's bed, e.g. near the inflow of streams. Beds/strata are characterized by covering large areas, having a much lesser hight than depth and width. Some beds cover areas of thousands of square kilometres, but just have a height of a few centimetres.

1.4.2 Veins

Veins (or *lodes*) usually develop from cavities within the earth's crust, originating from disturbances as vaults, fissures, fractures or volcanic chimneys. Magma or mineralized waters circulate within the cavity and cool down while approaching the surface. Dissolved minerals precipitate in order to their fusibility/solubility and adhere to the walls of the cavity. Thus, veins

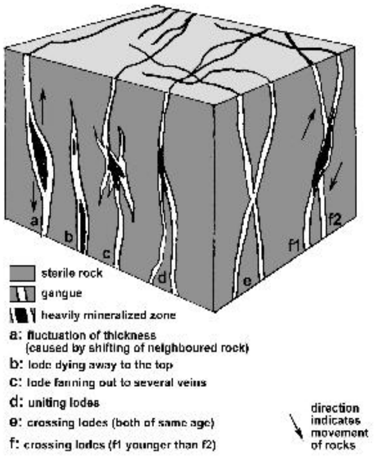

Figure 1: Typical lode constellations.

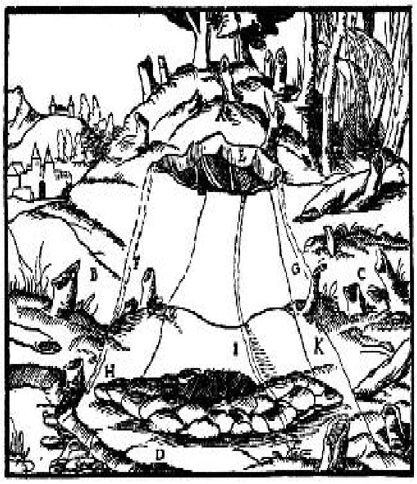

Figure 2: Storey.

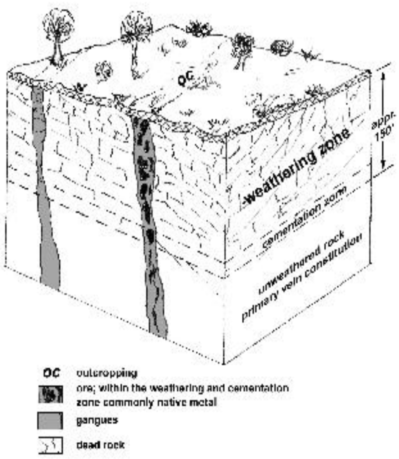

Figure 3 Typical top ending of an ore lode.

usually consist of several layers of different minerals, rich mineralized rock as well as *GANGUE ROCK*. Additionally, the proximal rock may be *IMPREGNATED* with different minerals.

Veins are often found in groups, forming parallel vein systems. Veins of a certain system show an equal *RUN OF LODE* (line formed by the surface outcrops of the veins) and *LINE OF LODE* (slope, angle between lode and surface).

Lodes may be influenced by later geologic processes (see **FIGURE 1**).

Near their surface outcrop, veins are usually altered by chemical and physical erosion (*WEATHERING*), often resulting in a concentration of valuable minerals (eg. native metals) within the so-called *WEATHERING ZONE*., just at the top ending of the lode (usually near the groundwater level and not deeper than 30 meters; see **FIGURE 3**).

1.4.3 STOREYS

When magma ascends into higher parts of the earth's crust, it may press itself between strata, expanding them and forming a compact mass when cooled down and solidified (see **FIGURE 2**). Thus, *STOREYS* are always formed by ingenious rock.

1.4.4 PLACER DEPOSITS

Native rock is attacked by change of temperature, wind, water and air. Those physical and chemical processes result in *WEATHERING* and finally in the *EROSION* of the rock. Streams wash out the debris and carry it along on their way to the sea.

When the current of the stream slows down, the carried along minerals settle down. Dense materials, as native metals and ores, sink down first, light materials as sand or loam, last. Other situations resulting in *SEDIMENTATION* may rely on a sudden change in the water's chemistry (eg. of the pH-value, presence of certain precipitants). Carried along solutes may *PRECIPITATE* and sedimentate on the ground of the river.

Waterfalls, cataracts, whirlpools, crevices in the bedrock of river channels and river bends are places with a natural graduation of the river sediments, due to the strongly varying speed of flow. Dense materials (as native metals or high graded ore) will be concentrated in the sediments at such places and form deposits called *PLACERS*.

Typical minerals recovered in placers are tin, gold, platinum, diamonds, titaniferous and ferrous iron sands, gemstones (rubies, emeralds, sapphires), and abrasives (rutile, zircon, garnet, monazite). All are minerals of high specific gravity and physical toughness. Also, under the conditions present at the earth's surface, they are chemically inert.

Placers are found in various forms and places:

1. *RIVER/STREAM PLACERS*
   This kind of deposit is found on the ground of a river or stream.
2. *RIVER TERRACE/BENCH DEPOSITS*
   In plain areas, streams and rivers will meander and change their beds regularly. Thus, a large area is covered with the river sediments, not only the actual river bed. Large rivers may create enormous strata of sediments over millions of years.
3. *BEACH/MARINE PLACERS*
   Along the shore of the sea or large lakes, preexisting or currently forming stream placers may be transformed to beach placers following the coastline as an result of the action of shore waves on the original placer.

Due to changes of the topography, all three kinds of placer deposits may get displaced, and thus their connection to water may not be obvious later on.

1.5 ORIENTATION OF DEPOSITS

Together with the deposit's *THICKNESS*, The *ORIENTATION* of a deposit is often used as a major characteristic. The orientation is noted as the deposit's dip, the dip's direction, and the strike.

1.5.1 DIP

The angle between the horizontal plane and the prolonged surface of the deposit is called its *DIP*. Depending on the degree of dipping, the miner differentiates between

- vertical (80-90°),
- steeply dipped (45-80°),
- flat/gently dipped (10-45°), and
- horizontal (0-10°) deposits.

Additionally, the *DIRECTION OF THE DIP* is given, which gives the direction to which the deposit declines.

1.5.2 STRIKE

The azimuth of the intersection of the prolonged surface of a deposit with the earth's surface is called its *STRIKE*. The strike is always perpendicular to the dip.

2 EXPLORATION

Figure 4: Prospecting in a riverbed.

Before a mineral deposit can be exploited, it must be spotted. This is, what a miner calls *exploration* or *prospecting*. We now consider the different methods applied to prospect a deposit.

2.1 Soil Hue

Some minerals can be easily identified by their characteristic colour. Portions of the minerals are solved and washed out by natural water. Based on the capillarity of the soil, they ascend to the surface and concentrate in the adjacent soil, e.g. near the top of an ore lode, and colour it thus indicating the strike of the lode. Rich deposits they may also colour the sediments of nearby water courses or the water itself. Iron can be indicated by brown, copper by blue or green colourings.

2.2 Indicator Plants

Most ore minerals are toxic to living organisms. Soils with high concentrations of metallic ions (especially copper and lead) are only suitable to specially adapted plants, resulting in a characteristic vegetation on top and below of such ore deposits.

2.3 Arcane Exploration

On Lythia, there exist various forms of magic (spell/rituals), that enable their wielder to find deposits of certain minerals, as ores or gems. Especially Khûzan Jmorvy Shek-Pvar are said to have and use such knowledge. A more popular form of exploration is the use of the *divining rod*. This is a a thin crotched twig or wire used by talented explorers called *dowsers*.[1] The dowser walks over the prospected area with two endings of the rod held in both of his hands, the third end carried horizontally above the ground. It is said, that the rod indicates the location of ore deposits or subterranean water by “striking out” to the ground or to the sky. Though there is no scientific explanation to this phenomenon, it is believed, that the rod acts as a kind of focus for a specific psionic talent of the dowser. While a talented dowser may become a sought prospector within the Miners' Guild, he may be accused of witchcraft on the other hand. Shamans of Lythia's tribal nations have been reported to enter the spiritual world to interview spirits in search for water or mineral deposits.

Figure 6: Dowser.

Figure 5: Exploration with a divining rod.

2.4 Surface Cuts/Trenches

Once a promising area is determined, *trenches* or *surface cuts* may be dug to spot heavily mineralized rock or veins. When such a deposit is found, prospecting will just turn into *opencast mining*.

---

[1] “Dowser” is also treated as a “Minor Talent” in the HârnMaster Gold 2.1 Game Master-Edition.

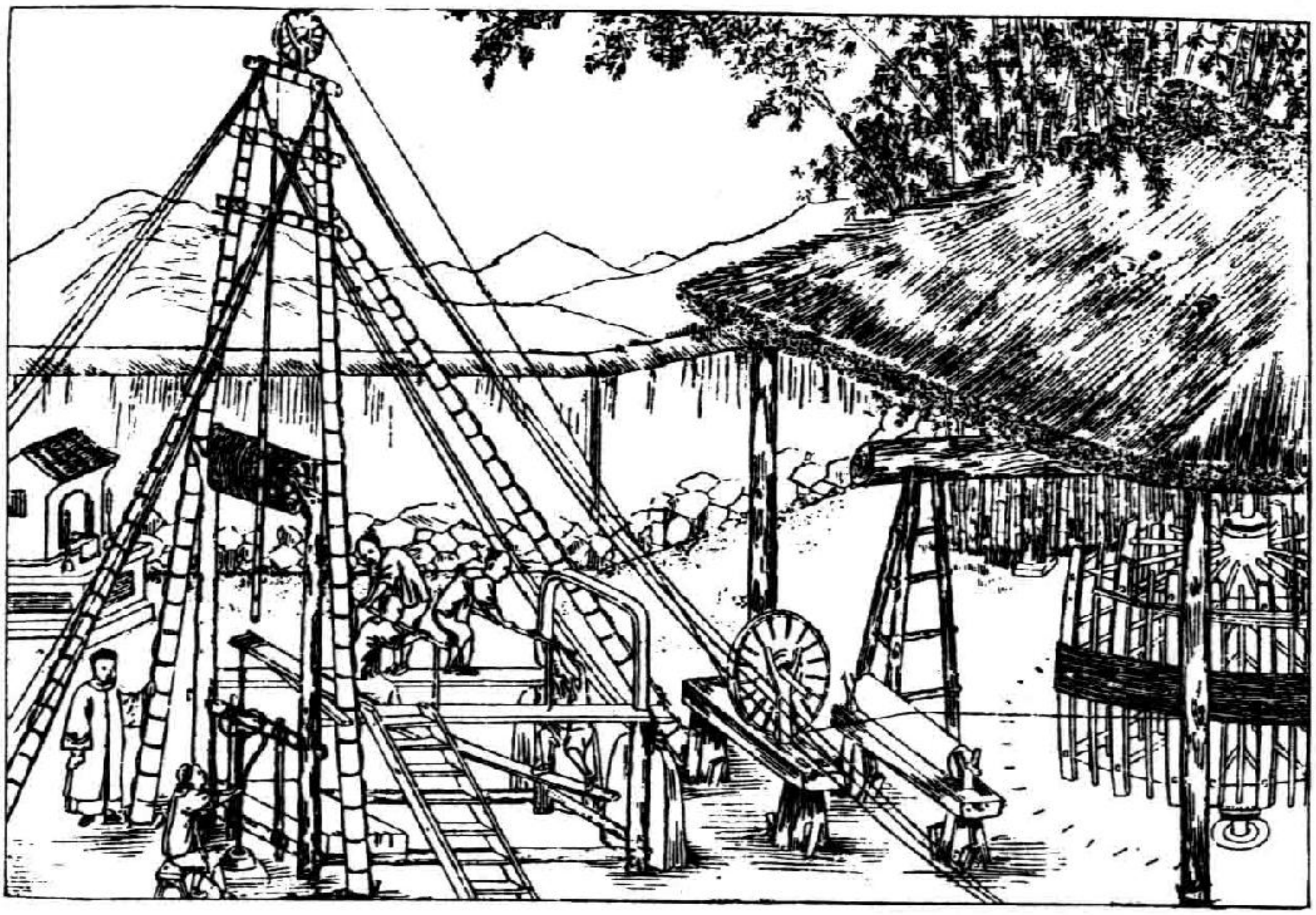

Figure 7: Rope drilling in eastern Lythia.

2.5 ROPE DRILLING

Drilling is practised in eastern Lythia, namely in Diramoan, Jankoria, Chomsun, Kaneum and Shoju. A *DRILLING ROT* made of bamboo shafts is sharpened at its end and attached to a rope. For drilling in solid rock, a massive and sharpened *CHISEL BIT* it attached to the lower end of the drilling rod and the rod is additionally weighted down with lead. The drilling rod is lowered by the *DRILLING ROPE* from a *DERRICK* into the *DRILL HOLE*. By lifting the heavy rod and suddenly releasing it, the chisel bit loosens the rock at the bottom of the drill hole. Complicated rope-and-lever systems are used to automatize this steps. The *DRILLING DUST* can either be lifted within the drilling rod (if it is hollow), or must be washed out with water. The drilling dust can be examined to determine the quality of found ores.

Using this design, up to 500 metres of depths can be reached at a rate of 1 metre per day.

In Diramoan, drilling is also used for general well construction, especially to access salt rock or brine. Even rock gas is exploited by drilling holes and is often used as fuel for the refinement of brines and rock salt by cooking and drying.

Drilling is one of the few human inventions in mining and is unknown to the Khûzdul (or at least not applied by them).

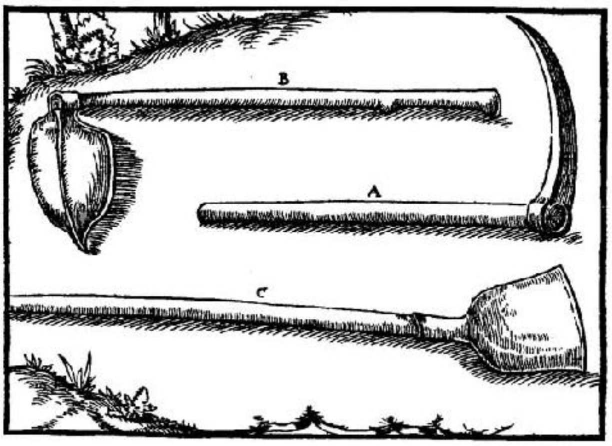

Figure 8: Tools for filling - pick (A), scraper (B) and scoop (C).

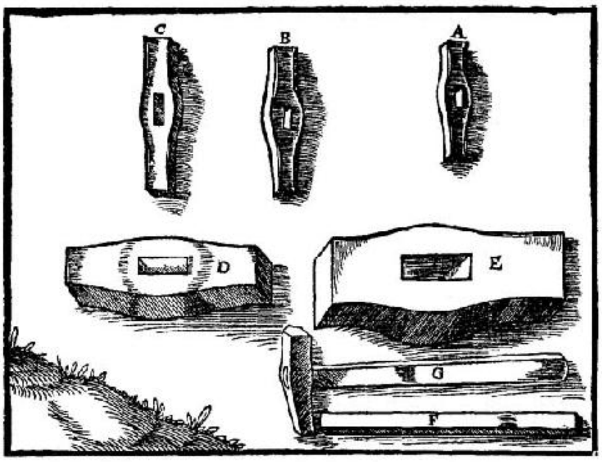

Figure 9: Mallets of different sizes (A - E), wooden handle (F), mallet mounted on a handle (G).

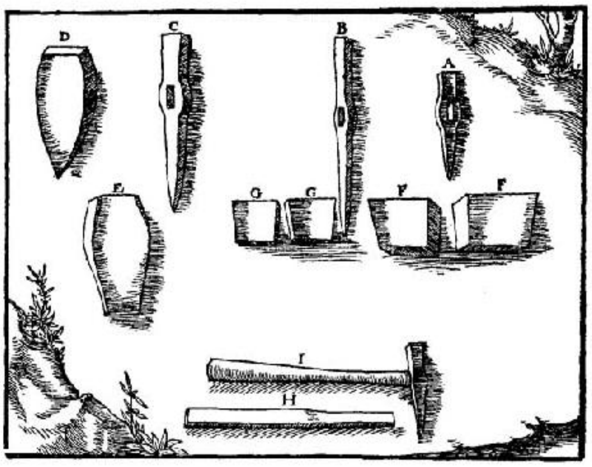

Figure 10: Different chisels (A, B, C), various kinds of wedges (D, E), nog (F), shims (G), handle (H), chisel mounted on a handle (I).

3 MINING TOOLS AND METHODS OF WORKING

In this section, we will introduce the different modes of operations and depict the applied tools.

3.1 Filling

Filling is the term for any kind of work concerning loading or unloading of loose rocks or other material. *Scrapers*, *pick* and *scoop* are the tools used for filling. Underground, fillers can move 12-18 tons of load per shift (of 8 hours). During a daylight-shift of 12 hours, a worker can lift 12 cubic meters of sand (20-22 tons of weight) to a height of 1.5 meters. Filling-tools are shown in Figure 8.

3.2 Cutting

Cutting is the work of loosening rock from its native bed. The tools used for cutting depend on the strength of the rock. The rock's *strength* depends on three factors: *hardness* (causing abrasion of used tools), *solidity* (resistance against pointed tools) and *cohesive strength* (resistance against cutting from the bounded rock). Miners distinguish between four grades of strength:

1. *loose masses* (winnable with bare hands: sand, rubble, mine rock)
2. *soft rock* (winnable with shovel or spade: clay, loam)
3. *crumbly rock* (winnable with the pick: soft coal, clay schist)
4. *solid rock* (winnable only with hammer and chisel: hard – limestone, sandstone; very hard – granite, conglomerates, quartzite, basalt)

Cutting solid rock is a difficult and hard work. The tools used for cutting are shown in **Figures 9 - 11**. The quality of the tools is significant for the success of the work, and the safety of the cutter. Picks, shims and wedges are made of high-quality, tough cold-forged iron with carefully sharpened and hardened points. As cutting through hard rock results in quick abrasion and blunting of the tools, cutters always take a set of

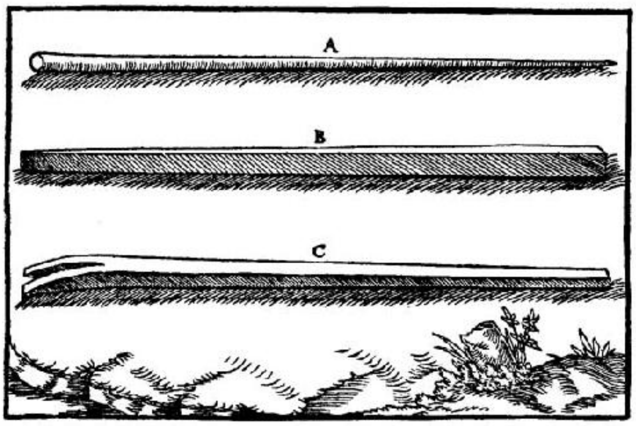

Figure 11: Different forms of crowbars (A – C).

several chisels with them, when entering the mine. After the end of their shift, the tools are handed over to a mine smith for maintenance – mainly sharpening and hardening the points. In rocksalt mines, iron is replaced by bronze, horn or wood, due to iron's high degree of corrodibility.

(Different forms of crowbars (A – C); Agricola 1557.) Most cutting is performed by driving a chisel into the rock by hitting its blunt back with a heavy mallet (see **Figure 12**).There are various patters for cutting rock: (1) beginning at the bottom of the face and then ripping down the rock from below; (2) beginning at the centre of the face and then extending towards the sides; (3) beginning at the top and extending downward. Methods (1) and (2) are both used for small galleries, while method (3) is used for drifting large galleries, especially for drainage galleries, which tend to be very long and thus raise need for more than one worker driving the gallery simultaneously in parallel or one above the other. Benefiting from natural or artificial cracks and cut notches, *wedges* penned between wooden *shims* and *crowbars* are used to *rip the wall/ceiling*, or to *dint the floor*.

Skilled miners can drive a gallery (0.5-0.8 meters wide and 1.5-1.8 meters high = 1.0m^2) through solid rock by a rate of 6.0 meters per month, when cutting continuously (e.g., in two 12h shifts per day). Typical shafts (rectangular with 1.0 meters of width = 1.0m^2) can be *sunk* by a rate of 4.0 meters per month through solid rock. Alternatively, shafts may be driven upwards, or *raised*, slightly faster as hoisting the debris is not necessary in this case. Both rates are based on continued work.

Advance Rates (per 1m^2 solid rock)	
Gallery	*0.20 m/day*
Shaft	*0.14 m/day*

Regarding this slow progress rates, for cutting long galleries – such as **draining galleries** – methods are employed to increase the rate of construction. The first one is the *two-end-method*, i.e. two adits are excavated from both ending points of the planned gallery, with the intention of meeting in the middle. This method is also called *mining from two directions* or *connecting leadings*. It halves the construction time, but difficulties arise from transferring the correct directions underground, thus raising the risk for both cutter-teams of missing each other underground. To cope with this difficulty, both sections are driven in such a way, that their projections meet with an obtuse angle. When a survey of both sections results in a total length near the assumed total length, cutting will be ceased in one of the sections, and work concentrates on the second one. If the surveyor is in doubt about the direction where to find the ending of the first section, he will continuously change the direction of the second section, thus forming a “hook”, and finally ensuring the connection with the first section.

For long tunnels, a special method, the *qanat-method* or *light-hole-method* is applied. First, several auxiliary shafts (called *light-holes*) are lowered along the surface projection of the planned tunnel down to the calculated depth of the gallery at that position. Then, from each shaft, the intended gallery is cut to both directions with the intended inclination, until the adits from neighboured shafts meet. This method is a generalized form of *mining from two directions*, and while

Figure 12: Cutting with chisel and mallet.

minimizing the risk of missing each other, it additionally increase the advance rate by far, if sufficient workers and a skilled mine surveyor are at hand. Additionally, the auxiliary shafts help increasing ventilation and limiting haulage of debris and running-in periods for the cutters.

Generally, to minimize the risk of gallery drifting, construction is started by narrow inclining *EXPLORATORY DRIFTS*, beginning several feet above the intended floor of the final gallery. When all gallery sections got connected, the floor is dinted and the walls are ripped to generate the intended profile and declination.

3.3 FIRE SETTING

A common method to loosen hard rock is to pile up dry wood next to the face of the wall and set it on fire. The heat of the flames will crack parts of the rock and weaken its cohesive strength. This effect can be enhanced by fastening the cooling by sprinkling cold water or vinegar onto the hot rock. The main problem with this method is consumption of fresh air (oxygen) and the production of poisonous smokes. The dead air must be removed before work can be taken on again (see: **MINE VENTILATION**). Additionally, the problem of starting an underground fire must be faced.

4 MACHINE DRIVES

Various types of machines are used to provide power to mechanisms like winches, pumps or bellows. As transmission of kinetic energy is problematic due to losses by friction, most drives are installed in proximity to the powered machinery powered by them. Most of the mentioned machines must be considered as "high tech" throughout Lythia. They can only be designed, constructed and operated by experts, as millwrights or specialized miners, resulting in extremely high costs. A pumping system may cost as much as 800 pounds of silver.

For more technical information on Hârnic machine drives, prices and rules, please read the instructive article "**MILLERS**" by *Nicholas Lowson.*

Figure 13: Fire setting, ventilation door.

4.1 GENERAL CONSTRUCTION OF MACHINES

Most machine parts are constructed from wood, e.g. frames, axle-trees, gear wheels and levers. Enforcements are usually crafted from iron. Sometimes, metal is used to reduce friction, especially within bearings: the terminal parts of the axle and the bearing brackets are often sheeted by metal. Gears and bearings have to be maintained and lubricated regularly and carefully (with grease or water) to avoid overheating, abrasion and malfunction.

BRAKES are used to stop movements, and rely on the friction of a brake wheel mounted on the axle, and and a pair of brake shoes that can be pressed against the brake wheel by a system of levers.

4.2 HASPS

Hasps have levers providing grip to the hands of workers, who use the power of their arms to move an attached central axle. Improvements are mechanisms that ease the operation, e.g. by applying counterweights (see double acting whinch, Figure 47), or saving absorbed energy (flying wheel, Figure 39).

4.3 TREADMILLS

While hasps use the power of men's arms to operate winches or other machines, treadmills enable the worker to profit from his stronger leg muscles. There are two basic forms of treadmills: The first (Figure 47) is a circular wooden platform attached to the axle of the winch. The platform has radially fixed wooden strips for a better grip of the workers' feet. The workers prop themselves on wooden bars while rotating the platform. The second type (Figure 52) has the form of a wooden cylinder, with the worker running on the inside of its mantle. With a treadmill, a worker can lift loads as heavy as ten times his own weight.

4.4 HORSE POWERED GINS

This machines (Figure 38) have a vertical axle with one or more horizontal crossbeams attached to it. Horses or mules are harnessed to the crossbeams and circle around the axle. To reverse the direction of the gin, the animals have to be changed, unless a (complicated) gear is used. Thus, animal powered machines are preferred for powering continual scoops, that have no need for changing directions.

The support of animals (stabling, feeding and care) is expensive and difficult or even impossible in most underground locations.

4.5 WATER WHEELS

When water is available, it can be used to power any kind of machines. A waterwheel uses the potential energy of water, so the height difference of the inflow and the outflow of the working water – the *HEAD OF WATER* – is crucial to its operation. There are overshot, undershot and middleshot waterwheels. *OVERSHOT WHEELS* require an inflow above the wheel's vertex and maximize the work provided by the water. Typical overshot waterwheels with a diameter of 15' have a net power of 5 hp and a degree of efficiency up to 60%. The relation of working water to pumped water is 18:1; this means, it takes 18 units of water powering an overshot waterwheel to power the pumps to lift one single unit of water.

Machine Drives	
Type	*Effective Power*
Treadmill	
per man	0.08 hp
Gin	
per ox	0.24 hp
per mule	0.18 hp
per man	0.06 hp
Waterwheel	
overshot	0.18 hp/ft
undershot	0.12 hp/ft

Power of machine drives, according to "Millers" by Nicholas Lowson.

The maximum diameter for a single overshot waterwheel is 17 meters. *UNDERSHOT WHEELS* only use the current of flowing water, making profit from minimal differences in height between inflow and outflow. The trade-off is a drastically lower efficiency (less than a third compared to overshot wheels, or equal to an efficiency of 20%). *MIDDLESHOT WHEELS* average the advantages and disadvantages of both base types.

Three main problems arise with using waterpower. First, the continual supply of working water must be guaranteed. This can be ensured by constructing artificial *RESERVOIRS* by means of *DAMS*. Second, a waterwheels can only exploit a height difference equal to its diameter. It the difference is higher than 15', multiple wheels might be arranged in a chain (Figure 54). Third, the working water must be lead to the wheel and drawn off later. Thus, waterwheels can only be installed above the lowest level of natural drainage within a mine.

These three problems result in the need for a carefully planned, constructed and maintained system of dams, canals, and drainage galleries, usually overseen by specialized *HYDRAULIC ENGINEERS*.

Additional problems arise from the large space for hydraulic engines. *MACHINERY ROOMS* for the wheels, *GULLETS* – tunnels for the *WHEEL RACES* (water inflow), *TAIL-RACES* (water outflow) and interconnecting galleries between single wheels – must be carved from the rock, consuming large amounts of time and money.

As waterwheels can run without human observation for a while, a bell (*MACHINE BELL*) may be attached to the machine and its constant ringing will indicate the correct operation of the machine. When the sound of the bell stops, the machine stopped its operation and thus something is obviously going wrong.

4.6 WIND WHEELS

Theoretically, wind wheels could be used to power mining machines. But due to the impossibility to control the wind and to its unsteadiness, most miners regard them useless to drive their pumps and hasps.

They are neither used to blow furnaces (for the mentioned reason), nor to power stamping mills, as windmills require exposed locations, usually atop of hills, where water is unavailable and the additionally uphill transport of the ore is regarded a waste of time.

5 EXPLOITATION

Exploitaition means to work off the target mineral from its natural position. Over the times, miners have developed and refined various methods to exploit mineral deposits. Which method is the best choice, totally depends on the actual case: the available technology and working resources, the deposit's characteristics, environmental conditions etc. Sometimes, especially in rich and old mining districts, observers may find a combination of different exploitation methods. **Figure 14** gives a brief overview.

5.1 Bench Stoping/Underground Benching

Bench stoping is a method to work steeply inclining deposits. It is the usual method to exploit surface deposits in opencast mining. An outcrop of the deposit is simply followed stepwise into the depth, starting with the floor (also called “*bench*”) and leaving an open pit. When the first “step” (called *bench* or *stope*) has been cleared, a second stope is begun. If enough workers are at hand, several stopes can be worked simultaneously. As the richest ores are usually found within the weathering zone, reaching down for approximately 30 meters, this is a profitable standard method. With increasing depths of the pit, problems with mine waters and stability increase, and underground mining is preferred. In underground workings, benching creates dip workings, resulting in problems with drainage. (See **Figure 14**, methods 1. and 2.)

5.2 Back Stoping/Overhead Stoping

While benching is exploiting an deposit downwards from the floor, its contra position, this is starting to win minerals from the roof (or back) upwards, is called *backstoping*. Advantages of stoping are: ease of dewatering of the working, ease of transport of loosened rock to the haulage drift. As the roof is ripped while winning the minerals, scaffolds needed to reach working face. The scaffolds can be removed to save material. To minimize haulage and hoisting, the won minerals are usually classified and only the more valuable compartment is passed by the *dropholes* for further processing, while the debris is used for *filling* of the excavation below the working level. (See **Figure 14**, methods 3. and 4.)

5.3 Longwall Face Mining

While stoping rips rock from the roof, with *longwall face mining*, the mineral is won by cutting horizontally through the rock. The cut minerals are classified and the debris is used for filling the excavation, thus enabling the miners to stand on the debris while cutting. (See **Figure 14**, method 5.)

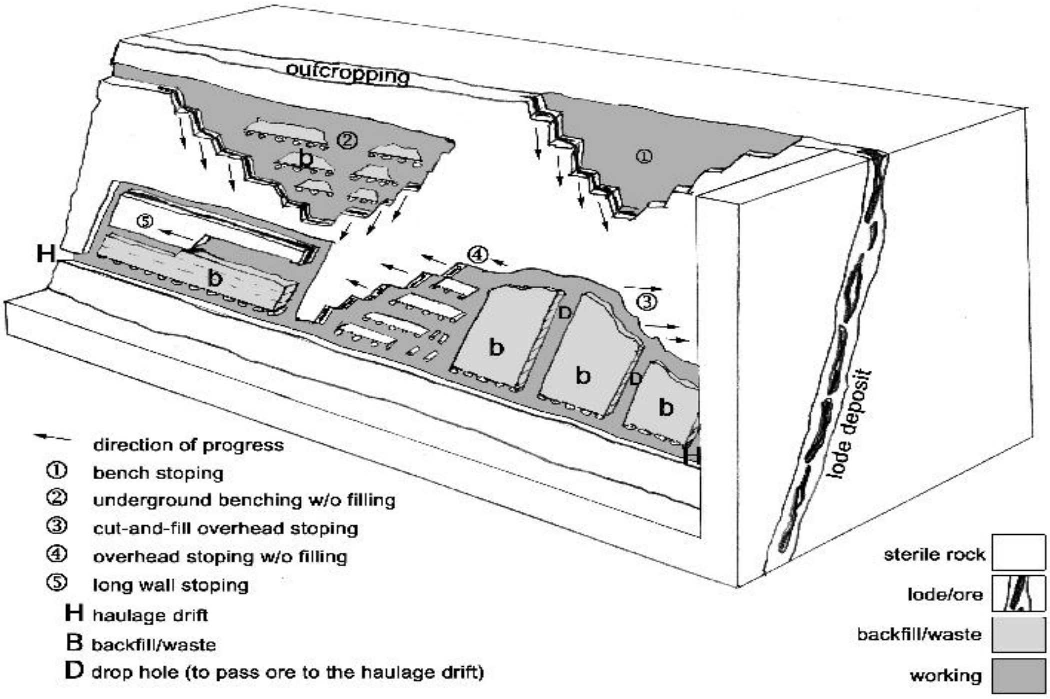

Figure 14: Five different methods of exploitation

5.4 BOARD-AND-PILLAR METHOD

For exploitation of massive deposits, as thick beds or storeys, the *BOARD-AND-PILLAR METHOD* is applied. The mineral is cut with leaving rock pillars unharmed in regular distances to prevent the rock from collapse. This method leaves huge excavations, that may collapse and inflict huge sink-holes at the surface, even centuries after the mine has been abandoned.

6 WORKINGS

All underground workings must be constructed and maintained by hard work, and so miners tend to minimize all underground rooms to the absolutely necessary dimensions, which basally rely on the function of the excavated rooms. So, underground constructions tend to be narrow and uncomfortable. Often, upright walking and passing each other is impossible, and the miners have to crawl through the drifts.

6.1 GALLERIES

Excavations of mainly horizontal extension are called *GALLERIES* or *DRIFTS*. The top of a gallery is called *ROOF* or *HANGING WALL*, its bottom *FLOOR*, *FOOTWALL* or *BENCH*, its flanks sidewalls, wall faces or simply faces and the short wall at its end is called *BREAST*, *ROADHEAD* or even *FACE*. Galleries are usually supported by timbering to prevent cave-ins (see "**PIT ARCH**"). Additionally, they may be fitted out with a *FLUME*, a dewatering canal cut into the floor, with *WALKING PLATFORMS*, covering the flume and easing walking and transport. In main haulage galleries, *TRACKS* for trucks or mine railways (see "**HAULAGE**") are common.

Galleries usually allow for a mining radius up to 180 meters around a central daylight shaft or mine entry. Further off, workings are only driven with strong reason, as longer underground distances raise problems with dewatering, ventilation and haulage.

6.1.1 DEVELOPMENT WORKS

To reach areas with deposits of winnable ores, tunnels must often be cut from the surface or a shaft. These galleries are called *DEVELOPMENT WORKS*.

6.1.2 DRAINAGE GALLERIES

To drain a mine from mine waters, slightly inclining tunnels are cut. The drainage gallery collects mine waters and leads them out of the mine. For more information, see **DEWATERING**.

6.1.3 PROSPECTING DRIFTS

Small galleries are driven into the rock to explore their content of winnable minerals or to search for a vein or stratum. Such *PROSPECTING DRIFTS* are narrow and low, usually only 0.50 m wide and 0.60 m high.

6.1.4 LEVELS

Main galleries that are connected to shafts are called *LEVELS*. Levels are usually dimensioned so that miners can easily walk upright and pass each other. *LEVEL* is also the term for a system of interconnected *CROSS-MEASURE DRIFTS* and *CROSS-DRIFTS* that covers a depth of 50 to 100 meters.

6.1.5 CROSS-MEASURE DRIFTS

On each level of a large mine, a mining field may be divided into several departments by parallel galleries called *CROSS-MEASURE DRIFTS*. These drifts act as main haulage tunnels and are interconnected by *CROSS-DRIFTS*.

6.1.6 CROSS-DRIFTS

The *CROSS-MEASURE DRIFTS* (Figure 15) are interconnected by smaller galleries, called *CROSS-DRIFTS*. Cross-drifts are the base for the winning of minerals (see "**EXPLOITATION**").

6.2 SHAFTS

Excavations of mainly perpendicular extension are called *SHAFTS*. They can be created top-down (*"TO SINK A SHAFT"*) or bottom-up (*"TO RAISE A SHAFT"*). The first method is primarily used or for *SURFACE* or *DAYLIGHT SHAFTS* (who reach up to the surface), while the second is popular with staple shafts.

Surface shafts often form the main access to a mine. Therefore, shafts must be carefully protected against flooding, rock thrust and cave-ins. To prevent the shaft faces from collapse, the shaft is carefully timbered wherever it seems necessary. Additionally, the rock within the immediate neighbourhood of a shaft is regarded as a protected area and excavation in this area is restricted to a minimum.

The upper terminus of a shaft is called SHAFT MOUTH. It is usually fitted out with a wooden frame and and a scaffold to operate a winch and to give access to a ladder descending into the shaft. This scaffold is called PITHEAD or PIT BANK. To protect a surface shaft from weather, its pit bank is usually covered by a SHAFT HOUSE. Usually, it comes in form of a narrow wooden hut; only more important shafts have larger shaft houses made of stone. Machines for hoisting or pumping may be installed within the shaft house.

When a surface shaft is sunken down, the debris is heaped around the shaft mouth, primarily due to avoid additional labour, but secondary the SHAFT HEAP effectively raises the shaft mouth and thus protects the mine from flooding.

Where a shaft interconnects to a gallery, a SHAFT STATION may be established. This is a place to fill minerals and debris into hoisting tons or skips and to receive material lowered through the shaft into the mine, e.g., wood for mine timbering. The shaft station is a dangerous place, as things tend to drop from above or may drop into the lower part. Thus, galleries are usually connected to a shaft by means of a short drift. Otherwise, the shaft is bypassed by additional drifts. In large mines, each shaft station is overseen by an experienced pitman called BANKSMAN. He is responsible for the proper filling of the hoisting tons, operation of the winches and compliance with the security policies within the shaft. He communicates with the other banksmen by means of calls and ringing the SHAFT BELLS.

The lowest part of a shaft is called its BOTTOM. Sometimes, the bottom forms a pumping sump, more often it is just the lowest shaft station.

Shafts may have a dedicated purpose (hoisting shaft, ventilation shaft, travelling shaft), but usually they have more than one function. To enhance the security for the miners, the shaft may be vertically separated into several SHAFT COMPARTMENTS by wooden frames: While one compartment is outfitted with a ladder and used by travelling miners, a second may be used for hoisting or pumping rods.

Hoisting shafts usually have a depth of not more than 90 – 105 meters, mainly due to the limited load-bearing capacity of used ropes and chains. While ropes, usually made of hemp, are light and sturdy, they are prone to abrasion and thus expensive. Iron chains are strongly resistant to abrasion but have a high net weight, restricting their practical use. While for ropes, the maximum depths is around 500 meters, that for chains is only 400 meters.

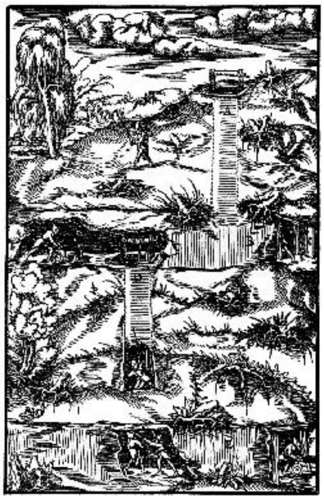

Figure 15: Cross-drifts and shafts. Shafts (A, D), cross-drift (BC), Adit (D), adit entrance (E).

Figure 16: Inclining shafts.

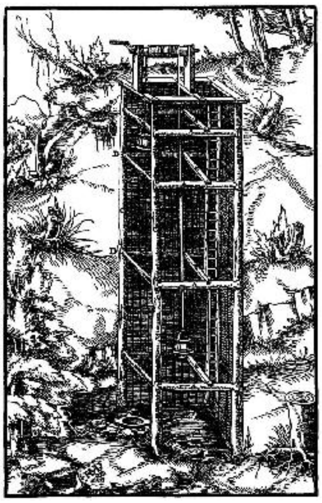

Figure 17: Shaft timbering. Posts (A), compartment separators (B), crossbeams (C, D).

Figure 18: Vertical shafts.

6.2.1 Inclined Shafts

When a ore vein crops out to the surface, miners will follow it into the earth. As most veins show some degree of inclination, the resulting excavation becomes a *inclined shaft* (Figure 16). From this shaft, galleries are cut into the flanks of the shaft to access neighboured deposits.

Miners usually prefer inclined shafts to vertical shafts, as valuable minerals can be won while sinking the inclined shaft, while the sinking of vertical shafts usually will produce lots of overburden, but few ore. Sometimes, vertical and inclined shafts are combined.

6.2.2 Vertical Shafts

Vertical shafts (Figure 18) are preferred for hoisting, as friction is less than with inclined shafts. Also, vertical shafts are shorter than inclined shafts when a certain depth must be reached. The disadvantage of vertical shafts is that their cost usually cannot be reduced by winning ore while sinking the shaft, as veins or beds are usually inclined.

6.2.3 Staple Shafts

Shafts, that don't reach up to the surface are called *staple shafts* or *blind shafts*. They are useful for hoisting, ventilation, pumping and as manways. They often connect *dip workings* to higher levels of the mining. Staple shafts can be both, inclined or vertical shafts.

6.2.4 Stairwells

One way to give access to mines or to connect different levels are *stairwells*. The usual design is a central shaft with the stairs along its perimeter. The stairs are either hewn from the native rock, or are timbered on wooden scaffolds, fixed to holings in the shaft walls. Another design is favoured by the Khuzan miners and masons, who connect short inclined shafts rectangularly and hew steep steps from the shafts' floors.

6.3 Hushing

Loose masses (as found with pacers) and soft rocks can be worked by hushing water against the rock face. The water is collected in a artificial pool at some high place. When enough water is collected, locks within the dam are opened wide and the water is lead through canals against the face wall, or – even better – from high above directly onto the deposit. The water's kinetic energy results in high pressure attacking and eroding the rock. The water and loosened minerals will then be drained through canals and lead through sluicing-boxes to separate valuable minerals or metals from useless debris.

Hushing makes a triple use of the working water: First, for driving; second, for transport; and third, for graduation. This makes hushing the most effective way of mining known on Lythia (see **Table 1**). Though, hushing is limited to large placer deposits in areas with enough water and sufficient height differences.

6.4 Hydraulicking

While hushing uses sudden flushes of water, hydraulicking works with continual flow of working water. The water is directed onto the surface of a placer deposit (often river terrace/bench deposits) and will erode the mineralized stratum.

Figure 19: Drought capturers and air partitions.

Figure 20: Ventilation caps.

Figure 21: Ventilation with waved sheets.

Figure 22: Drought capturers and air partitions.

The water is then directed through canals (*washing galleries*) with small artificial barriers to graduate the carried-along rock and minerals.

When applied to fine-grained, unconsolidated material from placers, tailings, alluvial or luteritic deposits, hydraulicking is relative efficient compared to other methods of working (see Table 1). It can only be applied in inclining areas with sufficient water.

6.5 River Mining

River curves act as natural graders for river sediments. Heavy minerals and native metals are deposited on the ground of the bending river, while sand and light minerals are washed away by the natural current of the river. Miners gain access to these deposits by diversion of the stream and draining the river's bed. This is done by cutting the river curve by means of a branch canal and damming the river upstream and downstream of the curve. The heavily mineralized sediments can then be easily won and graduated.

Method	Cost
washing pan	400
washing cradle	100
washing gallery	24
long tom	20
hushing	1.4

Table 1: Relative cost of different washing methods.

6.6 Leaching

Some water-soluble minerals can be won in an easy and efficient way: Water seeping through mineralized rock is collected and physical (vaporization) or chemical methods (precipitation) are used to separate the mineral from the water. The method is most often used to win salt from natural brines, but it can also be used to win metals, like copper from vitriols. If the natural inflow of water is insufficient, it can be substituted by leading water into the mineralized area.

Leaching can only be used to win certain minerals, but may be efficient even with mine waters or seeping waters from waste tips of abandoned mines. Crucial to the efficiency of leaching is the availability of water, precipitants or fuel to separate the solute from the water.

Figure 23: Winning vitriol by evaporation of mine water.

Many lythian people apply leaching to win copper from sulfidic copper ore. They break the ore into pieces, pile it into heaps and allow water to seep down through the heap. The water is collected. It contains dissolved copper sulfate. By appying iron to this solution, copper is precipitated, while iron dissolutes into the water.

Figure 24: Ventilation by usage of bellows and air ducts.

7 MINE VENTILATION

Within a mine, oxygen is consumed by the workers, by fires (for lighting and fire setting), by micro organisms (who permanently decompose organic materials as the wooden timbering) and chemical reactions of the rock. Instead, poisonous gases (carbon dioxide, carbon monoxide, methane, radon) are exhaled and dust is generated by the working. Miner call all these unhealthy gases *damps*. *Firedamp* is nearly always methane (CH_4), a highly inflammable gas and explosive when present in the air in a proportion of 5 to 14 percent. So-called *firedamp explosions*. are a not uncommon danger in coal mines. *White damp* is the miners' term for carbon monoxide (CO), which is a particularly toxic gas. As little as 0.1 percent can cause death within a few minutes. It is a product of the incomplete combustion of carbon and is formed in coal mines chiefly by the oxidation of coal. *Black damp* is called any atmosphere in which a flame lamp will not burn, usually because of an excess of carbon dioxide (CO_2) and nitrogen in the air. *Stinkdamp* is the name for hydrogen sulfide (H_2S), regarding to its characteristic smell of rotten eggs. *Afterdamp* is the mixture of gases found in a mine after fire setting, an explosion or mine fire.

Additionally to the damps, with increasing depth the temperature within a mine increases due to the approach to the hot, molten, magmatic core of the planet. The increase in temperature is approximately 3°C per 100m of depth (the rate is called *geothermal gradient*). High temperatures in great depths will stress the workers and limit their productivity.

Thus, the support of fresh air is an essential to mining. Additional, *dead air* and firedamps must be removed from the mine. To assure this exchange of air, ventilation must be considered in the construction of underground workings.

7.1 Natural Ventilation

Natural ventilation is based on the different density of fresh and used air. Within the underground workings, air is heated (by human breath, process warmth originating from fire and chemical reactions of minerals and water). Parallel, the air is moistened by mine waters, breath and fumes.

If a mine has interconnected accesses on different heights, a natural drought will cause a natural ventilation. The direction of this drought depends on the temperature outside the mine. In summer, denser moist air sinks to the ground of the mine and leaves through the lower galleries, while fresh air enters the mine by the upper shaft(s) or gallerie(s). In winter, the warmed-up air from within the mine rises to the uppermost parts of the mines and leaves the workings by their higher openings, while cold fresh air streams in by the lower galleries.

To support natural ventilation, the *ventilation current* must be maximized respectively the *air resistance* being reduced, e.g., by increasing the diameter of tunnels and shafts or by avoidance of obstacles within the air current.

When driving a long tunnel, shafts are deepened in regular distances to the intended level of the gallery. Thus, the tunnel can be completed faster by connecting leadings and ventilation is eased by shorter distances.

Dead ends are problematic due to the lack of air drought. To increase the ventilation of such galleries, air partitions are used. Air partitions are separations within a shaft or gallery, that divide the volume into two parts, one for in-streaming fresh air and one for out-streaming dead air.

Additionally, different sections of a mine can be separated into different ventilation systems by ventilation doors (see Figure 13). Thus, the separation of the ventilating current into several weak streams can be avoided and fresh air can be directed to certain areas of the mine (usually those still worked).

Figure 25: Ventilation machines.

7.2 Artificial Ventilation

When natural ventilation is not sufficient, measures must be taken to increase or even initiate ventilation.

Within dead ended galleries, air can be moved by waving sheets of cloth or leather (Figure 21).

The natural drought of a shaft can be increased by mounting a drought capturer or a ventilation cap on top of the shaft mouth (Figures 19, 20, 22). The cap catches the wind and leads it into the shaft. An other method is to heat the air within the shaft, reducing its density and thus provoking its rise within the shaft, resulting a an increased air drought. For this purpose, ventilation furnaces are used. They are constructed at a shaft bottom or at a shaft head to aspirate dead air from within the mine and release them together with their fumes. Ventilation hearths must be planned and used carefully, because a reversal of air current might result in the intoxication of miners within the mines. Additionally, large amounts of fuel are necessary to maintain the fire.

To provide fresh air to certain locations within a mine (e.g. the working face of a gallery), ventilation machines can be used. These machines consist of bellows or fans, powered by men, animals or even wind or water. By means of air ducts or air boxes (Figure 24), the air can be transported for some hundred meters. Ventilation machines tend to be expensive and less effective.

8 PIT ARCH

Only excavations in solid rock may be self-supporting, this is what is used with the board-and-pillar method. All other excavations are generally prone to cave-ins and must be secured from rock thrust to protect the mine and the working miners. By supporting the roofs and walls, pit arch hopefully prevents collapses and cave-ins. Measures intended to secure a mine against cave-ins are called pit arch.

To prevent accidents with falling rocks, it is important to fill any cavities between the native rock forming the roofs and walls of a tunnel and the pit arch. Usually, this is done with rubble or waste rock.

Pit arch has to resist the natural *rock pressure*, that continually raises with the depth of the working. The main pressure lasts on the workings' roofs, but also the lateral and floor pressure increases with depth and must be faced. Generally, the dimensions of the openings within the rock should consider the pressure and be adapted to prevent collapse.

In large depths (starting at 4.500 meters below surface), the enormous pressure additionally imposes workers to the danger of *rock blast*. The stressed rock may suddenly explode and splinters may cause harmful injuries to anyone standing nearby. On Lythia, only the inhabitants of the most ancient Khûzan mines have faced this risk.

The Khûzdul also have an innate sense of fault and stress, and this enables them to carve impressive self-supporting caverns and corridors in natural rock.

8.1 Timbering

Usually, wood is used for means of pit arch. Wood is the most resilient material available on Lythia. Round timber of softwood with a diameter of 10 to 20 cm is used to craft legs, caps and cap pieces. Panels or beams may only be used for the sheet piling. Before being used within the mine, the wood is peeled and air-dried to increase its resistance against decay. To cut the timber to the proper form, sharp hatchets are preferred about saws, which would weaken the wood. Softwood has the advantage of indicating a nearby breakdown by groaning, while steel or stone will suddenly break. A groaning timbering will alarm the miner to immediately leave the location and/or to strengthen the pit arch. The mayor disadvantage of timbering is that it is prone to decay. For example, timbering in contact to soil will last for only 3 to 5 years, so it must be maintained and exchanged regularly.


Figure 26: Khûzan timbering.


Figure 27: Jarinese timbering.

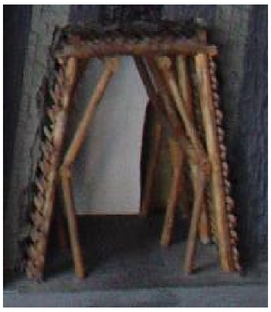
Figure 28: Khûzan timpering with polygon support.


Figure 29: Jointed timbering with single roof traversal.


Figure 30: Combined timbering.


Figure 31: Half khûzan timbering.


Figure 32: Jointed timbering with parallel roof traversals.


Figure 33: Combined khûzan/jarinese timbering.


Figure 34: Combined timbering with polygon support.

8.1.1 Frame Timbering

Frame timbering is formed by multiple *porch sets*, each consisting of two wooden *props* bearing a wooden *crossbeam*. The porch sets are interconnected by wooden *caps*, lining the roof, and wooden *sheet piling*, covering the walls. The props are fixed to the rock with small wooden wedges, called *cap pieces*. There are different geometries used for the porch sets, depending on the amount and direction of rock pressure. If lateral pressure is marginal, a rectangular frame is used: props and caps meat with a right angle. The term used by hârnic miners for this design is *Jarinese Timbering*. With higher lateral pressures, a trapezoid layout is applied, where props and caps inclose obtuse angles. On Hârn, this type of timbering is called the *Khûzan Timbering*. High pressures might call for a *polygon support* additionally built into the frame timbering. This scheme is expensive and further reduces the profile of the gallery. If pressure originates from a single direction, *half timbering* may suffice. To respond changing conditions, combinations of different timbering schemes are applied.

8.1.2 Square Timbering

When excavations are subject to large forces (including pressure from the floor), frame timbering is to weak to support shafts or galleries. This situation is often found within inclined shafts. In this cases, *square timbering* is used. Instead of porch sets, wooden square frames are used: As with the porch sets, each frame consist of two props and a crossbeam below the roof, but an additional crossbeam is laid across the floor. The single elements of the frames are plugged together and bear the caps and the sheet piling.

8.2 Masonry/Brick Lining and Tunnel Vaults

The main disadvantage of timbering is the lack of durability. Masonry is much more durable, though more expensive. Important rooms in unstable rock, most often the entrances of galleries and shaft mouths, sometimes drainage galleries, main shafts and machinery rooms, may be lined with artificial walls. Masonry is also used, when wooden timbering becomes too expensive due to a local shortage of wood.

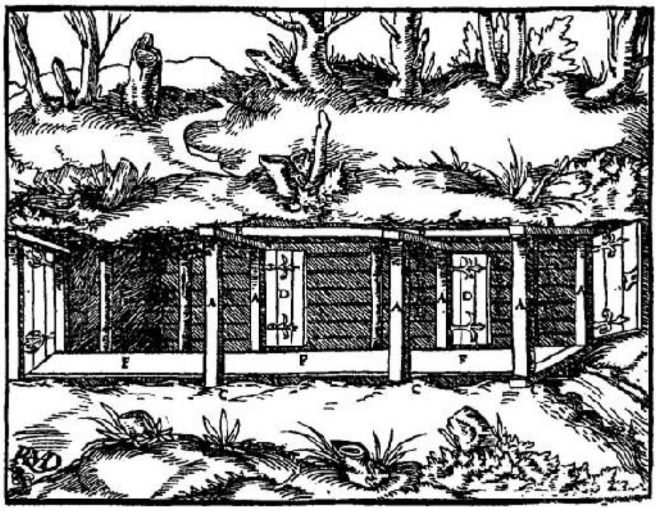

Figure 35: Square timbering. Props (A), caps (B), web (C), doors (D), sheet piling (E), flume covered by a walking platform (F).

As brick is mostly unknown throughout Lythia, dressed or undressed stone is used. The masonry is either carried out as *dry wall* or *cog* design, or as a stone-and-mortar wall. While a cog will allow mine water to seep into the drift, stone-and-mortar walls may allow for waterproof construction.

While sometimes wooden caps form the roof, it is also common to fit out rooms with complete *tunnel vaults*. To counter high rock pressure, *circular* or *elliptical vaults* may be built into a drift, which completely dress ceiling, walls, and floor of the drift. This can be found mainly within drainage galleries and some circular shafts (e.g., well-shafts). Khûzan mines and cities are known to have excellently crafted masonry and tunnel vaults lining their drifts, and cloister/cross vaults spanning their halls.

Figure 36: Horse sled (A), sled (B), dogs with pack saddles (D), bellows attached to a rope (E).

Figure 39: Double acting hasp with flywheel - winch beam (A), crosswise handles (B), crank (C), flying wheel (D, E).

Figure 37: Hoses with pack saddles (A), chute (B, C), single-wheeled cart (D), double-wheeled cart (E), track (F), wagon (G), foreman, noting the number of loads on a counter(K), ore bins (L).

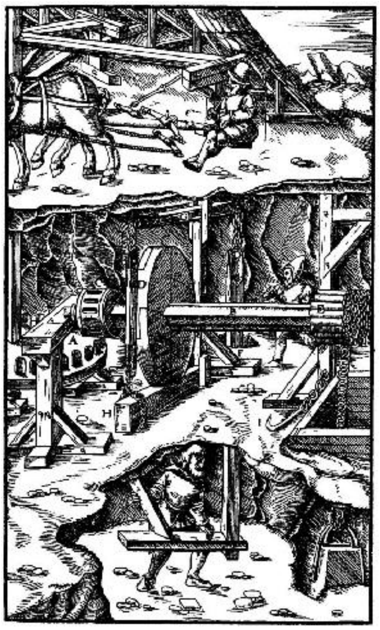

Figure 38: Horse powered gin - vertical axle-tree (A), horizontal axle-tree (B), gear (C), brake disc (D), winding drum(E), brake shoe (F), lever with two branches (G), brake block (H).

9 HAULAGE AND HOISTING

Underground transport of materials is a centrepiece of mining. Miners distinguish horizontal transport (haulage) from vertical transport, termed hoisting.

9.1 Haulage

Haulage is the horizontal transport of material through galleries. Porters may transport sterile rock (overburden) and ore using wooden trays or tubs or leather bags (Figure 40).

Advanced tools for haulage are barrows, one-wheeled carts driven by a single worker (Figure 41). The use of barrows doubles the effectiveness of haulage compared to the use of trays, tabs or bags.

Most efficient tools are trucks or tubs, wooden chests with three or four small wheels, running on wooden planks on top of the floor and guided by a tail-wheel running between these planks (Figure 42). The tub is pushed by one or two workers or pulled by a single horse. The Khûzdul have invented mine railways, consisting of iron tracks and small trucks with rimmed iron wheels running on them. This method reduces friction and increases productivity, but is very expensive. To save money, the tracks are sometimes made from wooden beams.

Carts and wagons are preferred for haulage in large galleries and at daylight.

Sleds (Figure 36) are used to transport materials within tunnels, and – on the surface – over iced slopes. When moving downhill, sleds don't need any traction, just moved by laws of gravity. For plain or even uphill travel, dogs, horses or manpower is needed to move the sled and its load. Sleds need broad paths with only slight declination.

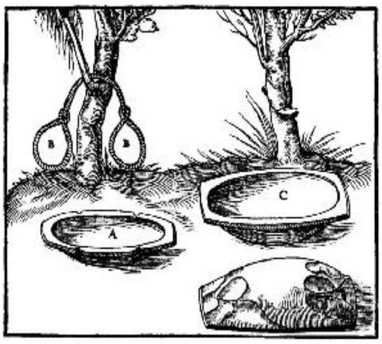

Figure 40: Vessels for haulage – ore tubs (A, C) and a rope for carrying them (B).

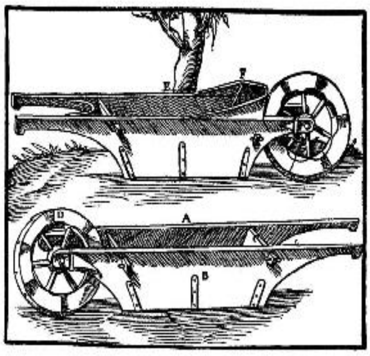

Figure 41: Borrows for haulage – small barrow (A), large barrow (E).

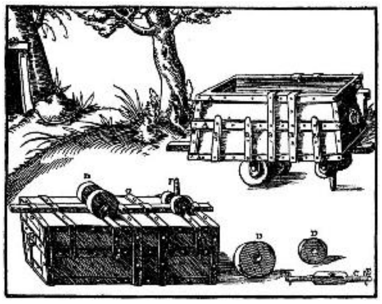

Figure 42: Trucks for haulage - iron reinforcements (A, B), iron axle (C), wooden wheels (D), iron leader nail (F).

If paths are narrow and steep, *PACK ANIMALS* can be used for haulage. Pack saddles are mounted on horses or mules and bags or tons are attached to the the saddles (Figure 36).

Wherever applicable, *BARGES* are used to transport heavy loads. While usually natural streams are used, in rich mining areas dedicated canals may be built to ease the haulage. Even underground, barging on underground streams or canals might be a solution for haulage. For each ton of load, 7-8 towing men or one draught horse is needed to move a barge.

As most galleries are very narrow, ore tubs, sleds and trucks are pushed over head, or pulled with a cord, which may be fixed to the wrist or the ankle.

9.2 Hoisting

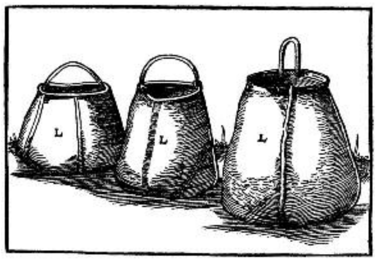

Figure 43: Leather bags.

Hoisting is the vertical transport of material, namely through shafts. It is one of the most tiring and dangerous jobs within a mine, as workers are prone to get injured by objects falling into the shaft from above. Material can be carried in baskets on the back of the miners, but usually ropes or chains are used in combination with a hasp and some kind of vessel (Figure Figure 43). Several kinds of drives are used to power the hasp (see section on "**MACHINE DRIVES**" above). For example, a hasp driven by a gin turned by four horses may lift 46 – 48 tons to a height of 180 meters within a nine-hour shift.

10 DEWATERING

Water is a constant threat to mines, even those at arid locations (as rock or sand deserts). It originates from precipitation (rain, snow), surface waters, underground streams, and fossil water reservoirs. It enters a mine through porous rock, clefts and fissures in the walls, floors and ceilings, usually slowly seeping into the galleries, but sometimes rushing in huge volume and under high pressure.

Miners prevent flooding from surface water by a carefully locating all mine heads above the flood level of nearby streams. Discarding overburden circularly around a shaft head or opencast pit further increases the mine's safety. Shafts and galleries may be lined with waterproof stone or brick to stop seeping.

Even small amounts of water entering the mine must be removed to prevent a gradual flooding. Miner calls the applied methods *DEWATERING*.

10.1 Passive dewatering (Drainage)

The preferred method of coping with mine waters is to use the natural gravitation where ever possible. To drain a mining complex, a *DRAINAGE GALLERY* is drifted from a suitable point about the high water level of a near draining stream, but as low as possible above sea level.

This gallery is constructed with a slight incline (1-5‰ are sufficient) towards the mine workings and connected to the mine. Underground waters can now leave the mine through the drainage gallery, as long as their source lies above the level of the lowest drainage gallery. The more a drainage gallery lowers the drainage level of a mine or mining district (miners say: "the drainage gallery brings in a depth of so and so much feet"), the more ore becomes winnable.

When the exploitation makes it necessary to work below the drainage level (such workings are called DIP WORKINGS), a new drainage gallery may be drifted below the old draining level, or pumping is used to lift the water onto the drainage level.

An additional advantage is the possibility to use the height difference from the surface to the deepest drainage gallery to power water wheels inside the mine. The water is lead into the mine through ordinary shafts, galleries or through dedicated galleries (LEATS or GULLETS). It powers one or more cascaded overshot waterwheels installed in machine rooms inside the mine. The wheels power pumps, winches or other machines within the mine. The working waters finally leave the mine through the drainage gallery.

The main problem with drainage galleries is their cost. The more depth the gallery shall bring in, the longer and more expensive its construction becomes. Drainage minimizes the operating costs for dewatering, while calling for possibly enormous initial expenses. Drainage is less expensive within hilly or mountainous areas, while within plain areas, drainage is almost impossible.

The construction of expensive drainage galleries is usually the task of the guild or specially contracted miners (called DRAINING GALLERY OWNERS or TUNNEL OWNERS), who gain shares (usually the thirteenth part) of the ore won in all mines, their gallery dewaters.

10.2 ACTIVE DEWATERING (PUMPING)

Pumping must be used, where drainage is not applicable. The mine waters are conducted to the deepest point of the mine, the SUMP. From here, the waters are lifted to the drainage level or even up to the surface. There are different methods to lift the water.

10.2.1 INTERMITTENT SCOOPING

Porters (called WATERBOYS) use vessels like leather buckets to scoop the water and port it out of the mine. This can be done by single waterboys or by lines of them, handing over the vessels from hand to hand along galleries and over ladders through the shafts.

Scooping is a simple way of dewatering a mine. There are almost no initial investments, but the operation costs will increase dramatically with the size and depth of the mine and the amount of mine waters.

Scooping will be used in small mines, within low-tech cultures and in mines with few mining waters. In areas, where slaves are available, scooping is used also in large mines.

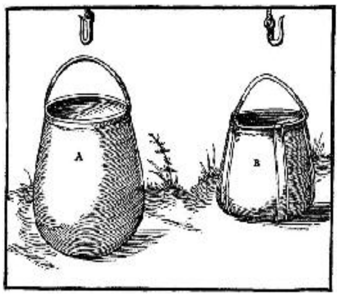

Figure 44: Leather bags for scooping ("bulges") – Self filling "ringed bulge" (A), normal "stroke bulge" (B).

The next step is to hoist the waters with winches and large vessels from the sump to the drainage level. The vessels are made of wood (TONS), metal or leather (BULGES – Figure 38).

The windlass is usually operated by manpower of WINDERS. Hand operated windlasses can be used to hoist waters from depths up to 40 m. The lift height is limited by the weight of the rope/chain and the number of winders (four per hasp being the maximum). To lift water from greater depths, multiple windlasses must be combined to form a consecutive transport chain. Throughout Hârn, Ivina and western

Lythia, this form of scooping is the prominent method of active dewatering.

In important mines with extensive dip workings (workings extending below the drainage level), ANIMALPOWER might be used. Windlasses of this type are characterized by a maximal head of water of 200 m; they are usually powered by horses attached to gins; changing the direction of the rope is complicated by the fact, that the animals have to be turned around.

The most developed method is to use waterpower, requiring the WATER POWERED RETURN WHEEL (Figure 48). This is a very advanced method, combining two overshot contra-oriented waterwheels on one axis; the machinist can control the sense of rotation by changing the water supply from one wheel to the other. Return wheels are found only within Khûzan (dwarfish) mines and in the most advanced areas of Lythia. They are extremely expensive, but even effective: they can cope with lifting heights up to 500 meters. The maximal head of water is dictated by the rope used. While iron chain ropes only reach to 400 m due to their high dead weight, ropes made of hemp work up to depths of 500 m, but they are expensive and prone to abrasion and rotting. However, most shafts have depths of 90 – 105 meters.

10.2.2 INTERMITTENT PUMPING

Even in early times machines were used to lift mine waters. this are the *ARCHIMEDEAN SCREW* and the *BAILING WHEEL*. They are driven by sheer muscle power.

10.2.2.1 ARCHIMEDEAN SCREW

The *ARCHIMEDEAN SCREW* (Figure 50) consists of an wooden axle with usually three threads formed by lead sheets nailed helically to the axis. The screw is finished by a wooden hull fixed above the threads. The machine is installed with an incline of approximately 33%. Thus, a normal screw of 4.5m length would lift the water for 1.5m of height. To operate the screw, a worker simply treads on rafters fixed on the outer surface of the hull to set the complete screw into rotation. Elsewhere, cranks are used to operate the screw. When the lower end of the screw dips under water and the screw gets rotated, water is lifted through the threads within the hull and leaves the screw at its top end. Several Archimedean screws are combined with water crates to form a transportation chain from the sump to the drainage level.

Archimedean screws are an expensive way to scoop waters, as many workers are needed to operate them. The advantage is the continual flow of water and the relatively high fault resistance.

Figure 45: Simple hasp - winch beam (A), crossbars (B), supports (C), haulage rope (D), angle pulley (E), mine timber being brought into the mine (F).

Figure 46: Double acting hasp – pit bank (ABCD) hasp supports (E), iron bearing (F), winch beam (G), crank (K), rope (L), rope hook (M), hoisting bucket (N).

Figure 47: Winch with thread mill.

10.2.2.2 Bailing Wheel

Wooden vessels are attached to the rims of a large wooden spoke wheel with a diameter of up to 4.5m. By grasping into the spokes, two or three workers set the wheel into rotation, lifting water from a water crate for 3.6m. The water leaves the vessels when passing the top of the wheel and is collected in an upper water crate. Thus, several wheels can be combined to form a transportation chain. The degree of effectiveness averages 61-66%.

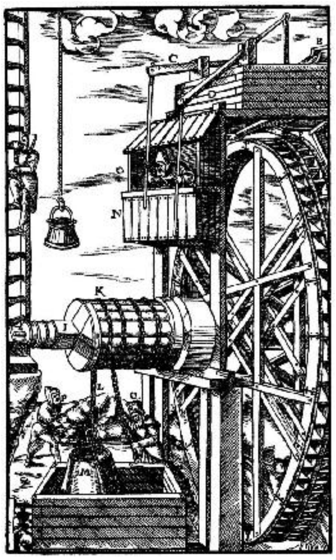

Figure 48: Scooping with a water powered return wheel – reservoir for machine water (A), levers (C, D), wheel races (B, E, F), two rims with contra oriented vanes (G,H); haulage chain (L), bulge (M), platform (N), machinist (O), workers who empty the bulge (P).

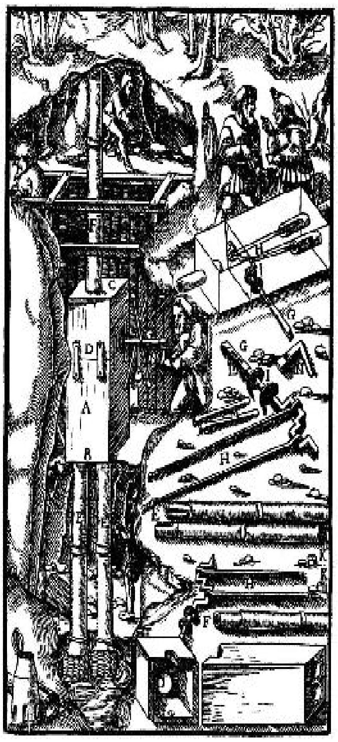

Figure 49: Double acting pump.

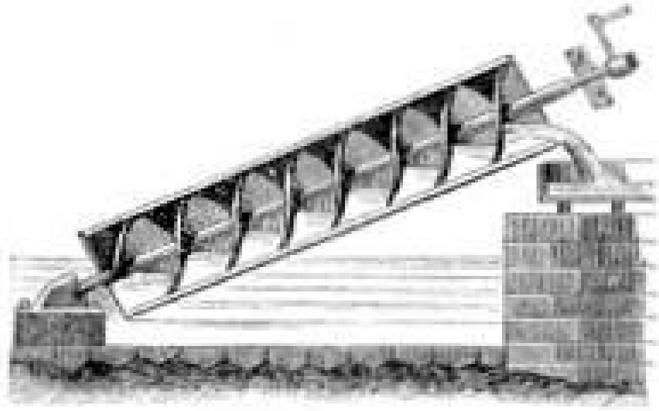

Figure 50: A chain of Archimedean Screws and water crates.

Also bailing wheels result in high operational costs. Their use only pays to make very high-graded ores workable and if manpower is cheap (e.g. if slaves are available). In comparison to the Archimedean screw, additional costs arise from the necessity of multiple dedicated wheel chambers to be cut into the rock.

10.2.2.3 Pump

Figure 51: Manually driven piston pump.

Simple piston pumps (Figure 51) can be used for intermittent pumping. A *piston* is moved by means of a gear and lever within a *cylinder* up-and-down, lifting the water within the cylinder. The lifting height is limited to 8-10 meters.

10.2.3 Continual Scooping

When a mine is endangered by large amounts of mine waters, machines for continual scooping might be installed. There are two main types of machines for continual scooping: *bucket* or *scooping chains* and *chain-and-leatherball scoops*.

10.2.3.1 Bucket chains

Bucket or scooping chains (Figure 53) consist of several equal buckets, fixed to a closed chain of flexibly connected chain links. The lower end of the chain dips into the sump. When the chain is set into movement, water is scooped from the sump and lifted within the buckets. When a bucket passes the upper end of the machine, it is emptied by natural gravitation; the water flows away through a wooden outflow and the bucket is lowered towards the sump again.

Figure 52: Treadmill driven bucket chain, treadmill (A), axle-tree, double chain (B), a single chain link (D), buckets (E), brackets to fix the buckets to the chain (F,G).

The construction of Bucket chains is expensive. Due to the heavy weight of mobile parts, bucket chains are subject of heave wear and tear (high operational costs), though they are easy to maintain when constructed of standardised parts.

10.2.3.2 Chain-and-leatherball scoops (“Heinzenkunst”)

This type of machines (Figure 53) consists of a pipe usually made from a hollowed-out stem. It is fixed vertically within a shaft, its upper end reaches above the drainage level, its lowest part dipping into the sump. A closed metal chain or hemp rope, to which balls of leather are fixed in regular distance it pulled through the lumen of the pipe. The diameter of the chained leather balls slightly exceeds the diameter of the pipe lumen, so that the balls function as a seal, when the chain gets pulled upwards through the pipe. Thus, water entering the lower end of the piped is lifted upward by the ascending balls and leaves the pipe at its upper terminus. The balls then descend outside of the pipe through the shaft. This machine can be powered by man power, animals or waterpower.

Figure 53: Chain-and-leather-ball scoop – beam (A), chain drum (B), chain (C), stuffed leather balls (D), brackets (E).

Maximal head of water: 60-70 m

Chain-and-leatherball scoops base upon a simple design scheme, but they are prone to failure by leaking.

10.2.4 Pumping

Simple pumps consist of a (usually wooden) *cylinder* and a *piston* moving inside cylinder. On one side, the piston is *sealed* with leather and tow, forming a *check valve*. The lower end of the cylinder forms the *pump intake* and reaches down into the sump. When the piston is moved upward, the valve closes and lifts the water column, until it leaves at the upper end of the cylinder. Moving down, the valve opens and allows the water to flow in. More complicated pumps use additional valves at the top and the bottom of the cylinder to control the in- and outflow of water into/out of the cylinder. Such pumps with increased efficiency are: *suction pump*, *pressure pump* and *double acting pump*.

The maximal head of water averages 8-10 m per pump. 3-10 pumps may be combined to form a *pump set* (Figure 55). Single pumps might be operated by man power (see "**intermittent scooping**"), big pumps or even pump sets are generally powered by waterwheels. The latter kind of mechanized pumps is the most advanced known on Lythia. It has been used within the Khûzan mines on Hârn and Ivinia for millennia, but the Khûzdul have concealed this technology. Humans had to re-invent pumps and so they did in the far-east. In western Lythia, pumps still are seldom found and only the most travelled and skilled hydroengineers are familiar with their design.

Figure 54: Pumping with two consecutive water wheels – wheel of the upper/lower machine (A/D), its pump (B/E), its tail race (C/F).

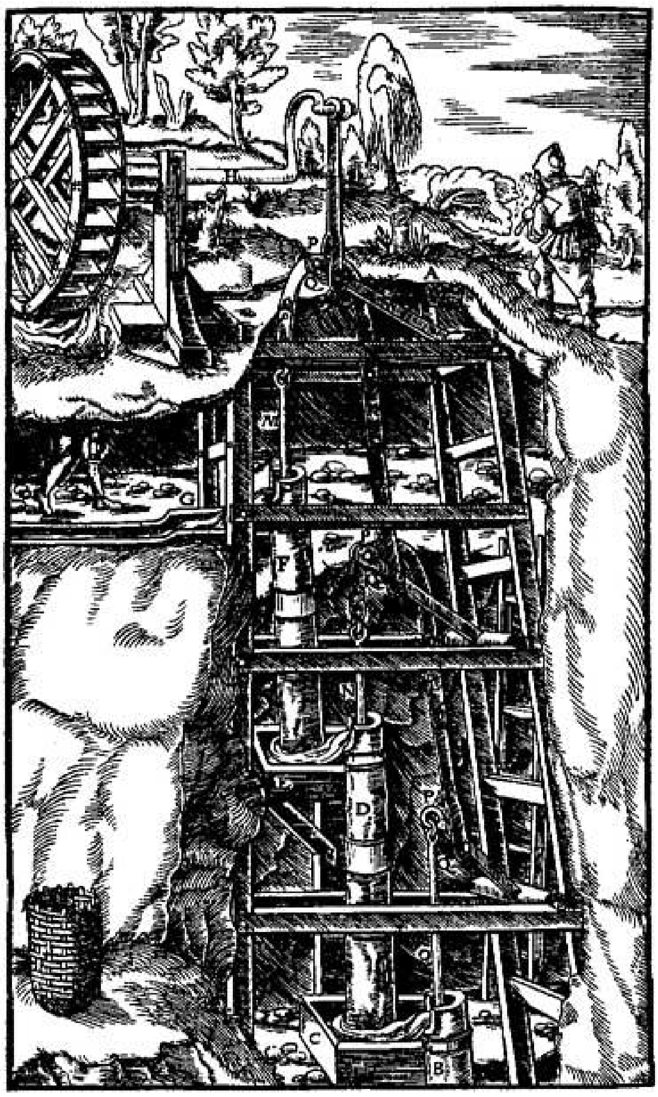

Figure 55: Pumping set of three coupled suction pumps – machine shaft (A), pumps (B, D, F), water crates (C, E), leat (G), axle-tree (H), pump rods (I, K, L, P, Q), pistons (M, N, O).

11 MINE SURVEYING

A mayor problem of mining and underground working in general is the lack of orientation. Since the miners are surrounded by rock while drifting, the only fixpoint they have is in their back and thus out of direct sight. Markings on the face wall will be destroyed with progress of cutting. If miners want to cooperate in drifting, e.g. to construct a gallery using the two-end method or the qanat-method, they are forced to apply complicated mathematical or geometric methods to ensure their adits will meet. Their working progress must be attended by regular control measurements and calculations to ensure the drifts accord to the intended routes.

11.1 PROBLEMS OF MINE SURVEYING

To survey claims and to collect data for surveying underground structures, it is necessary to survey the topography above ground. The relative locations and heights of shaft mouths, adit entrances and other features, like water supplies, is needed to settle conflicts between claim holders, to calculate taxes and fees, to select routes for hydroengineering and underground constructions and to establish fixpoints for surveying underground.

Not only underground, inside a mine, but also above ground, direct measurement is often impossible due to obstacles (like elevations, vegetation or buildings) blocking the direct line of sight. In all such cases, indirect measurements have to be carried out by the surveyor.

11.2 MEASURING DEVICES

Typical tools for surveying are:

1. *MEASURING ROPES* to measure distances,
2. *PLUMB LINES* to measure differences of height,
3. *SPIRIT LEVEL*, *PROTRACTOR*, *ASTROLABE* or *DIOPTRA* to determine horizontal and vertical angles between two straight lines,
4. *CHOROBAT*, *GROMA* or *DIOPTRA* and some *SURVEYING RODS* to align two or more points, this is to ensure that all the points lie on a common straight line.
5. A slate or wax-coated slate to note angles and distances

These tools enable the surveyor and his assistants to make triangulations and polygoniometry traversings, thus measuring distances, angles and height differences directly or indirectly.

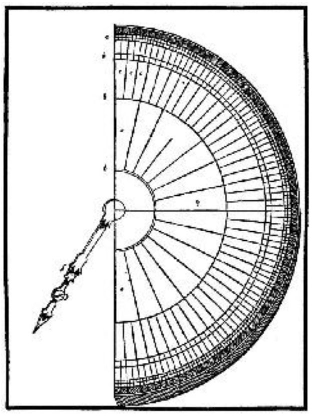

Figure 59: Spirit level.

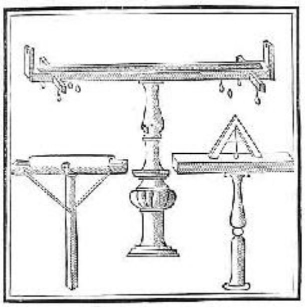

Figure 58: Chorobates (Vitruvius).

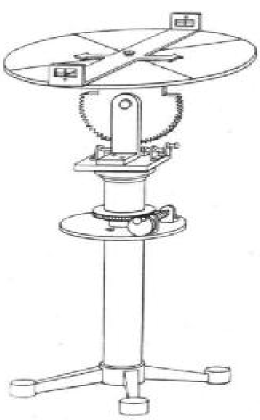

Figure 57: Dioptra.

Figure 56: Determining the lenght of a drift by simple trigonometry.

As knowledge of mathematics and geometry is rather basic throughout Lythia, many surveyors prefer the physical reconstruction of the traversings (measured angles, distances, heights differences) by means of measuring rods and measuring lines on a wide, levelled field (the *surveyor's ground*) or on a frozen sea to the pure mathematical calculation. Since on the surveyor's ground there (resp. The frozen sea) are no ostacles, any distances that could not be measured directly in situ, can be measured directly here. This method also helps eliminating several sources of error in surveying.

11.3 Levelling

The knowledge of the relative height of measure points and fixpoints is an important requirement for the calculation of exact distances, angles depths. The relative height of any point can be successively determined by the accumulation of pairwise height differences of a chain of neighboured surveyance points: On the location of each point, a surveying rod is held horizontally. Between both points, an aiming device, e.g. a chorobat or a dioptra, gets aligned and calibrated to a horizontal position. Then the surveyor aims at both surveying rods and instructs his assistants to mark the level s/he aimed at on the rods. The difference between both marks equals the height difference and is noted.

11.4 Transferring Directions to Below Ground

Once the route for an adits to be driven to another underground construction has been selected, the route will be pegged out above ground. At least two fixpoints are needed to enable the cutters to align the new adit. Usually one rod is located at the adit entrance, while the second is located several hundred feet away to increase the precision. By looking back, the cutter can control the direction of the adit by checking whether both rods coincide. If it is impossible to find a suitable location for the second rod, the second fixpoint will be located on the surface projection of the adit under construction. A vertical shaft, the *aiming shaft*, is sunk. After the adit got interconnected to the aiming shaft, a plumb line is installed within the shaft and can be used to determine the correct drifting direction by aiming at the first fixpoint.

If a gallery shall be drifted using the qanat-method, a similar method is used. The location of each lighthole (auxiliary shaft) is surveyed and each shaft is lowered to the calculated depth. A scaffold is constructed above the shaft head and aligned to the surface projection of the planned gallery. Then two plumb lines are hung from the outermost points of the scaffold into the shaft. On the shaft's floor, the drifting direction can now be determined by aligning both plumb lines. Since the shaft's dimensions are usually restricted to 1–2 m, the precision of this method is rather small. Therefore the distances between the lightholes must be chosen carefully to ensure the single sections to meet underground despite of the inevitable diversion of the selected route.

11.5 Surveying Underground

Underground surveying is necessary to control the direction of a drift and to settle conflicts of neighboured mines. The latter occurs, whenever a drift from one mine archives a *cut-through* to the workings of another mine. Guild regulations require both parties to report the cut-through to the local guild council. The guildmaster then assigns the Master Mine Surveyor to survey both mines. When finished, the surveyor marks the *boundary line* between the mines by an official marking engraved into the walls of the interconnecting drift.

Underground surveying is started from a surface fixpoint. From there, a *polygonal course* is drawn through the drifts of the mine by means of measuring ropes, that are fixed to *observation points* on the walls. This points are marked on wooden boards fixed to the wall or by directly engraving the wall. The angles and distances between the measuring ropes are measured by means of some kind of a protractor (see section on **Measuring Devices** above). With the data from the polygonal course, any information may be directly computed or – more likely – be measured after the reconstruction of the polygonal course on the surveyor's ground.

12 SEASONAL MINING

The preceding sections have described much of the situations found within mines and the applied methods of working. Many of this methods depend on natural conditions, as hardness of the rock, availability of wood (for mine timbering, fire setting, and further processing of the ore) and water (for powering machine drives, and the concentration process applied to the ore).

In most regions, these conditions vary throughout the year, according to the actual season. For example, in the subarctic and cold temperate climates, water is unavailable during winter, as is in winter in several areas with arid climates during summer. Snow will hinder transports to and from the mine, especially in glacial and mountainous areas, as will long rainfalls in south-eastern Lythia during the monsoon, which will also destabilize cleared slopes and raise the danger of sudden mine flooding. In permafrost regions, surface mining can get nearly impossible during winter, while transport is restricted to the winter months, as during summer the surface changes into bog and swamp.

Some of these problems can be solved by piling stocks (e.g. of ore, wood), by technical measures as damming streams to store water in large ponds, recycling of used water or replacement of rare resources (e.g., using amalgamation instead of washing to win silver or gold).

Nevertheless, in several areas, mining is applicable only during certain periods of the year. The miners often abandon these mines for the rest of the year, and change to some other profession (like herding, hunting/trapping or agriculture). Sometimes the miners spend one half of the year on mining ore, and the other half on refinement and smelting of the ore. The layout of such seasonal mines must reflect this practice, e.g. only passive dewatering is applicable within seasonal mines.

13 NATIONAL & REGIONAL DIFFERENCES

As all other crafts, mining is influenced by the miners' cultural background. This is reflected by the social position of miners, by the state of mining technology achieved and by different preferences in the choice of applied methods and technologies.

13.1 Ivinia & Orbaal

Though their proximity to the Khûzdul of Kondasgel, the Ivinians learned nothing from their neighbours, who withdrawed into the security of their subterranean mountain stronghold when they learned on the nature of the invaders. Even the indigenous humans of Ivinia, the peaceful Yarili, did not learn much from their secretive hosts at Kondasgel.

13.2 KHÛZDUL

The Khuzdul are the most formidable miners of Kethira. They are adopted to subterranean life and seem to have innate senses for both, underground dangers and values. Besides these natural gifts, they have developed an outstanding mining technology, which they perform as maybe the foremost of all their practiced arts.

As a central aspect of Khuzan culture, mining related knowledge is passed from generation to generation by folklore, while mining skills are enhanced during decades of practical instruction and experience.

"It seems natural that the Khuzdul are the most competent tunnelers among the speaking people. Only the Gargun come anywhere close, and their mines and cave-complexes are crude, unpleasant places by comparison. On Harn, the dwarves of Azadmere control the only active gold mines, and the only truesilver deposits known anywhere. It is probably no accident that the city of Azadmere sits astride rich deposits of gemstones, gold, silver, and iron. All of these are mined and exported in both worked and unworked form. Among the Khuzdul, of course, the arts of the miner, embalmer, and mason overlap considerably." **(AZADMERE, KHUZDUL 3)**

13.3 SINDARIN

For millenia, the elves have not mined on Hârn. Their preference for a living in harmony with their natural environment is deemed a reason for their absence from mining.

"The elves do not mine, and must import their metals and minerals. Lead is imported from Chybisa to be implemented in their glasswork, producing crystal. Amber is brought from Orbaal, and is worked to produce exquisite forms of sculpted jewelry. Gems and jewelry of Azadmere are imported for use in elven artwork, as are silver, gold and platinum. Iron is obtained from both Azadmere and the Thardic Republic for weaponcrafting and metalworking." **(EVAEL, SINDARIN 4)**

However, it remains questionable, whether the Sindarin have mined in times predating the Codominium, used other ways to obtain metals and gems, or just did not use these resources. Regarding their crafters' expertise and efficience, they may even have brought most of their metal with them, reusing it during the millenia since their arrival on Kethira.

13.4 GÂRGUN

The gârgun have an innate wisdom of mining and metallurgy, which does not seem to develop, being fixed by their genome. Despite the Gargu-arak, all species prefer natural cave complexes or artifical tunnels as habitats:

"Although Kyani sometimes roam in nomadic woodland bands like the Gargu-arak, they more often build cave complexes in alpine locations covered by snow year round. [...] They also produce finer artifacts than the other subspecies of Gargun. They are particularly creative with silver, a metal they treasure above all else. They will engage in trade with non-Gargun, especially if silver is offered, which they will exchange for an equal weight of gold!" **(NASTY, BRUTISH AND SHORT, GARGUN 5)**

*"As mining engineers, Gargu-hyeka are second only to the Khuzdul. Chambers and passages in a Hyeka cave complex tend to run in straight lines, although irregular natural caverns may be included. Numerous redounts, blindways, pits, and other traps designed to foil intruders are commen. Most complexes contain iron mines and armouries which can produce fairly*good weapons, notably passable scale and mail armour, but most wear leather armour or none at all."* **(NASTY, BRUTISH AND SHORT, GARGUN 5)**

"Small bands [of Gargu-khanu] may dwell alone in a cave complex, but they are most often found as the ruling elite in a hybrid culture

with Araki and/or Hyeka as slaves. The Khanu are not great builders and typically, if they find themselves without a home, will attack and attempt to conquer a colony of these two weaker species" **(NASTY, BRUTISH AND SHORT, GARGUN 5)**

14 BEYOND MINING

In some situations, miners are sought engineers whose skills are not only used to mine minerals. Such situations may become promising backgrounds for adventurous campaigning.

14.1 ROAD TUNNELS

Sometimes, especially in mountainous area and at the seaside, the construction of roads has to cope with obstacles like steep cliffs or narrow paths along a deep canyon. In such cases, tunnels and galleries may be built to make path for the traffic. While road tunnels are almost unknown throughout Hârn (the only examples being the Hazmadul, Harazul, and Ohin Tunnels on the Silver Way from Zerhun to Azadmere, the longest having a length of 1.6 km), on mainland Lythia, especially in the Azeryan Empire, there are several examples of such underground constructions.

14.2 AQUEDUCT TUNNELS

Large cities face the problem to supply sufficient water for their population. When the capacity of water wells is reached, aqueducts are constructed to transport fresh water from springs in the hinterland to the city. Aqueducts use the natural gravity gradient to transport the water. The route of the aqueduct has to be carefully planned to guarantee the ideal gradient of 1-5‰: lower gradients prevent the flow of water, higher gradients will result in a steady current, able to damage the canal by erosion. The critical points with route planning are the preservation of as much height potential as possible, and to reduce the length of the aqueduct to limit the costs of construction and maintenance. For this purpose, dams, bridges, syphons (to pass valleys and other depressions), and tunnels (to pass hills, mountains, or rock spurs) are regularly found as parts of aqueducts. Miners will be consulted with the planning and drifting of such tunnels.

14.3 RIVER-DIVERSION TUNNELS

Sometimes, the natural course of a river needs to be changed by the humans to win arable land, or to enable the construction of roads, aqueducts, or town walls. In such cases, an artificial riverbed may be digged out, sometimes containing a tunnel. Then the river might be diverted into the new bed and original flow of the river be blocked by means of a dam crossing the natural riverbed.

14.4 DRAWDOWN TUNNELS

In natural depressions, precipitation usually accumulates at the depression's deepest point, forming a natural lake (like in a maar). For inhabitants of the depression, it may become necessary to regulate the level of the lake to prevent settlements and fields from regularly being flooded. This can be archived by means of an artificial drainage. Often, this can be done by a canal or lowering the natural drainage (if present) of the lake. In some cases, draining galleries are drifted below the natural lake level from the outside towards the depression. An inlet building with sluices is constructed to regulate to inflow of water into the drainage gallery.

14.5 SIEGE TUNNELS

In times of war, besiegers often undermine the enemy's fortifications, either to weaken the wall's foundations and cause a structural collapse, or to sneak in a prize crew behind the lines of defence and take the place by a surprise coup. The defenders try to detect the vibrations of the drifting of such a *MINE* (e.g., by observation of the surface of a water-filled pot) and will drift *COUNTERMINES* to intercept the enemy and block the tunnel by burning the timbering or flooding the tunnel, or simply discourage the sappers by killing their workers. Since siege engineers are expensive experts, commanders may hire miners, or simply abduct and force them to serve as sappers.

15 RISKS OF UNDERGROUND WORKING

Miners are exposed to many hazards, that arise from their special situation working underground. Safety measures are usually expensive and will therefore be restricted to an acceptable minimum. After an working accident has occurred, rescuing the injured or unconscious persons is often difficult, as they must be transported through narrow tunnels and shafts, sometimes over long distances.

15.1 GENERAL WORKING CONDITIONS

Miners must work under extreme working conditions, as their places of work are not suitable for easy performance: The tunnels tend to be narrow and flat, so they must work while lying or kneeling on the floor, sometimes in stagnant water. Breathing is hindered due to the air being hot, damp and foul. Only the weak, flickering light of the pit lamps drives back the total darkness.

Splinters of rock or damaged tools may harm the eyes, hands and skin of cutters.

Entering, leaving and travelling the shafts and tunnels is risky: shafts and drop holes open into the floor and ceiling of galleries, so inattentive people will drop into them or get hit by falling objects. Additionally, in large mine complexes, the *RUNNING-IN* and *RUNNING-OUT TIME* (the time miners need to reach their place of work/leave the mine) is very long – sometimes 1-2 hours – and strenuous.

Floors, planks and ladders are moist and slippery and often give only a treacherous support. Hoisting ropes or chains may break and severely injure workers being around. Hoisting buckets, woods lowered into the shafts or other burdens might fall into the shaft, hitting and sweeping away ascending or descending miners and inflicting damage to the installations and timbering.

15.2 CAVE-INS

As mining progresses, pits, tunnels, galleries, shafts and caverns are cut into the native rock. Immense forces, inflected by ground movement and rock pressure last on the ceilings, walls and floors of all underground constructions. Timbering is used to stabilize them, but if it is to weak due to inadequate construction or corrosion, parts of the ceiling or walls will loosen from their native bed and break into the cavities.

Depending on the architecture of the mine, such a cave-in will be fatal for the miners working within, if it blocks their only escape route:

- In lack of fresh air, they might suffocate,
- fuel will run low and finally imprison them in complete darkness,
- lack of fresh water and food will weaken them,
- they might even drown, if the cave-in has blocked the drainage.

Usually, the comrades of the buried miners will try to excavate them by clearing the collapse and supporting the tunnel, but that is hard work and might last too long to recover their comrades alive. Other methods to reach the buried parts of the mine, as sinking relief shafts or galleries, are usually hopeless, as they take too much time. Though, they will be applied to reopen cut off parts of the mine, that include rich workings, if clearing the cave-in turns out to be impossible (e.g. due to sloughing caprock).

To prevent cave-ins, miners regularly control the timbering. As visual control is difficult due to lighting conditions, miners prefer to use kinds of wood for timbering, that “moan” under heavy load. If they hear this typical sound, they immediately leave the tunnel or start to support the actual timbering.

15.3 FOUL AIR

Foul air is the main danger in many mines. As mentioned above (see “**MINE VENTILATION**”), oxygen is consumed by workers, open fire, chemical reactions and micro organisms, and carbon dioxide is exhaled. Insufficient ventilation results in foul air (carbon dioxide and carbon monoxide, methane) sinking to the lowest parts of the mine, slowly "filling" it up. A miner might not notice the danger, until the level reaches his head and he drowns. To evade this situation, miners developed two methods to warn them from *BLACK DAMP* and *WHITE DAMP*: First, they place their pit lamps near the floor. If the concentration of poisonous gases becomes too high, the lamp will loose its brightness or bee extinguished. Second, a small cage with a bird (like a sparrow) will be placed on the ground. If the bird gets tired or unconscious, the miner will immediately leave or try to improve ventilation. The Khûzdul seem to possess certain instincts, alarming them in the presence of foul air.

15.4 FIREDAMP EXPLOSIONS

Explosions may occur where inflammable gas (methane) gets concentrated within a part of the mine. Coal mines are affected in first case, but also salt mines (with cavers of enclosed rock gas) or any other old mine (where micro organisms permanently decompose wooden timbering). If a critical concentration of gas and oxygen is reached, a small spark will suffer to ignite the so-called *FIREDAMP*. Dust-explosions may occur, when finest particles of reactive material (like coal-dust) are dispersed into air with sufficient oxygen and ignited by a spark or open flame.

In both cases, the result is an explosion, that gets canalized by the narrow underground structures. It will effect miners, timbering and machinery and thus inflict mine fires or cave-ins. Additionally, the explosion consumed large quantities of oxygen.

Firedamp cannot be detected by smell or taste, but skilful miners might notice a slight change of the colour of his/her pit lamp's flame.

15.5 MINE FIRES

Mine fires can be started by careless fire setting, by accidentally breaking a pit lamp and igniting the spilled fuel, by a firedamp explosion or by spontaneous ignition of coal or timber.

The fire depends on the availability of fuel and oxygen. Wooden timbering and organic strata (coal) are candidates for the fuel, oxygen is drawn from the air. If sufficient oxygen is available (e.g. near a ventilation shaft), underground fires can reach extreme temperatures (similar to a blast furnace). By destabilisation of the native rock and destruction of the timbering, fires often cause cave-ins.

When a fire starts, miners may find trapped in isolated tunnels by the flames or smoke. Without an alternate escape route, they have few chances to survive.

Underground fires are hard to control, as access to the source of fire is hard to impossible due to poisonous smoke and extreme heat Methods of choice all cut off the oxygen supply, usually either by damming all accesses to the affected mine area with massive walls and/or by flooding it. After this step is done, one has to wait until the fire gets extinguished before reopening and/or draining the area. This period may last at leat several days, but in some coal mines, fires have been reported to burn for several months.

15.6 FLOODING

Flooding is a constant threat for all mines. Cutting into a water-bearing stratum ("*FEEDER*") or underground stream might suddenly increase the inflow of water and flood lower parts of the mine, especially dip workings. Other sources of sudden inflow are gullets blocked by cave-ins or torn by collapses, and blocked flumes or drainage galleries.

16 OCCUPATIONAL DISEASES

Working in damp, smoked or dusty atmosphere too often makes miners and smelters suffer from painful diseases. Some of these illnesses are so characteristic, that Lythian physicians have discovered their relation to the work in mines and smelteries.

16.1 SILICOSIS

A common disease of cutters and haulers after years of hard work in the dusty atmosphere of the mine is the *SILICOSIS* or *PNEUMOCONIOSES*. Symptoms include cough with ejection, progressive difficulty in breathing with chest pain, usually a restrictive impairment of ventilation, and on a long-term basis the development of a cardiovascular disease. Silicosis is effected by lung-travelling, flint-acid dust that produces connective tissue based nods and fibrotic modifications within the lungs. The disease is a predisposition for tuberculosis (see below). There is no causal therapy known in Lythia.

16.2 POISONINGS

16.2.1 LEAD POISONING

In lead and silver mines, miners are exposed to poisonous lead. The metal is inhaled in form of lead-containing dust, smoke or steam. Symptoms of the lead poisoning is its insidious beginning with tiredness, inappetence, stomach-ache, headache and pains of the joints, obstipation, gastrointestinal colic attacks and paleness. Later possibly shrinking kidneys, angina pectoris attacks, gangrene of the extremities, chronic encephalopathia. Children are specially affected by damages to their growing skeletons, resulting in osteosclerosis. Additional symptoms are painful peripheral nerve paralysis. The poisoning can be diagnosed by a black-blue to slate-grey lead seam of the gums. A causal therapy would use substances to eliminate heavy metals from the body (chelating agents), but this is unknown on Lythia.

16.2.2 ARSENIC POISONING

Intoxication with high-poisonous white arsenic may happen by inhaling smokes resulting from fire-setting or smelting arsenic ores. Over the time, this results in a chronic arsenic poisoning with following symptoms: A dark gray pigmentation (arsenic melanosis), wart-like proliferations of the palms and soles (arsenic ceratosis), Mees-strips, acne-like skin lesions of the face, possibly carcinoma of the skin, hepatopathy, polyneuropathy, encephalopathy. The effect of white arsenic is based on a damage of the blood capillaries. No therapy is known on Lythia.

16.3 CONSUMPTION

Consumption (the hârnic term for tuberculosis) is among the most frequent causes of death. It is caused by *MYCOBACTERIUM TUBERCULOSIS*, which is transmitted by airborne particles. Most people get infected during childhood, but most of those *PRIMARY INFECTIONS* – almost 90% – heal completely without further complications. In 10% of all primary infections, a *SECONDARY INFECTION* occurs – half of them immediately after the primary infection (so called *MILIARY TUBERCULOSIS*), the other half possible years after. The primary infection leaves the so-called *TUBERCLES*, typical nodes of necrotic tissue that may contain infectious bacteria, encapsulated by granulation tissue.

The **PRIMARLY INFECTION** usually affects the lung (90%, *PHTHISIS PULMONUM*,), but also the cervical lymph nodes, the intestine or the skin. The symptoms are usually weak with an increased temperature, nodal skin irritations, inappetence, and loss of body weight (therefore the name “consumption”) over a period of 3 – 4 weeks.

The **SECONDARY INFECTION** may affect nearly any organ (including intestines, bones and skin). Typical courses of the **MILIARY TUBERCULOSIS** are *MENINGITIS TUBERCULOSA* (in 50% of all cases; high fever and sickness; bad prognosis), *PLEURITIS TUBERCULOSA* (fever, pain while breathing and couching; later abdominal pain and swelling of the abdomen), *TUBERCULOSIS CUTIS* (bluish red nodes expanding from lymph nodes and developing into pustules; or: papules of the skin, ulcerations, swelling of regional lymph nodes).
LATER SECONDARY INFECTIONS are the tuberculosis of the bones and joints (swellings and pain). The outbreak of secondary infections strongly relates to the general physical constitution of the patient – particularly the state of his immune system. When the patient gets in poor condition

(the usual malnutrition; hot, wet and dusty climatic conditions underground; stress/missing recreation), he has risk of an outbreak of the latent infection.

An adequate therapy uses antibiotics like Quessel or Yulpris. While quessel may stop the disease or recurrent infections at an early stage, Yulpris additionally gives a relative chance of eliminating bacteria persisting in infectious tubercles.

16.4 LUNG FIBROSIS

Inhaling metallic dust for a long time may result in chronic inflammations of the lung tissue. Finally, the lung framework changes into a scarred connective tissue. Secondarily, this leads to the development of a restrictively impaired ventilation with the formation of a chronic cardiovascular disease. Symptoms are a dyspnea, fist under load, later even quiescent, cough, fever thrusts, decrease of weight, clubbed fingers, cyanosis. There is no causal therapy.

16.5 WORM DISEASES

16.5.1 ANCLYMOSTOMIASIS

ANCYLOSTOMA DUODENALE (called PIT WORM) is a reddish-white thread worm, a blood sucking parasite of the small intestine. Its eggs are excreted with the faeces (within mines abandoned galleries and drifts are used as latrines), the larvae develop on the ground and can penetrate the miner's skin, particularly when going barefoot. Symptoms of an infection are a itching of the skin with forceful scratching (ground itch), a bronchitis and other pulmonal symptoms while the worms wander through the lung; an enteritis during the intestinal stage, and finally the development of an anemia due to the chronic intestinal loss of blood and protein. Consequences of the anemia are apathy, development disturbances, and a general reduction of resistance. To prevent an infection, miners should use fixed footwear, and use latrines within the mine. Fern extracts will prevent the nidation of the worms within the intestine and are used to treat an infection.

16.5.2 STRONGYLOIDIASIS

STRONGYLOIDES STERCORALIS is a dwarf thread worm. As the pit worm, it is excreted with the faeces and its larvae can penetrate the skin. The infection is often accompanied by an itching papuloid and pustuleoid dermatitis as result of a secondary bacterial infection of the skin where it is perforated by the larvae. The larvae's migration through the lung results in an acute pneumonia; intestine symptoms, like vomit and diarrhea, occur in the intestinal phase. In case of a substantial infestation symptoms as emaciation, anemia, and ileus may develop. Prophylactic measures are include the use of fixed footwear, and dedicated latrines.

16.6 NYSTAGMUS

Bad lighting conditions and unhealthy angles of vision are extremely tiring for the ocular muscles. As an result from years of underground work, a nystagmus may develop. This is an involuntary, rhythmic tremble of the eyeballs. Though a therapy is unknown, good lighting and working conditions help to prevent the disease.

16.7 NOISE TRAUMA DEAFNESS

The exposure to the noise of hammering, crushing rock etc. For many years may result in a progressive, irreparable damage of the ear. It exists no therapy. The use of earmuffs is the only known prophylaxis.

17 SIDE EFFECTS OF MINING AND METALLURGY

This section wants to discuss the side effects of mining and processing ores. Mines and smelteries consume vast quantities of natural resources, as fuel (primary wood) and water (both as power source and process water), first using the local, later related ones. Extensive mining will also change the landscape itself: hollowing out mountains, piling up heaps of possibly poisonous overburden, ashes and slags. The needs of large installations as smelteries or mines will cause changes in the local infrastructure and economic system: trails will be build to transport raw materials and products, specialised workshops to supply the specific demands of tools and their maintenance, markets to deal with food and products.

Though the true impact of these effects will not be apparent to the kethirans, some of the aspects are rather direct and obvious (forest destruction, changes in the landscape) – others will slowly cumulate, but finally change the conditions more significantly (contamination, pollution, mining subsidence, changes of the ground water level). Thus, this section can be seen as a guideline for gamemasters to shape both, active and former, mining regions. Some of the effects may also give good starting points for roleplaying scenarios or campaigns.

17.1 EFFECTS ON THE ENVIRONMENT

17.1.1 SOIL CONTAMINATION

Toxic substances set free by mining, coaling and smelting get deposited within waste tips or in the sediments around the industrial area and in the beds of streams draining the area. There, they may constantly contaminate their environment – or rest for long periods until they get mobilized by erosion or changing chemical factors.

Especially heavy metals (lead, iron, copper, arsenic) are very poisonous and will rest within the environment for long times (centuries or even millenniums). Depending on the concentration of the toxins, contaminated areas are unusable for agriculture, stock breeding, or even forestry – often for many generations.

Affected areas are usually the mine head, smelting place and coaling places, waste dips and the river beds and sediments of streams draining the area. By erosion, the poisonous sediments may get transported miles away from their primary source.

Indicator vegetation may hint the expert to the poisonous character of the ground. Otherwise, chronic diseases and intoxication symptoms (weakness, pale skin, hair losses) will affect the local population (both animals and men).

17.1.2 WATER POLLUTION

Water is a crucial resource for mining and metallurgy. Most processes are somehow related to water as a mean of transport, energy supply or physical medium.

During most of these steps, minerals dissolve within the water and get carried away and reach streams or other stretches of water. Depending on the chemistry of the dissolved agents and the water (temperature, pH-value, microbiotic fauna), the toxins may stay dissolved or precipitate and settle down in the sediments (see "SOIL CONTAMINATION").

Where polluted water is used for irrigation, to water livestock or to prepare food, toxic substances may affect plants, animals and men.

Obviously, aquatic plants and animals are affected strongest. They may get poisoned and probably extinguished within the contaminated stretches of water (by getting direct harmed or indirect, when their food gets extinguished). This may rise problems even for fishing further downstream, as fish often spawn in the upper reaches of rivers.

A second danger arises from finest undissolved particles, that have been carried away during grinding or grading, and from dissolved minerals, that precipitate due to a sudden change of environmental conditions. These particles may block or otherwise harm the gills of aquatic animals and thus finally kill them.

ACID MINE DRAINAGE (AMD) refers to the outflow of acidic water from (usually) abandoned mines. Mines can generate highly acidic mine discharges where the ore is a sulfide or is associated with pyrites. Such discharges may not seem visibly polluting to the naked eye, but the environmental damage may be considerably greater. Metal sulfides, often pyrite, newly exposed to air and water are broken down into metal ions and sulfuric acid by colonies of BACTERIA and ARCHAEA. These microbes, called EXTREMOPHILES for their ability to survive in harsh conditions, occur naturally in the rock, but limited water and air supplies usually keep their numbers low. Many acid mine discharges contain elevated levels of toxic metals especially nickel and copper with lower levels of a range of other metals. In some AMD systems temperatures reach 50°C, and the pH can be as low as -3.6. AMD-causing organisms can thrive in waters with pH very close to zero.[2]

17.1.3 AIR POLLUTION

Mining and smelting set free various toxic substances – as heavy metals, organic agents (soot, tar) and gases – in form of gases and air borne particles.

These particles are spread with the wind. Usually (the use of high chimneys is almost unknown), they remain within the proximity of their source. The biggest portion will finally settle down on the surface and will be washed into the soil or stretches of water (see above).

Small parts of the toxins are directly absorbed by plants, animals and men by respiration and absorbed through exposed surfaces (leaves, skin). They can cause chronic intoxications and allergic reactions.

Additionally, some toxins are accumulated and concentrated in livestock through the food chain.

17.1.4 FOREST DESTRUCTION

The forest is harmed in first by large scale lumbering, as wood is used for mine timbering, construction of buildings and machines and fabrication of tools, but above all as fuel for the smelteries.

It is not unusual, that the complete surroundings of a mine or saltpan are deforested within several years.

Additionally, wood may be cleared to practice agriculture and thus support the miners with food.

As a long term effect, the vegetation is harmed by pollution of the air, water and soil. Dewatering and water resources management may change of the ground water level, resulting in areas becoming marshy or a withering of the vegetation.

The forest destruction leads to a change of the native flora. The specific effects depend on the local topology and clime. First, erosion of the topsoil increases. As a consequence, landslides may occur in steep slopes an endanger miners and other residents. Fertile soil may get washed away with critical effects on vegetation, agriculture and herding.

The local vegetation may change into hearth, steppe or even desert (under arid or alpine conditions). This will finally affect the local fauna and microclime.

In large mining districts, miners will usually employ an elaborated forestry system, to ensure sufficient supplies of wood. The foresters will prefer to plant fast growing trees, as conifers.

17.1.5 CHANGING THE LANDSCAPE

Mining activity may change the landscape in large. The direct effects of opencast mining are obvious. But also underground mining will affect the surface of the landscape by mining subsidence, surface damages and changes of the ground water level.

Advanced water resource management will change the course of streams, create new or destroy native strives of water (dams, reservoirs, canals). Consequences are effects on the local microclime, vegetation and fauna (e.g. dams will block the migration of fish).

Heaps and waste tips, roads and trails, settlements, agriculture and stock breeding will change the face of the landscape, as will the effects of FOREST DESTRUCTION.

---

[2] *See: http://en.wikipedia.org/wiki/Acid_mine_drainage.*

17.2 ECONOMIC EFFECTS

Mines have a major effect on the economy and the social structure of the region the lie in.

17.2.1 INFLUENCES ON THE LOCAL INFRASTRUCTURE AND ECONOMY

A mine will attract lots of people. Some are directly connected to mining and metallurgy, as miners, smelters, smiths, charcoalers, and jewellers.

In rich mines, miners and smelters are highly specialized craftsmen, who cannot or are not willing to spend their time and work on agriculture or herding and thus need to obtain at least foodstuff from third party. So others groups can profit from those specialists by selling products or services of daily need, as do chandlers, merchants, innkeepers, potters, masons, woodcrafters, litigants, hideworkers and many other crafts.

So, large mines attract lots of people and finally result in highly specialized communities. An ambivalent thing is the attraction of runaway serfs, adventurers and criminals, longing for their personal luck and fortune. First, they ensure a frequent inflow of cheap working power, but they also create social problems.

Negative effects of mining are the massive destruction of the forest, a central economic resource for the community: Wood is a crucial resource for construction and as fuel and the forest serves as an important source of food (herbs, nuts, mushrooms, game) and fodder.

Fishing may be affected as described above (see "WATER POLLUTION"), as might be the case with agriculture and herding, when erosion or poisoning of soil and water occurs.

Additionally, the demand for any kind of resources will result in increasing prices for fuel, food and services in the environment of a mine.

17.2.2 INFLUENCES ON FINANCIAL POLICY AND GLOBAL ECONOMY

Rich mining areas are a focus of investments and will bind large amounts of financial capital. Thus, the fate of the mining district can affect the local economy only, or that of a larger area, as a hundred, a kingdom or (in very rare cases) even the global economy.

Mines are the sources of wealth and valuable resources, and thus become the target of political interests and strategic considerations. Opposing forces will try to occupy productive mines to increase their situation. They may also try to raid mines to plunder available resources, abduct miners and craftsmen or simply to destroy the opponent's source of income or reduce his supplies.

As underground mines depend strongly on dewatering, the destruction of dewatering machines or abduction of workers is critical. But also the collapse of mine heads or destruction of refinement installations hinders the profitable operation of a mine for considerable time.

The winning of precious metals like silver and gold, often leads to an increased minting of currency and then will result in an inflation with its large scale effects.

18 REFERENCES

[Agricola1557] Agricola, Georgius: De Re Metallica Libri XII, Basel 1556 (lat.), Basel 1557 (german by P. Bech).

[AlterBergbau] Steuer, Heiko; Zimmermann, Ulrich [editors]: Alter Bergbau in Deutschland, (special issue of: Archäologie in Deutschland), Hamburg 2000. ISBN 3-933203-35-X.

[Czaya1990] Czaya, Eberhard: Der Silberbergbau, Leipzig 1990.

[Freise1908] Freise, Friedrich: Geschichte der Bergbau- und Hüttentechnik. Erster Band: Das Altertum, Berlin 1908.

[Grewe1998] Grewe, Klaus: Licht am Ende des Tunnels. Planung und Trassierung im antiken Tunnelbau. Mainz: von Zabern 1998. ISBN 3-8053-2492-8.

[Greeves1978] Greeves, T.A.P: An outline archaeological and historical survey of tin mining in Devon, England, 1500-1920; in: ICOHTEC Internationales Symposium zur Geschichte des Bergbaus und Hüttenwesens Freiberg 1978 - Vorträge Band 1; Freiberg 1978.

[Healy1978] Healy, John F.: Mining and metallurgy in the greek and roman world, London 1978.

[LdBk1] Heise, Fritz; Herbst, Friedrich: Lehrbuch der Bergbaukunde. Mit besonderer Berücksichtigung des Steinkohlenbergbaus, (Vol. 1), 6th ed., Berlin 1930.

[LdBk2] Heise, Fritz; Herbst, Friedrich: Lehrbuch der Bergbaukunde. Mit besonderer Berücksichtigung des Steinkohlenbergbaus, (Vol. 2), 7th ed., Berlin/Göttingen/Heidelberg 1950.

[Liessmann1997] Liessmann, Wilfried: Historischer Bergbau im Harz, 2nd corrected and extended edition, Berlin/ Heidelberg/ New-York 1997.

[Pschy1994] Pschyrembel Klinisches Wörterbuch, 257th ed., Berlin/New York 1994.

[Rosumek1982] Rosumek, Peter: Technischer Fortschritt und Rationalisierung im antiken Bergbau. (Habelts Dissertationsdrucke: Reihe Alte Geschichte; H. 15), Bonn 1982.

[VGE1999] Brabeck; Lyons; Scharlibbe: VGE-Bergbau-Fachwörterbuch, Essen 1999. ISBN 3-7739-1216-1.

[Wagenbreth1985] Wagenbreth, Otfried; Wächtler, Eberhard [editors]: Der Freiberger Bergbau. Technische Denkmale und Geschichte, 1st ed., Leipzig 1985.

[Wilsdorf1987] Wilsdorf, Helmut: Kulturgeschichte des Bergbaus. Ein illustrierter Streifzug durch Zeiten und Kontinente, Essen 1987.

[Winkelmann1956] Winkelmann, H.: Schwazer Bergbuch, [Hrsg.: Gewerkschaft Eisenhütte Westfalia], Bochum 1956.

InfoMine. Mining Dictionary. http://www.infomine.com/dictionary/

EduMine. Online Professional Development, Continuing Education and Technical Reference for Minig. http://www.edumine.com/

rock	*density*	*price per ton*
granite/syenite	2.80	50-100D
diorite/gabbro	2.90	
Quarzporphyr	2.68	
basalt	3.00	50-100D
basaltic lava	2.28	
Diabas	2.85	
quarzite/graywacke	2.63	
other kind of quartz sandstone	2.33	20-50D
other kinds of limestone	2.15	
travertine/calc-tufa	2.45	
volcanic tufa	1.90	
gneiss/granulite	2.83	
serpentine	2.68	
marble/dolomite	2.75	40,5f
sand	1.80	
all-in gravel	1.90	
screened gravel	1,70	
loam	1,60	
clay (wet)	2.00	
soil	1.70	
marl	2,15	