Safety and health in mining: Part 2

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Safety and health in mining is a position paper summarising key occupational safety and health risks in mining and their prevention. The paper is a joint effort by the members of the Scientific Committee on Mining Occupational Safety and Health (SC MinOSH) of the International Commission on Occupational Health (ICOH). The position paper will be published in three parts, in *Occupational Health Southern Africa*. The abbreviations and references used will be listed for each of the three parts. References are numbered consecutively across the three parts. The paper will also be published in its entirety on the ICOH website, as an output of SC MinOSH.

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PART 2

3. KEY OCCUPATIONAL RISKS AND DISEASES (CONTINUED)

3.5 Toxic chemicals

Exposure to toxic substances in mining may occur when the ore is excavated, when the ore is crushed, and in the extraction process. When the ore is excavated and crushed, toxic substances including arsenic or lead embedded in the ore may be released into the surrounding environment, causing contamination of air, soil and water. The toxic exposure may be caused by either the mined product, e.g. mercury or manganese, or by the substances added in the subsequent extraction processes, e.g. mercury and lead. Generally, the nature of exposure to toxic substances is the same for formal and informal mining. However, the exposures in the informal sector are known to imply much higher health risks, due to the use of inadequate equipment, illiteracy, lack of training, awareness and resources, lack of protective equipment, limited or no regulation by authorities, etc.[24] Thus, the focus of this section is on the informal sector, and in particular on the health impact of exposures related to gold mining.

3.5.1 Risk and prevalence

Small-scale mining includes mining of minerals and materials that typically occur near the surface or within unconsolidated rocks. The minerals and materials include precious metals and gemstones but also construction materials like clays and limestone, tin, tungsten, bismuth, sulphur, lithium, salt, and uranium. However, metals like copper, iron, manganese, and nickel normally cannot be extracted on a small-scale basis.[86] The problems associated with intoxication in artisanal and small-scale gold mining (ASGM) are illustrated here. The intoxications related to such mining are well documented, and ASGM accounts for 20-30% of total global gold production. It is estimated that 10-15 million people in Southeast Asia, especially in the Philippines and Indonesia, and in several African and South American countries, work as artisanal gold miners, with another 85-90 million being indirectly dependent on this activity.[87]

In ASGM, huge amounts of metal mercury are used to amalgamate with gold in order to separate the gold from other metals and minerals in the ore or silt. After amalgamation, the mercury is evaporated, often under very primitive conditions using a blow torch, leaving the gold.[88] In this process, not only is the miner exposed to toxic vapours, but so are the residents and family members in the mining area and its surroundings. It has also been shown that gold merchants, who burn the gold again after buying it from the miners, are exposed to even higher mercury concentrations and more often.[42] Mercury is left in the tailings where it is slowly washed out in the rivers and transformed into the even more toxic methylmercury, the organic form of mercury. Several studies have shown higher levels of metallic mercury among miners and residents, resulting in sub-acute and chronic mercury intoxication as well as acute poisoning.[89] ASGM exposes workers to vapours containing high levels of metallic mercury. These exposures, in turn, lead to symptoms of sub-acute intoxication that are commonly known as the triad of mercurialism, i.e. a fine tremor; increased salivation and inflammation of the gums; and severe behavioural and personality changes and loss of memory and insomnia (mercurial erethism).[90] When chronically exposed at these levels, the central nervous system is the critical target organ. Irreversible neurological damage may be seen with signs of reduced motor skills and mild cognitive impairment. In very high doses, the lungs are the primary target, with symptoms of erosive bronchitis with interstitial pneumonitis.[42,90-92]

Mercury is released in the environment and can therefore also cause environmental exposure. When inorganic mercury circulating in the environment reaches oceans and lakes, it dissolves in the fresh- and seawater and is transformed into methylmercury, which is then ingested by fish and shellfish, and becomes part of the ecological food chain. Fish eaters are then exposed to this form of mercury. The intoxication symptoms of methylmercury caused by ingestion of polluted nutrients differ from those caused by metallic mercury. Severe chronic poisoning leads to paresthesia and ataxia, as well as hearing and visual impairment (Minamata disease). Methylmercury readily passes the blood-placental barrier causing infantile cerebral palsy.[90-92]

Another technique for gold extraction is performed in cyanidation plants. In this process, exposure to the highly toxic hydrogen cyanide is a health risk. The level of hydrogen cyanide is dependent on factors like air temperature, ventilation, the volume and concentration of the material being processed, etc.[93] Headaches and vertigo are early warning symptoms of poisoning, followed by irritation of the eyes, nose and throat, dizziness, vomiting, seizures and cardiovascular shock. The evidence for long-term chronic health effects is limited.[94] Before the ore undergoes the process of cyanidation, a substance called litharge (lead monoxide) is used in fire assay techniques.[42] As litharge contains lead, its use can also cause exposure to lead, another neurotoxic metal.

Artisanal small-scale gold miners from the Kabihug tribe in Camarines Norte digging for gold sediments in a creek in the Philippines

Photograph: Rasmus Køster-Rasmussen

3.5.2 Prevention

In recent years, alternative mercury-reducing (e.g. retorts) or mercury-free gold extraction methods have been introduced. A promising technique is the gravity-borax method, where a heavy mineral concentrate is produced by gravitation.[95] When borax is added to this concentrate, it lowers the melting point, enabling gold to be melted out of the ore with the use of inexpensive equipment. When properly implemented, this technique yields more gold than mercury amalgamation.[96] There have been concerns about the use of borax because of the adverse reproductive effects seen in animal studies of rodents exposed to high concentrations of borax. However, human studies of boron mining workers' exposure to high boron levels have not shown any conclusive adverse effects on reproduction.[97] It has been shown that boron crosses the placenta, and inverse associations have been found between boron concentrations in placenta and the activity of the enzyme δ- aminolevulinic acid dehydratase in umbilical cord blood, thus affecting the haeme biosynthetic pathway in the developing foetus.[98, 99]

It is important to note that the boron exposure associated with the gravity-borax method in gold mining is very low, compared to the exposure experienced in the mining of boron.

The United Nations (UN) 2013 Minamata Convention, calling for governments to reduce mercury use and emissions, has been signed by 128 countries and ratified by 25. The United Nations Environment Programme (UNEP) has a Global Mercury Partnership engaged in assisting countries to effectively manage mercury activities.[100] The Ministers of Health globally have endorsed their role in supporting the implementation of the Minamata Convention, as described in the 2014 World Health Assembly Resolution A67.11. This includes enhancing awareness and intervention on the part of primary healthcare providers in mining areas. To facilitate this process, the World Health Organization (WHO) is seeking to contribute to institutional capacity development in the health sector of countries with significant ASGM.

WHO is in the process of developing global guidance and practice standards on training healthcare providers and on developing public health strategies on health and ASGM.[101.]

3.6 Hearing loss

Noise-induced hearing loss (NIHL) is a permanent affliction that interferes with mine workers' ability to communicate with family, friends, and co-workers. It also creates a safety hazard when mine workers are unable to hear moving machinery and warnings. In addition, many afflicted with NIHL also experience tinnitus – a ringing or buzzing sound that persists in the absence of any real sound – which can be intensely stressful and annoying. The risk increases with long-term exposure, and the prevalence of NIHL among miners is greatly underestimated because of the delay in the manifestation of symptoms.

3.6.1 Risk and prevalence

NIHL is a problem in formal mines in countries at all levels of development. NIHL is cited as one of the most reported occupational diseases in mining in recent articles from India, Iran, South Africa, Poland, Sweden, Chile, Canada, the USA and Australia.[6] The noise levels in mining operations such as drilling, crushing, screening, blasting, etc., are often far higher than recommended or regulated levels. In India, a survey in an underground metal mine found that almost 75% of the mine workers had evidence of NIHL. Another survey of 682 workers in opencast mines showed that 20-25% had evidence of NIHL.[102] In the USA, one out of every four mine workers has a severe hearing problem. Even worse, four out of five mine workers have a hearing impairment when they reach the mid-60s retirement age. Hazardous noise is the primary culprit: 76% of mine workers are exposed to hazardous noise, the highest prevalence of all major industries.[103]

In 2016, Disability Adjusted Life Years (DALYs) were calculated among workers to estimate the burden of hearing loss on quality of life.[104] The DALYs calculation takes into account life limitations caused by hearing loss as a lost portion of a healthy year of life, resulting in the number of healthy years lost by a group of people over a specific period. The report indicated that 2.5 healthy years were lost each year for every 1 000 noise-exposed USA workers because of hearing impairment (hearing loss that impacts day-to-day activities). Workers in the mining sector had the highest burden, with an estimate of 3.5 healthy years per 1 000 workers.

NIHL is also a problem in small-scale mining. Potential sources of excessive noise in small-scale surface mines include compressors, drilling machines, pick-hammers and other mechanical equipment.[15] Additional sources, for example in artisanal gold mining, include intense noise from the use of dynamite in excavation processes and from the extended use of shovels and picks; both miners and nearby communities can be exposed to the noise.[106]

In addition to noise, several chemicals used in mining have been identified as being toxic to the auditory system, and for increasing the negative effects of noise. Such chemicals include solvents, fuels, metals, asphyxiants, pesticides, and polychlorinated biphenyls (PCBs).[107]

Other health risks have been associated with noise exposure. Recently, a small-scale gold mining pilot study in Ghana found increased cortisol levels and heart rate associated with continuous noise. About 95% of the subjects were found to be exposed to noise levels above the WHO recommended noise guideline of 70 dB(A) (the measure of sound level, in A-weighted decibels, to account for the varying sensitivity of the human ear to different frequencies of sound), over a 24-hour exposure period. The study participants included miners and residents from the surrounding areas, indicating risk to the community as well as the miners.[108]

The use of mining equipment, such as this roof bolting machine in an underground coal mine in Pennsylvania, USA, exposes the drilling operator to very high noise levels, as he must stand in close proximity to the equipment to perform his job tasks. Typically, roof bolting machines generate noise levels of up to 112 dB(A) when drilling, which is well in excess of Permissible Exposure Limits (PELs)

Photograph: Workplace Health Branch of NIOSH, Pittsburgh Mining Research Division

3.6.2 Prevention

The International Labour Organization (ILO) provides codes of practice, tools, and guidance manuals to improve the work and life of miners, and to assist countries with the practical implementation of the Hours of Work (Coal Mines) Convention (No. 31) from 1931, and the Safety and Health in Mines Convention (No. 176), which was adopted in 1995.[109] National regulations regarding noise levels in mining operations are in place in many countries, but they are not adequate to address the problem of NIHL.

Miners are often still dependent on hearing protection devices for the prevention of NIHL. This prevention approach presents many challenges. For example, the wearing of conventional hearing protectors leads to reduced audibility or confusion about spoken words, and to an increased risk of miners being struck by moving equipment, or errors in communication with co-workers. Miners will often remove their hearing protectors to overcome these obstacles. To address this problem, new hearing protection technologies are available, including the fit-testing of hearing protection. The objective measurement of attenuation provided gives the user the required feedback to ensure adequate protection. Significant advances in engineering noise controls and the use of administrative controls provide evidence of effective approaches.[110] Some programmes and tools for reducing NIHL in the formal mining industry are available at no cost from NIOSH, USA.[111] For example, engineering control solutions have been developed in formal mining for some underground coal continuous mining machines and roof bolting equipment, and efforts in many countries are also focusing on noise controls for mobile equipment in underground mines, with an emphasis on haul trucks. National 'Buy Quiet' programmes encourage companies to purchase or rent quieter machinery and tools.[112] The Determination of Sound Exposures Software (DOSES) enables mine management and safety personnel to simplify the record-keeping and analysis associated with time-motion studies and worker noise exposures, making it easier to identify and solve noise problems. The software relies on a time-motion study that profiles the workers' daily activities, and the programme displays information about the workers' accumulated noise dose over time.[113]

Prevention of NIHL in small-scale mining is more difficult to achieve, and continued research is needed, along with development, implementation, and sharing of good practices. The ILO provides basic practices for small-scale surface mining to reduce noise emissions by muffling with acoustic absorbing material, by increasing the distance between the noise source and the exposed workers, and where control measures are not possible, by the use of personal hearing protection devices for all persons exposed to noise levels exceeding 90 dB(A).[15]

3.7 Heavy work and musculoskeletal disorders

The term 'heavy work' generally refers to any activity that calls for great physical exertion characterised by high energy consumption and high strain on respiratory and cardiovascular functions. The traditional picture of the working conditions in mining and quarrying is that the work is physically demanding and dangerous due to heavy and awkward loads, unstable underground structures, heavy tools and equipment, and an increased risk of accidents. This may be the situation in artisanal and small-scale mining in many countries, but does not necessarily reflect the working conditions in formal mining companies today. Mechanisation, computerisation and automation have changed working conditions in formal mining and much heavy manual work has disappeared. On the other hand, the same process of mechanisation may increase the risks for musculoskeletal disorders.[6]

3.7.1 Risk and prevalence

There are a number of factors of physical and psychosocial origin, including repetitive and forceful work, static or awkward postures, mechanical stress and vibration, that result in adverse outcomes for the musculoskeletal system. Particular care must be taken if the musculoskeletal system is frequently subjected to excessive loads or subjected to loads for long periods. In extreme positions, e.g. bending, the joints are more likely to be injured. Awkward positions may give considerable load to certain parts of the body. In many countries, however, musculoskeletal disorders are not recognised as work-related and there is a lack of statistics and awareness. In many high-income countries, musculoskeletal disorders are among the most common causes of long periods of sickness absence and early retirement. In low-income countries where nutrition is poor, diseases that affect musculoskeletal structures are common in both childhood and adult life, and people are exposed to heavy loads in both their occupational and domestic life. However, such problems may be overshadowed by other risk factors which have a more acute effect on health and quality of life.[114]

Although there is a lack of systematic epidemiological studies, musculoskeletal disorders are reported to have high prevalence in formal mining for workers in Spain, Sweden, India, Iran, USA and Australia.[6] Even if formal mining has become increasingly mechanised, there is still a substantial amount of manual handling. Cumulative trauma disorders continue to constitute the largest category of occupational disease in mining and often result in prolonged disability. Overhead work is common underground, during ground support, and during the suspension of pipes and electrical cables. This can cause or exacerbate shoulder disorders.[115]

As for informal mining, a global report on artisanal and small-scale mining, commissioned by the Mining, Minerals and Sustainable Development Project of the International Institute for Environment and Development (IIED), reported on extreme exertion from highly labour-intensive jobs and stress caused by economic and other pressures.[24] A Brazilian study presented high prevalence of musculoskeletal disorders among mine workers, with greater problems in the lumbar and dorsal regions. Age, length of service in the mining industry, and the working hours contributed to the prevalence of musculoskeletal disorders.[116]

A study from South Africa states that a number of ergonomic hazards are associated with mining ventures, and the risk factors involve awkward body posture, manual materials handling (MMH), repetitive motions, force and vibration. The advantages of applying sound ergonomics principles in small-scale mining include enhancing efficiency and eliminating significant occupational safety and health risks.[117] Activities such as digging, lifting and hauling, particularly of heavy loads, can result in injury, stress and fatigue. Risks are greater when miners rely on highly manual techniques: breaking rocks with hammers and chisels, mucking and loading with shovels and hauling with simple buckets or bags. Children engaged in these activities are particularly vulnerable, as damage to their musculoskeletal systems can impair their growth and development.[118]

An underground drilling machine that has replaced hand-held drilling equipment used in the past, thereby increasing the efficiency, reducing the manning and eliminating physically demanding work. Depending on the design of the operator's cabin, chair and controls, he or she may be exposed to risks for musculoskeletal disorders, and/or NIHL

Photograph: Boliden

3.7.2 Prevention

Heavy work and musculoskeletal disorders may be minimised or reduced by an effective combination of planning, control measures, training and supervision. A risk management process will identify and evaluate risks with control measures being put in place with ongoing monitoring. A simple checklist can be a useful means of ensuring that nothing is overlooked. User-focused design of cabins and other equipment is also essential.[8,114]

MMH is of special interest in relation to the prevention of physical exertion and musculoskeletal disorders. MMH risk control is best accomplished by a combination of efforts to eliminate manual handling, the introduction of mechanical handling equipment, and the provision of suitable training. The reduction of loads and improved handling training should be the first line of control, while more effective long-term solutions are found. As stated by S. Jerie,"The primary approach to preventing work-related musculoskeletal disorders due to MMH of loads is the ergonomics redesign of work in order to optimise the workload. The preferred approach to control ergonomic problems is to find engineering solutions. If an engineering solution is not feasible, administrative controls become the next order for implementation".[117]

The NIOSH mining webpage has an extensive section on human factors and ergonomics, including guidelines for MMH and prevention of musculoskeletal disorders.[119] In response to the numerous occupational health and safety risks facing artisanal and small-scale miners, a handbook on 'Safety and Health in Small-Scale Surface Mines' was issued by the ILO in 2001, which includes descriptions of engineering controls, administrative measures and training for the prevention of heavy work and musculoskeletal disorders.[15] The Communities, Artisanal and Small-Scale Mining (CASM) initiative includes a review for development planning regarding conditions causing extreme physical exertion and musculoskeletal disorders.[12]

3.8 Vibration

Exposure to vibration in mining operations occurs when miners use vibrating hand tools or mining vehicles. Miners working with hand tools experience vibration primarily in their hands and arms, and mining vehicle operators experience vibration over their whole body. Therefore, occupational exposure to vibration is classified into two main categories: hand-arm vibration and whole-body vibration.

3.8.1 Risk and prevalence

Prolonged and extensive exposure to hand-arm vibration, in both formal and informal mining, can lead to a number of health effects, primarily in the peripheral blood circulation and in the nervous and musculoskeletal systems. The effect on peripheral blood flow is traditionally called vibration-induced 'white fingers'. Workers using hand-held vibrating machines for prolonged exposure times can experience episodic attacks of clearly demarked finger blanching, in response to exposure to cold and cooling conditions. The effects on the peripheral nervous system can be seen either in the form of nerve entrapment at various locations, or in the form of diffusely distributed nerve symptoms manifested by pain, numbness, or tingling in the hands or fingers. The musculoskeletal system may also be influenced by vibration resulting in impaired sensory-motor function or adverse effects such as pain in the joints or bones. The resulting symptom complex is now collectively summarised as hand-arm vibration syndrome (HAVS).[120]

Long-term occupational exposure to whole-body vibration is associated with an increased prevalence of self-reported musculoskeletal pain, especially in the lower back, neck and shoulder regions. The contribution from whole-body vibration to these health problems is not fully understood, and it appears that the probability and severity of vibration-related symptoms are influenced by several factors such as the exposure time, magnitude of the vibration exposure, the occurrence of high-impulse shocks, and environmental conditions, as well as ergonomic factors such as the static posture with restrained movements that vehicle driving entails.[121]

Among workers in formal mining, exposure to whole-body vibration has now become more common than exposure to hand-arm vibration, due to changes in the work tasks required in modern mining operations. However, in informal mining (artisanal and small-scale mining) exposure to hand-arm vibration is still dominant.[15]

Observations on elevated prevalence of 'white fingers' and adverse effects on peripheral nerves have been reported for more than 100 years, related to mine work where vibration exposure occurred from rock drills, impact wrenches, and grinders. In various studies among miners, the prevalence of 'white fingers' nowadays varies from 15-85%, and the prevalence of nerve symptoms varies from 8-81%. The prevalence of 'white fingers' is found to be low in tropical or subtropical areas and higher in temperate zones due to differences in outdoor temperature. There is also a clear exposure–response relationship, with an increased prevalence of symptoms evident among workers exposed to high levels of vibration.[120]

Operators of vehicles used in mining operations such as haul trucks, excavators, and track dozers are exposed to considerable whole-body vibration for relatively long work periods, and studies have shown that the prevalence of self-reported musculoskeletal pain is higher among exposed miners, compared to non-exposed miners. The prevalence of lower back pain among drivers of mining vehicles varies from 43-85%, and neck/shoulder pain varies from 30-62%. The prevalence of self-reported musculoskeletal pain increases with increased vibration exposure.[121]

This modern haul truck and excavator illustrate a situation where exposure to whole-body vibration from vehicles occurs in the mining environment

Photograph: Umeå University

3.8.2 Prevention

There are many actions that can be taken to reduce the risk of vibration damage.[122-124] These measures may be technical or organisational, and the action which has the best effect depends on the circumstances at the workplace. Measures that can be utilised include the use of alternative production methods, avoiding prolonged vibration exposure, and training in working techniques, as well as service and maintenance of machines/vehicles.[125,126] In order to perform a risk assessment, it is necessary to determine what factors and elements give rise to vibration exposure. It is very important to take a holistic approach to the measures that are implemented to prevent vibration risks so that other problems such as noise, dust, and fumes do not become worse.

Periodic medical check-ups have been shown to be an effective method of early detection of health risks. Medical examinations have varying degrees of accuracy and may consist of a questionnaire or include physical examinations. Repeated medical check-ups may be part of the evaluation of the preventive actions taken to reduce exposure to vibration. Medical evaluations can also be used to identify adverse changes in the work environment, work technique, or an individual sensitivity to vibration. Medical examinations can be performed by occupational health services personnel or the equivalent.[124]

The ILO has listed vibration as an occupational hazard and recommended that measures be taken to protect employees from vibration exposure.[109] Moreover, the ILO has also stated that the responsible authorities must establish criteria for determining the danger and define exposure limits. National regulations regarding vibration exposure in mining operations are in place in many countries, for preventing adverse health effects caused by occupational exposure to vibration, and the ILO provides guidance manuals to improve the work environment. The WHO has classified complaints of exposure to mechanical vibration as an occupational disease and offers information regarding hand-arm vibration.[127]

3.9 Heat and cold stress

Miners are exposed to heat stress in open pit mines in warm climates, in close proximity to hot machines and processes, and in deep underground mines, while they are exposed to cold stress in open pit mines in cold climates.

Human heat balance is a result of the thermal environment, metabolic heat production and thermal insulation of clothing. Consequences of thermal stress can be discomfort, performance and productivity degradation, negative health effects, thermal injuries, and even death. Heat and cold stress also increase the incidence of accidents.

3.9.1 Risk and prevalence

Heat stress caused by working in a warm or hot mine (air temperature above 28 °C) is worsened by humid air (evaporation of sweat is hindered), little or no air movement (reduced ability of convective heat loss), heavy physical work (high metabolic heat production), thick clothing (high thermal and evaporative resistance), heavy garments (increased work load and heat production), and direct exposure to sunlight or working near hot surfaces (radiating heat load). An increased core temperature is the indicator of heat stress.[128]

Heat stress disorders range from discomfort, performance degradation and irritations, to potentially fatal conditions. According to a large meta-analysis, thermal stressors greatly reduce both psychomotor and perceptual task performance. Excessive sweating causes skin irritation (heat rash) which is a red, bumpy skin reaction with severe itching. Heat stress also causes several types of heat illness. Heat cramps are painful muscle cramps that occur suddenly during strenuous activity due to low salt and electrolyte levels in muscles, caused by excessive and prolonged sweating. Heat fatigue impairs work performance. Heat syncope is the loss of consciousness during or after physical work in the heat. Heat exhaustion is the consequence of excessive loss of water and salt through excessive sweating, resulting in a rectal temperature above 38 °C. The most serious heat-related disorder is heat stroke, which is potentially fatal. This occurs when rectal temperature is above 40 °C and symptoms include a confused mental state, headache or dizziness, rapid pulse, and hot, dry, red skin, and in the late stages, syncope and convulsions.[129]

Drilling in an open pit mine in northern Finland in an early afternoon in January. The ambient temperature was -15 °C

Photograph: Hannu Rintamäki

Cold stress caused by working in a cold mine is worsened by wind (increased convective heat loss), insufficient thermal insulation of clothing and light physical work or inactivity (low metabolic heat production). Low peripheral skin (hands, feet, and head) temperatures are the most common signs of cold stress. Results from Arctic open pit mines show that workers have very few complaints from cold at ambient temperatures above -10 °C. However, at temperatures of -10 °C to -20 °C, 25% of workers report a cold sensation in their fingers most of the time.[123]

The cold stress disorders range from discomfort, performance degradation and negative health effects to cold injuries. Psychomotor, perceptual and cognitive task performances are decreased substantially, as in the case of heat stress. A special feature in the cold is the decrement of manual performance, as the hands are usually the first body parts which cool in cold conditions. A sharp decrement in manual performance occurs at skin temperatures below 13 °C. Cold pain and numbness occur at skin temperatures of 13 °C and 6 °C, respectively. There are several types of cold injuries. Frostnip (freezing of the most superficial layer of skin) causes only temporary and slight problems. Although frostbite (freezing of superficial or deeper tissues) can develop at all sub-freezing temperatures, its prevalence increases sharply at temperatures below -22 °C. Chilblain (pernio) develops after frostbite or strong cooling, producing lumps in the skin or subcutaneous tissues, usually in the hands or feet. In heavy physical work, constriction of the upper respiratory tract may occur, causing wheezing breath. Hypothermia (core temperature below 35 °C) is very rare in controlled occupational conditions but may occur during immobilisation caused by accidents or sudden seizures. Long-term exposure to the cold is also associated with an increased prevalence of musculoskeletal symptoms.[129]

3.9.2 Prevention

For the prevention of heat stress it is important to quantify the magnitude of the stress. Wet-bulb globe temperature (WBGT) is one of the most commonly used indices in the evaluation of heat stress.[130]

Prevention of heat stress starts by providing information and training about the risks and preventive measures. Adequate work/rest regimens with exposure time limits allow for body cooling and recovery. Adequate drinking prevents the risk of dehydration. Heat acclimation/acclimatisation, which takes between 1-2 weeks, decreases heat stress but does not eliminate the risks. Ventilation increases convective and evaporative heat loss. Personal protective equipment such as cooling vests can be worn to decrease heat stress, at least for short periods of heat exposure.[131] Regular monitoring of workers' health is important, especially in the case of workers with decreased tolerance to heat.[128]

In the cold, the wind chill index quantifies the effect of convective heat loss, the combined effect of low air temperature and wind. The ISO standard (IREQ, Insulation Required) takes into account thermal environment, physical activity, and clothing.[132]

The use of adequate multilayer clothing is essential to prevent cold stress. Inexperienced workers also benefit from information and training about the risks and prevention of cold stress. Protection of hands and feet is especially important, as they tend to cool first. Adequate work/rest regimens with exposure time limits allow for body warming and recovery. Cold acclimation/acclimatisation, which can take up to 10 days, decreases cold stress and improves circulation in hands and fingers in cold conditions. In addition to clothing, personal protective equipment such as electrically-heated gloves, insoles, and vests can be worn, as well as respiratory heat and moisture exchangers. Regular monitoring of workers' health helps to identify workers with decreased tolerance to cold. Aging and most illnesses decrease tolerance to both cold and heat.

3.10 High altitude

It is well known that the pressure of oxygen in the mixture of atmospheric gases decreases with increasing altitude. The consequence is a reduction of oxygen diffusion into tissues, leading to a condition known as hypoxia. This is the direct cause of all functional alterations that occur with brief or prolonged exposure to high altitude.

3.10.1 Risk and prevalence

Mining at high terrestrial elevations is a common practice in Chile, Peru, Bolivia, USA, and many other countries. Hypoxia is not the only risk for miners working at high altitude, because other physical agents are usually present, such as low temperatures, low humidity and high solar radiation. Furthermore, for a miner, the adaptation to life at high altitudes involves a gradual change in lifestyle, away from large urban areas, sometimes living in mining camps, far from family, facing extreme environmental conditions and isolation. This exposes the body to a major overload, which can lead to a deterioration of the physical and mental health of the exposed person, if proper precautions are not taken.[133]

There are three main types of exposure to altitude:

- Acute exposure occurs when exposure is for a short period, and not at regular intervals. It is characteristic of people performing recreational or sporting activities
- Chronic exposure is characteristic of people living and/or working permanently at high altitude
- Chronic intermittent exposure affects people who frequently move between different altitude areas, including the workers engaged in mining operations

The relationship between oxygen consumption and energy production is a biological constant that does not change with fluctuations in the ambient oxygen concentration. When oxygen availability decreases in highland areas, the exposed organism responds with a series of physiological changes to maintain tissue oxygen concentration at levels compatible with life. Humans have the ability to protect themselves against changes in temperature and humidity, but they are not able to control barometric pressure. Hence, the pressure at which oxygen reaches the tissues depends on one's ability to adapt to altitude. This process, known as acclimatisation, is an individual physiological response which includes increases in pulmonary ventilation and heart rate, morphological and functional changes, and increased levels of haematocrit and haemoglobin.[133]

The lack of acclimatisation can trigger the onset of diseases, such as acute mountain sickness, acute pulmonary oedema and acute cerebral oedema. Acute mountain sickness is a condition that can occur in people who ascend rapidly to high altitudes. Symptoms include headache, dyspnoea, vomiting, cough, insomnia, and oedema of the eyes, face, hands and ankles. The symptoms occur 4-8 hours after reaching altitudes above 2 400 m.[134] A serious complication that affects about 1% of those exposed to high altitude is the acute onset of pulmonary and cerebral oedema. Both conditions are hazardous to life, and constitute an extreme emergency. The affected person must descend and receive medical attention urgently.[135]

Chronic mountain sickness can occur in people who have lived at high altitude for some time. It presents with symptoms such as headaches, dizziness, insomnia, fatigue and impaired mental performance, accompanied by signs of hypoxemia and elevated haemoglobin values, above those expected for residents at high altitudes. In the advanced stages, there is a severe cardiovascular compromise, with congestive heart failure. It is postulated that the origin is the increased blood viscosity. Other risk factors for chronic mountain sickness are age, obesity and chronic respiratory disease. It has been observed that the prevalence of excessive erythrocytosis increases with age, from 7% between the ages of 20-29 years, to 33% in those older than 50 years.[136]

It is important to highlight the widespread lack of knowledge about the recommended precautions which should be taken to avoid fatigue in miners who are exposed intermittently to high altitudes.[133] This can occur, for example, when working 12 hours daily and rotating shifts, so the person has seven days working followed by seven days resting, or 10 days working followed by 10 days resting. Fatigue affects activities of high mental demand, and also activities with high physical requirements. No doubt these are difficult topics to study, especially with regard to the standardisation of research, but these challenges must be addressed as soon as possible, to mitigate the risks of working at high altitude. In this regard, there is a pressing need for the establishment of programmes that will lead to improved quality of working life for miners at high altitudes.

3.10.2 Prevention

Actions that will contribute to preventing health effects due to working at high altitude include the following:

- Performance of pre-employment medical examinations to determine: impaired respiratory function, hypertrophic cardiomyopathy, hypertension or other medical contra-indications for working at high altitude
- Implementation of a programme of epidemiological surveillance for workers at risk of developing hypobaric hypoxia (when the body is deprived of adequate oxygen supply at tissue level)
- Organisation of a service with qualified health personnel and medical

facilities in close proximity to the work site and feasible means of transport for workers, in cases when symptoms of hypoxia occur
- Training of workers about the symptoms of acute mountain sickness
- The availability of oxygen at all times
- Work organisation and design to reduce the physiological load. Hypoxia causes a decrease in work capacity in proportion to the reduction of oxygen partial pressure of inspired air[137]
- Reduction of the expected output of manual work, proportional to increasing altitude. (It has been estimated that for every 1 000 m of ascent, above 1 500 m, a decrease of 10% occurs in the capacity for dynamic work)
- Protection of workers against other environmental agents such as cold, wind, humidity and radiation
- Ensuring the camps meet conditions of thermal and acoustic insulation that are conducive to restful sleep. For workers with sleep disorders, oxygenated sleeping quarters may be helpful

3.11 Psychosocial risks

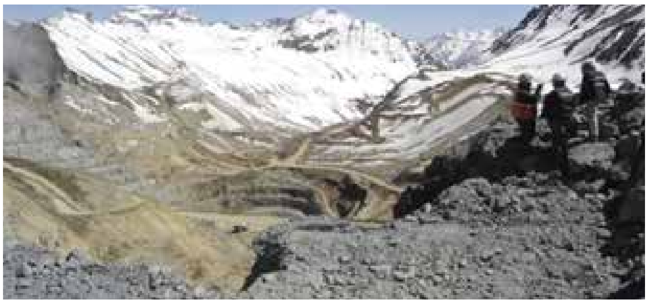
Psychosocial wellbeing is a multi-dimensional concept that includes both psychological wellbeing and the impact of specific domains of life in which this is manifested, especially interpersonal, social and societal.[138] The workplace as such is an important determinant. However, the impact of mining on psychosocial wellbeing is not restricted to the workplace. Mining regions contribute to a range of psychosocial hazards for local communities and employees living in these areas. Some mining impacts are beneficial, such as provision of jobs and infrastructure. However, the rapid in-migration and economic growth (in periods of mineral boom) and rising levels of unemployment and stark economic decline (in periods of mineral downturn) exact severe social consequences.

Although many low-income countries have both formal and informal mining, the working conditions and psychosocial impacts differ from those that are evident in formal mining in high-income countries.

In formal mining, the risks attendant on the workplace that impact on psychosocial wellbeing are usually associated with high productivity demands; monetary incentives which may impact on health and safety practices; dedicated state-of-the-art equipment that requires constant use, maintenance and upgrading; work organisation and administrative controls in the form of shift work, job rotation and fatigue management.

In informal mining, the risks that impact on psychosocial wellbeing are different, principally because the work falls outside of legal and regulatory frameworks, and in many cases, the work is carried out at subsistence level to secure meagre livelihoods, under arduous working conditions, with no benefits such as knowledge of, or access to, health and safety standards and practices, even at a basic level.

In many cases, the work is manual and carried out by individuals or families, with women having traditionally played a very active role in informal mining activities. In these harsh working environments where work is very often seasonal, unstable and carried out by vulnerable and under-served populations, psychosocial aspects include child labour with the associated lack of schooling; violence and bullying against vulnerable and indigent populations; conflicts between mining migrants and local residents, large-scale mining companies, the police and security forces; organised crime; sex trade; overexertion and uncontrolled working hours; the psychological burden associated with the ongoing battle for finite resources; and the lack of access to finance, capacity or technical support. It is well recognised that the affiliation of workers to unions promotes health and safety at work, improves working and living conditions, and contributes to job security. The fact that there is seldom any union representation in small-scale and informal mining further augments the psychosocial risks and their impacts.



A Chilean copper mine situated at 3 700 to 4 200 m above sea level. The mine has both underground and open pit operations. Besides fine copper concentrate, it produces molybdenum. The mine has a staff of about 1 700 employees with around 2 800 subcontractors supporting the operation. Most workers live in a small town, which is located 38 km from the mine site

Photograph: Elias Apud

3.11.1 Risk and prevalence

Psychological stress in formal mining may have origins both in and outside the workplace, and the value of understanding psychosocial wellbeing is slowly beginning to gain traction in the mining industry.[139] This is a significant development because the historically male-dominated mining profession has not easily embraced mental health.

Symptoms of stress are commonly those associated with anxiety and depression and other physical manifestations of ill health such as musculoskeletal pain,[140] making this a complex area to track. A study of Chinese coal miners using self-rating scales reported signs of anxiety (27%) and depression (36%).[141] Another study, on Chinese underground coal miners, using self-administered questionnaires, found the prevalence of depressive symptoms to be 63%.[142] A few studies provide evidence for post-traumatic stress disorder in the mining sector.[143] Stress is also closely associated in some instances with fatigue. An Australian study showed the introduction of different shift systems had negative impacts on stress and fatigue levels.[144] In general, workers with depressive symptoms are more likely to be absent, to have reduced levels of productivity and be more at risk for occupational injury.

Although the mine workplace is hazardous and therefore stressful, symptoms of stress are not restricted to this physical aspect. Depressive symptoms in Chinese coal miners[142] were found to be closely associated with other workplace factors such as ‘effort reward imbalance’ (including wages) and ‘work-family conflict’. This finding is echoed in studies in South Africa that show mine workers report financial stress and are heavily indebted.[145] Financial stress and incentivised payments to meet production targets are a toxic mix that is continually linked to a culture of risk-taking and short cuts with respect to safety in an already highly hazardous work environment.

Other serious psychosocial stressors are the violence, bullying, intimidation and discrimination that pervade some mining workplaces.

An example is the deteriorating industrial relations partially fuelled by financial stress in southern Africa, which culminated recently in incidents of strike and related violence that caused the killing of 34 mine workers.[146] In African mines, workplace culture can be one of blame and fear with workers having little opportunity for actions within their workplace,[147,148] and women entering the mine workplace have faced sexual harassment and abuse.[149]

Substance use and abuse are associated with psychosocial distress (specifically alcohol and illicit drug use). Research indicates that rates of heavy alcohol and illicit drug use and dependence vary across industries and occupations. Globally, heavy alcohol use is considered to be high amongst miners. A study of US workers found heavy alcohol use amongst miners (18%), which was twice that of an average across all industries (9%).[150] While it is reported that only 12% of the mining industry workforces in Australia engage in illicit drug use, the industry records a higher than average rate of short-term risky drinking, with 22% drinking high levels of alcohol at least monthly.[151] A study commissioned by the South African Safety in Mines Research Advisory Committee in 2003 and carried out across seven mines, showed that the percentage of study participants who were likely to be dependent on alcohol varied between 10-25% (versus 10% among the general adult population); the prevalence of cannabis use across the same study mines ranged from 5-22%.[152]

Higher rates of alcohol use have been found amongst miners who have only ever worked underground, compared to those who work aboveground, and amongst miners with a heavy workload. Daily use of coca in Latin-American mining was also found to be significantly higher among miners with a heavy workload.[153] Absenteeism, sick leave, increased health service utilisation and accidents have been found to be higher among workers who use excessive alcohol.[152]

Shift work is one of the better-researched factors influencing psychosocial wellbeing and the fatigue of mine workers. Shift work worldwide varies in form, between day and night shifts; the fly-in and fly-out (FIFO) shifts that may be seven days on and off, or 14 days on and off; to the oscillating migrancy that describes the lifestyle and shift system historically associated with mine work in southern Africa,[154] where mine workers are sourced from labour-sending areas outside the vicinity of the mine and allowed home for leave at the end of the year. All of these arrangements have adverse impacts on mine worker health and psychosocial wellbeing. Impacts include increased injury rates during night shift,[155] serious health problems such as cancers being associated with shift work[156] and long-term sleep loss and fatigue.[157]

Fatigue is the state of physical and mental impairment that results in lower alertness and performance. This is usually caused by a combination of factors that include the length of time an individual has been awake, the amount and quality of sleep, the type of work performed, and the time of day work is performed. Stress is closely associated with fatigue because it is both a cause of sleep and rest disruption, as well as an outcome. Fatigue closely correlates with accidents, and contributes to absenteeism.[157]

3.11.2 Interventions and prevention

The prevention of psychosocial stress in the workplace does not fit neatly into a tidy intervention programme. Rather, it is argued that psychosocial wellbeing is a fundamental challenge to improved working conditions and workplace culture.[158] This is borne out in a study of miners in Australia which found that while some mental health issues are inherent to the mining profession, interpersonal relationships such as family contact, co-workers, management and organisational support can positively impact on the wellbeing of miners.[159,160]

Most interventions to respond to psychosocial stress in the formal mining sector rely on occupational medical practitioners or production supervisors identifying symptoms of stress and/or substance use, and should endeavour to manage and mitigate the risk, on an on-going basis. A drug- and alcohol-free workplace relies on policy, guidance on the use of testing for substance use, education and awareness. Employee Assistance Programmes may refer mine workers for on-site counselling, to a substance use programme or for other forms of support, such as debt counselling.

Fatigue risk management programmes, which are well integrated into occupational health and safety management plans in formal mining, aim to reduce the impact of fatigue and break the dismissive ‘toughen up’ attitude that persists in mining. These programmes vary in sophistication and design but may involve education and awareness, on-line monitoring tools (to record active and extended work periods, for example) and the use of technology to detect signs of fatigue (such as eye closure and blinking rates in machinery and truck operators).

Subsequent interventions to support fatigue risk management include ensuring sufficient staffing levels, the optimisation of shifts and schedules with circadian rhythms, improved sleeping quarter design, temporary sleeping quarters on site for miners returning from a shift before travelling home, access to drinking water, and improved nutrition.

In the informal mining sector, psychosocial risks are one of many health and safety issues that are inadequately addressed at present. Reference is made to the next section, 4.3, where suggestions are given for long- and short-term actions to improve the working conditions in informal mining.

ABBREVIATIONS USED IN PART 2

ASGM	Artisanal and small-scale gold mining
CASM	Communities, artisanal and small-scale mining
DALYs	Disability Adjusted Life Years
DOSES	Determination of Sound Exposures Software
FIFO	Fly-in and fly-out shifts
HAVS	Hand-arm vibration syndrome
ICOH	International Commission on Occupational Health
IIED	International Institute for Environment and Development
ILO	International Labour Organization/International Labour Office
MMH	Manual materials handling
NIHL	Noise-induced hearing loss
NIOSH	National Institute for Occupational Safety and Health, USA
PCBs	Polychlorinated biphenyls
PELs	Permissible Exposure Limit(s)
SC MinOSH	Scientific Committee on Mining Occupational Safety and Health

UN	United Nations
UNEP	United Nations Environment Programme
US/USA	United States/United States of America
WBGT	Wet-bulb globe temperature
WHO	World Health Organization

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