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# A review of the AMM & CMM resources in the Kuznetsk (Kuzbass) Coal Basin, Russia

Sustainable & Renewable Energy Programme

Internal Report IR/05/135

BRITISH GEOLOGICAL SURVEY

SUSTAINABLE & RENEWABLE ENERGY PROGRAMME

INTERNAL REPORT IR/05/135

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N S Jones

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# Summary

This report describes some of the results of a visit to Russia between 7-17th June 2005 to study the Coal Mine Methane and Abandoned Mine Methane resources of the Kuznetsk (Kuzbass) Coal basin, Siberia, Russia. Coal Mine Methane (CMM) refers to gas drained from working coal mines and Abandoned Mine Methane (AMM) refers to mine gas derived from closed mines. This visit formed part of the UK – Russia Cleaner Fossil Fuel Technology Transfer Project: AMM/CMM Technology Transfer Opportunities in Russia. The UK team comprised experts from Wardell Armstrong, British Geological Survey (BGS), IT Power and Climate Mitigation Works; Uglemetan provided support whilst in Russia. The role of the BGS was to evaluate the CMM and AMM resources of the Kuzbass Coal Basin and, if possible, to apply the UK scheme for resources and reserves assessment on the basis of such data as was available in Russia. However, due to significant problems in obtaining suitable data whilst in Russia, a Kuzbass-wide assessment of AMM and CMM resources was not possible. Hence this report represents a review of existing published and non-published data and meetings held during the visit to Russia in 2005, where they impact on AMM and CMM resources. This report is not a definitive assessment of the CMM and AMM resources and reserves of the Kuzbass and the conclusions reached are tentative. Hence it is recommended that more detailed studies be carried out in order gain a better understanding of the CMM and AMM resources and reserves in the Kuzbass.

The Kuzbass Coal Basin covers an area of approximately 26,000 km$^2$ and is thought to contain 63.7 billion tonnes of coal reserves. The main coal-bearing intervals are from the Permo-Carboniferous Kolchuginsky and Balakhonsky stages and, typically, the coal to overburden (non-coal) ratio is about 3.5:1. The area is geologically complex, with large folds and thrust folds dominating. The working underground mines generally operate around the western periphery of the basin, mostly exploiting coals with ranks varying from High Volatile C Bituminous to Low Volatile Bituminous. More than 100 seams, with an average thickness of 2.5 m, have been mined at depths varying from 300-800 m. Ash and moisture contents average about 20 % and 7 % respectively and the gas content averages 12 m$^3$/t.

Coalbed methane resources of the Kuzbass coal basin are thought to be over 13 trillion cubic metres but so far there has been limited exploration for and exploitation of methane. There are presently about 36 working underground mines and there are considerable CMM resources. Annual methane emissions into the atmosphere from Kuzbass coal mines amount to 1-2 billion cubic metres, equal to the annual natural gas consumption in the region. In 1994, out of a total emission of approximately one billion cubic metres of methane, ventilation systems emitted 860 million cubic metres and methane recovery systems emitted 196 million cubic metres following collection. Four examples of potential CMM schemes are described within the report, from Abashevskaya, Chertinskaya, Komsomolets and Pervomaiskay mines. There appears to be a link between high coal productivity and increased methane emissions. In 2005 there are only 13 mines that use degasification systems. Most mines use air from the ventilation system to dilute the methane to safe (non-explosive) concentrations. Hence, for the majority of working mines, capturing the ventilation air methane (VAM) would be the most sensible approach to utilising the CMM.

There are 43 abandoned coal mines in the Kuzbass, many of which have potential for AMM utilisation. On closure it has been estimated that a typical Kuzbass mine emits $10^7$ $m^3$ of methane. The mine closure agency Gorsh is responsible for monitoring mines after closure. Of the 43 closed mines 13 are fully flooded, 15 are partially flooded, and 15 are maintained dry through pumping out of water. There are a further 17 mines that have no documentation or monitoring. Following mine closure and the cessation of pumping, groundwater levels rise quickly, with mines typically flooding within 3-7 years. Hence an understanding of minewater rebound is critical to any successful AMM scheme in the Kuzbass. Data provided by Gorsh show that 86% of the mines have 65% or more of their total volume flooded. Therefore the number of possible AMM schemes is severely limited as a result of minewater recovery and there are perhaps 5-7 suitable prospects.

# 1 Introduction

Between 7-17th June 2005, a party of representatives from the UK travelled to Russia to investigate the potential for abandoned mine methane (AMM) and coal mine methane (CMM) in the Kuznetsk (Kuzbass) Coal Basin, Siberia. This visit formed part of the UK – Russia Cleaner Fossil Fuel Technology Transfer Project: AMM/CMM Technology Transfer Opportunities in Russia (see http://www.dti.gov.uk/energy/coal/cfft/cct/pub/pp361.pdf). The UK team were from Wardell Armstrong, British Geological Survey (BGS), IT Power and Climate Mitigation Works, and Uglemetan provided support whilst in Russia. The aim of the visit was to allow the UK team the opportunity to discuss with Russian counterparts research results, data interpretation, further information needs and technology transfer issues of specific interest relating to AMM and CMM in the Kuzbass.

The role of the BGS was to introduce the methodology used in the UK for the evaluation of CMM and AMM resources and adapt it to produce a methodology to calculate CMM/AMM resources on the basis of such data as is available in Russia. The methodology was to be tested using data from the Kuzbass coal basin and projected to provide a countrywide assessment of CMM and AMM in Russia. This represents Task 2 of the project and this report forms the main deliverable of this task. However, due to the significant problems in obtaining suitable data whilst in Russia, it was not possible to calculate the AMM or CMM resources of the Kuzbass, or indeed project the data to provide a countrywide assessment. Hence this report represents a review of existing published and non-published data and meetings held during the visit to Russia in 2005 where they impact on AMM and CMM resources. Due to the problems in gaining access to data and the sometimes conflicting statements made by coal mine operators regarding methane emissions from underground mines, this report is not a definitive assessment of the CMM and AMM resources and reserves of the Kuzbass and the conclusions reached are tentative.

## 1.1 COAL RESOURCES AND RESERVES

There is no standard coal resource and reserve classification system that is applied worldwide. Two of the most widely used are the system adopted by the U.S. Geological Survey for use in the United States (Wood et al. 1983), and the system used in the former Soviet Union (Bybochkin 1983; Modelevsky 1979). In the U.S. system a **coal resource** is defined as: "*That amount of coal present in such form and quantity that economic extraction is currently or potentially feasible*". Such a resource can be either identified or undiscovered (Figure 1). An identified coal resource is that whose location, rank, quality and quantity are known or estimated from specific geologic evidence and can be reported in terms of Inferred, Indicated and Measured categories (Wood et al. 1983) (Figure 1). A **coal reserve** is defined as: "*A resource that can be economically recovered now using present-day technologies*". Thus resources and reserves are very different - in essence a resource defines what is in the ground, whereas a reserve defines what is presently economically recoverable with current technology (Figure 1).

The system used in Russia is slightly different, in that the term "resources" is rarely used, and only in the sense of total geological resources (Bybochkin 1983; Modelevsky 1979; USGS 1997). Usually, the term "reserves" is used throughout the classification system, and is not dependent on the price of coal (USGS 1997). The term "(total) geological reserves" is roughly equivalent to the U.S. usage of the term resources (USGS 1997). In the Russian system "total geological reserves" are divided into "identified reserves" and "undiscovered reserves" (USGS 1997). "Identified reserves" are divided into "balance reserves" and "out-of-balance reserves" (USGS 1997). "Balance reserves" are potentially recoverable and are roughly equivalent to the economic portion of the identified resource category in the U.S. system and "out-of-balance reserves" (non-commercial) are roughly equivalent to the subeconomic portion of the identified resource category of the US system (USGS 1997).

## 1.2 KUZBASS COAL BASIN

The Kuzbass Coal Basin is a highly folded inter-montane depression which contains coal of Permian and Carboniferous age (Brunner 2000) (Figure 2). It covers an area of approximately 26,000 km$^2$ and is thought to contain 63.7 billion tonnes of coal reserves (Uglemetan 2002). The main coal-bearing intervals are from the Permo-Carboniferous Kolchuginsky and Balakhonsky stages and, typically, the coal to overburden (non-coal) ratio is about 3.5:1 (Marshall et al. 1996; Kuuskraa 2000) (Figure 3). Coals also occur in the Jurassic Tarbagansky Stage (Marshall et al. 1996). There are presently about 36 working underground mines, operating generally around the western periphery of the basin, mostly exploiting coals of High Volatile C Bituminous to Low Volatile Bituminous in rank (Brunner 2000). Within the coalfield, more than 100 seams, with an average thickness of 2.5 m, have been mined at depths varying from 300-800 m (Marshall et al. 1996). Ash and moisture contents average about 20 % and 7 % respectively (Kuuskraa 2000). The gas content averages 12 m$^3$/t. Many of these underground mines face difficult conditions in deepening coal reserves with high in-situ gas content (Brunner 2000). The Kuzbass Coal basin can be divided into a number of tectono-stratigraphic units, all with different characteristics in terms of their structural geology, stratigraphy and coals (Figure 3). Some of details of these divisions are summarised in Table 1.

Coalbed methane resources of the Kuzbass coal basin are thought to be over 13 trillion cubic metres with 6,631 billion m$^3$ attributable to the Balakhonsky succession and 6,454 billion m$^3$ attributable to the Kolchuginsky Stage (source: Uglemetan). So far there has been limited exploration for and exploitation of methane carried out. In 1998 in the Erunakova region, two CBM pilot boreholes were drilled to 1350 m depth (Uglemetan 2002). Test and research results indicate that the total coal seam thickness intersected by these wells is in the excess of 80 m, with the in-situ gas content varying from 19-25 m$^3$/t and coal seam permeability ranging from 20-150 mD (Uglemetan 2002).

Annual methane emissions into the atmosphere from Kuzbass coal mines amount to 1-2 billion cubic metres, which equals the annual natural gas consumption in the region (Uglemetan 2002). In 1997 1.5 billion cubic metres of natural gas was supplied to the region, so the annual methane emissions equal the annual natural gas consumption (Uglemetan 2002). In 1994, out of a total emission of approximately one billion cubic metres of methane, ventilation systems emitted 860 million cubic metres and methane recovery systems emitted 196 million cubic metres following collection (U.S. EPA 1996).

### 1.3 DEFINITIONS OF AMM AND CMM

The gas found naturally occurring in coal seams predominantly comprises methane (typically 80-95%) with lower proportions of ethane, propane, nitrogen and carbon dioxide (Creedy et al. 2001). These gases, together with water vapour, air and associated oxidation products are usually collectively termed ‘mine gas’ or, in the U.S., Coal Mine Methane (CMM) (Creedy et al. 2001). However, in this report CMM refers to gas drained from **working** coal mines. The term CMM has also been applied to mine gas derived from abandoned or closed mines. In order to reduce this confusion a further term, Abandoned Mine Methane (AMM), was introduced for the mine gas derived from **closed** mines.

The methane is stored in the micropore and fracture (cleat) system of the coal primarily through physical adsorption but, in the larger voids also as a free gas (U.S. EPA 2004). Coals have the ability to store large volumes of gas due to the large internal surface area of the coal matrix (i.e. coal has large microporosity). If the partial pressure of methane decreases, methane desorbs from the coal and moves into the cleat system as a free gas that obeys Darcy’s Law. As there is a pressure differential between the cleat system and the open mine void the methane is able to move into the mine. The rate of gas flow will depend on the seam gas content, permeability, and the number and thicknesses of seams in the disturbed zone (Creedy et al. 2001). The principal of AMM and CMM is that methane is sourced from the de-stressed coals and strata above and below the workings. Any gas sources (e.g. coal or sandstone) within the disturbed zone will release a proportion of their gas, which will flow towards the workings.

# 2 Coal Mine Methane (CMM)

Methane is an underground hazard as it can be explosive when mixed with air, so deep mines vent methane to atmosphere during mining operations as a safety requirement. The following section describes some general concepts for the calculation of CMM resources and some actual examples of CMM utilisation in the Kuzbass.

### 2.1 CMM RESOURCE CALCULATIONS

The CMM resource is the volume of gas in coal and surrounding strata (gas-in-place) that will be released by longwall extraction over the remaining life of a mine (Creedy et al. 2001). This gas is not only released at the coalface from the mined seam, but also from seams and non-coaly strata (such as sandstones) in the collapsed and fractured strata surrounding the mined seam. Longwall mining may de-stress strata from 160-200 m above and 40-70 m below the worked seam, with the extent of the zone depending on the length of the coalface, the strata strength, the depth of working and the effects of previous workings (Creedy 2001; Creedy et al. 2001) (Figure 4).

The CMM resource area is defined as the planned extent of workings for each seam within a mine. The recoverable reserves are the volumes of gas that can be captured and delivered to a utilisation plant. Creedy et al. (2001) produced a generalised calculation of the CMM reserves for the UK = 1,620 x $10^6 m^3$. This was based on the assumption that the average life of the remaining gassy deep mines was 10 years, with an average of 15 faces each producing 1 x $10^6$ tonnes of coal per annum; 6 m disturbed roof coal; an average gas content of 6 $m^3\ t^{-1}$; worked seam thickness of 2 m and 60 % of roof gas available for emission or capture. Assuming a 50 % capture efficiency and no use of ventilation air methane (VAM) the amount of usable reserves would be 810 x $10^6 m^3$ (Creedy et al. 2001). It would be possible to use the above calculation in the Kuzbass, changing the parameters where relevant but, as the discussion in Section 2.2 indicates, this might not necessarily be the best approach.

Another solution would be to determine the specific emissions (in $m^3$/tonne) for a mine, which represents the volume of methane released into the mine per tonne of coal extracted (Creedy 2001). This can be calculated for a coalface district or the entire mine and would represent the CMM resource or, if captured, the reserves. Creedy (2001) has described a methodology for predicting the likely methane emissions into a longwall district of a UK mine, which is based on the MRDE firedamp prediction method developed by the former British Coal Corporation (Airey 1971; Dunmore 1981). The method requires the following parameters to be known:

- Depth and thickness (less dirt) of all coal seams within 200 m of the roof and 70 m of the floor of the worked seam
- Proposed face extraction parameters, such as face height, length, ash content of coal, extraction rate and length of panel (face run)
- The gas content of the worked seams
- The positions of old workings above or below the proposed face panel.

A computer program (FPPROG) was written to implement the MRDE prediction method and, using this program, Creedy (2001) suggests that the predicted flows are generally within 20 % of the measured flows. A simplified form of this was published by Creedy & Kershaw (1988). This method can be used for all faces within a mine to give an estimate of the likely methane flows into the ventilation system (i.e. ventilation air methane or VAM).

It is possible to calculate the specific emissions (in $m^3$/tonne) for a mine, which represents the volume of methane released into the mine per tonne of coal mined (Creedy 2001). This can be calculated for a coalface district or the entire mine and would represent the CMM resource or, if captured, the reserves. The rate of gas flow depends on the gas contents, number and thicknesses of seams in the disturbed zone, the proximity of the seams to the worked seam, the age of the district and, most importantly the rate of face advance or retreat (Creedy 2001).

Monitoring the total volume, rate and quality of gas vented from existing shafts or gob vent boreholes over time needs to be carried out to determine the yearly average rate of methane emissions. This will help to establish a baseline emission rate for possible future greenhouse gas (GHG) emission reduction trading.

Tailakov et al. (2004) have also proposed a methodology for the prediction of methane emissions from Kuzbass mines:

For a general case, with known variables, the methane resources of an individual coal seam within a mine's area can be calculated as:

$$GIP_i^{layer} = \iint_s f\ (x, y)\ dxdy$$

where

$$f\ (x, y) = m\ (x, y)\ \rho\ (x, y)\ \cos\alpha\ (x, y)\ \chi\ (x, y)\ \frac{(1 - A\ (x, y) + W\ (x, y)}{100}$$

where $GIP^{layer}$ = gas in place per layer
methane resources = i
mine area = s
coal seam heights = m (x, y)
angle of dip = $\alpha$ (x, y)
ash content = A (x, y)
moisture content = W (x, y)
methane content = c (x, y)
coal density = $\rho$

## 2.2 CMM IN THE KUZBASS

Presently there are thought to be 36 working collieries in the Kuzbass. Mines typically comprise a number of shafts accessing the underground workings, at depths ranging from 400-600 m, with multiple, often thick, seams worked by longwall methods. Seam dips are quite variable (5-20°) and reverse faults (thrust belts) are common. Longwall faces are typically 200 m in length with face runs of 1500 m and are often accessed by single entry systems (Brunner 2000). The uppermost seams (i.e. those above about 100 m) are generally low in methane and are thought to have naturally degasified over time. In general the deeper seams are more gassy. There is a north-south variation in seam gas content, with seams in the south being more gassy. Many mines have difficult mining conditions and outbursts, stress problems, coal seams with high gas content and poor reservoir characteristics are common features (Brunner 2000). The in-situ gas contents for coals in the Kuzbass vary from 12-28 $m^3$/tonne, with a mean of 16.7 $m^3$/tonne (Figure 5). These figures are derived by using canister methods (the Skochinsky Mining Institute Method) to determine the in-situ gas content of coal, and numerical methods are used to project these gas contents across mining reserves (Brunner 2000). Brunner (2000) suggests that these figures appear high considering the mine ventilation information provided by Uglemetan.

Most mines in the Kuzbass operate without significant methane drainage (degasification) schemes, having adopted gas control systems involving ventilation and gob gas bleeder shafts that vent methane to the surface at concentrations between 5 and 25 % (Brunner 2000). This technique was widely adopted in the Kuzbass following the installation of explosion-proof surface exhaust fan systems in 1980, which was approved by the mine safety regulatory agency (Brunner 2000). Due to the cost implications of installing and maintaining degasification systems, many mines quickly adopted a ventilation-based approach to gas control (Brunner

2000). As a result of this, in 2005 there are only 13 mines in the Kuzbass that use degasification systems, out of a total of 36 open mines (Figure 6). Degasification figures in Kuzbass have also reduced. The amount of methane captured through degasification systems reduced from 216 million $m^3$ in 1990 to 113 million $m^3$ in 1998 and 104 million $m^3$ in 2002 (Figure 7). The methane concentration varies considerably, dependent on, amongst other things, the individual mine, the location within a mine and coal production rate. Hence any CMM scheme would most likely have to look at using either the VAM or methane collected from gob bleeder systems. VAM systems have been used successfully applied elsewhere in the world. For example the Appin Colliery in New South Wales, Australia, utilises VAM at concentrations of <1 % (U.S. EPA 2000). One problem with VAM is in maintaining suitable concentrations. M. Durnin (pers comm. 2005) suggests VAM concentrations varying between 4-10 % are not uncommon from Yuzhkuzbassugol mines and hence would require some treatment.

Overall emissions are monitored on a mine-by-mine basis with data commonly available for single emission points (such as bleeder boreholes) per mine. Hence fairly accurate figures are available for overall emissions. Mines in the Kuzbass are known to be generally quite gassy (Figures 8 and 9) and, in 2000, it is estimated that around 0.8 billion $m^3$ of methane was vented to the atmosphere against a total underground production of c.55 MM tonnes (Source Uglemetan) (Figure 10). There is a clear link between the production volumes and methane emissions, with an overall decline in production figures matched by a similar overall decline in methane emissions (Figure 10). Much of the data for the open mines is held by the mine owners and access to these data should be negotiated with the owners. For example, each working mine keeps records of the flow rate and concentration of methane vented at individual emission points such as bleeder shafts or degasification systems. In the case of Pervomaiskaya Mine, this data is held in both journals and digitally. Gosgortekhnadzor (The Federal Inspectorate for Mining and Industry) also monitors gas levels and keeps methane emission records and Uglemetan also hold some of these gas emission data in digital form (in Excel). Each mine typically also keeps copies of any exploration data such as, for example, boreholes. In the case of the Pervomaiskaya Mine these are nearly all fully cored, and the data held includes a borehole log, together with all the relevant metadata for each borehole, such as a borehole number, the depth and thicknesses of seams encountered and the surface level. There are gas content data for each coal encountered in these boreholes. Other data that exists includes measured gas contents and coal reserves assessment for the Kuzbass region (Skochinsky Mining Institute 1991).

In terms of an overall CMM prospectivity in the Kuzbass it can be concluded that the resources are plentiful, with numerous mines having good potential. Brunner (2000) concluded that the mines with better geological and mining conditions form the best CMM targets as they are higher production mines, which is ultimately linked to higher CMM emissions. In addition to this, Brunner (2000) also believes that the gassier mines provide the most options to recover CMM as their methane emissions are likely attributed to gas-charged overlying or underlying sources (suitable for gob gas recovery techniques), or favourable reservoir conditions (suitable for methane recovery in advance of mining), in addition to their higher coal production rates. Hence Brunner (2000) suggests that the best CMM prospects will be those that utilise gob gas recovery in addition to gas drained in advance of mining.

## 2.3 CMM CASE STUDIES: ACTUAL AND POSSIBLE EXAMPLES

This section assesses four Kuzbass mines that may have potential for CMM utilisation. This is based on a review of existing published and non-published data and interviews held during the visit to Russia in 2005. The lack of data prohibits a comprehensive appraisal of all mines with CMM potential.

### 2.3.1 Abashevskaya Mine

A detailed summary of this mine is available in a 1996 U.S. EPA report on methane emissions from coal mines in Russia (U.S. EPA 1996). The mine is located in the southern part of the Kuzbass, on the SE flank of a NE plunging syncline, with typical mine dips ranging from 6 to 25° (Figure 2). The mine has one working level that is accessed by 5 shafts, with the coal worked by longwall methods. There are 4 mined seams, with the seams averaging 1.88 m thick and ranging from 1.3-3.0 m, worked at a current mining depth of 550 m. The seams are high volatile bituminous B coals, and seam gas content is about 20 $m^3$/tonne (source Uglemetan).

Methane reserves are estimated by the U.S. EPA at 2.3-9.7 billion cubic metres for all balance coal reserves and from 1.4-5.7 billion cubic metres for the industrial coal reserves (U.S. EPA 1996). This mine was the highest producer of CMM in the Kuzbass during the period 1990-1998 (data source: Uglemetan) (Figure 11). In 1998 the mine emitted c. 48,000 tonnes of methane (source Uglemetan). Compared to the UK, these emissions are quite high. For example Harworth Mine, in North Nottinghamshire, burnt 11,000 tonnes of methane in 1999 and produced around 100 GWh of electricity, enough to supply power to 30,000 households (see http://www.defra.gov.uk/environment/climatechange/cm4913/4913html/27.htm).

In 1994 the Abashevskaya mine drained 5 % of the methane it liberated as a result of mining operations (U.S. EPA 1996). The mine utilises an in-mine drainage system via horizontal boreholes drilled into the unmined coal seams. The methane from these boreholes is extracted via 10 vacuum pumps, 4 of which are on the surface and the remainder underground (U.S. EPA 1996). Methane drainage from surface boreholes would not be possible because 3 other mines lie above Abashevskaya Mine (U.S. EPA 1996). Currently none of the methane is utilised, it is all vented at the surface. In theory this mine should have good CMM potential due to the large emissions of methane. However, the recovered gas has low methane concentrations and needs to be improved if is to be suitable for utilisation (U.S. EPA 1996).

### 2.3.2 Chertinskaya Mine

The Chertinskaya Mine is located in the west-central part of the Kuzbass, about 8 km south of the city of Belovo (U.S. EPA 1996) (Figure 2). Three seams are mined using longwall methods from two levels, with seam thicknesses averaging 2.14 m (U.S. EPA 1996). The workings, currently at about 500 m, are accessed via three shafts (US-EPA 1996). The in-situ gas content is about 18 $m^3$/tonne (source: Uglemetan). High levels of methane are known from this mine, with reserves estimated at 1.3-4.9 billion $m^3$ for all balance coal reserves and 1.0-3.8 billion $m^3$ for the industrial coal reserves (U.S. EPA 1996). Interestingly, during 1994 when coal production fell to 0.88 millions tonnes, the total methane production actually showed a marked increase to 41 $x10^3$ tonnes (Source: Uglemetan) (Figure 12).

The main degasification system used is in-mine drainage, using cross-measures and horizontal boreholes drilled into seams prior to working (U.S. EPA 1996). Methane is also drawn off from gob areas. The methane is drained from the working part of the mine via a number of pumping stations. The output of these varies from 1.2 – 6.4 $m^3$/min, with a concentration varying from 6-55 % (U.S. EPA 1996). Gas is also extracted at the surface from abandoned parts of the mine. Sixteen vertical gas drainage boreholes have been drilled from the surface to intersect parts of the old workings. These boreholes have been connected to a 420 mm polychlorvynil pipe system, which stretches 3.2 km back to the colliery (Burrell & Kershaw 2000; Uglemetan 2002). The gas is recovered via 3 vacuum pumps which run on electric power produced by a generator rated at 200 kW capacity and fuelled with methane (Uglemetan 2002). The gas is extracted at a rate of 20 $m^3$/min, with a purity of about 60-80 %. (Uglemetan 2002). By the time it reaches a 1 MW power Caterpillar generator unit at the surface the methane amount is 5 $m^3$/min (Uglemetan 2002).

In terms of the CMM resource, Tailakov et al. (2004) estimate that, between 1952-2002, a total of 1.88 million $m^3$ of methane was liberated from this mine and that the residual resources of methane are approximately 0.5 million $m^3$. Considering a 25 % efficiency for the degasification system, the reserves would be 0.12 million $m^3$ (Tailakov et al. 2004).

### 2.3.3 Komsomolets Mine

The Komsomolets Mine is located in the west-central part of the Kuzbass, 2 km south of the city of Leninsk-Kuznetsk (U.S. EPA 1996) (Figure 2). There are 13 seams being mined from one level, with seam thicknesses averaging 2.65 m (U.S. EPA 1996). The working level, at 450 m, is accessed via 4 shafts (U.S. EPA 1996). The mine is considered extremely gassy and gas contents are typically 20 $m^3$/tonne (Source: Uglemetan) (Figure 13). A CMM scheme is being operated at this mine, set up as part of the United Nations Development Program – UNDP/GEFRUS/03/G31P "Russian Federation – Removing Barriers to Coal Mine Methane Recovery & Utilization". Methane is being recovered from a sealed gob area within the mine via a borehole (Borehole No. 301) at a rate of 20 $m^3$ per minute, with a concentration of 25 % (O. Tailakov pers. comm. 2005). Compare this with Tower Colliery in South Wales, UK, where CMM is produced at a rate of 1000 $ls^{-1}$ (60 $m^3$/min) although, depending on the amount of overworking of adjacent/subjacent seams, this varies from 400-1350 $ls^{-1}$ (24-81 $m^3$/min), with a gas purity from <35 % to 60-70 % (DTI 2000).

At Komsomolets Mine a pump on top of the well extracts 50 $m^3$ of air per minute. At the wellhead the concentration is 50-60 % methane, but this reduces to 25 % at the pump due to leakages (O. Tailakov pers. comm. 2005). The leaks occur along a section of small pipe less than 20 m in length that links the well with the compressor station/vacuum pump (O. Tailakov pers. comm. 2005). At the moment these leakages do not present too much of a problem because the methane is currently being vented. However, in order to utilise the methane in the future these leaks must be sealed. It is proposed that the methane will be used in boiler systems.

### 2.3.4 Pervomaiskaya Mine

The Pervomaiskaya Mine is located in the north-eastern part of the Kemerovo region within the Berezovo-Berjulinsky Formation coal deposit located in the northern part of the Kemerovo region (Figure 2). There is one mined seam (Seam 27), which is typically 2 m thick (up to about 2.4 m), dips at 18° to the south and is worked at depths of about 300 m. The mine workings are dissected by a series of NNE-SSW-trending thrust faults. Typical mine production is about 4000 tonnes per day from 1 longwall face, and the gas content averages 10-25 $m^3$/tonne, although this varies considerably and gas contents of between 40-50 $m^3$/tonne are predicted elsewhere in the mine from the same seam. This is thought to be depth-related, with the higher figures related to the coal being at about 560 m depth, compared to 300 m. Methane outbursts are a problem in this mine with instantaneous methane rising to 50,000 $m^3$ during one outburst. Another measured outburst produced 15,000 $m^3$ of methane almost instantaneously.

The Pervomaiskaya Mine liberates and drains 14,000 tonnes of methane per year. Currently methane is drained via 3 boreholes. Gas comes out of these boreholes typically at a rate of up to 50 $m^3$ per minute at a concentration of 6 %, but this typically only occurs when coal is being produced. A project has been proposed to utilise some of the methane emitted from this mine (U.S. EPA 1998). If funded, the project will involve enhanced drilling, creation of a centralized system to collect and transport the methane and conversion of boilers to co-fire 6,750-t/yr coalbed methane with coal.

It is estimated that there are 7.8 million tonnes of mineable coal reserves. Annual methane emissions are generally less than the 3 mines discussed previously (Figure 14); the U.S. EPA (1998) estimate annual emissions of between 8-20 million $m^3$. With a recovery efficiency of 50 %, between 4-10 million $m^3$ of methane would be available for use. According to geological exploration data, the methane reserves within the first 1080 m length section of planned longwall 370 would be 5.8 million $m^3$ (U.S.EPA 1998). The proposed project, which was submitted to the 'National Pollution Abatement Facility' domestic programme for funding, would require in-seam drilling of 1000 m-long boreholes into the coal panel for gas drainage in advance of mining. This could recover at least 20 $m^3$/min of methane, and allow an increase in coal production of up to 30 %. The methane will be contained in a gas mixture having an average methane concentration of 40 % or greater, and a potential energy equivalent of 9.6 Gcal/hr (U.S. EPA 1998).

# 3 Abandoned Mine Methane (AMM)

## 3.1 INTRODUCTION

Abandoned Mine Methane (AMM) consists of the fuel gas (mainly methane) fraction of the free gas trapped within abandoned coal mines, plus any methane that can be desorbed from the coal seams in the strata surrounding the mined seam by applying suction to the mine workings (Creedy et al. 2001a). Mines which worked coal seams that initially contained <1m$^3$/tonne coalbed gas commonly emit mixtures of carbon dioxide and de-oxygenated air referred to as blackdamp. These mines are unsuitable for AMM production.

Many factors can impact on the rate of CMM emissions from abandoned mines. Clearly, the total gas (methane) content of the coal is important, but it is not necessarily critical, because initial testing at some low gas content but extensive mines indicates high gas flows can be achieved (Creedy et al. 2001). In such cases it is the extent of interconnected, dry workings, and hence the physical volume of the reservoir, rather than gas content that is the significant factor (Creedy et al. 2001). Also important is the time since abandonment, as the mine's methane emissions decline steeply as a function of time elapsed since closure. This can be represented as a decline curve, which describes the rate at which methane continues to desorb from the coal after abandonment. Another critical factor controlling the availability of methane from closed mines is the rate of minewater recovery in the area of the mine. Flooding will effectively sterilise the resource as gas cannot be extracted in commercial quantities from a flooded mine and pumping out a mine is likely to be too costly (Creedy 2001). Other factors impacting the rate of methane emission include mine size, sealing and the coal's permeability, porosity and degree of water saturation.

AMM represents a considerable resource. In the UK, for example, the Association of Coal Mine Methane Operators (ACMMO) estimate an annual methane production of about 235,000 tonnes of methane from unflooded closed mines with vents and about 381,000 tonnes of methane from mines without vents (Sage 2002). More recently, IMC White Young Green Environmental (2005) have estimated that, in 2004, there were 8.6 million m$^3$ of AMM reserves in the UK.

## 3.2 AMM RESOURCE CALCULATIONS

Coal is the primary source of methane in an abandoned mine, and gas can be produced from the unmined part of the worked seam and the unmined coal in the immediate roof and floor to the mined seam. The gas reservoir could include the goaf area of the mined seam, roadways and shafts, and destressed areas of the roof and floor, where the gas can be held, for example, in fractures or in porous sandstones. It has been estimated by British Coal that the destressed zone surrounding a longwall worked seam extends for 40-70 m into the floor and 160-200 m into the roof. The precise origin of any produced methane will be indeterminate and therefore the whole mine complex and its associated fracture systems can be considered to form a boundary to the reservoir (Creedy et al. 2001).

The AMM resource consists of the volumes of gas remaining in coal seams that have been de-stressed by mining and that could potentially be extracted from abandoned mineworkings (Creedy et al. 2001). The reserves are the volumes of gas expected to be recoverable, having taken into account various factors such as groundwater recovery (Creedy et al. 2001). The resource area is the extent of underground workings that could contribute methane that is not submerged by recovering or recovered mine water levels. In practice the resource area is best restricted to the longwall areas or other 'total extraction' workings

There are a number of methods for estimating AMM resources and reserves which differ in detail, but all involve trying to calculate the amount of gas remaining in the abandoned mine that could be extracted either by applying a suction pressure or by being forced out as groundwater recovers. Raven Ridge Resources for example use a numerical modelling system, using a three dimensional computational fluid dynamics (CFD) simulator, to provide an AMM production forecast for a given recovery technique. IMC carried out a study for Alkane Energy calculating the methane emissions from abandoned mines (IMC 2001). They firstly used measured emission data from working mines and applied an emission decay function to correct for the reduction in emissions after closure (Sage 2002). They also used monitored data from abandoned mine vents. Estimates were then based on gas reserves in place prior to mining, gas lost during mining and gas left in place after abandonment (Sage 2002). More recently IMC White Young Green Environmental (2005) have published another methodology for estimating methane emissions from abandoned mines in the UK. Calculating the methane emissions of an abandoned mine is a complex issue and factors that need to be considered include:

- The volume of unmined coal likely to be in good pressure communication with the abandoned workings. This coal is likely to have an enhanced (fracture) permeability due to roof collapse and floor relaxation
- The initial gas content data for the seams that are likely to contribute methane
- The volume of this gas that can be desorbed from the coal at a given suction pressure. This is a function of the adsorption isotherm, which defines the gas storage behaviour of the coals that contribute to the methane production. The steeper the adsorption isotherm at low pressures, the more gas will adsorb or desorb per unit pressure change (U.S. EPA 1996)
- The volume of void space in the longwall (mined-out) areas in contact with the extraction point needs to be known. This acts both as a gas storage area and as a conduit to the extraction point (borehole or shaft). It is also important to try to identify volumes that may be isolated from the main workings by in-mine stopings (seals). These areas may have to be exploited individually
- An estimate of the permeability of the coals and other strata that might transmit gas needs to be established
- Minewater recovery rates. Clearly, the opportunity for AMM exploitation reduces as the groundwater levels in abandoned mines start to recover
- Status of mine (e.g. sealed or venting to atmosphere)
- An indication of the underground volume of mine gas can be obtained from passive tests including monitoring the quantity of air that passes in through the surface vent during times of low barometric pressure and of mine gas that passes out through the vent at

times of high barometric pressure, or by a calculation based on the outflow under constant barometric pressure (cf. Massen et al. 1998).

The method described here for estimation of AMM resources is that developed by Creedy et al. (2001), which assumes that the recoverable gas in a mining-disturbed seam is the calculated residual gas minus the gas adsorbed at a final absolute pressure of 50 kPa. Firstly the total thickness of coal that would contribute methane to the abandoned mine was calculated. This was determined by summing the thickness of coal encountered in a borehole up to 150m above the worked seam and 40m below the worked seam. The thickness of the worked seam was discounted from this calculation. Then an average value for the remnant seam gas contents was calculated. Measurements of virgin seam gas content are available for many coalfields in the UK but have to be estimated for others (Creedy et al. 2001). Finally, using an empirical relationship established by Wardell Armstrong (Creedy et al. 2001), the residual gas-in-place in worked areas of coal can be approximated as:

*0.4 x virgin gas content x thickness of coal affected by mining x area of workings*

Reserves then need to be estimated by applying a correction factor to account for the proportion of AMM considered to be inaccessible due to flooding (Creedy et al. 2001). The level of uncertainty is relatively high due to the gross assumptions and a detailed assessment is needed to confirm the result. An alternative methodology was also proposed by Creedy et al. (2001), using data from the Barnsley Seam, Selby Coalfield:

| One seam extracted (Barnsley Seam) | |
|---|---|
| Gas content | 5.3 $m^3$ per tonne (taken from Stillingfleet) |
| Approximate thickness of coal within zone 150m above and 40m below Barnsley Seam | 6.28m (measured from an NCB borehole) |
| Assuming 40% of virgin gas content gas in surrounding seams potentially available for production to a pressure of 50kPa | 0.4 x 5.3 x 6.28 per $m^2$ of mine area<br>= 13.3$m^3$ per $m^2$ of mine area<br>= 13.3 million $m^3$ per $km^2$ |

This methodology would probably not be suitable for the Kuzbass, where mines typically extract more than one seam.

## 3.3 AMM IN THE KUZBASS

There are 43 abandoned coal mines in the Kuzbass, many of which have potential for AMM utilisation (Table 2). On closure it has been estimated that a typical Kuzbass mine emits $10^7$ $m^3$ of methane (Burrell & Kershaw 2000). In the Kuzbass the geological situation is different to that of the UK in that the mines are dominated by large faults and severe folding, which act to partition blocks of coal, thus restricting the size of the likely reservoirs (Burrell & Kershaw 2000). There may be the potential for surface connections caused by subsidence and fracturing (Burrell & Kershaw 2000).

In the Kuzbass, the mine closure agency GORSH is responsible for monitoring mines after closure and currently there are a total of 43 mines under their jurisdiction. Of these 13 are fully flooded, 15 are partially flooded, and 15 are maintained dry through pumping out of water (Table 2). GORSH has operated since 1998 and reports that there are a further 17 mines which closed prior to their existence that have no documentation or monitoring. The method of closure is known as 'conservation', with wet conservation equivalent to switching off any pumps and allowing the mine to flood and dry conservation essentially continuing pumping. The wet conservation method is more commonly applied whereas dry conservation is mainly used where abandoned mines are close to existing (open) mine workings.

Following mine closure and the cessation of pumping, groundwater levels rise quickly, with Burrell & Kershaw (2000) suggesting mines typically flooding within 3-4 years. GORSH data for 4 mines shows that 3-7 years is a common time period for full groundwater recovery to take place (Figure 15). If such figures are applicable across the entire Kuzbass it means that an understanding of minewater rebound is critical to any successful AMM scheme as they will only have a limited lifespan. This is of course the case where mines are not pumped, whereas those that continue to be dewatered obviously have potential over greater periods of time.

Figure 15 shows that the vast majority of the closed mines (where data is available) are close to full recovery, with 86% of the mines having greater than 65% of their workings flooded. Hence, whilst GORSH (2005) ranks 15 mines as Group 2, Partially Flooded, the number of possible AMM schemes is severely limited as a result of minewater recovery and there are only perhaps 5-7 prospects (Table 2). No geological data was available for these mines during the course of this study. Data from abandoned mines is not necessarily easy to acquire. Gorsh keep copies of all the abandoned mine plans, store all the documentation and have an archive. However, they do not have data for all the coal companies, and estimate that they hold only approximately 70 %. Two mining companies hold their own abandoned mine data. They have permission from the Ministry and keep the data because they are mining adjacent areas.

## 3.4 AMM CASE STUDIES: ACTUAL AND POSSIBLE EXAMPLES

### 3.4.1 Kapitalnaya Mine

This mine forms part of the Zapadnaya-Kapitalnaya mine complex and worked coal at a depth of about 700 m. This is next to the Chertinskaya Mine which is one of the few mines to have a normal degasification system. The Zapadnaya-Kapitalnaya mine complex partially closed in 2003/04, although it is believed that one part of the mine is still operating. This mine complex has the advantage that it was closed using the dry conservation method and hence has been chosen by the Skochinsky Institute of Mining as having good AMM potential. It would also appear that there is interest in using this mine for a UCG scheme (G. Polevshikov pers. comm. 2005). GORSH have provided the Institute with all the monitoring data in order for them to site a borehole. The in-situ gas content of coals in this mine was measured at 22 $m^3$/tonne (source: Uglemetan).

### 3.4.2 Kirov Mine

It is reported that the Kirov Mine was the first AMM pilot project undertaken in Russia. It aimed to produce 400kW of electrical power from two converted T34 tank engines (Hird et al. 2003). The project failed because the extraction borehole was found to be full of water, indicating that minewater recovery was complete (Hird et al. 2003).

### 3.4.3 Kolchunginskaya Mine

The Kolchunginskaya mine, closed in 1993, was the first AMM scheme carried out in the Kuzbass. A c.210 m long, 426 mm diameter vertical borehole was drilled from surface (Figure 17). A further 20 m was then drilled in order to intersect the old workings of Face 32 and 33 of Coal Seam 5 (Figure 17). The borehole was cased and the lower part was slotted. The methane flow rate was found to be low and the workings flooded (in 1 year) before a pump could be fitted. A drainage borehole initially took the water away, but when the methane pump was switched on the water level rose from 0 m datum to +120 m, and the pump was switched off (Figure 17). The mine started to flood in March 2001 and, in June 2003, the water was at a level of +65 m. It is now ranked by GORSH as partially flooded, although their figure of 99.9 % of the mine workings flooded can be taken to indicate that the minewater has fully recovered. A second borehole trial was carried out at Kolchunginskaya using a Caterpillar engine. There were methane purification problems this time, suggesting some contamination and the Caterpillar engine failed (G. Polevshikov pers. comm. 2005).

### 3.4.4 Zyryanovskaya Mine

The Zyryanovskaya Mine is next to the working Abashevskaya Mine (owned by Yuzkuzbassugol) which is a known producer of high methane emissions. The gas content from Abashevskaya Mine can reach 120 $m^3$/minute absolute methane emissions from individual faces, and coal production is up to 1,200,000 tonnes per year. Methane at 25 $m^3$/minute with concentrations of 3-4 % has been drained from the gob area at Abashevskaya and a degasification scheme is in use here. The worked coals (Coal seams 14 and 16, 1.2 and 1.8 m thick coals respectively) are connected to the Zyryanovskaya Mine and hence the Zyryanovskaya Mine may have AMM potential (M. Durnin pers. comm. 2005). However, M. Durnin suggests that it would not be practical to extract methane only from the closed mine, and would be more sensible to combine it with the working one and perhaps drain the methane through the working one.

# 4 Conclusions

From the review of available data it would appear that there are considerable CMM and AMM resources and reserves in the Kuzbass. Further work is obviously need to evaluate the resources in more detail as this report only covers the issues in a generalised manner. Hence it is recommended that more detailed studies be carried out in order gain a better understanding of the CMM and AMM resources and reserves in the Kuzbass. It is important to secure access to the data and this is where problems may arise. Coal companies are reluctant to make available commercially sensitive information and one company suggested a contractual agreement would need to exist between the two interested parties prior to releasing data.

There are 36 working underground collieries in the Kuzbass. In terms of CMM there are considerable resources available for utilisation. However, the general lack of conventional degasification systems in Kuzbass mines restricts the use of such systems for CMM to 13 mines. The others discharge CMM to the atmosphere via the ventilation system and therefore any CMM scheme involving the other 23 mines would either need to utilise the VAM or, if available, methane from gob gas bleeder boreholes.

The AMM schemes that have been tried previously have mainly failed due to technical difficulties which are out of the scope of this report. AMM resources are large, but it is clear that AMM is likely to be controlled by the state of minewater recovery. AMM schemes would need to be planned with this in mind, as most of the mines that have closed using the ‘wet conservation method’ are now totally or nearly flooded.

Mine planning is also slightly differently to that operating in the UK. In the Kuzbass it is quite common for more than one mine to occur in the same area, with different mines lying above other mines, and working coals at different depths. Most of the closed mines that are still being pumped are those close to existing, open mines and is has been suggested that there need not be such a clear distinction between AMM and CMM, as the best way to access the methane in the closed mines in such situations would be from an adjacent working mine.

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| Region | Main coal-bearing unit | General comments on coal deposits | Structure/tectonic setting | Coal rank | Volatile content % | Example Mines |
|---|---|---|---|---|---|---|
| Anzhersky | Balakhonsky | Coal-bearing deposits belong to Lower Balakhonsky and to the bottom of Upper Balakhonsky, where Mazurovsky, Alykaevsky and Promezhutochny formations of 1130m total thickness occur. Alykaevsky Formation has the highest commercial value, with up to 20 operational coal seams | The area is dominated by 3 synclines: Anzherskaya, Andreevskaya and Kozlinskaya | coking, leaned baking and lean | 10-23 | Sudzhenskaya, Anzherskaya |
| Aralitchevsky | Balakhonsky | Coal bearing deposits represented by Promezhutochny, Ishanovsky, Kemerovsky and Usyatsky formations of Upper Balakhonsky Stage | Large-scale dome-shaped anticline with additional minor folds, of which the Aralitchevskaya and Redakovskaya anticlines being the most prominent among them | No information | No information | Ordzhenikidze, Dimitrova, Redakovo-Zapadnaya |
| Baidaevsky | Kolchuginsky | The main coals are within the Ilyinskaya and Erunakovskaya divisions of Koltchuginsky Stage The Ilyinskaya division incorporates coal seams (1-26 a) of the Uskatsky Formation. The Erunakovskaya divisions has coal seams (26 a-38) attributed to Leninsky Formation | The Baidaevsky Syncline and its northern continuations, the Antonovskaya Syncline and the Esaulskaya Syncline constitute the major structural elements of the area. The Baidaevsky Syncline is asymmetric with a steep western limb (45-75°) and a flatter eastern limb (10-25°). The fold plunges to the north at 12-15°. In the eastern part of the area are numerous additional synclines e.g. Antonovsky and Esaulsky, and thrust faults with displacements of up to 300m | gas (G), gas fat (GF) and fat (F) | 30-39 | Esaulskaya, Polosykhiskaya, Yubileynaya, Novokuznetskaya, Zyryanovaskaya, Nagornaya, Abashevskaya, Baidaevskaya |
| Barzasky (Devonian) | Kolchuginsky | No information | No information | No information | No information | No information |
| Batchatsky | Balakhonsky | No information | No information | No information | No information | No information |
| Belovsky | Kolchuginsky | Coal deposits are from the Kolchginsky Stage, with mined intervals from the Leninsky (3-7 operational coal seams), Gramoteinsky (8 operational coal seams), Uskatsky (8 operational coal seams) and Kazankovo-Markinsky (18 operational coal seams) formations, where coal seams thickness varies between 0.7-3.8 m. Vitrinite content reaches 85-95% | Mainly comprises a zone of linear folding. There are 3 tectonic blocks divided by Afonino-Kiselevsky and Kutonovsky ramps with displacements of 750-3500m. Within the blocks are a series of folds, including the Belovskaya, Chertiskaya and Ubinskaya synclines, separated by Babanovsky, Novorossiysky and Kalinovsky anticlines | gassy, fat | 30-39 | Pionerka, Chertinskaya, Zapadnaya, Novaya |
| Bunguro-Tchumyshsky | Balakhonsky | Coal deposits belong to Balakhonsky Stage | Four coal-bearing structural zones: Berezovsky, Bungursky, Listvaynsky and Chumyshsky | No information | No information | Bungurskaya underground mine, Listvaynsky opencast |
| Doroninsky (Jurassic) | Kolchuginsky | No information | No information | No information | No information | No information |
| Erunakovsky | Kolchuginsky | The coal content of the Kazankovo-Markinsky Formation varies from 0.2% to 0.5%. The coal content increases from 1.2% to 5.3% in the Uskatsky Formation. In the Leninsky Formation the coal content ranges from 3.4% to 5.7%. In the Taylugansky Formation the coal content fluctuates from 6.3% to 9.1% | The area is structurally complicated. In the SW part linear folds and faults occur, oriented parallel to the Prisalaeer range structures. Numerous large thrusts occur. | long flame (LF), gas (G), gas/fat (GF) and fat (F). | No information | Katakansky, Sokolovsky, Severo-Taldinsky, Narykskу, Novokazansky, Taldinsky, Kukshinsky, Zhernovsky, Erunakovsky, Tagaryshsky, Krasulinsky |
| Kemerovsky | Balakhonsky | Commercial coal bearing deposits occur in the Alykaevsky Formation, numbering up to 8 operational coal seams of 0.8-3m thickness. Commercial coal content also occurs in parts of the Promezhutochny, Ishanovsky and Kemerovsky formations; the latter numbering from 6 to 10 operational thickness coal seams, where the highest one is Volkovsky coal | Major structural element is the Kemerovsky syncline, which is tight on the northern limb and more open on the southern. The eastern limb features monoclinal bedding at 15°-20° to 35°-40° sediments dip, marked by numerous small faults. The western limb dips at 35° -50° and is complicated by additional folds, possessing mainly steep and sometimes vertical limbs. The limb is sometime faulted, with one fault with a known throw of 400m | gas/fat to lean | 11-32 | Pervomaiskaya, Biryulinskaya, Berezovskaya,Severnaya, Butovskaya, Yagunovskaya, Volkova, Yuzhnaya |

**Table 1. Generalised tectono-stratigraphic and coal data for different areas within the Kuzbass Coal Basin.**

(compiled from data supplied by Uglemetan, 2005). These areas are illustrated in Figure 3.

| Region | Main coal-bearing unit | General comments on coal deposits | Structure/tectonic setting | Coal rank | Volatile content % | Example Mines |
|---|---|---|---|---|---|---|
| Kondomsky | Balakhonsky | Coal bearing deposits occur in nine zones. Coals are concentrated within Lower and Upper Balakhonsky stages. The Lower Balakhonsky incorporates Mazurovsky and Alykaevsky formations, and the low one by Promezhutochny, Ishanovsky, Kemerovsky and Usyatsky formations with their cumulative thickness varying between 970-1200m | | No information | No information | Shushtalepskaya, Alarda, Malinovskaya |
| Krapivinsky | Balakhonsky | No information | No information | No information | No information | No information |
| Leninsky | Kolchuginsky | Coal deposits are within the Erunakovsky (upper) and Ilyinsky (lower) divisions of the Kolchuginsky Stage. Erunakovsky is divided into 3 formations, with a total thickness of 1610m thickness. The Ilyinskaya is up about 1540m in thickness | Wide, flat synclines including the Nikitinskaya, Leninskaya and Egozovo-Krasnoyarskaya. | No information | No information | Kiriva, The 7th of November, Zarechnaya, Komsomolets, Polysaevskaya, Oktaybrskaya and Kuznetaksaya, Yaroslavskogo, Kolmogorovskay |
| Mrassky | Balakhonsky | No information | No information | No information | No information | No information |
| Osinovsky | Kolchuginsky | Coal bearing deposits mainly from the Kazankovo- Markinsky and Uskatsky formations of the Koltchuginsky Stage. Within the region these deposits are subdivided into three productive units: Polkashtinskaya, Kandaleosakaya and Elbanskaya. There are up to 30 coal seams, 20 of which are of operational thickness | The main area's structure is the asymmetric Shelkinsky syncline that has open limbs and a flat bottom, with the axis trending NE-SW. The SE limb is flatter (10-30°). The syncline's NW limb is steeper (35-50°, locally up to 70-80°) and has associated smaller scale folds and numerous thrust faults | No information | No information | Vysokaya, Kuzbasskaya, Kapitalnaya |
| Plotnikovsky | Kolchuginsky | No information | No information | No information | No information | No information |
| Prokopjevsko-Kiselevsky | Balakhonsky | Coal deposits occur in the Mazurovsky and Alykaevsky formations of the Lower Balakhonsky Stage and Promezhutochny, Ishanovsky, Kemerovsky and Usyatsky formations of the Upper Balakhonsky Stage. All coal mines of this area are ranked as gassy | Large-scale folds with steeply dipping limbs (50°-80°) are well developed, together with numerous faults, with displacements of hundreds or even thousands metres. From west to east these syncline folds are named Prityrganskaya, Nulevaya, I,II,III, IV,V,VI,VII, Maganakskaya, all divided by anticlines. The area numbers about 15 large thrust faults spaced at 10 km or larger distances. The largest ones, from west to east, include Tyrgansky thrust, Afonino-Kiselevsky and Kiselevsky ramps | No information | No information | Zenkovskaya-II category; Dalnye Gory, Kiselevskaya, Prokop'evskaya,-III category; Tyrganskaya, Dzerzhinskogo, Vakhrusheva, Surtaikha, Taibiskaya, No.12, Cherkasovskaya, Krasnokamenskaya, Maganak; Ziminka, Kalinina, Krasnogorskaya, No.5-6, Nogradskaya, Koksovaya, Tsentralnaya, Severny Maganak, Krasny Uglekop |
| Saltymakovsky | Balakhonsky & Kolchuginsky | No information | No information | No information | No information | No information |
| Tersinsky | Balakhonsky | No information | No information | No information | No information | No information |
| Titovsky | Balakhonsky | No information | No information | No information | No information | No information |
| Tom-Usinsky | Balakhonsky | The best coal bearing deposits are from the Leninsky, Kazankovo-Markinsky formations of the Koltchuginsky Stage and Usyatsky, Kemerovsky and Ishanovsky formations of the Balakhonsky Stage. Balakhonsky Stage deposits incorporate not less than 100 coal seams, about 34 of which possess operational thickness. Coking coals make up about 50 % of total reserves | Four parallel zones extended from north-west to south-east: comprising a band of western monoclines, a central zone of complex folds, a zone of flat folds and an eastern monocline.The band of western monoclines corresponds to a main south-eastern limb of the Kuzbass trough | coking, leaned baking and lean | 11-24 | Tomskaya, Usinskaya, Lenina, Shevyakova, Raspadskaya |
| Tutuyasky (Jurassic) | Kolchuginsky | No information | No information | No information | No information | No information |

Table 1 continued

| No. | Underground mines | Open/ closed | Minewater recovery status | % of mine drowned | Notes |
|---|---|---|---|---|---|
| 1 | 7 Nojabrja | Open | N/A | N/A | |
| 2 | Abashevskaja | Open | N/A | N/A | Next to Zyryanovskaya |
| 3 | Alarda | Open | N/A | N/A | |
| 4 | Berezovskaja | Open | N/A | N/A | |
| 5 | Bol'shevik | Open | N/A | N/A | |
| 6 | Chertinskaja | Open | N/A | N/A | Next to Zapadnaya mine |
| 7 | Distant gory | Open | N/A | N/A | |
| 8 | Dzerzhinskogo | Open | N/A | N/A | |
| 9 | Esaul'skaja | Open | N/A | N/A | |
| 10 | Fizkul'turnik | Open | N/A | N/A | |
| 11 | Gramoteinskoe | Open | N/A | N/A | |
| 12 | Jubilinejnaja | Open | N/A | N/A | |
| 13 | Kirova | Open | N/A | N/A | |
| 14 | Kiselevskaja | Open | N/A | N/A | |
| 15 | Koksovaja | Open | N/A | N/A | |
| 16 | Kolmogorovskaja | Open | N/A | N/A | |
| 17 | Komsomolets | Open | N/A | N/A | CMM scheme |
| 18 | Kostromovskaya | Open | N/A | N/A | New mine; no data |
| 19 | Kranokamenskaja | Open | N/A | N/A | |
| 20 | Krasnogorskaja | Open | N/A | N/A | |
| 21 | Kuznetskaja | Open | N/A | N/A | |
| 22 | Kyrgajskaja | Open | N/A | N/A | |
| 23 | Lenina | Open | N/A | N/A | |
| 24 | Leninskoe | Open | N/A | N/A | |
| 25 | Mine 5-6 | Open | N/A | N/A | |
| 26 | Novaja | Open | N/A | N/A | |
| 27 | Oktjabr'skaja | Open | N/A | N/A | |
| 28 | Pervomaiskaja | Open | N/A | N/A | |
| 29 | Polosuhinskaja | Open | N/A | N/A | |
| 30 | Raspadskaja | Open | N/A | N/A | |
| 31 | Shahta N12 | Open | N/A | N/A | |
| 32 | Tomskaja | Open | N/A | N/A | |
| 33 | Tyrganskaja | Open | N/A | N/A | |
| 34 | Usinskaja | Open | N/A | N/A | |
| 35 | Zarechnaja | Open | N/A | N/A | |
| 36 | Zenkovskaja | Open | N/A | N/A | |
| 37 | Ziminka | Open | N/A | N/A | |
| 38 | Anzherskaya - Juzhnaja | Closed | Group 1 | 97.8 | |
| 39 | Bungurskaja | Closed | Group 1 | 98.9 | |
| 40 | Butovskaja | Closed | Group 1 | 100 | |
| 41 | Cherkasovskaya, Surtaiha | Closed | Group 1 | 83.4 | |
| 42 | Karagaykinskaya | Closed | Group 1 | 74.9 | |

**Table 2. Status of mines in the Kuzbass.**

(data source Gorsh 2005 & Uglemetan)

| No. | Underground mines | Open/ closed | Minewater recovery status | % of mine drowned | Notes |
|---|---|---|---|---|---|
| 43 | Lapichevskaya | Closed | Group 1 | 98.7 | |
| 44 | Severnaja | Closed | Group 1 | 100 | |
| 45 | Severny Kandysh | Closed | Group 1 | 100 | |
| 46 | Shushtalepskaya | Closed | Group 1 | 100 | |
| 47 | Sudzhenskaya | Closed | Group 1 | 97 | |
| 48 | Volkova | Closed | Group 1 | 98.3 | |
| 49 | Yagunovskaja | Closed | Group 1 | 98.5 | |
| 50 | Yuzhnaja | Closed | Group 1 | 100 | |
| 51 | Baidaevskaya | Closed | Group 2 | 100 | Below Zyryanovskaya & Abashevskaja |
| 52 | Dimitrova | Closed | Group 2 | 96.2 | Possibly a high methane emitter |
| 53 | GSHU Mine 2 | Closed | Group 2 | 82 | |
| 54 | GSHU Mine 3 | Closed | Group 2 | 100 | |
| 55 | Kalinina | Closed | Group 2 | 21.9 | |
| 56 | Kolchuginskoye | Closed | Group 2 | 99.9 | |
| 57 | Krasny Kuzbass | Closed | Group 2 | 12.5 | |
| 58 | Krasny Uglekop | Closed | Group 2 | 84 | |
| 59 | Nogradskaya | Closed | Group 2 | 67.6 | |
| 60 | Orjonikidze | Closed | Group 2 | 100 | |
| 61 | Pionerka | Closed | Group 2 | 100 | |
| 62 | Sheviakova | Closed | Group 2 | 1 | |
| 63 | Smychka | Closed | Group 2 | 100 | |
| 64 | Taybinskaya | Closed | Group 2 | 75.5 | |
| 65 | Tsentralnaya | Closed | Group 2 | 54.8 | |
| 66 | Zapadnaya | Closed | Group 2 | 14.3 | Next to Chertinskaya mine |
| 67 | Biryulinskaya | Closed | Group 3 | 82.3 | This is pumped by Pervomaiskaya |
| 68 | Inskaya (Energeticheskaya) | Closed | Group 3 | Ukwn | |
| 69 | Kapitalnaya | Closed | Group 3 | Ukwn | Thought to be a good AMM prospect |
| 70 | Mine 5-6 | Closed | Group 3 | Ukwn | |
| 71 | Nagornaya | Closed | Group 3 | 93.3 | |
| 72 | Novokuznetskaya | Closed | Group 3 | Ukwn | |
| 73 | Polysayevskaya | Closed | Group 3 | Ukwn | |
| 74 | Severny Maganak | Closed | Group 3 | 96 | |
| 75 | Sibirskoye | Closed | Group 3 | 100 | |
| 76 | Signal | Closed | Group 3 | 74.5 | |
| 77 | Surtaikha | Closed | Group 3 | 68.6 | |
| 78 | Vakhrusheva | Closed | Group 3 | 71.2 | |
| 79 | Vysokaya | Closed | Group 3 | Ukwn | |
| 80 | Yaroslavskogo | Closed | Group 3 | Ukwn | |
| 81 | Zyryanovskaya | Closed | Group 3 | Ukwn | Next to Abashevskaja |

Group 1 = Flooded mines
Group 2 = Partially flooded mines with water pumped to the surface
Group 3 = Flooded mines with water flowing to workings of other mines

Table 2 continued

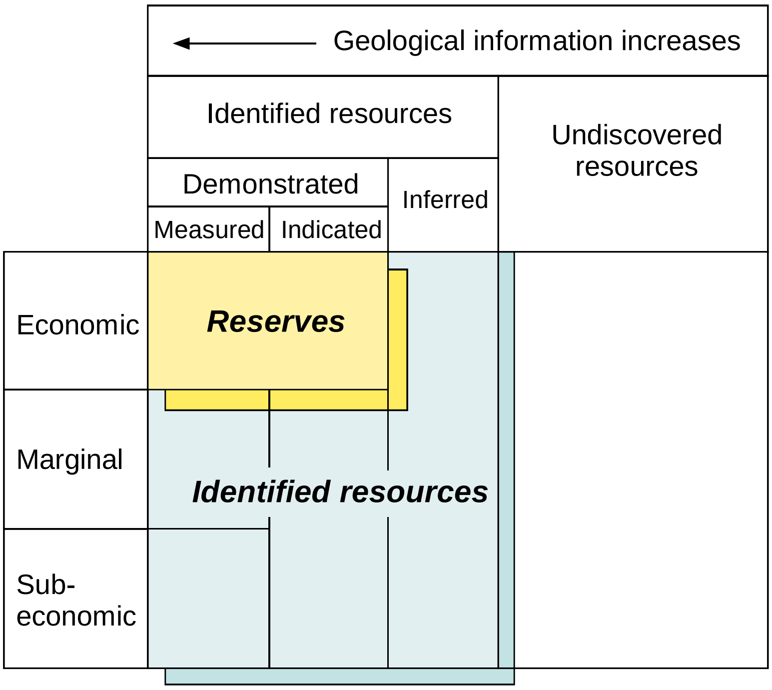



Figure 1. Diagrammatic representation of coal resources and reserves.

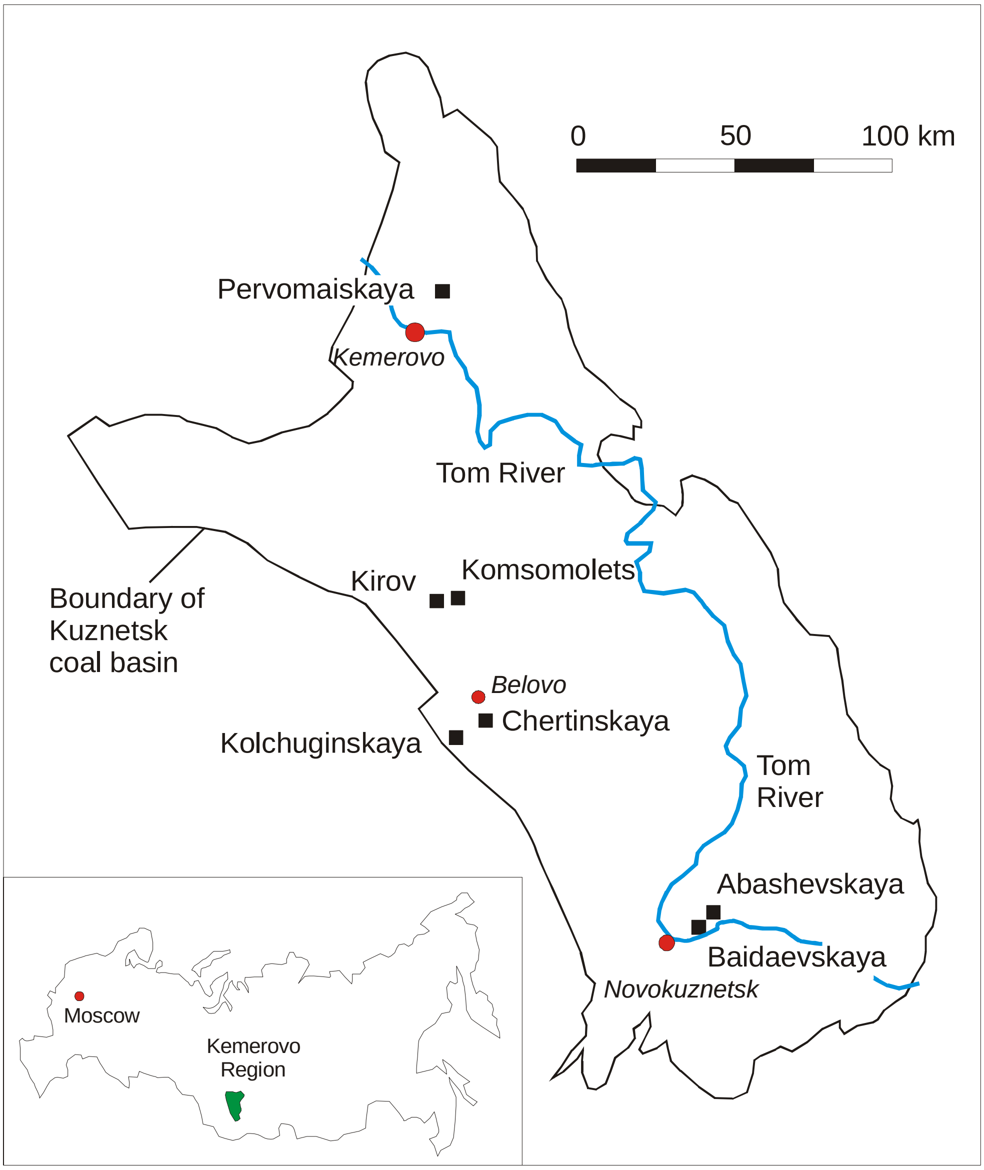
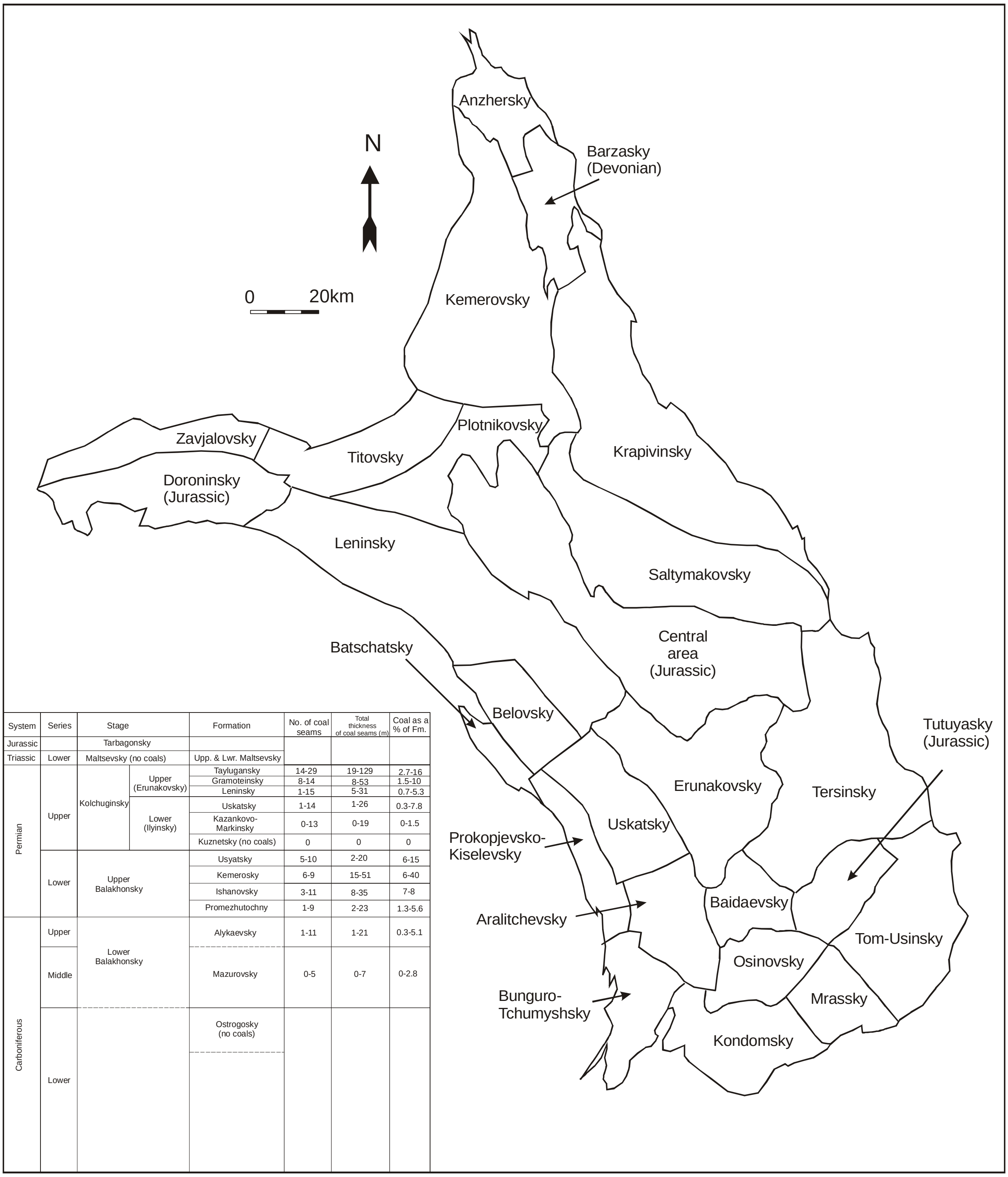



Figure 2. General location map of the Kuznetsk (Kuzbass) Coal basin, Siberia, Russia.




| System | Series | Stage | | Formation | No. of coal seams | Total thickness of coal seams (m) | Coal as a % of Fm. |
|---|---|---|---|---|---|---|---|
| Jurassic | | Tarbagonsky | | | | | |
| Triassic | Lower | Maltsevsky (no coals) | | Upp. & Lwr. Maltsevsky | | | |
| Permian | Upper | Kolchuginsky | Upper (Erunakovsky) | Tayluganskу | 14-29 | 19-129 | 2.7-16 |
| | | | | Gramoteinsky | 8-14 | 8-53 | 1.5-10 |
| | | | | Leninsky | 1-15 | 5-31 | 0.7-5.3 |
| | | | Lower (Ilyinsky) | Uskatsky | 1-14 | 1-26 | 0.3-7.8 |
| | | | | Kazankovo-Markinsky | 0-13 | 0-19 | 0-1.5 |
| | | | | Kuznetsky (no coals) | 0 | 0 | 0 |
| | Lower | Upper Balakhonsky | | Usyatsky | 5-10 | 2-20 | 6-15 |
| | | | | Kemerosky | 6-9 | 15-51 | 6-40 |
| | | | | Ishanovsky | 3-11 | 8-35 | 7-8 |
| | | | | Promezhutochny | 1-9 | 2-23 | 1.3-5.6 |
| Carboniferous | Upper | Lower Balakhonsky | | Alykaevsky | 1-11 | 1-21 | 0.3-5.1 |
| | Middle | | | Mazurovsky | 0-5 | 0-7 | 0-2.8 |
| | Lower | | | Ostrogosky (no coals) | | | |

Figure 3. Main tectono-stratigraphic areas within the Kuzbass Coal Basin.

The inset shows the generalised stratigraphy of the main coal-bearing formations (modified after Marshall *et al*. 1996, with coal thickness data from Uglemetan).

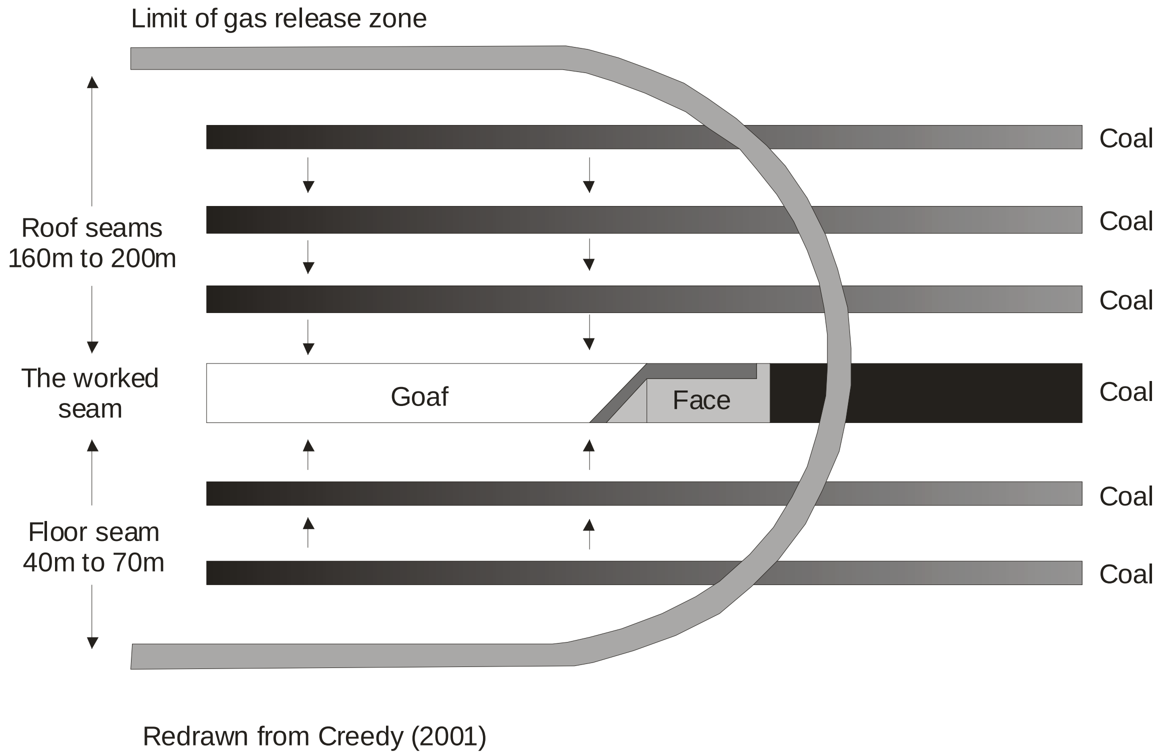
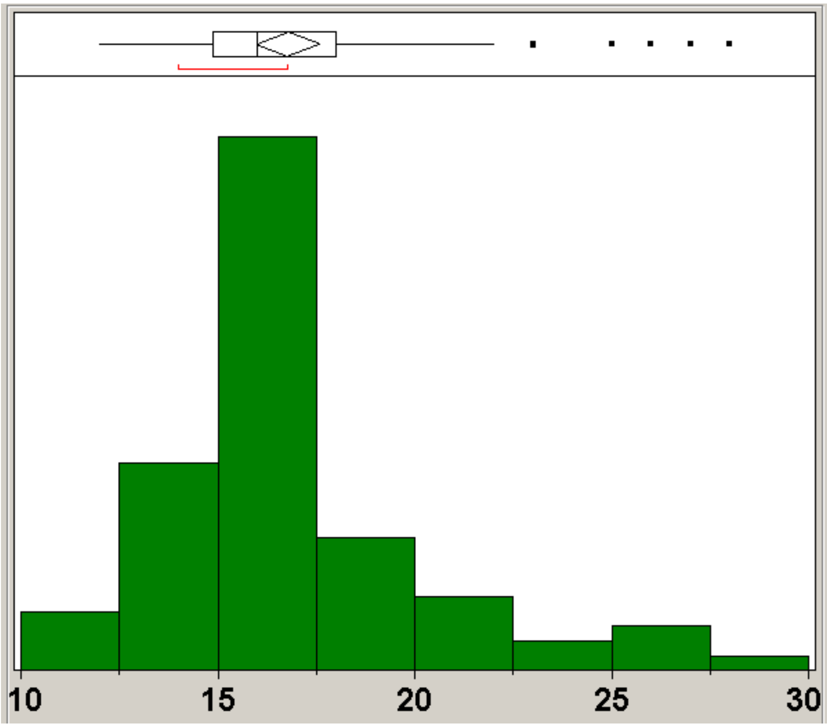



Figure 4. Gas emission from longwall workings (redrawn from Creedy 2001).




**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 28.000 |
| 99.5% | | 28.000 |
| 97.5% | | 27.125 |
| 90.0% | | 21.500 |
| 75.0% | quartile | 18.000 |
| 50.0% | median | 16.000 |
| 25.0% | quartile | 14.875 |
| 10.0% | | 13.000 |
| 2.5% | | 12.000 |
| 0.5% | | 12.000 |
| 0.0% | minimum | 12.000 |

**Moments**

| | |
|---|---|
| Mean | 16.776486 |
| Std Dev | 3.4085748 |
| Std Err Mean | 0.3962388 |
| upper 95% Mean | 17.566189 |
| lower 95% Mean | 15.986784 |
| N | 74 |

**Moments**

| | |
|---|---|
| Mean | 16.776486 |
| Std Dev | 3.4085748 |
| Std Err Mean | 0.3962388 |
| upper 95% Mean | 17.566189 |
| lower 95% Mean | 15.986784 |
| N | 74 |

Figure 5. Distribution of gas content data for Kuzbass mines.
(Data source Uglemetan)

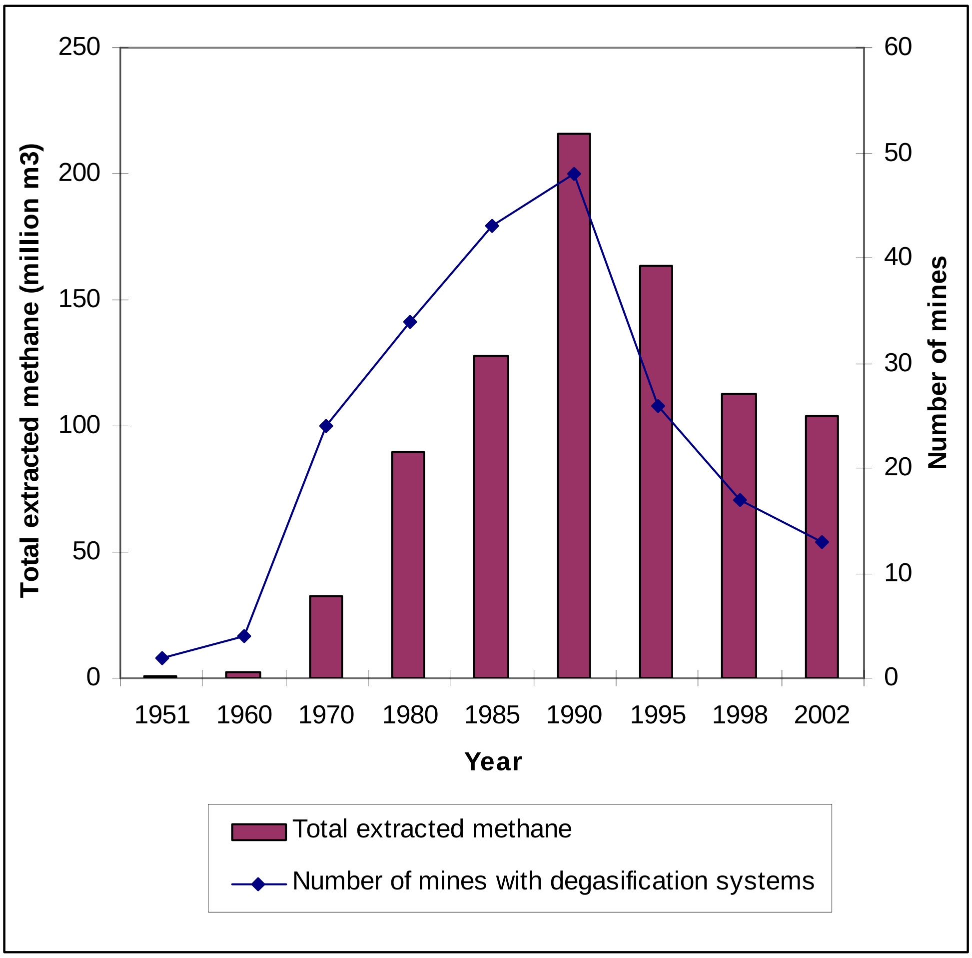



Figure 6. Graph of the number of mines in the Kuzbass with degasification systems against the total extracted methane.

Data source: Gosgortechnadzor (2005).

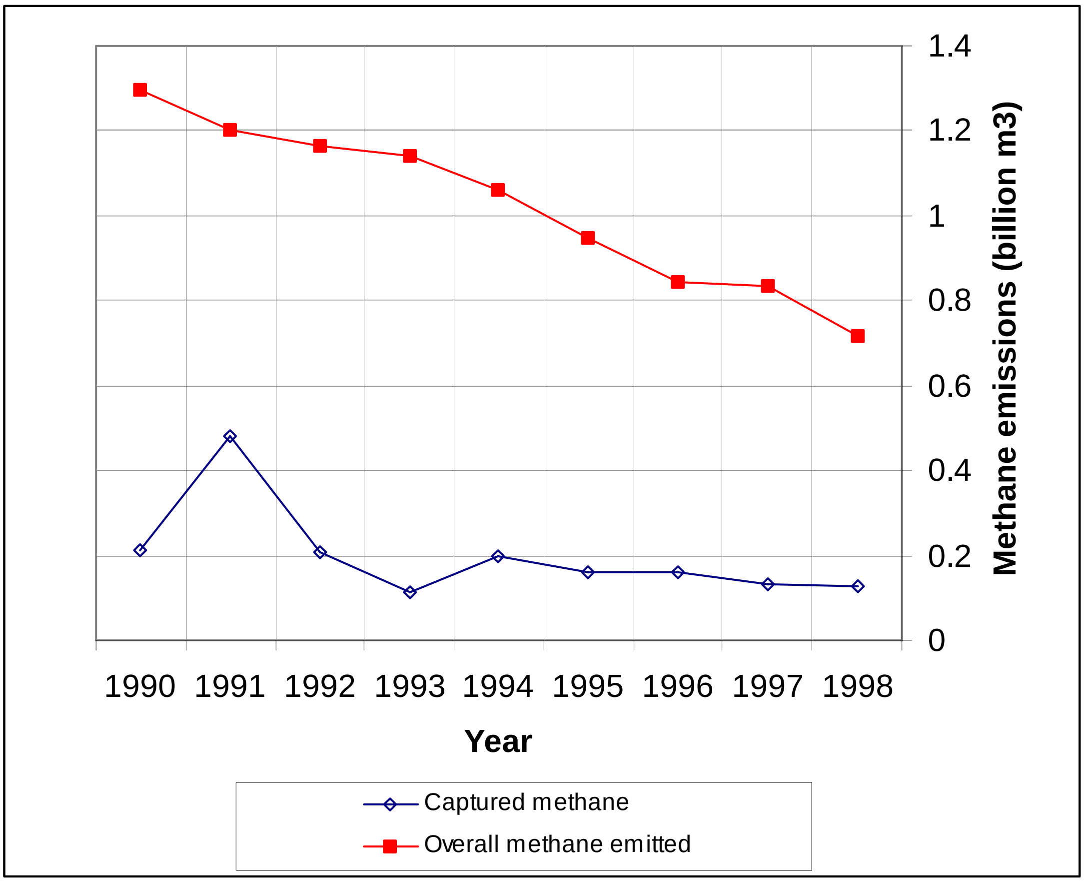



Figure 7. Graph of Kuzbass mine emissions per year for captured methane against overall methane emitted.

(Source Uglemetan). It is clear that the amount of captured methane represents a small component of overall methane emitted.

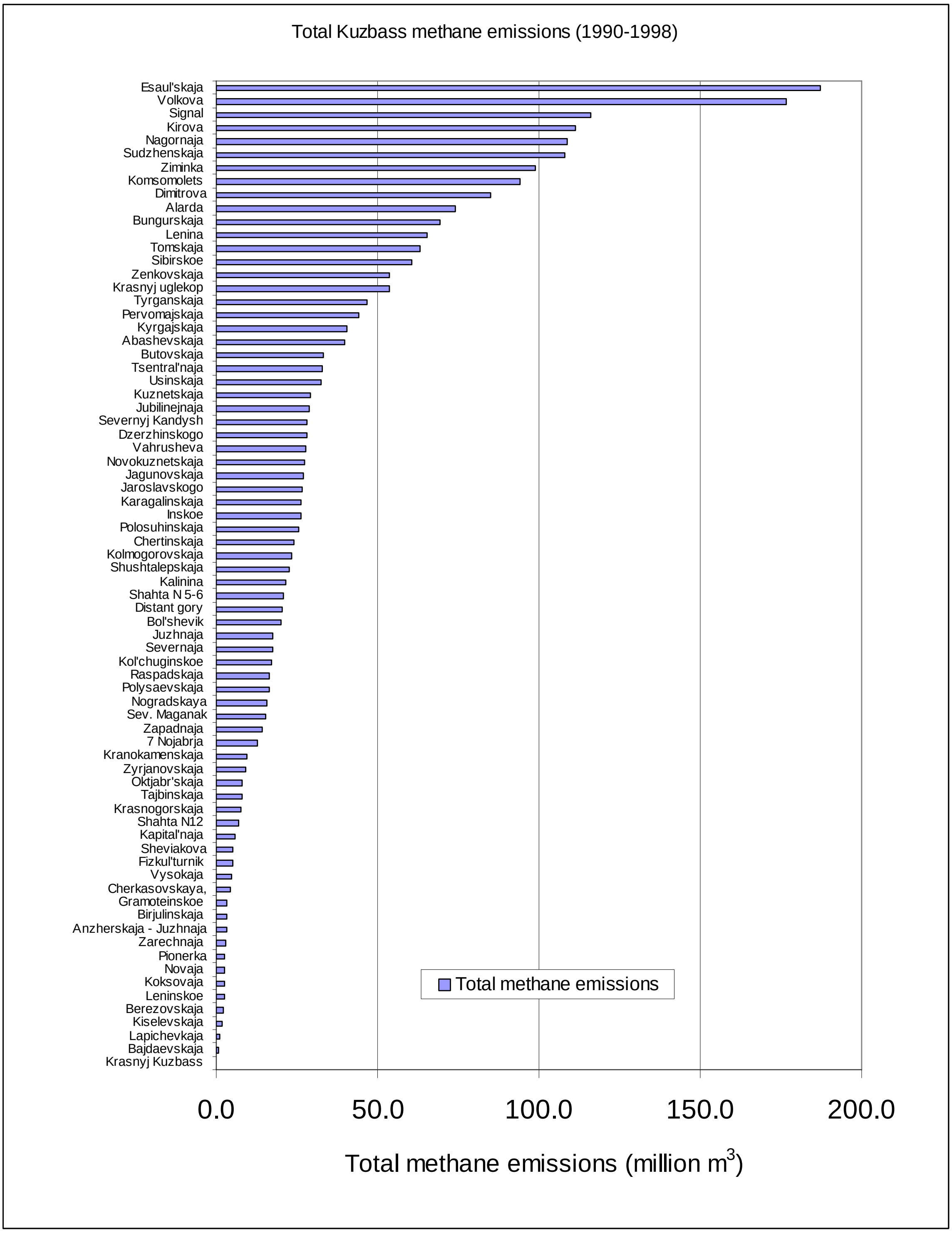



Figure 8. Total methane emissions per mine (in million cubic metres) for the period 1990 to 1998 for all open underground mines in the Kuzbass.

(Data source Uglemetan).

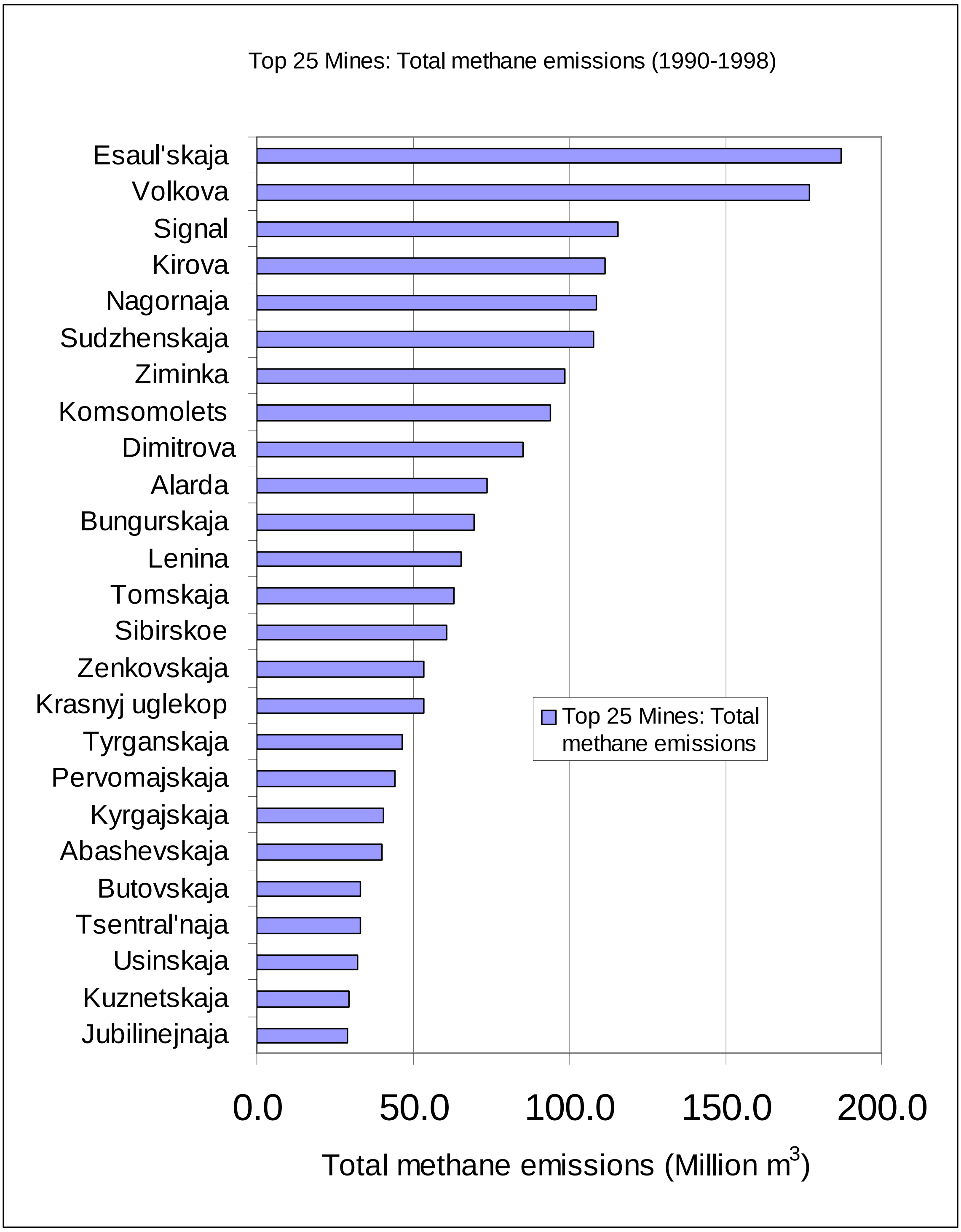
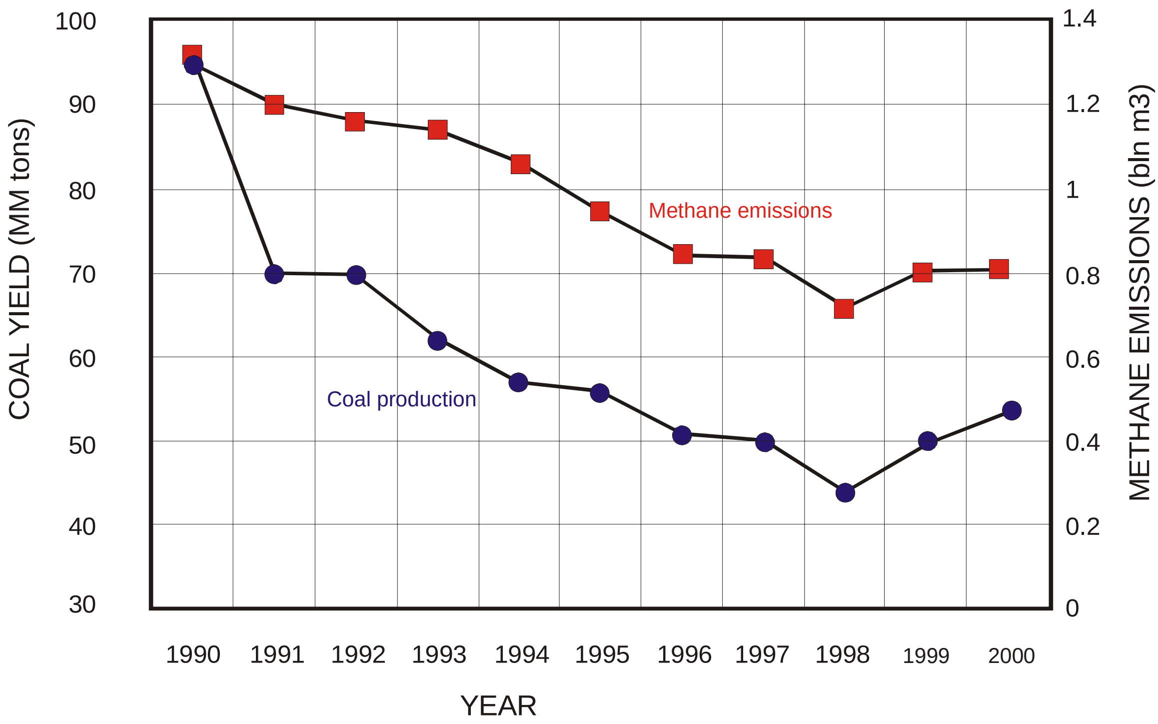



Figure 9. Total methane emissions per mine (in million cubic metres) for the period 1990 to 1998 for the 25 highest methane emitting underground mines in the Kuzbass.

(Data source Uglemetan).




Methane emissions and underground coal production in the Kuzbass (source: Uglemetan, 2000)

Figure 10. Graph of methane emissions plotted against underground coal production in the Kuzbass.

(Data source Uglemetan).

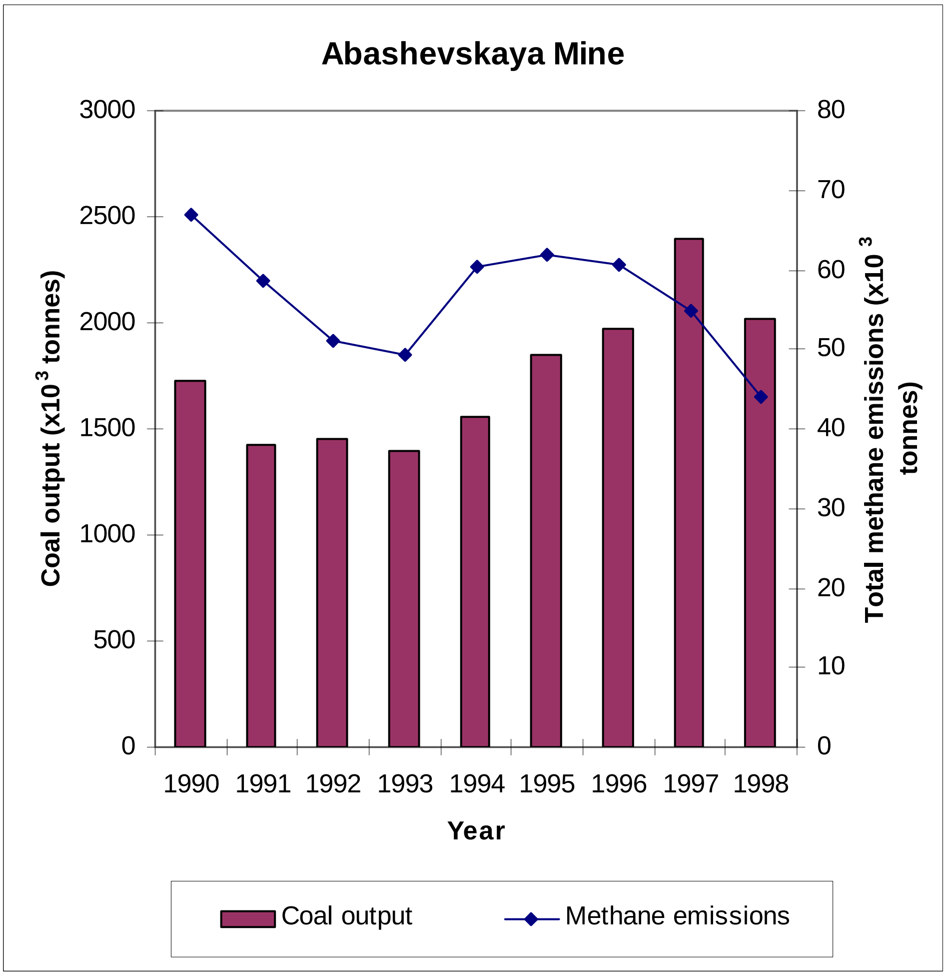



Figure 11. Graph of coal production and methane emissions for the period 1990-1998 for the Abashevskaya Mine.

(Data source Uglemetan).

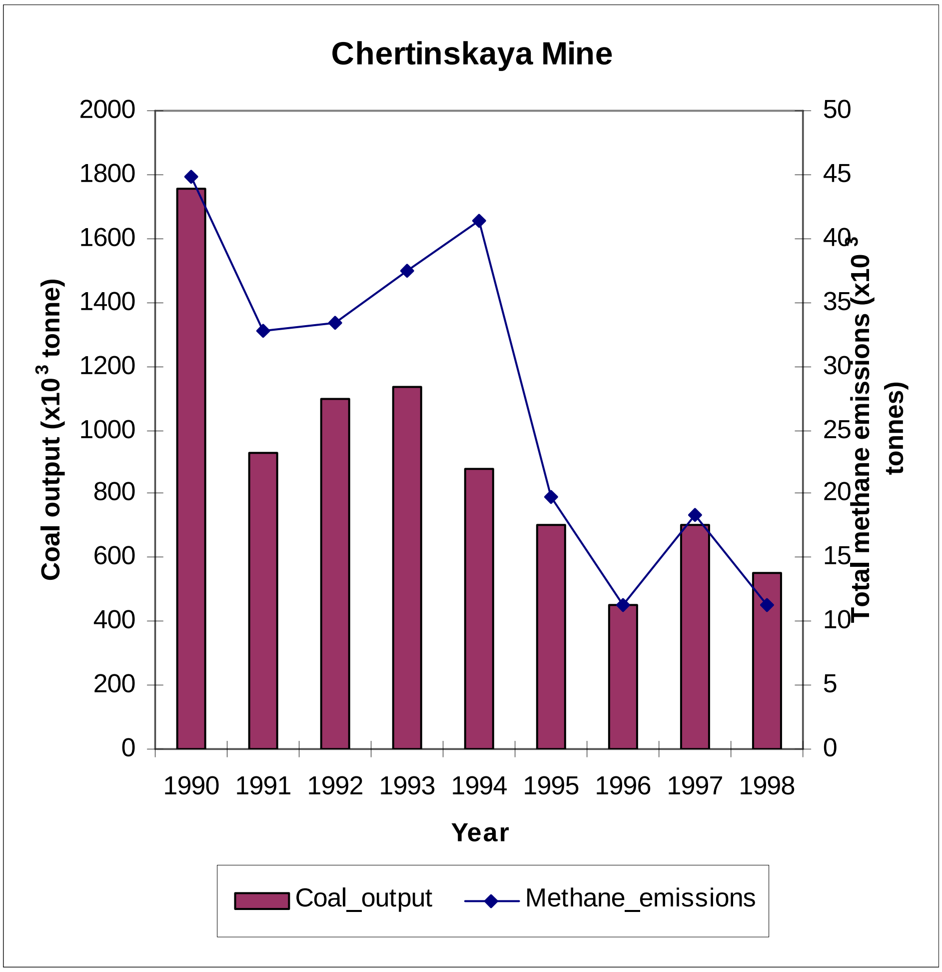



Figure 12. Graph of coal production and methane emissions for the period 1990-1998 for the Chertinskaya Mine.

(Data source Uglemetan).

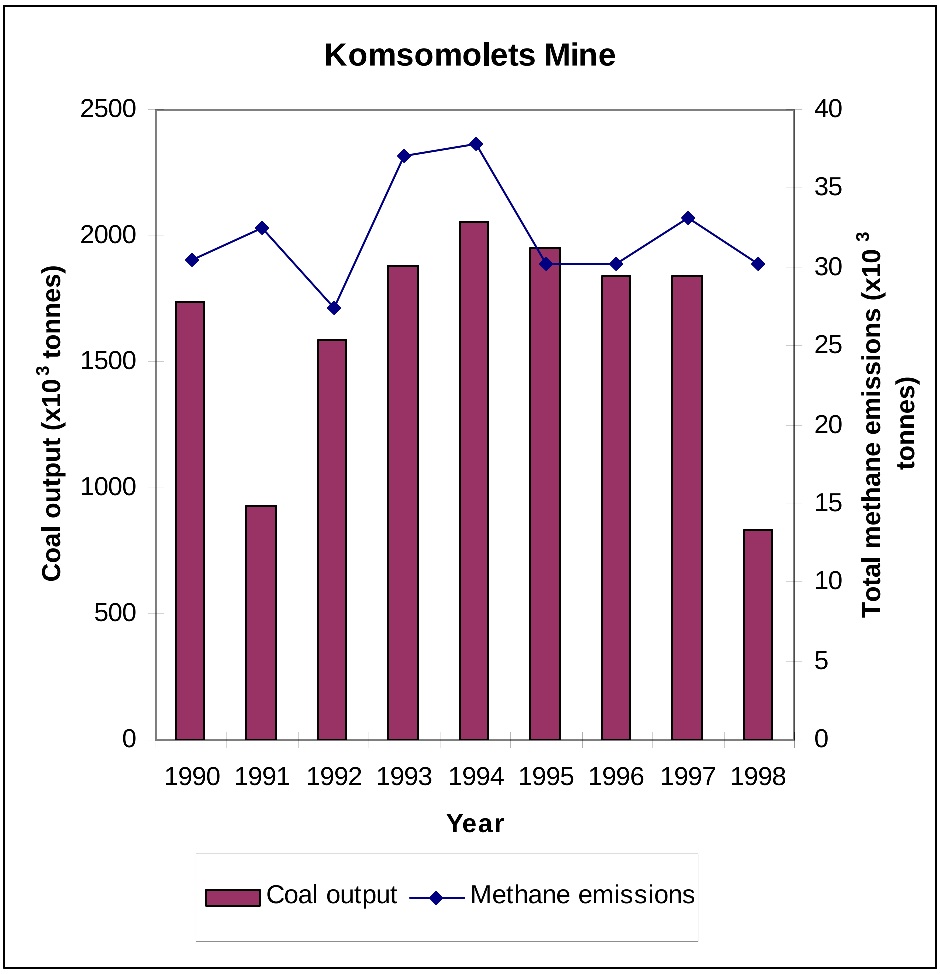



Figure 13. Graph of coal production and methane emissions for the period 1990-1998 for the Komsomolets Mine.

(Data source Uglemetan).

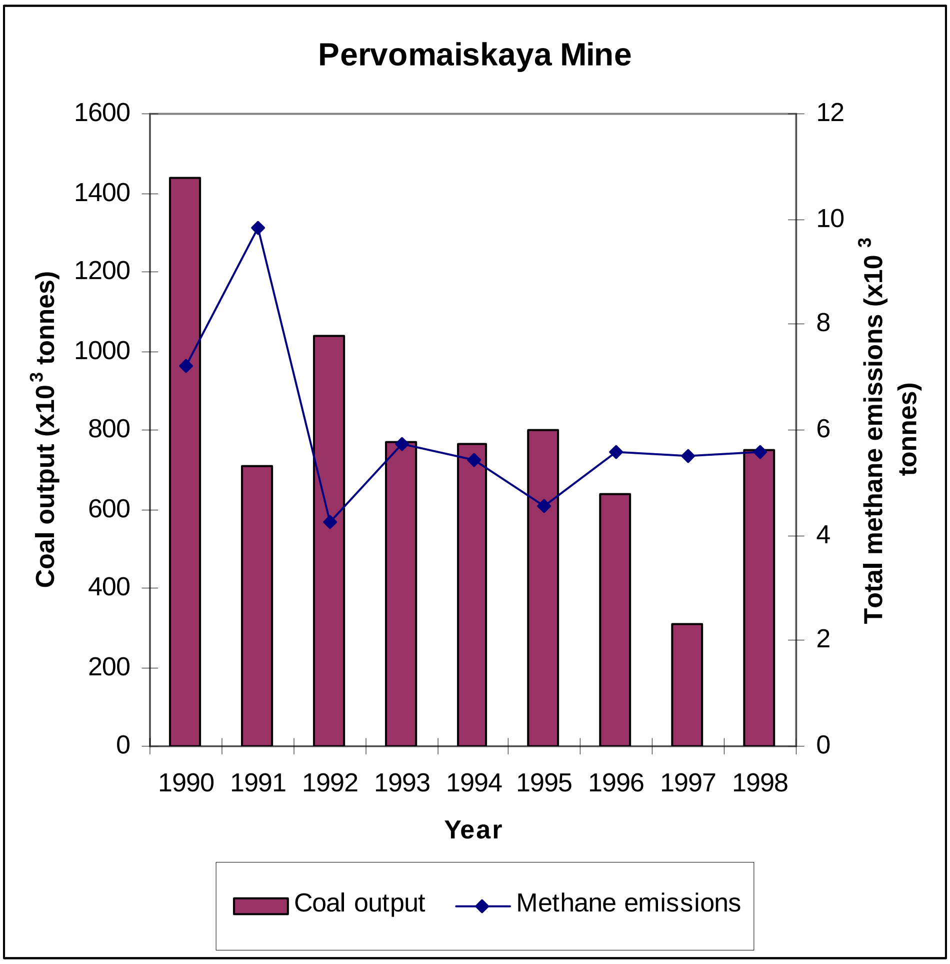



Figure 14. Graph of coal production and methane emissions for the period 1990-1998 for the Pervomaiskaya Mine.

(Data source Uglemetan).

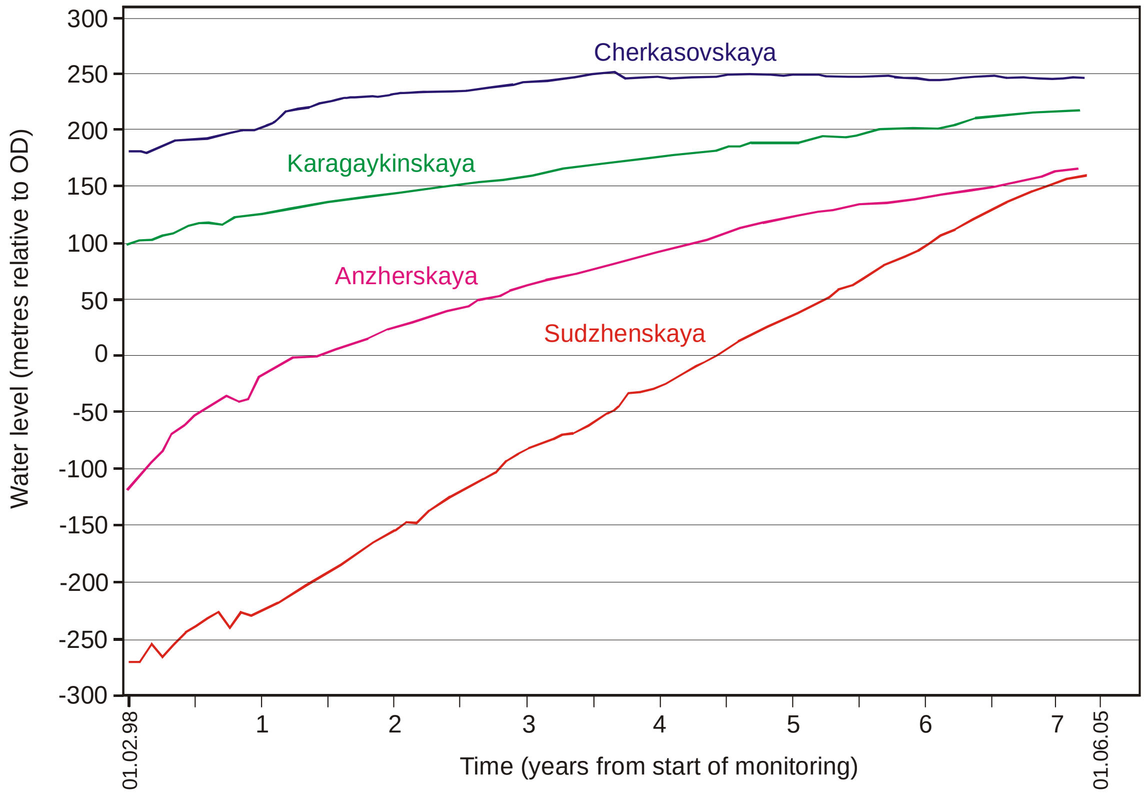



Figure 15. Graph of groundwater recovery for 4 closed mines in the Kuzbass.

(Data source: Gorsh 2005). Water levels are plotted against time, with complete groundwater recovery indicated in each case by a flattening of the curve. Cherkasovskaya Mine for example can be seen to have fully recovered after 3.5 years.

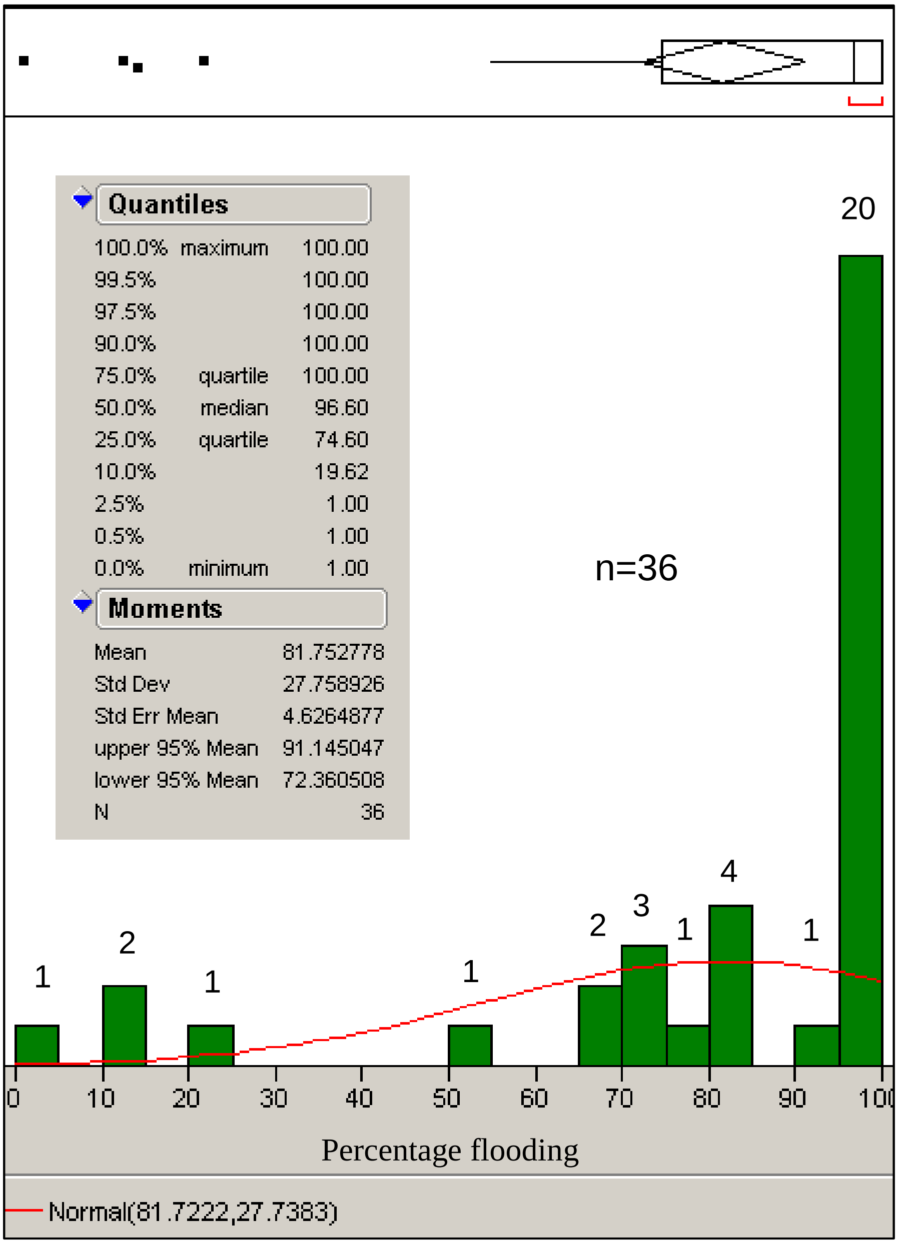



Figure 16. Distribution of the percentage of flooding measured within Kuzbass abandoned mines.

(Data source: Gorsh 2005). The number of mines per column is marked, with data available for 36 mines.

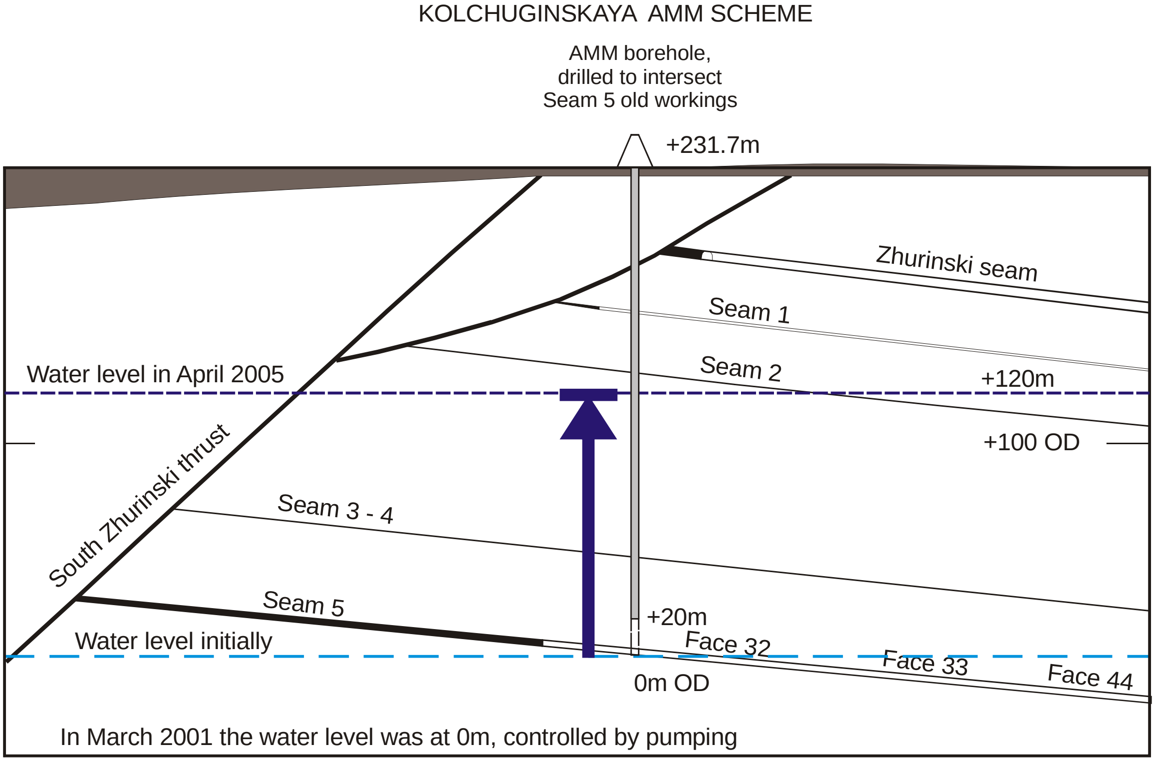



Figure 17. Sketch cross-section of the AMM scheme at the Kolchuginskaya Mine. Redrawn from an original kindly supplied by Gorsh.