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Coalbed Gas in Hungary—A Preliminary Report

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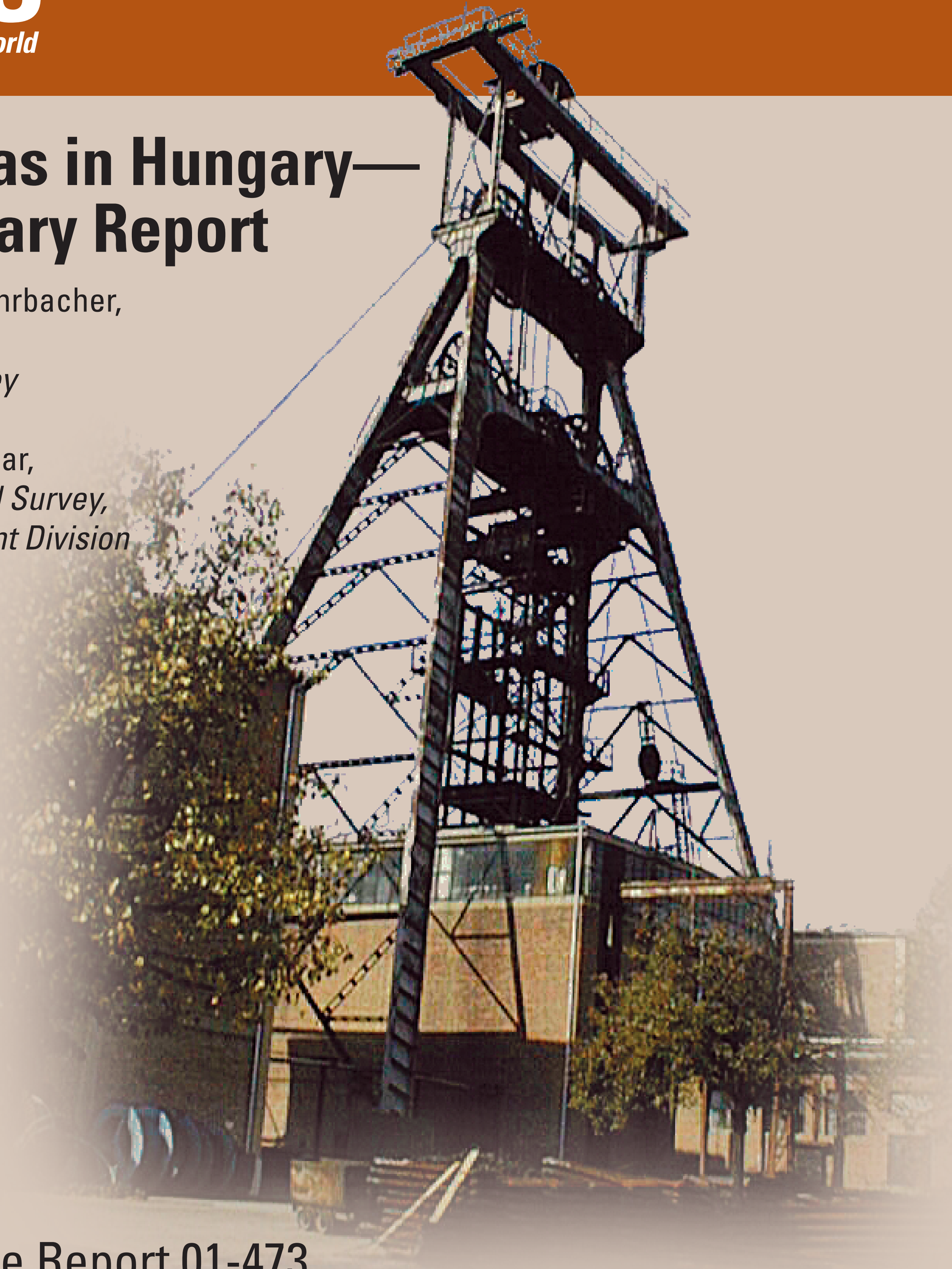

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U.S. Geological Survey

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EXECUTIVE SUMMARY

The coalbed gas resource potential of Hungary was identified as worthy of further investigation during cooperative research conducted with support from the U.S.-Hungarian Science and Technology Joint Fund. Formal and informal cooperation between personnel of the U.S. Geological Survey and the Hungarian Geological Survey has resulted in this report.

Of the total energy (domestic production plus imported) available for use in Hungary in 1999, approximately 38 percent was derived from natural gas and associated liquids. More than 73 percent of the natural gas was imported. About 14 percent of the natural gas consumed was used to generate electricity, about 7 percent for heat supply (with cogeneration) in public power plants, about 31 percent for domestic purposes (largely household heating and cooking), about 46 percent in manufacturing and about 2 percent in agriculture and transportation. Any increase in domestically produced natural gas (methane) would lessen dependence on imported energy.

The coalbed gas (largely methane) released during underground mining has been monitored, studied, diluted, and expelled in Hungarian mines for many years. In the Mecsek coalfield of southwestern Hungary, the gas has been gathered in advance of mining for safety purposes and then utilized for municipal heating. Subsequent attempts to produce the coalbed gas as an independent resource were not successful, but have resulted in information that may assist further exploration activities.

The developed coalfields of Hungary have been well explored and the basic geologic information to support mining is known and available. In contrast, much of the particular information needed to understand the coalbed gas resources is unknown or unavailable. In this very preliminary study we have reviewed and evaluated the available information, and obtained a limited amount of new data.

The available information supplemented by studies and tests conducted for this report indicate that:

1. Coals of the Mecsek Basin in southwestern Hungary contain substantial quantities of coalbed gas. Measurements of the gas storage capacity of samples collected for this study confirm previous studies that report a large coalbed gas resource potential. Two preliminary estimates cited in this report show in-place gas resources in the Mecsek Basin study area of almost 1 trillion cubic feet (TCF) to nearly 4 TCF, which identifies that area as a target for coalbed gas exploration. All available information should be gathered, synthesized and interpreted with the goal of developing an exploration plan for direct measurement by drill hole of the coalbed gas reservoir properties in the Mecsek Basin. Completion of such an exploration program would allow determination of the coalbed gas resource potential and development of the subsequent strategies and tactics needed for the economic production of coalbed methane.

2. Coalbed gas resource potential may also exist in other known coalfields of the nation. Areas in which the gas potential may currently be considered small may be worthy of future consideration.

3. The coalbed gas resource potential of undeveloped coal areas of the country should be studied. For example, coals of Miocene and Pliocene age have reportedly been penetrated by oil and gas exploration drill holes in the large, deep, Pannonian Basin in southern Hungary. As an initial step, opportunities should be sought to collect samples from active drill holes for direct measurement of gas content, or to obtain and analyze existing samples for coal characteristics and gas storage capacity.

In conclusion, the coalbed gas (methane) resource potential of Hungary should be further investigated in order to evaluate its potential impact on future energy budgets of the nation.

INTRODUCTION

In 1989, The United States and Hungarian governments agreed to establish a science and technology joint fund to encourage and support a wide range of scientific and technological cooperation.

Cooperation between the Minerals Management Division of the Hungarian Geological Survey (HGS), the U.S. Bureau of Mines and U.S. Geological Survey (USGS) was established in 1994 as Joint Fund Project Number 401, continued in 1996 as JFNo.: 539, and completed as JFNo.: W/1/99. A variety of products have resulted, and joint research continues informally.

PURPOSE OF RESEARCH

During the last decade, the energy system of Hungary has been deeply involved in the transition from a centrally planned economy to a market-economy system. To assist that transition and to aid in rational planning for recovery and utilization of the indigenous energy sources of the nation, cooperative studies of aspects of recovery, transportation, utilization and environmental regulation of coal in Hungary were undertaken. As a result, the potential for recovery and utilization of coalbed gas was recognized and this preliminary study was initiated.

So-called "natural gas", a fossil fuel desirable for domestic (household) purposes and for generation of electricity, is primarily composed of the gas methane. Coalbed gas also is primarily composed of the gas methane. For transportation and utilization purposes the methane gas found in coal beds and the methane gas found in conventional reservoirs are interchangeable. However, gas in a coalbed reservoir is classed as an unconventional resource because most of the gas is sorbed internally in the coal and is immobile until the permeability of the coal is increased in some manner.

Since the beginning of underground coal mining in Hungary about 200 years ago, the miners in several of the coal areas of the nation have endured the dangerous presence of coalbed gas that is liberated during mining. In particular, the coals mined in the Mecsek Basin in southwestern Hungary (fig. 1) were found to contain and to yield large quantities of coalbed gas, primarily composed of methane. In addition to ventilation programs designed to dilute the gas and expel it safely from the mines, various programs to recover the gas from the coal beds prior to and after mining were initiated. Most of these attempts were conducted within the mines themselves and were closely related to the mining process, both spatially and temporally. All of the underground mines in the Mecsek Basin are now closed.

In 1980, an attempt to produce coalbed gas by drilling to underlying coal beds in the Mecsek Basin (J. Kiss, 1995) was unsuccessful. Another attempt in 1993-1994, involving four drill holes, yielded considerably more information (J. Kiss, 1995). However, the program was unsuccessful in establishing gas production.

The small number of studies and the amount of research done to date serve to indicate that the potential for recovery of coalbed gas should not be ignored. This report is an attempt to summarize and synthesize available information and present the results of some new research. Combined with other reports resulting from U.S.–Hungarian cooperative

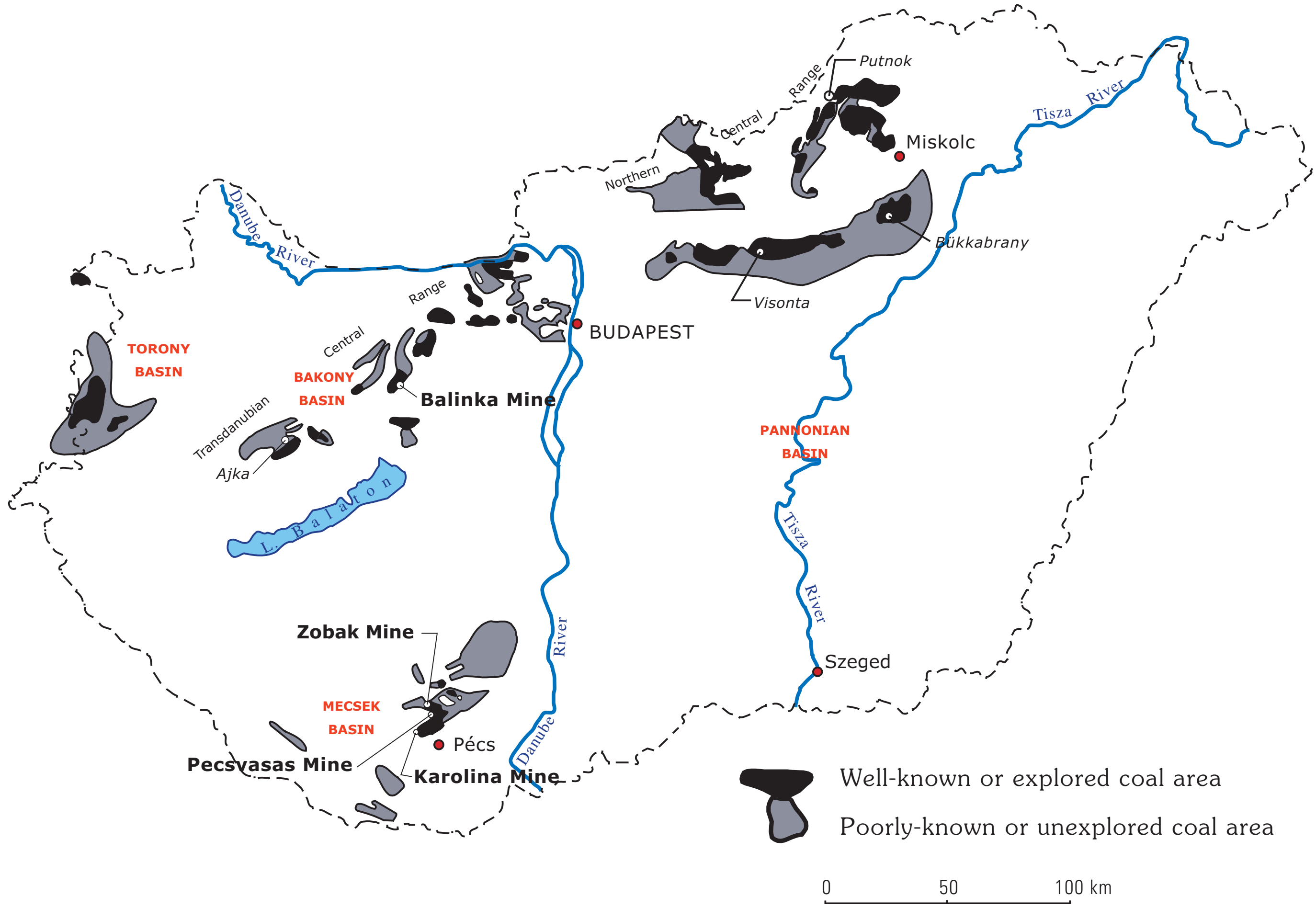


Figure 1. Coal resource areas of Hungary.

efforts, this report is intended to 1) provide necessary background information and data for administrators and policy-makers, 2) aid efforts to privatize the mineral and energy production systems of Hungary, and 3) assist the nation in becoming less dependent on imported energy.

ENERGY BACKGROUND

In 1999, the bulk (almost 58 percent) of the energy available for use in Hungary was imported, including more than 73 percent of its natural gas. Approximately 14 percent of the total amount of gas consumed in Hungary was used to generate electricity, 7 percent for heat supply in public power plants, 31 percent for domestic purposes (largely household heating and cooking), 46 percent for manufacturing, and about 2 percent for agriculture and transportation.

A summary of the total energy (domestic production plus imported) available for use in 1999 indicates that approximately 38 percent was derived from natural gas and associated liquids, 32 percent from oil and oil products, 14 percent from coal and related materials and 13 percent was from domestic nuclear power. Of the total energy imported, about 48 percent was imported in the form of natural gas, 46 percent as oil and oil products, 5 percent as coal and related materials, and 2 percent as electricity.

About 93 percent of the total energy produced in, or imported into, Hungary in 1999 was consumed in the nation, and the remainder was exported. More than one-third of the total energy available for use in 1999 was utilized in the form of electricity. About 59 percent of the electricity came from thermal plants, 38 percent from a nuclear power plant, less than 1 percent from hydropower plants and 3 percent was imported. Of the electricity produced in the thermal power plants of the nation, 34 percent was produced from natural gas, 43 percent from coal and 23 percent from fuel oil. All of the above-cited statistical data are from A Magyar Villamos Muvek Kozlemenyei (2000).

In recent actions that affect energy supplies, inefficient coal mines dependent on government subsidies have been closed, thus reducing the amount of coal available for conversion to electricity and production of heat for other purposes. If the trend continues and the nation's domestically produced energy supply is reduced, increased imports of natural gas and electricity may be sought elsewhere. Increased supplies of natural gas derived from coalbed gas, produced economically in Hungary, could be an important factor in the nation's and in the region's future energy balances.

ACKNOWLEDGEMENTS

This report is primarily the conception of one of the co-authors, Bela Fodor. He and Gizella Gombar contributed their knowledge of existing pertinent information and provided the required translations of the Hungarian literature. In addition, they were responsible for the collection of the three coal samples that were studied for this report. We especially want to thank H.J. Gluskoter of the USGS for leadership, assistance, and inspiration during these cooperative endeavors. The management and staff of the three mines that were sampled for the studies reported herein were supportive and helpful and are deserving of thanks. R.M.B. Earth Science Consultants Ltd., performed the laboratory analyses under contract to the U.S.G.S. Tracey Mercier, consultant to the U.S. Geological Survey, was responsible for much of the GIS support and illustration preparation. The time and efforts of Vito F. Nuccio, Gary D. Stricker, Richard Keefer, and Katherine L. Varnes for their editorial reviews and to Kenneth I. Takahashi for his layout and design of the CD ROM were greatly appreciated.

A report of this type, consisting largely of an overview of available information, involves input from many sources. Most of those whose work assisted in its preparation are appropriately cited, but for contributions not specifically recognized we extend our sincere thanks and appreciation.

PREVIOUS WORK

BACKGROUND

Most attempts, worldwide, to alleviate the problem of coalbed gas in operating coal mines involve ventilation schemes. The ventilation programs are designed to keep the methane content of the air in the mines below the amounts (in volume percentage) that are explosive and/or that might contribute to pulmonary problems. A maximum of one to two percent methane is a common aim or requirement for the air being used in the working areas of a mine. Almost all ventilation programs expel the methane-bearing air into the atmosphere with no attempt at recovery of the methane. This is both wasteful of a valuable resource, and contributes to the amount of so-called “greenhouse gas” in the earth’s atmosphere. The amount of methane wasted to the atmosphere is large, but recovery from expelled mine air is not deemed economically practical at many of the world’s underground coal mines.

Occasionally, the amount of methane released during the mining process is large enough to overload ventilation systems. In such cases, programs to drain methane from the coal prior to mining are applied. Underground mines in the Mecsek Basin of Hungary had successfully operated methane-recovery systems developed for safety considerations and had subsequently utilized the methane as a heat source in mine offices and nearby facilities such as homes and a hospital. By design, none of these gas recovery programs were large enough or long-term enough to contribute significantly to the satisfaction of Hungary’s energy budget. Efforts to efficiently recover methane from mine exhaust gas in other parts of the world, such as in China, are primarily driven by energy resource considerations but do result in the beneficial reduction of methane discharged to the atmosphere as well (Anonymous, 1997).

RESOURCE RECOVERY ATTEMPTS

Past attempts to recover coalbed gas from the coals of the Mecsek Basin were unsuccessful but each contributed to our knowledge of this potentially important source of energy for Hungary. The following summary is largely derived from a translation by Bela Fodor of the Hungarian Geological Survey of a published report by J. Kiss (1995).

Underground Mine Recovery

The earliest successful attempts to recover coalbed gas in advance of mining in the Mecsek Basin included plans for its utilization (J. Kiss, 1995). Eventually, six underground mines supplied a connecting pipeline that provided gas to local homes, offices, a hospital, and other facilities. About 325 million cubic meters of gas was produced during the life of the program. All of the underground mines are now closed.

Drilling Exploration, 1980

In 1980, a Hungarian company (name unknown, but affiliated with the Hungarian oil industry) drilled a single hole in the Maza-Del coal area in the northeastern part of the Mecsek Basin. The Maza-Del area is unmined, but contains an estimated geological coal resource of about 937 million tons. The coal-bearing rocks in that area are faulted and intruded by igneous rocks.

Attempts to stimulate production of gas were made in different portions of the penetrated rock sequence, each of which was presumably composed mostly of coal. The well was cased and in the tested intervals the casing was perforated (technique unreported). The uppermost treated coaly sequence, between 429 – 436 meters in depth, was injected with 20 cubic meters of water under an initial pressure of 120 bars and an ending pressure of 70 bars. The next attempt to stimulate production treated two coaly sequences. One sequence was between 493 – 501 meters in depth and the other was between 503 – 531 meters in depth. The treatment was pressurized injection of 60 cubic meters of unspecified fluid accompanied by 10 tons of sand. The initial pressure of 140 – 150 bars was continued for 30 minutes. The lowest treated coaly sequence was between 681 – 687 meters in depth and treatment consisted of an unspecified amount of water injected at 150 – 170 bars pressure.

Other information about drilling technology, records, and testing procedures, is unavailable. However, geophysical logging was used to define the stratigraphic sequences that were penetrated. The well was mostly drilled without coring, was about 1,000 meters deep, well casing was 7 inches in diameter, production technology common to the conventional natural gas industry was used, and there were no coal samples available for testing. With the information available, the relative effects of the geologic factors and the testing methodology cannot be evaluated, but the attempt to produce coalbed gas was unsuccessful.

Drilling Program, 1993-94

By 1991 interest in the coalbed gas in the Mecsek Basin was renewed, and the Hungarian Geological Institute, a part of the Hungarian Geological Survey, prepared a summary report on the known geological conditions in the Mecsek Basin that were assumed to be important to future exploration and production attempts (HGI, 1991). In 1992, invitations were requested for bids on an exploration and production project. In 1993, Radnia and Bakai-Papp presented a paper on the coalbed methane exploitation possibilities in Hungary at an International Coalbed Methane Symposium. Also in 1993, a Canadian firm entered a joint venture agreement with Mecseki Szenbanyak FA (Mecsek Coal Mines) (Anonymous, 1997). Hungarian oil industry firms were involved in drilling, logging and well testing. The primary goal of the project may have been to identify the technical and economic parameters for successful production of coalbed methane in the basin, based on the expectation that the available information about the geologic setting and knowledge of the resources was sufficient to successfully guide an exploitation program.

Holes were drilled at four sites in the basin. The amount of core drilling that had been planned was not accomplished, and the amount of measured rock data (for example, fracturing patterns and permeability determinations) needed to guide completion activities was, perhaps, inadequate. It is unknown whether desorption tests were conducted on core or cuttings to measure the amount of gas in the penetrated coals to allow reliable estimates of gas-in-place. At three of the drill sites, there were attempts to fracture penetrated coal seams by injections of liquid carbon dioxide and sand. Attempts to dewater the coal seams prior to production testing were not done or were unsuccessful. None of the three fractured wells yielded economically recoverable quantities of gas.

At the fourth drill site, a 10 meter-thick coal seam at a depth of 850 meters was selected for an open-hole, cavernous completion. Initially, the recovery attempt was apparently successful with large (but unmeasured) quantities of methane released. However, within a short time (duration unreported) the drill hole became choked with coal and after ten days of effort, during which about 300 cubic meters of coal mud were removed from the drill hole, the work was terminated. A final report on the project results has not been publicly available.

TESTS, ANALYSES AND REPORTS

During the previous programs to remove coalbed gas that was a mining hazard, and the attempts to recover the coalbed gas as a valuable energy resource, various tests and analyses have been made that provide data relative to the coalbed gas resource potential of the Mecsek Basin.

Through the years of coal mining in Hungary a very large amount of data on the amount and composition of coalbed gases was obtained as a necessary part of safety considerations. Although generally of little value for resource and/or reserve evaluations, such data provides information regarding the presence or absence of coalbed gas and some measures of the quantity of gas released during mining activities.

As previously mentioned, the Hungarian Geological Institute prepared a report to assist potential cooperators in a mid-90s attempt to produce coalbed methane in the Mecsek Basin. The report assembled, interpreted and summarized the available information regarding coalbed gas, geologic factors and resource estimates in a study area of more than 70 square kilometers, on a square kilometer basis. The study area is part of a larger area that is underlain by coal-bearing rocks of Jurassic age. Much of the information came from mines and from more than 200 exploration and development drill holes (table 1). Drill hole information was concentrated in mine areas, but was sparse elsewhere. The HGI (1991) report warns about the "—very discordant degree of certainty in the geological knowledge of the area."

Table 1. Parameters used by the Hungarian Geological Institute for coalbed methane resource calculations in the Mecsek Basin study area (HGI, 1991).

Vertical thickness of the coal seams	=	30 meters
Coal density	=	1.5 tons per cubic meter
In-situ gas content	=	50 cubic meter per ton
Recoverable gas content	=	39 cubic meter per ton
Gas content in GOB (mined-out) areas	=	16 cubic meter per ton

A total of about 113 billion cubic meters of coalbed methane was estimated to be present in the Mecsek study area. Of the cited total, almost 103 billion cubic meters were estimated to be in-situ and the remainder to be in mined-out areas.

The cited estimates were derived by applying the parameters listed in table 1 to a series of eleven map sheets, each covering an area of 20 square kilometers, that display the areas underlain by coal-bearing strata, isolines drawn on the top of the uppermost coal seam (using a sea-level datum), locations of data points, and pertinent coal resource estimates.

Other geologic factors were then considered and an evaluation of gas-recovery potential was assigned to each map sheet. Five classifications were used, ranging from *excellent* to *bad*. The report (HGI, 1991) recommends that "Before starting with the production activities experimental wells should be established in areas with "excellent" classification."

GEOLOGIC SETTING

SAMPLE SITES

Samples collected and analyzed for this report were obtained in two of the coal areas of Hungary, the Mecsek Basin and the Bakony Basin. The Mecsek Basin is the primary known area of gas-bearing coals in the nation and the Bakony Basin may represent some of the younger coal areas presently mined in western Hungary that have lower reported CBG potential.

MECSEK BASIN - KAROLINA AND PECSVASAS MINES

The Mecsek Coal Formation comprises a sequence of Upper Triassic and Lower Jurassic rocks composed of sandstone, claystone and mudstone, with coal seams in the middle and upper (Early Jurassic age) parts (Csaszar, 1997). The formation ranges in thickness from about 100 meters in the northeastern part of the basin to as much as 1,200 meters in the southeastern part. The coal seams occur in three groups and the number of individual coal seams more than 0.5 meters thick ranges between 10 and 38 (Hetenyi, 1964). The upper and lower coal groups (fig. 2) were deposited in paralic environments and the seams of the middle group were deposited in limnic environments (Fodor and others, 1998).

The area in which the Mecsek Coal Formation (fig. 3) was deposited was considerably larger than the area it now occupies. Erosion while the formation was exposed during the time span from Early Cretaceous to Miocene age, plus folding and faulting, have combined to reduce the area underlain by the Mecsek Coal Formation and to fragment the formation into discrete blocks (fig. 4). Igneous intrusions of Early Cretaceous and Miocene ages have destroyed or altered the coal in places (Fodor and others, 1998). The Mecsek Basin that is described in HGI (1991), herein called the study area, contains about 73 square kilometers.

The geologic history of the Mecsek Basin strongly affects the potential for recovery of coalbed gas. The portions of the basin in which the coal-bearing formation is overlain by rocks of Tertiary or Quaternary age may have lost gas through leakage during surface exposure and/or by leakage to unconsolidated sediments. Also, exposure to heat from igneous rocks may have adversely affected the retention of gas. Information about the geothermal gradient in the basin, derived from more than 200 exploration and development drill holes, is shown in table 2.

The total geological coal resources of the Mecsek Basin are estimated at about 1,596 million metric tons and the economically extractable reserves at about 199 million metric tons (Fodor and Gombar, 1999). The underground mines in the Mecsek Basin are now closed and coal production at the present time is from surface mines. The authors visited

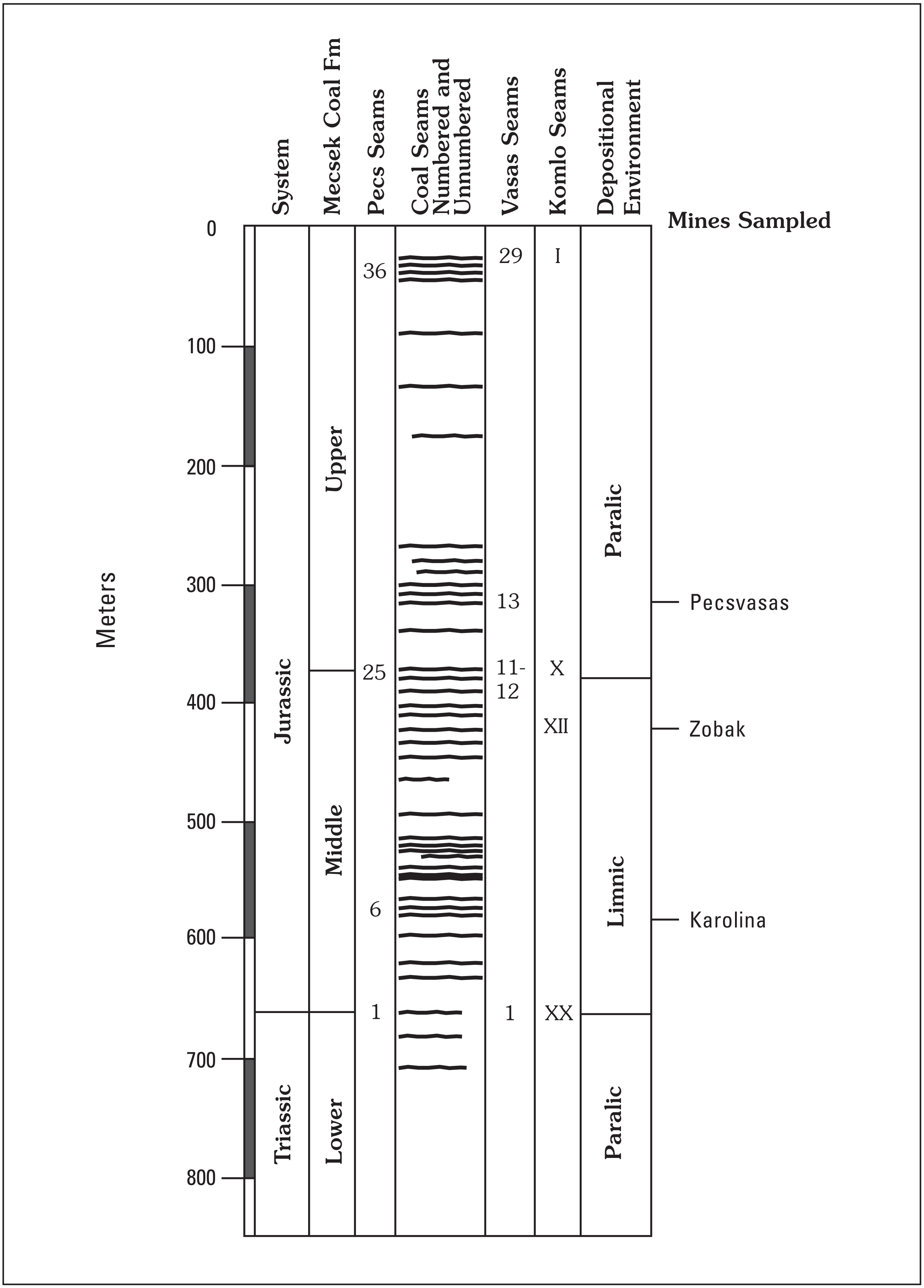


Figure 2. Coal sequence in the Mecsek Basin, Hungary. The numbering and stratigraphic location of the Pecs, Vasas, and Komlo Seam names indicate interbasin coal bed correlations.

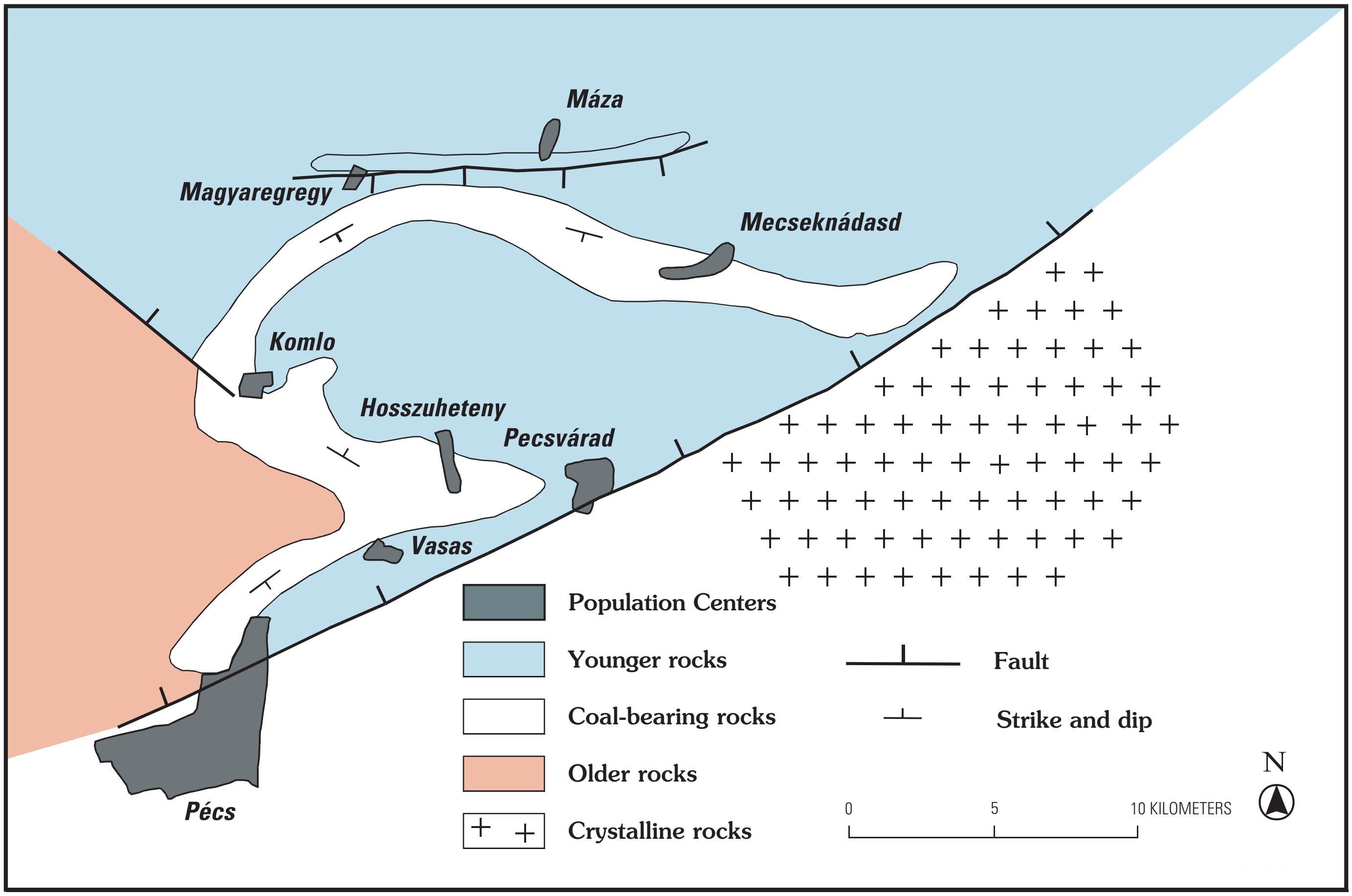


Figure 3. Simplified geographic and geologic map of the study area in the Mecsek Basin, Hungary (see figure 1).

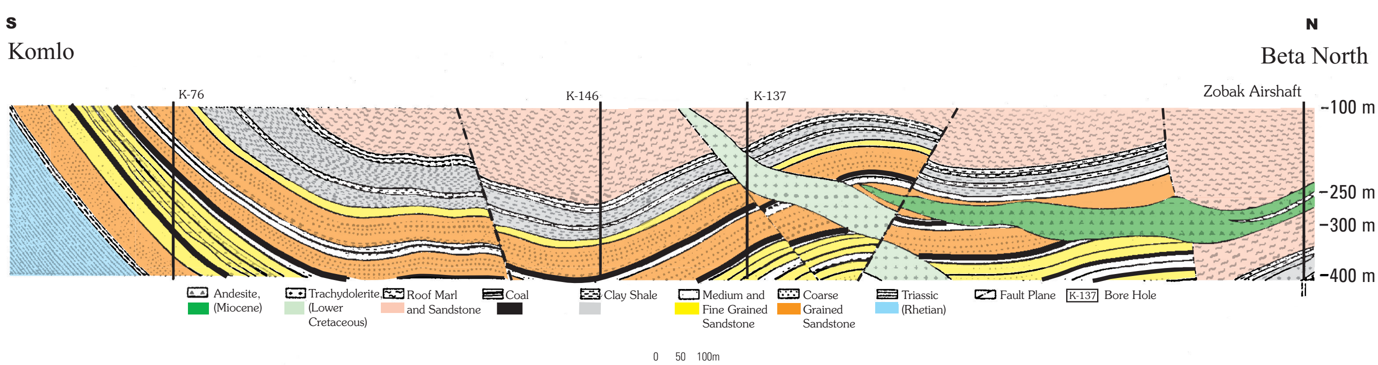


Figure 4. North-south cross-section showing typical structural history in the Mecsek Basin, Hungary (from HGI, 1991). Section located on Figure 7. Geologic interpretation supported by borehole and mine workings data.

the last operating underground mine, the Zobak Mine, in October, 1998. Air at the longwall face contained nearly 2 percent methane as detected with a handheld methanometer. However, mine supervisors noted that air in the caved area behind the longwall face (gob area) contained 8 to 12 percent methane.

Table2 Average geothermal gradient in the Mecsek Basin, Hungary (Z.E Kiss, 1995).

Area	Drill Holes Examined	Average geothermal gradient (m / deg C) Coaly Formation	Overlying Beds	Average of Mecsek Basin Coaly Formation	Overlying Beds
Komlo	110	18.5	21.0		
Pecs	19	22.0	24.0		
Hosszuheteny	27	21.5	23.0	20.4	22.8
Rucker (Vasas)	18	21.0	24.0		
Maza-Varalja	61	10.0	22.0		

Coal Quality

The quality of coal is generally described in three categories - rank, grade and type. Each of these categories has relevance in the search for and economic recovery of the gases in coals. Available descriptions of the coals produced in the Mecsek Basin suggest that most of the coal is of bituminous rank in the classification system of the American Society for Testing and Materials (ASTM) (1999). Somos, Zubovic and Simon (1985) reported analytical results for two coal samples collected from different mines. Table 3 shows the proximate analysis for the two samples reported by Somos and others plus the seam weighted average for Seam XII in the now-closed Zobak Mine. The six samples used to derive the seam-weighted average were collected within a year prior to the closing of the mine and represent the coal being mined at that time. The sample data indicate that the coals are of high volatile A bituminous rank according to the ASTM system of classification.

Table 3. Comparison of Mecsek Basin, Hungary coal samples, as-received basis (all in weight percent except heat value)

	Sample #1*	Sample #2*	SWA-6 samples**
Moisture	2.3	1.4	3.4
Ash	15.5	13.6	36.9
Volatile Matter	29.3	27.5	22.7
Fixed Carbon (FC)	53.0	57.5	37.0
Sulfur	2.2	2.1	3.7
Heat Value-Btu/lb	12,110	12,870	8,650
Dry,			
Mineral-matter-free FC	7	69	67 6

* Somos and others (1985), mines and seams unrecorded

**Seam Weighted Average, Zobak Mine, Seam XII, USGS files

Classification by grade; that is, according to the amount of deleterious constituents, shows that some parts of the coaly sequence are of medium to high ash content (<15 percent and >15 percent) and of medium sulfur content (>1 percent - <3percent). However, the seam weighted average analysis indicates that the product of mined seams may characteristically be high in ash and sulfur.

Published descriptions allowing type classification of the Mecsek coals have not been studied for this report, but a variety of data reportedly exists (Paal, 1969, Horvath, 1985, and Nemedi-Varga, 1995b).

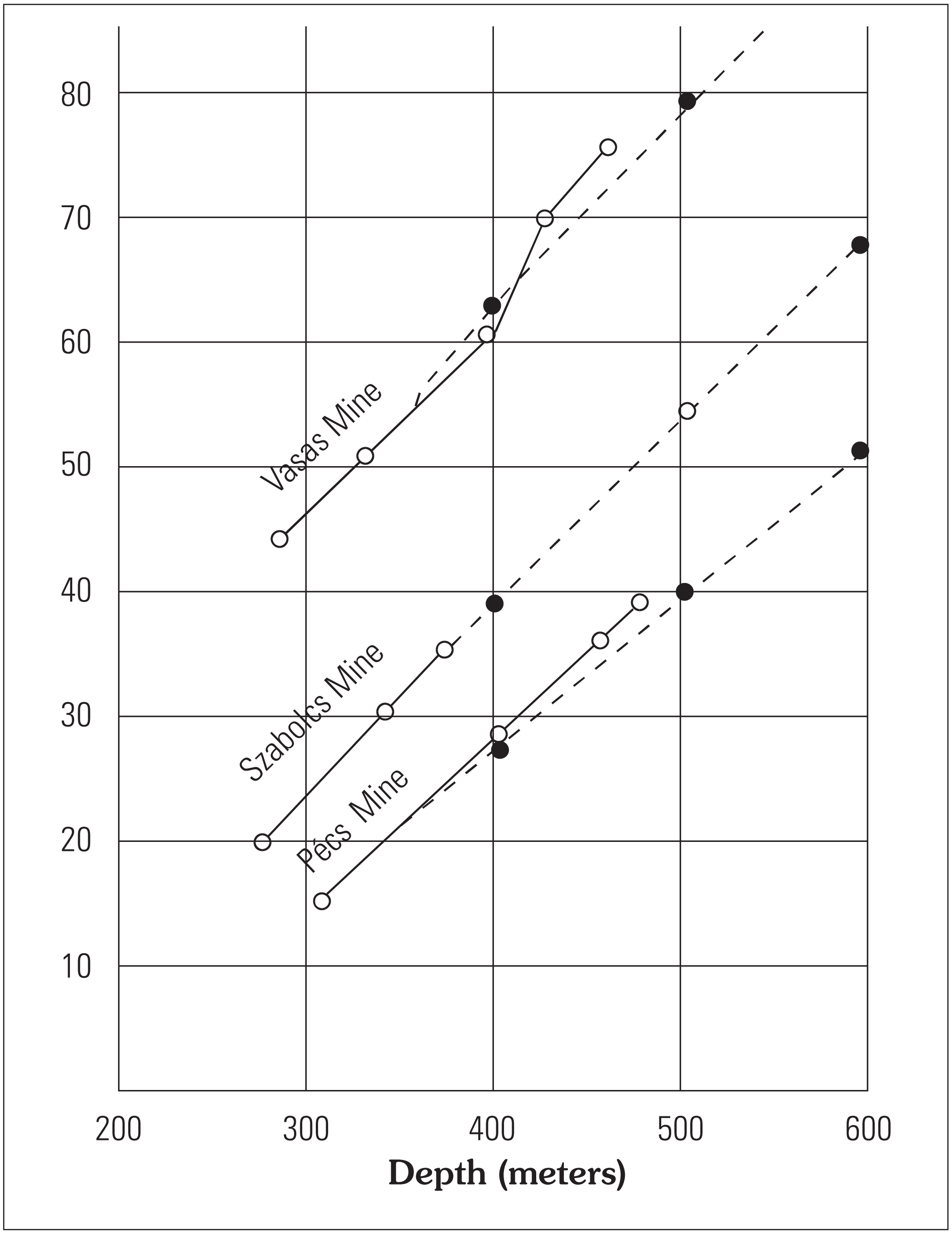


Figure 5. Increase of specific degassing as a function of depth in the Mecsek Basin, Hungary. Dashed lines and ● represent projected values, collected data are represented by solid lines and ○.

Coalbed Gas Content

The amounts of coalbed gas (particularly methane) that are released during mining are routinely measured in the underground mines of Hungary. Mines are grouped in classes according to the greatest specifi c emission of methane (in methane volume/crude coal production) in any ventilating district of the mine. The Zobak Mine was in the most

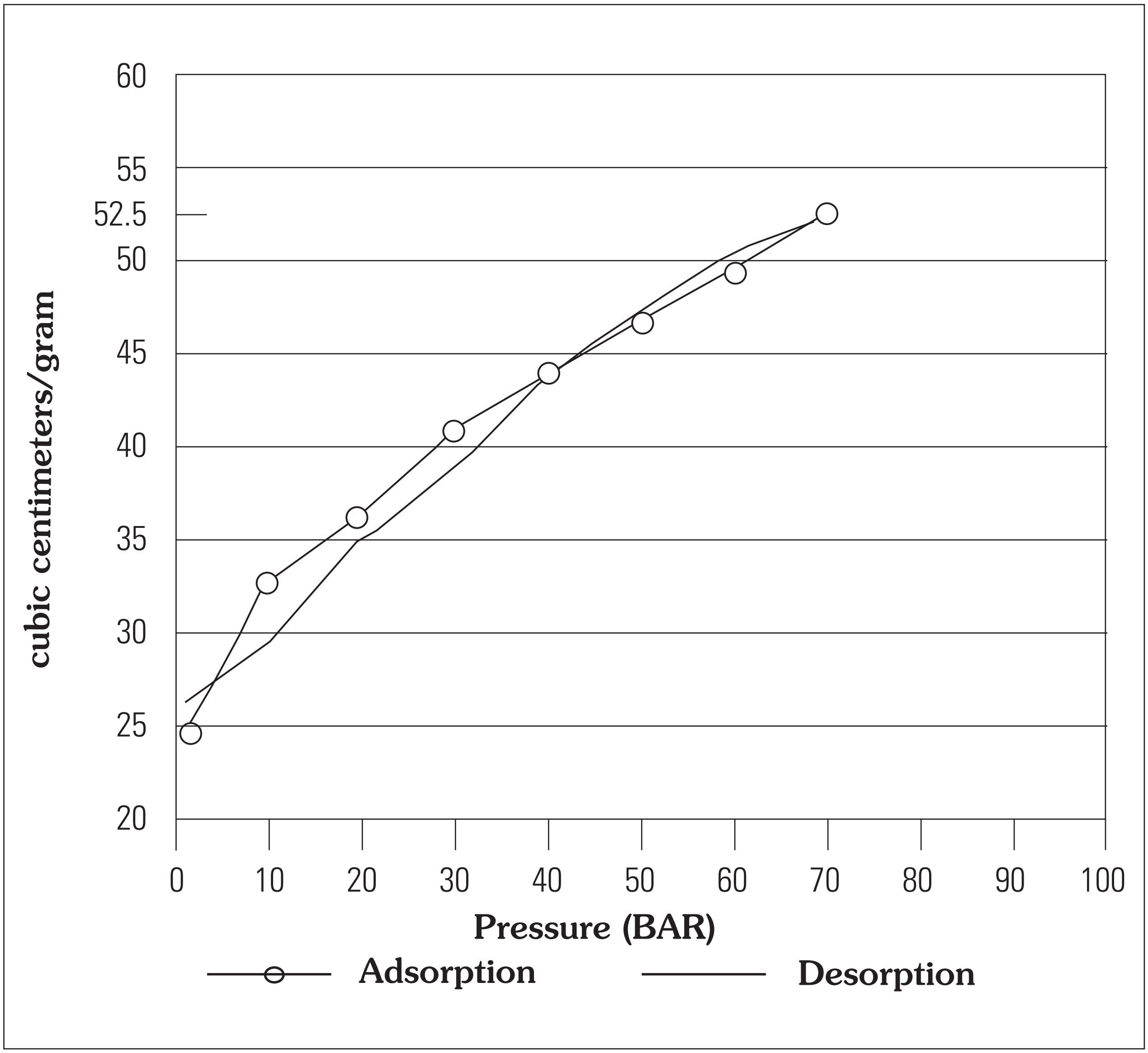


Figure 6. Adsorption/desorption isotherm of a Mecsek Basin, Hungary coal sample.

hazardous class, Class III, because the amount of methane measured was consistently greater than 15 cubic meters per ton of coal produced.

J. Kiss (1995) presented several sets of data derived from methane measurements in the mines. Figure 5 shows data from three mines in the Mecsek Basin that verify the presence of considerable amounts of methane in the coal seams and the amounts that are released as a function of mining depths. However, as pointed out by J. Kiss (1995), the information is useful for planning mine ventilation, "--but does not show the total (sorbed+free) methane content of the coal seams."

HGI (1991) cited several adsorption/desorption tests made on coals from the Mecsek coal basin, but no data were provided regarding the source of the samples, what they represent or the analytical technology. Figure 6 replicates one of the resulting double curves; the results imply that the samples could accept and yield considerable quantities of methane.

HGI (1991) reported that “-insitu gas is a high (pipeline) quality methane gas” with characteristics as listed in table 4. Gas from mined-out areas could be of considerably different composition and would almost certainly have a lesser heat value than the in-situ gas.

Table 4. Mecsek Basin, Hungary coalbed methane quality (from HGI, 1991).

CH_4	C2+	H2	Inerts	CO_2	Heat Value kJ/kg
95%	0.8%	0.005%	4%	0.8%	36,000

Fodor and Gombar (1999) summarized pertinent data about the coalbed gas potential of the Mecsek Basin as follows:

Gas content = 50 cubic meters per metric ton (1602 cubic feet per short ton)
Gas pressure = 20-100 bar (290-1,450 psia)
Permeability = 0.001 to 0.1 millidarcies

The gas content is from HGI (1991); the gas pressures were obtained from drill holes. Rocks in the Mecsek Basin vary in thickness and composition and include relatively impermeable layers, thus making pressures very unpredictable. The low permeability may be a gas production problem. Radnai (1991) report extremely low permeability measurements (0.00039).

BAKONY BASIN - BALINKA MINE

The Balinka Mine in western Hungary is in the northeastern part of the Bakony Basin. The Balinka Mine was selected to provide a suite of information for comparison to the Mecsek Basin coalbed gas data and because the coal may represent the coals of Tertiary age that are mined in northwestern Hungary.

The coal-bearing rocks in the Balinka coal area are of Middle Eocene age and are included in the Dorog Formation of Late Lutetian age. They unconformably overlie limestone of Late Triassic age and marl, limestone, and claystone of Cretaceous age, are overlain unconformably by claystone and marl of Late Eocene, Oligocene and Miocene ages and sediments of Quaternary age. Folding and faulting that occurred both before and after deposition of the coal-bearing rocks are major factors in the complex geologic history of the Balinka coal area.

The Eocene rocks in the Balinka coal area range in total thickness from about 125 meters to almost 350 meters. The lower part contains a sequence of sandstone, shale and coal about 30 meters to 35 meters thick that is commonly overlain by marl. Within the coaly sequence, three relatively persistent coal beds are recognized and numbered from the top down. Bed I is as much as 4.5 meters thick and is the most economically important bed of the three. Bed I characteristically is present in two benches separated by marl. The lower bench is the thickest. The sample collected for this study is from the lower bench of Bed I.

Coal Quality

Available descriptions of the coal produced at the Balinka Mine indicate that most of the coal has an apparent rank of subbituminous C in the ASTM system for classifi cation of coals by rank. The coal is classifi ed as fenytelenbarnakoszen (Hungarian system) or mattbraunkohle (German system) (Fodor and Gombar, 1999). A suite of fi ve samples, representative of the mined product, were collected for analysis in 1998. The results are shown in table 5.

Table 5. Seam weighted average of proximate analyses of samples from Seam I, Balinka Mine, as-received basis. (From USGS fi les, all in weight percent except heat value)

	SWA-5 samples*
Moisture	24.0
Ash	13.3
Volatile Matter	35.4
Fixed Carbon (FC)	27.4
Sulfur	4.1
Heat Value-Btu/lb	7,800

*Seam Weighted Average, Proximate Analysis, Balinka Mine, Seam I, USGS files

Of the total sulfur content, 3.6 percent is in the form of organic sulfur and less than 0.5 percent is in the pyritic form of sulfur. Some research on the petrographic composition of the Balinka coals has been done, but was not translated for this study (Laczo, 1971).

Coalbed Gas Content

The Balinka Mine is in Firedamp Hazard Class I. That is, the greatest specifi c emission of methane (in methane volume/crude coal production) in any ventilating area of the mine has not exceeded 5 cubic meters of methane per ton of coal produced. No other information about the coalbed gas potential of the coals in the Balinka Mine area has been found. However, other nearby coal mines are also in Firedamp Hazard Class I.

RECENT RESEARCH

STUDY OBJECTIVES

During earlier studies of the coal resources of Hungary and their relation to the energy balance of the nation by some of the authors of this report, the possibility of adding coalbed gas in the form of methane to the nation's energy mix was recognized. Review of available information affecting this possibility shows that detailed data are available about the exploited coal deposits of the nation, but complete, reliable information especially pertinent to the exploration, development and production of coalbed gas in Hungary is not readily available or does not exist. Actual measurements of the coalbed gas content of coals-in-place are needed to verify quantity extrapolations from mine-derived data and laboratory adsorption tests of coals. In addition, more descriptions and measurements of the permeability of in-place coal are needed. These needs can be met by the drilling of carefully selected and tested exploration boreholes and the analysis of core samples. Until then, evaluation of coalbed gas potential remains preliminary and incomplete. However, during the present study a limited amount of new data was obtained regarding adsorption characteristics and coal quality of a few samples from different mines and different coal seams in two of Hungary's coal basins. The Mecsek Basin in southwestern Hungary has long been known to contain very gassy coals and has been the site of several coalbed gas recovery efforts—one successful, the others not. The Balinka sub-basin of the Bakony Basin of northwestern Hungary contains coals that yield only small quantities of coalbed gas during mining activities and was selected for comparison to other coal areas in Hungary and other coal areas worldwide.

COALBED METHANE ASSESSMENT METHODOLOGY

The assessment of coal bed methane is conventionally approached by calculating the coal tonnage in place by unit-depth intervals and applying the mean gas content for each of these intervals. For these purposes, a structure contour map can be constructed to show elevations on the top of given interval that leads to determining drilling depths (fig. 7). Two methods of assessment are commonly used, direct and indirect (McLennan and others, 1995). The direct method is preferred and requires measurement of the gas content. However, if only the gas storage capacity (as shown by the adsorption analyses) is known, or if gas content is otherwise assumed, indirect methods must be used (as was necessary for the present study, as discussed below).

HGI (1991) calculated an indirect assessment of the gas content of their study area based on coal resources by depth coupled with the parameters shown in table 1. The estimated total is 1.13E+11 cubic meters or 39.90E+11 cubic feet (about 4 TCF) (table 6).

Direct Method – Gas Desorption in the Field

The direct method involving drilling, coring and collection of fresh coal core samples in a pressure-tight canister is preferred. This procedure is designed to obtain samples that are representative of reservoir rocks in their present environment. The gas content of the collected samples is then measured during desorption tests. The direct method of gas measurement using desorption techniques, however, could not be used for this report for lack of the necessary drilling and analytical information, as discussed earlier.

Indirect Method – Gas Adsorption in the Laboratory

In place of a direct method, an indirect gas measurement method was employed based on measuring the adsorption characteristics of moist, as-received coal channel samples under laboratory conditions. High-pressure adsorption isotherm analyses conducted for this study were performed using a high-pressure volumetric adsorption technique similar to that described by Mavor and others (1990). The apparatus used (fig. 8), which is based on

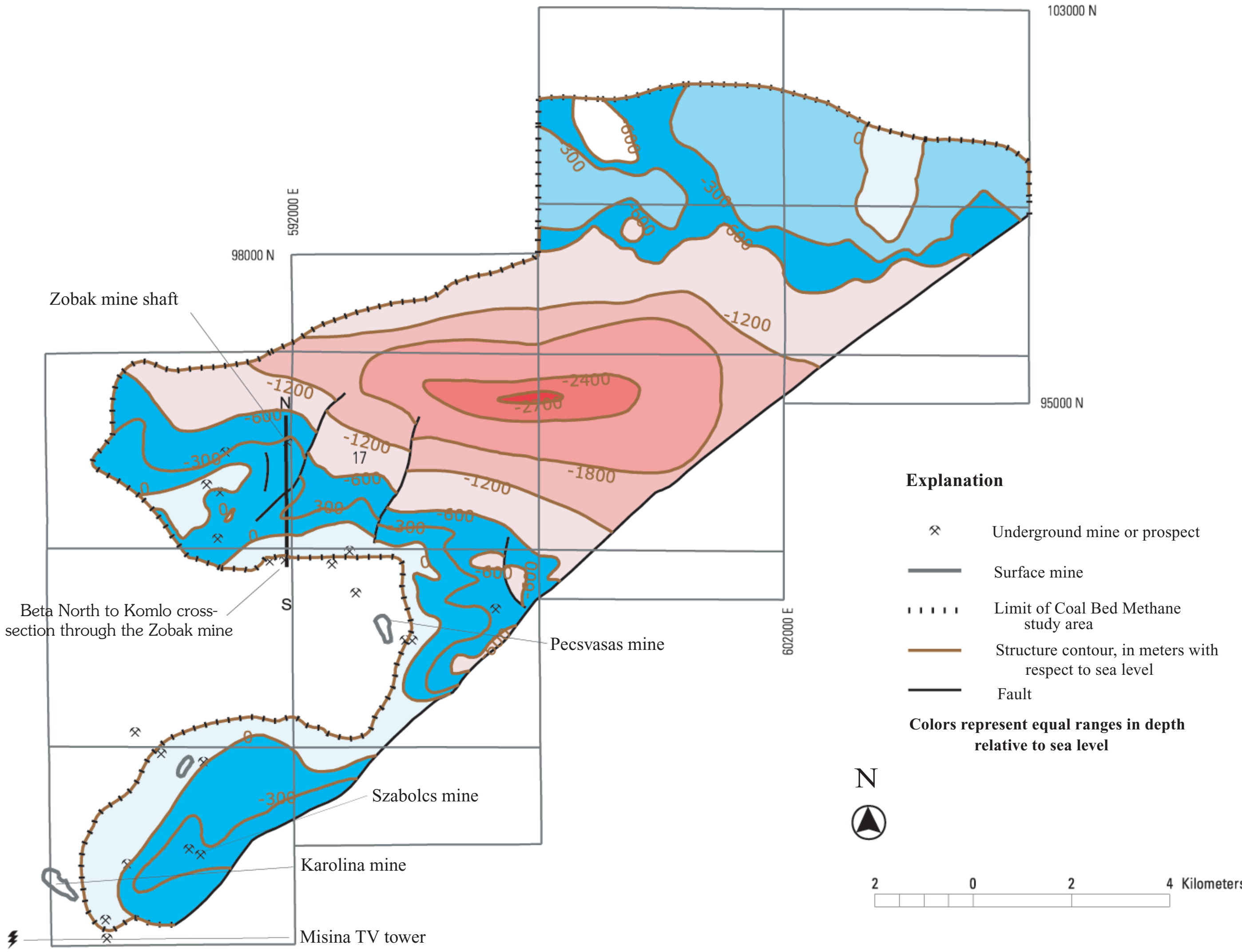


Figure 7. Structure contour map on the uppermost coal seam of the Mecsek Coal Formation (fig. 2) in the Mecsek Basin, Hungary study area (modified from HGI, 1991).

Boyles Law, allows a known volume of gas within a reference cell to be used to dose a sample cell that contains the test sample –usually weighing 100 grams. As gas is adsorbed by the sample, the pressure decreases in the reference cell until a state of equilibrium is reached in the sample cell; that is, the condition where no more gas can be adsorbed by the sample at that pressure. The amount of gas adsorbed in the sample cell is then determined based on changes in pressure. Normally, adsorbed volumes are measured at 10 or more pressure points so a meaningful spread of data are obtained.

The adsorption test provides an estimate of the gas storage capacity; that is, the amount of gas that the sample might contain under the specified temperature and pressure conditions of the laboratory test. If the reservoir is saturated the adsorption test also provides an estimate of the actual gas content of the coalbed reservoir at the applicable temperature and pressure. The gas storage capacity is an important property of coal because there is little incentive for further exploration of a potential gas reservoir if the storage capacity is small.

Table 6. Coalbed gas based on coal resources by depth for the Mecsek Basin, Hungary study area (modified from HGI, 1991).

Depth below SL (meters)	Depth limits (meters)	Tons of Coal Resources	Total Gas Resources (cubic meters)
+300	+300 to 0	1.18E+08	5.88E+09
0	0 to -100	2.39E+08	1.20E+10
100	-100 to -200	3.04E+08	1.52E+10
200	200 to -300	2.53E+06	1.26E+10
300	-300 to -400	2.67E+08	1.33E+10
400	-400 to -500	2.31E+08	1.15E+10
500	-500 to -600	2.07E+08	1.03E+10
600	-600 to -700	1.69E+08	8.45E+09
700	-700 to -800	1.42E+08	7.08E+09
800	-800 to -900	9.98E+07	4.99E+09
900	-900 to -1000	8.54E+07	4.27E+09
1,000	-1000 to -1100	8.15E+07	4.07E+09
1,100	-1100 to -1200	6.35E+07	3.18E+09
Total		2.26E+09	1.13E+11

Note: * Coal resources shown here were back calculated from the gas resource data published in HGI, 1991 and assume a coal density of 50 cubic centimeters/gram for in-situ coal. Gas in the mined-out and caved areas (Gob area) above a depth of 300 meters below sea level (-300 meters) were not included in these estimates

Gas storage capacity is a function of coal properties such as rank, ash and moisture content and organic matter composition. Storage capacity also varies with temperature and pressure. As temperature increases, storage capacity decreases, and as pressure increases, storage capacity increases.

When the results of adsorption tests on gases in microporous solids are plotted, a Type I isotherm is produced (Gregg and Sing, 1982). Type I isotherms typically show a steep increase in adsorption at low pressures followed by flattening into a near-plateau as pressure increases and completion of a mono-layer of adsorbed gas is approached. From a reservoir standpoint, the relative steepness of the initial part of the isotherm curve is important because of the pressure/ productivity relation it displays. The isotherm displays storage capacity as it is related to coal properties (moisture and ash content) and varying pressures under constant temperature conditions. During the testing process reported herein the temperature of the reference and sample cells was maintained at a constant 25 degrees C.

The relations displayed on an isotherm are critical for estimation of: 1) the pressure at which the coalbed reservoir will begin to yield gas, 2) the amount of gas that will be released as pressure is reduced, and 3) the amount of gas that will remain in the reservoir when production ends.

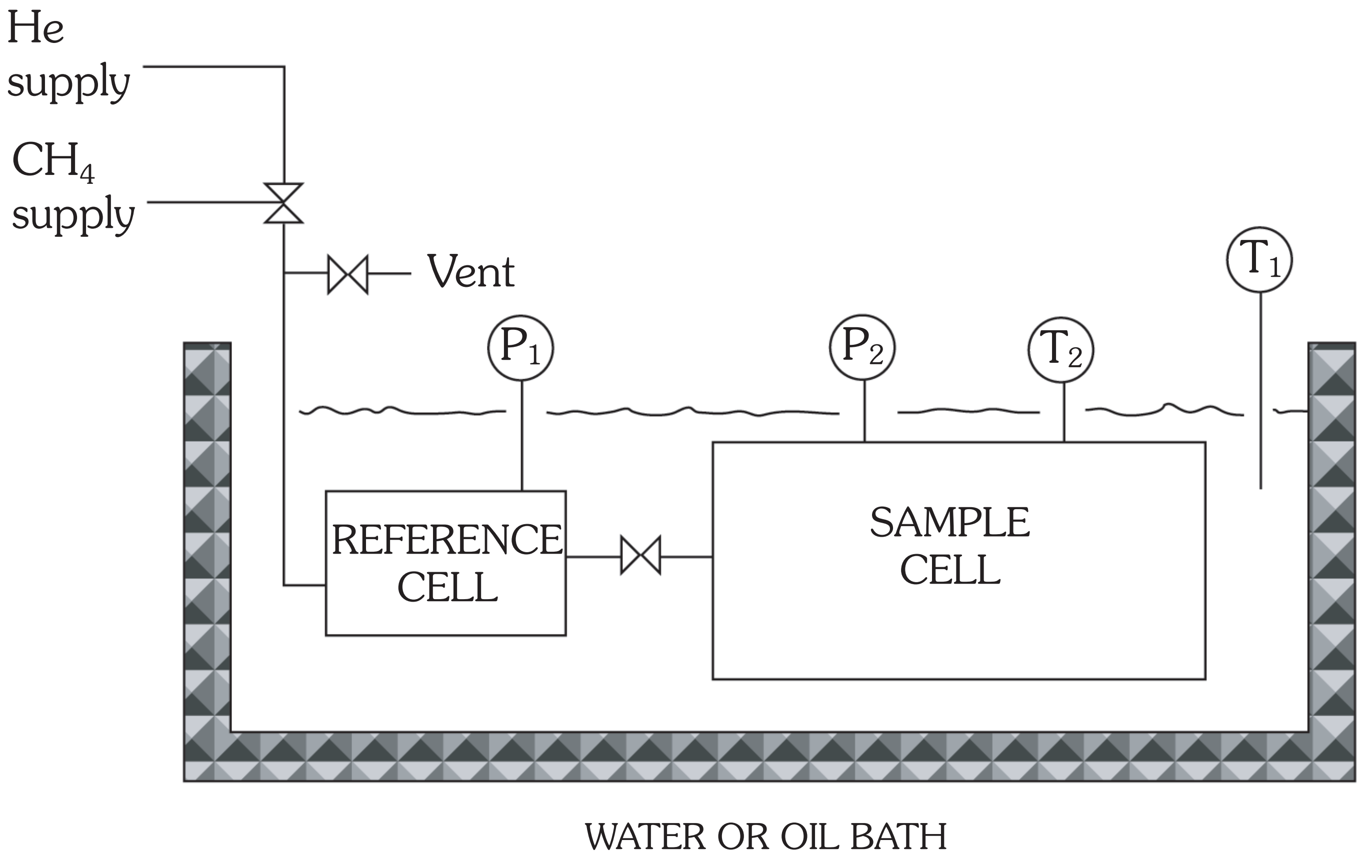


Figure 8. Simplified diagram of adsorption apparatus (P, pressure; T, temperature).

SAMPLES FOR THIS STUDY

Channel samples were collected by the Hungarian Geological Survey (Fodor and Gombar, 1999) from two operating surface mines in the Mecsek Basin, the Karolina and Pecsvasas Mines, and from the Balinka underground mine in the Bakony Basin. Figure 9 presents stratigraphic and thickness data for these samples. As previously mentioned, some of the Mecsek Basin coals were deposited in limnic environments and some in paralic environments (Fodor and others, 1998). The coal sampled at the Karolina Mine, Seam #6, is of limnic origin. The coal sampled at the Pecsvasas Mine, Seam # 13, is of paralic origin. The Balinka Mine sample is from Seam I and is probably of paralic origin.

RESULTS OF ADSORPTION ANALYSES

The samples used for this study were submitted to the R.M.B Earth Science Consultants Ltd., for high-pressure adsorption analyses, petrologic study, and proximate analyses. Summaries of the resulting data are shown on figures 10, 11 and 12.

The isotherm information was combined for the Karolina and Pecsvasas Mines and regression analysis was performed on the resulting data. The experimental isotherm pressures were then converted to equivalent depth by assuming a freshwater hydrostatic gradient [9.8 kiloPascals per meter (kPa/m) or 0.433 pounds per square inch per foot (psi/ft)] from the ground surface downward (that is, assuming the soil and overburden rock are water-saturated down to the coal bed) (fig. 13).

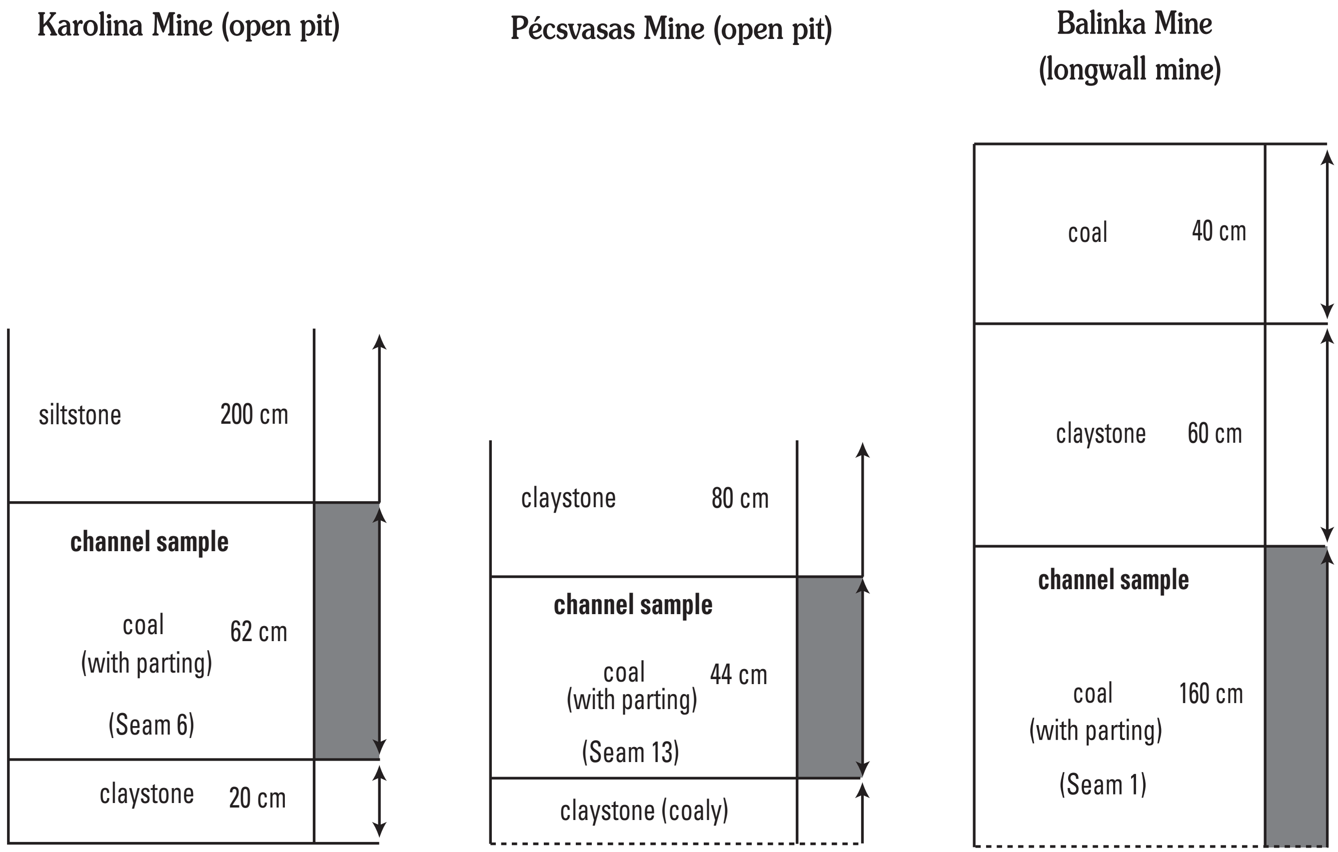
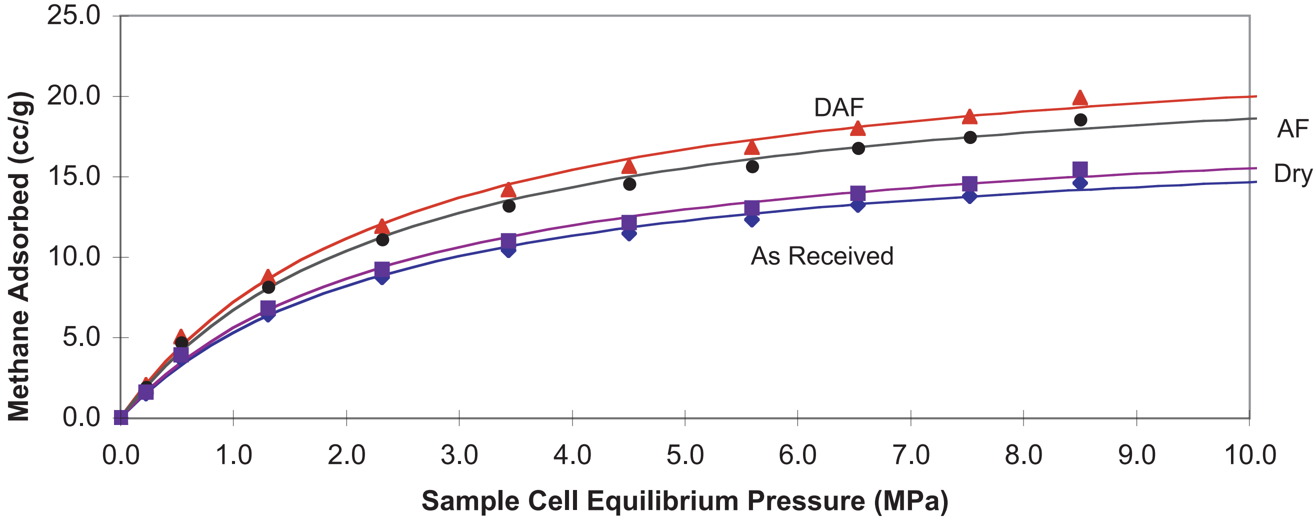


Figure 9. Coal beds sampled for adsorption tests at three Hungarian coal mines [cm, centimeters].

The information shown on figure 13 was then used to create table 7, which shows the estimated mean gas content per 300-meter depth interval. (Note that the depth intervals in table 7 are measured from ground level, which is assumed to be 300 meters above sea level.)

The structure contour map (fig. 7) on the top of the uppermost coal seam (HGI, 1991) was digitized so that areas in which the coal sequence (30 meters thick, from HGI, 1991) within particular depth ranges (300 meters) could be measured and the corresponding coal mass could be calculated. The resulting data were then combined with the estimates of gas content by depth interval in table 6 to calculate the estimated gas content of the coal sequence in the Mecsek Basin study area (table 8). (Note that the depth intervals in table 8 are measured above and below sea level, in contrast to table 7.

The total estimated coalbed gas resources for the Mecsek Basin study area (table 8) are 2.8E+10 cubic meters or 9.9E+11 cubic feet (almost 1 TCF). The difference between the results in table 8 and the results shown in table 6 are considerable (a factor of 4). It should be emphasized that both of these estimates lack the detailed geologic, topographic, coal characteristic, gas content and Geographic Information System (GIS) databases that are needed for more accurate estimates. However, it is also important to note that in the CBG industry, 1 TCF of gas potential could justify an exploration program. Although some of the needed information exists, substantially better gas content and coal permeability data are required to guide future exploration activities.



Pressure (MPa)	Adsorbed Methane (cc/g) As Received	Dry with Ash	Moist Ash Free	Dry Ash Free
0.22	1.49	1.58	1.89	2.03
0.53	3.69	3.90	4.68	5.02
1.31	6.43	6.80	8.15	8.76
2.32	8.73	9.24	11.08	11.91
3.44	10.39	10.99	13.18	14.17
4.51	11.47	12.13	14.55	15.63
5.60	12.33	13.04	15.64	16.80
6.53	13.21	13.98	16.76	18.01
7.53	13.75	14.55	17.44	18.74
8.51	14.61	15.46	18.54	19.92

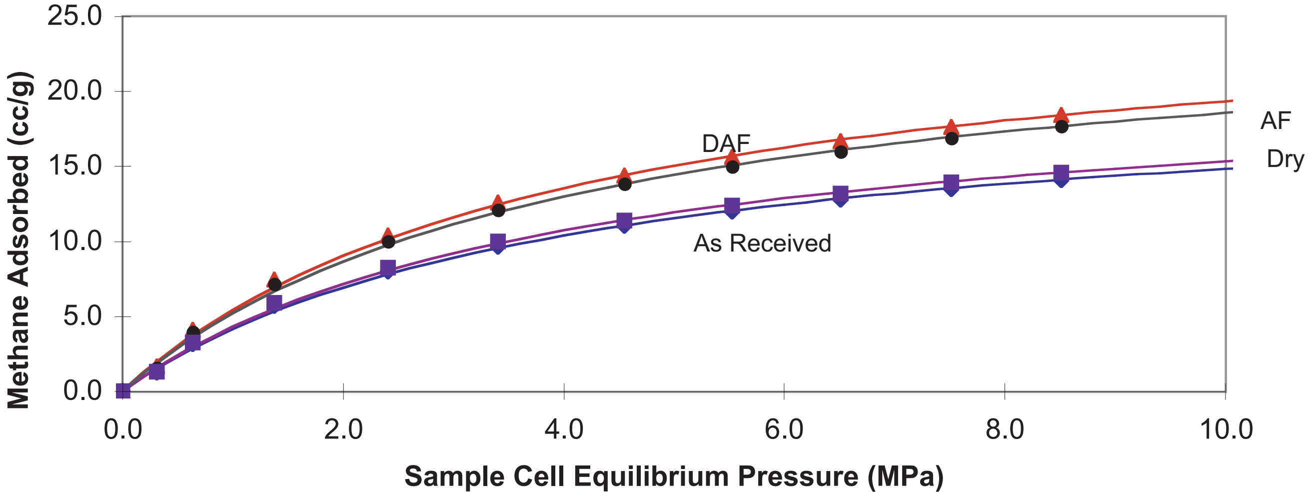
Langmuir Parameters

	As Received	Dry with Ash	Moist Ash Free	Dry Ash Free
Vol. (cc/g)	18.26	19.32	23.16	24.89
Pressure (MPa)	2.46	2.46	2.46	2.46

Isotherm Temperature: 25.0 ºC
Goodness of fit of Langmuir regression: 1.00
% Ash= 21.17 % Moisture = 5.46
cc/g, cubic centimeters/gram; DAF=Dry, Ash-free (▲); AF = Ash-free (●)
MPa, pressure in mega pascals; Dry=0% water (■); As-received = (◆)

Figure 10. Summary of adsorption tests, Karolina Mine, Mecsek Basin, Hungary (in International System of Units, SI units). RMB Consultants, Analysts.

The measured gas storage capacity of the sample from the Balinka Mine was much less than that of the samples from the Mecsek Basin, indicating only a small gas resource potential. Consequently no attempt was made during the present study to evaluate the resource potential of the Balinka area. Further information should be sought as opportune because present perceptions about resource potential may change in the future.



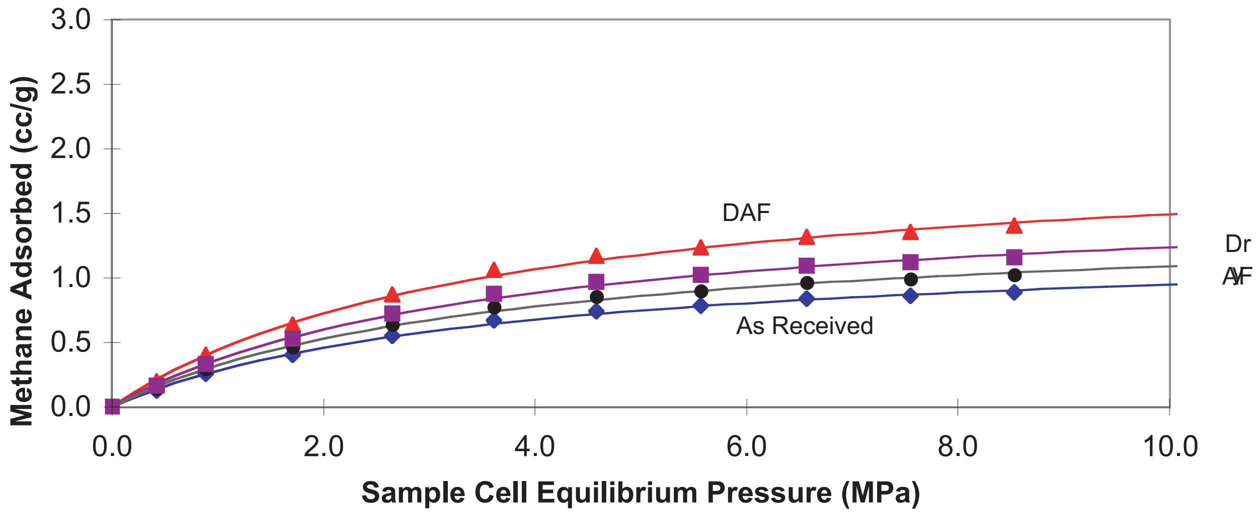
Pressure (MPa)	Adsorbed Methane (cc/g) As Received	Dry with Ash	Moist Ash Free	Dry Ash Free
0.31	1.24	1.29	1.56	1.62
0.64	3.14	3.24	3.93	4.09
1.38	5.69	5.88	7.13	7.43
2.41	7.96	8.23	9.97	10.39
3.41	9.65	9.97	12.08	12.59
4.55	11.02	11.40	13.80	14.39
5.53	11.96	12.37	14.98	15.62
6.51	12.76	13.19	15.97	16.65
7.52	13.48	13.93	16.87	17.59
8.52	14.10	14.57	17.65	18.40

Langmuir Parameters

	As Received	Dry with Ash	Moist Ash Free	Dry Ash Free
Vol. (cc/g)	20.74	21.44	25.97	27.08
Pressure (MPa)	4.01	4.01	4.01	4.01

Isotherm Temperature: 25.0 ºC
Goodness of fit of Langmuir regression: 0.99
% Ash= 23.13 % Moisture = 3.26
cc/g, cubic centimeters/gram; DAF=Dry, Ash-free (▲) AF = Ash-free (●)
MPa, pressure in mega pascals; Dry = 0% water (■) As-received = (◆)

Figure 11. Summary of adsorption tests, Pecsvasas Mine, Mecsek Basin, Hungary (in International System of Units, SI units). RMB Consultants, Analysts.



Pressure (MPa)	Adsorbed Methane (cc/g) As Received	Dry with Ash	Moist Ash Free	Dry Ash Free
0.43	0.12	0.16	0.14	0.20
0.89	0.26	0.33	0.29	0.40
1.71	0.40	0.53	0.46	0.63
2.65	0.55	0.72	0.63	0.87
3.62	0.67	0.88	0.77	1.06
4.58	0.74	0.97	0.85	1.17
5.57	0.78	1.02	0.90	1.23
6.57	0.83	1.09	0.96	1.32
7.55	0.86	1.12	0.99	1.35
8.53	0.89	1.16	1.02	1.40

Langmuir Parameters

	As Received	Dry with Ash	Moist Ash Free	Dry Ash Free
Vol. (cc/g)	1.29	1.68	1.48	2.03
Pressure (MPa)	3.64	3.64	3.64	3.64

Isotherm Temperature: 25.0 ºC

Goodness of fit of Langmuir regression: 0.99

% Ash= 13.13 % Moisture = 23.54

cc/g, cubic centimeters/gram; DAF=Dry, Ash-free (▲); AF = Ashfree (●)

Mpa, Pressure in mega pascals; Dry = 0% water (■); As-received = (◆)

Figure 12. Summary of adsorption tests, Balinka Mine, Bakony Basin, Hungary (in International System of Units, SI units). RMB Consultants, Analysts.

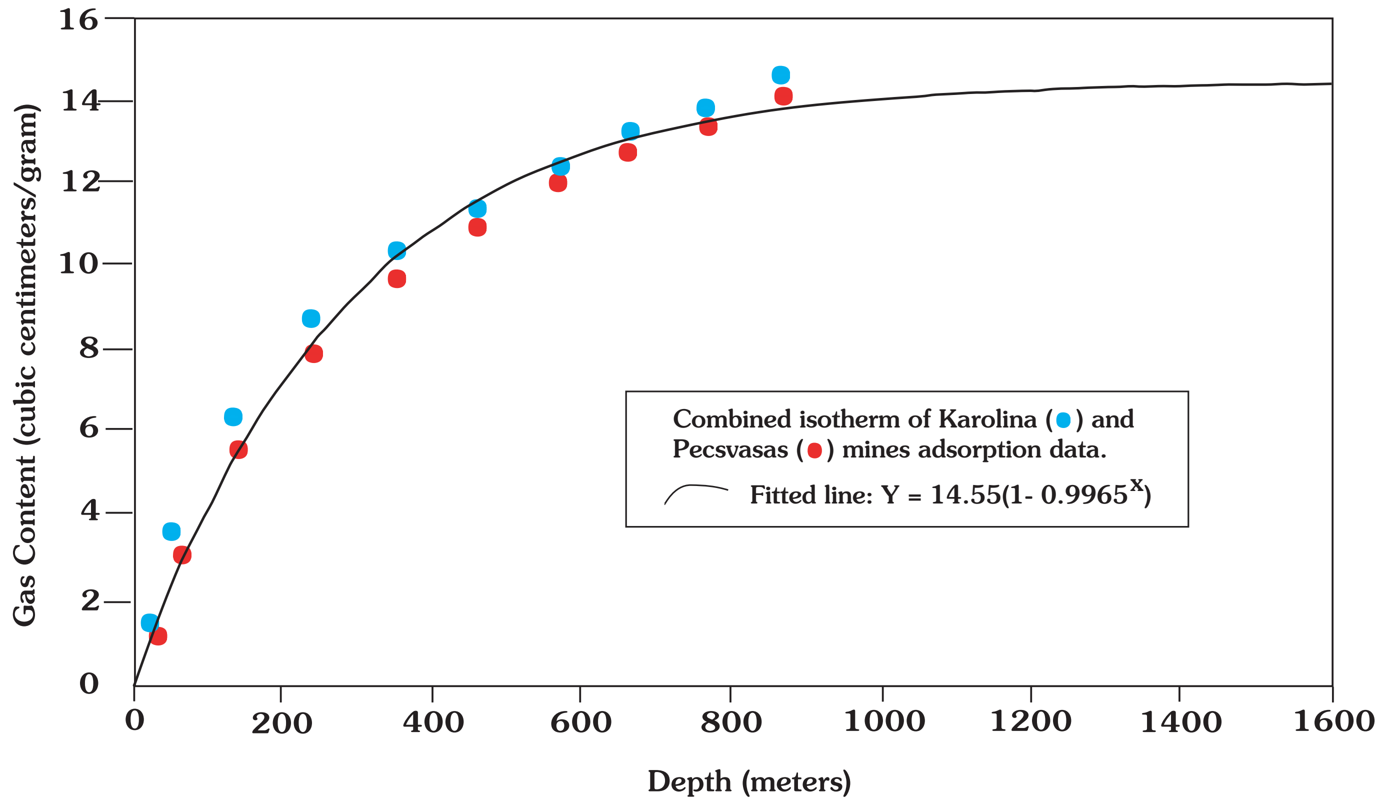


Figure 13. Regression analysis of combined isotherm data for the Karolina and Pecsvasas Mines, Mecsek Basin, Hungary.

RESULTS OF OTHER STUDIES AND TESTS

In addition to the adsorption tests discussed above, studies and tests of the petrographic character and some of the standard coal analytical characteristics of the samples were made (R.M.B., 2000). Also, the Langmuir constants for volume and pressure were calculated and displayed in figures 10, 11, and 12. Table 9 summarizes the results of these studies.

The samples from the Karolina and Pecsvasas Mines in the Mecsek Basin both have relatively large vitrinite maceral group contents, medium amounts of the inertinite group, and small amounts of the liptinite group. The sample from the Balinka Mine has a relatively large amount of the vitrinite group, a small amount of the inertinite group, and a medium to large amount of the liptinite group. In general, coals with relatively larger quantities of the vitrinite maceral group have better gas sorption capacities, and greater potential for formation of natural fractures (cleat) than do coals with relatively larger quantities of macerals of the inertinite and liptinite groups. Macerals of the liptinite and vitrinite groups have high to medium potential for coalbed gas generation and the inertinite group has low potential. Development of permeability within the coal matrix itself is generally considered to be poorest in the liptinite group and of medium to high potential in the vitrinite and inertinite groups.

The various macerals and submacerals recognized within the maceral groups of coals all have a range of individual and combined effects on the gas storage capacity, actual amount of gas generated, and the ability of gas to move within the matrix of the coal and within the natural fracture systems of the coal reservoir. The large vitrinite content of all three samples is a favorable factor in evaluating their coalbed gas resource potential.

Table 7. Regression analyses data for coalbed gas versus depth of resource, Karolina and Pecsvasas Mines, Mecsek Basin, Hungary.

Top depth Interval (BGL)* (meters)	Bottom depth interval (BGL)* (meters)	Estimated gas content top cc/g)	Estimated gas content bottom cc/g)	Mean gas content cc/g)	Mean Gas Content (SCF/ton)
0	300	0	9.5	4.7	151
300	600	9.5	12.8	11.1	356
600	900	12.8	13.9	13.4	427
900	1200	13.9	14.3	14.1	452
1200	1500	14.3	14.5	14.4	461
1500	1600	14.5	14.5	14.5	464

Note: *BGL, below ground level; ground level is assumed to average 300 meters above sea level. Cubic centimeters/ gram, cc/g;
Standard Cubic Feet/short ton, SCF/ton.

Table 8. Estimated coalbed gas resources for the Mecsek Basin, Hungary study area.

Depth below Sea Level (meters)	Depth Limits* (meters)	Combined Depth Class (meters)	Coal Resource by Depth Class (tons)	Mean Gas Content - R.M.B. Isotherms (m3/ton)**	Gas in Place Resource Estimate (m3)
+300	+300 to 0	+300 to 0	1.18E+08	4.7	5.52E+08
0	0 to -100	0 to -300	7.96E+08	11.1	8.84E+09
100	-100 to -200				
200	-200 to -300				
300	-300 to -400	-300 to -600	7.04E+08	13.4	9.44E+09
400	-400 to -500				
500	-500 to -600				
600	-600 to -700	-600 to -900	4.10E+08	14.1	5.79E+09
700	-700 to -800				
800	-800 to -900				
900	-900 to -1000	-900 to -1200	2.30E+08	14.4	3.32E+09
1000	-1000 to -1100				
1100	-1100 to -1200				
Total				Total Gas =	2.79E+10
		Total gas =	9.87E+11 ft3 ,	TCF =	0.987

Note: * Gob gas above -300 m was not included in these estimates. In the northern portion of the study area the water table is closer to ground surface than in the southern portion. Gas resources in the north were estimated using minimum gas content for the +300 to -300 m depth intervals.
** Mean gas contents are from CBG adsorption results from the Karolina and Pecsvasas Mines.
(m3/ton cubic meters/metric ton)

Table 9. Summary of petrographic studies, analytical tests, and derived Langmuir constants.

MINE	Karolina	Pecsvasas	Balinka
Petrographic Analyses - %			
Vitrinite	94	91	89
Inertinite	4	8	1
Liptinite	2	< 1	10
Maturity Rmax-mean	1.63	0.87	0.29
Proximate Analyses-%			
Equilibrium Moisture	5.46	3.26	23.54
Ash-as received	21.17	20.13	13.13
Volatile Matter-dry ash free	21.81	36.05	55.36
Langmuir constants (as-received)			
cubic feet/short ton (ft3/ton)	621	706	44
cubic centimeters/gram (cc/g)	18.26	20.74	1.29
Pounds/square inch absolute (Psia)	357	581	528
Mega Pascals (MPa)	2.46	4.01	3.64

Analysts: RMB Consultants.

Measurement of the reflectivity of vitrinite in coals is a standard and widely used method to express the maturity of coaly organic matter. It can be used either independently or collaboratively with elements of standard coal analyses to establish the rank of coals. The maturity data shown in table 9 agrees with the other presented information on the metamorphic state of the sampled coals.

Both moisture and ash content are considered depreciatory to coalbed gas potential. Moisture content because it reduces the gas storage capacity of coals and ash content because the mineral matter from which the ash is derived does not generate gas, usually does not store it, and may inhibit movement. The two samples from the Mecsek Basin have relatively high ash contents and low moisture contents. The seam weighted averages for the Zobak Mine see previous discussion) indicates that even larger ash contents may be encountered in the coal sequences of the Mecsek Basin. The sample from the Balinka Mine in the Bakony Basin has considerably more moisture than the Mecsek samples but exhibits less ash content. The seam-weighted averages for the Balinka Mine indicate essentially the same moisture and ash content. Both the Zobak Mine and Balinka Mine seam weighted averages show high sulfur contents (3.7 percent and 4.1 percent, respectively), but the sulfur in the Zobak samples is largely in the pyritic form, which may reduce either, or both, the matrix permeability and fracture permeability. The bulk of the sulfur in the Balinka samples is in the organic sulfur form and may not affect permeability.

The Langmuir constant (also called parameter) for volume is the theoretical gas content of a coal sample at a particular temperature and at infinite pressure. The Langmuir constant for pressure is the pressure at which the sample's gas content is one-half the Langmuir constant for volume (Olszewski and Schraufnagel, 1992). The Langmuir constants are calculated using variations of equations proposed by Langmuir (1916, 1917, and 1918) during his studies of the phenomena of adsorption of gases on the surface of solids. The Langmuir constants calculated from the adsorption test results are presented in table 9 on the as-received basis and in both Imperial and SI units. In figures 10, 11 and 12 they are presented on the as-received, dry with ash, moist ash-free, and dry ash-free basis. The Langmuir constants (parameters) serve to characterize the isotherm from which they are derived for comparisons and reservoir evaluation purposes.

CONCLUSIONS

1. The coals of the Mecsek Basin in southwestern Hungary contain substantial quantities of coalbed gas. Measurements of the gas storage capacity of samples collected for this study confirm previous reports of considerable coalbed gas resource potential. Preliminary estimates cited in this report show total gas contents ranging from 1 to 4 TCF (Trillion Cubic Feet). Further studies of geologic, engineering, and marketing factors are needed to determine if production of methane gas is economically feasible. Exploration targets should be identified and state-of-the art drilling plans formulated to create the resource and reservoir information needed to establish workable strategies for adding coalbed gas (methane) to the nation's energy balance.

2. A sample of coal from the Balinka Mine in the Bakony Basin exhibits a gas storage capacity of relatively small size. Similar studies of other developed coal areas should be made, even though the presently perceived gas resource potential is small.

3. Studies of the coalbed gas resource potential of undeveloped coal areas of the nation should be initiated. For example, information on the reservoir properties of the coals penetrated at considerable depths in the Pannonian Basin in southern Hungary should be gathered.

4. The present energy system of Hungary requires importation of substantial quantities of energy in the form of natural gas (methane) and may require increasing quantities of imported energy in the form of electricity. Development and production of domestic energy resources to replace, or supplement, imported energy could be a priority in future energy plans of the nation.

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