Geothermal use of mine water

*L.M. Lara, I. G. Colinas, M.T Mallada, A.E. Hernández-Battez, J.L. Viesca**

In the Vital Álvarez Buylla Hospital in Mieres (Asturias, Spain), the energy supply for the heating and air conditioning system relies on a geothermal facility that uses mine water from the abandoned and flooded Barredo-Santa Bárbara system of coal mines. This water is being used in the most powerful geothermal facilities in Spain and one of the biggest of its kind in Europe, where water pumped out of the Barredo mine shaft yields up to 3.5 MWt passing through a heat exchanger. The Research Building of the University Campus of Mieres (University of Oviedo, Spain) is also heated by the same geothermal resource.

An important role is played by the use of the mine water, and the energy benefits derived from it represents a rational and sustainable use of a traditional mining area after cessation of its activity, aiding environmental and economic development in places where mining activity once ruled the local economy.

A l'Hôpital "Vital Alvarez Bullya" de Mieres (Les Asturies, Espagne), la fourniture de l'énergie pour le chauffage et le système d'air conditionné dépend d'un aménagement géothermique qui utilise l'eau provenant des galeries abandonnées et noyées, des mines de charbon de Barredo-Santa Barbara. Cette eau est utilisée au sein des installations géothermiques les plus puissantes en Espagne et l'une des plus importantes de la sorte en Europe, où l'eau pompée à partir d'un puits de la mine de Barredo fournit jusqu'à 3.5 MWt en traversant un échangeur thermique. Le bâtiment de recherche de l'Université du Campus de Mieres (Université d'Oviedo, Espagne) est également chauffé par la même ressource géothermique.

L'eau de la mine joue un rôle important et le bénéfice énergétique que l'on en tire représente une utilisation rationnelle et durable d'une zone minière traditionnelle après l'arrêt de ses activités, contribuant au développement environnemental et économique de secteurs dont l'économie locale était autrefois tributaire de la seule activité minière.

La climatización del Hospital Vital Álvarez Buylla de Mieres (Asturias, España) basada en la utilización de un sistema geotérmico que emplea agua de mina, constituye la instalación geotérmica más grande de España y una de las mayores de Europa de este tipo. En dicha instalación se aprovecha el agua de bombeo procedente de la unidad Barredo-Santa Bárbara a través de un intercambiador de calor de 3,5 MWt. Además, el Edificio de Investigación del Campus Universitario de Mieres (Universidad de Oviedo, España) es también climatizado utilizando el mismo recurso geotérmico.

De esta forma, la utilización de las minas abandonadas e inundadas de la zona, adquieren un papel importante, permitiendo un uso racional y sostenible de las infraestructuras mineras una vez cesa la actividad, pudiendo ir acompañada de beneficios económicos y medioambientales que repercutan en las zonas donde la actividad minera era el principal motor económico.

1. Introduction

The Central Coal Basin of Asturias (hereafter CCBA) occupies an area of about 1400 km^2 and is the biggest outcrop of materials from the Carboniferous period in Spain. Over more than two hundred years the mining activity in the basin evolved from drift mining or "mountain mining" to mining by means of vertical shafts, with some reaching depths of 700 m or even more. These mining works have been interconnected by complex networks of galleries.

Since mining work began, 300 pits, drift mines and 73 vertical shafts have been opened, so the hydraulic system of small multilayer aquifers has evolved into a karst type hydraulic system (Pendás and Loredo, 2006) due to traditional mining methods

*Aula Hunosa de la Geotermia y la Biomasa. University of Oviedo. Edificio de Investigación del Campus de Mieres, 33600-Mieres (Spain), viescajose@uniovi.es

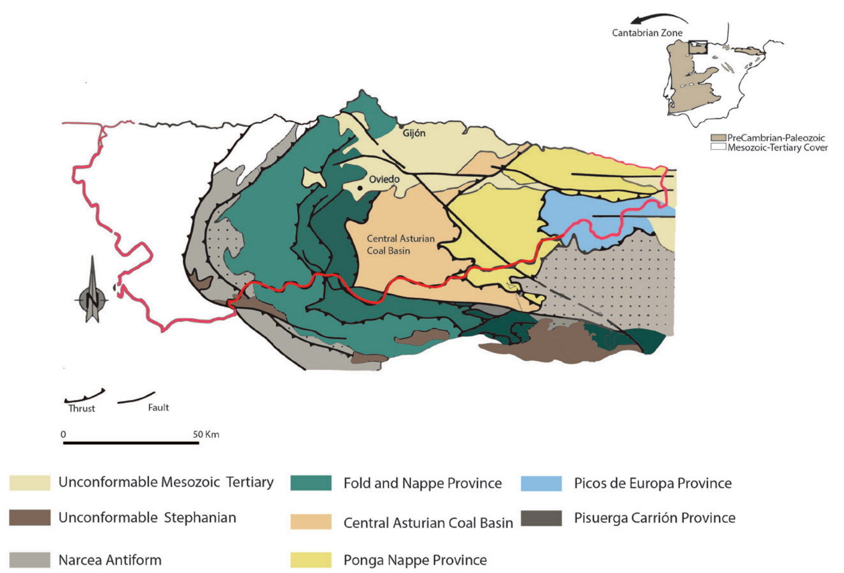

Figure 1: Location of the Central Asturian Coal Basin in the Cantabrian Zone (Iberian Masif) (Bastida et al.*, 1995).*

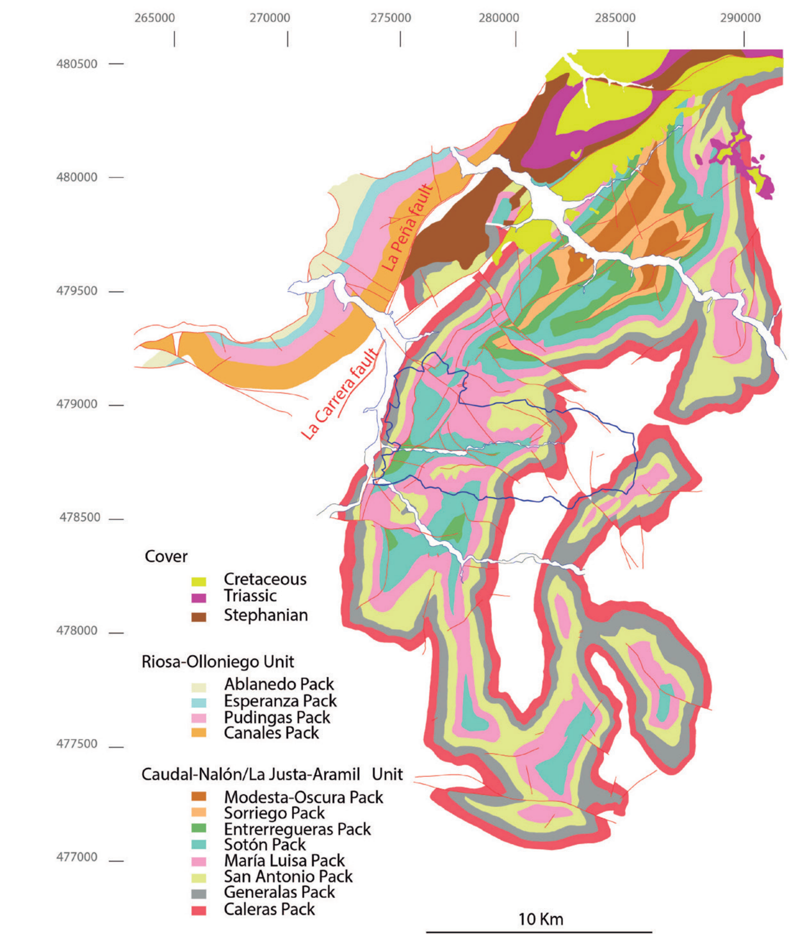

Figure 2: Geological map (Grupo Hunosa) and studied area.

and the thousands of kilometres of galleries that have cracked the surrounding rock mass.

Mining companies bear the operational and maintenance costs costs of the mine water pumping system, and these can be significantly reduced by heating and air conditioning buildings using heat pump technology that makes use of the heat energy of mine water.

The state-owned mining company Hunosa has built a Geothermal Facility that utilises the energy contained in the drainage water of the Barredo-Santa Bárbara system coal mines, extracted from the Barredo mine shaft in Mieres, Asturias, to heat and air-condition the Vital Álvarez Buylla Hospital (4.3 MWt), the Research Building on the University of Oviedo's Mieres campus (720 kWt) and a building of the Fundacion Asturiana de la Energía (125 kWt).

2. Geology

The CCBA is one of the regions defined by Julivert (1967), located in the Cantabrian Zone and inside the Iberian Masif (Lotze, 1945) (***Figure 1***). It is a synorogenic basin formed in relation to the Variscan orogeny and has been affected by several phases of deformation, which have led to an intensely folded and fractured structure.

Its western and southern boundaries are the Aramo thrust and the León fault. The Laviana thrust to the west borders with the Región de Mantos, and the northern part is covered by Mesozoic-Tertiary materials. The productive zones of the CCBA can be subdivided into different units from west to east limited by faults: the "Riosa-Olloniego Unit", the "La Justa-Aramil and Caudal-Nalón Unit" (***Figure 2***).

The Carboniferous sediments of the CCBA reach 6,000 m in thickness, aged from the Namurian B to the Westfalian D. The succession of materials has been traditionally divided into two main groups (***Figure 3***); the lower Lena Group comprises limestones and a few narrow coal seams, and the overlying Sama Group comprises a few siltstones, numerous sandstone layers, some conglomerate levels and workable coal seams. Both the Lena and Sama Groups are divided into a lithostratigraphic series referred to as "Packs" in mining terminology (García-Loygorri *et al.*, 1971) and which, arranged from bottom to top, are: Fresnedo, Levinco, Llanón, Tendeyón and Caleras (Lena Group), Generalas, San Antonio, María Luisa, Sotón, Entrerregueras, Sorriego, Modesta and Oscura (Sama Group). The section related to this project is the Caudal-Nalón Section, which includes the upper "pack" of the Lena Group (Caleras Pack) and all the "packs" of the Sama Group.

3. Hydrogeology

The Carboniferous sediments in the area studied present a monotonous succession of shales, siltstones, sandstones, many coal seams and some levels of limestone of variable thickness.

These materials have very different hydrogeological characteristics, as summarised in ***Table 1***.

Very low permeability materials: Shales and siltstones, with permeability values of 0.005 m^2/day and 2.96 x 10^{-8} m/s (ITGE, 1995). Different values of primary permeability (Fandos *et al.*, 2004) have been obtained by other researchers, estimated from pump trials and time series of potentiometric level measurements in areas without mining activity, obtaining values of below 10^{-7} m/s, and values ranging from $5x10^{-7}$ to 10^{-6} m/s in a natural fractured rock mass.

Low permeability materials: Calcareous and clay sandstones, siliceous microconglomerates (called "micro pudingas") and siliceous conglomerates (called "pudingas"). In these rocks the hydraulic conductivity

Table 1: Hydrogeological characteristics.

PERMEABILITY TYPE	MATERIALS	TRANSMISSIVITY (m^2/day)	PERMEABILITY (m/s)
Very Low	Shales or siltstone	0.005	2.96 10^{-8}
Low	Calcareous and clay sandstones, siliceous microconglomerates ("micro pudingas") and siliceous conglomerates ("pudingas")	6.5	3.92 10^{-5}
Variable due fissuring and/or karstification	Limestone and dolomites	Depending on the level of karstification and type of backfill	

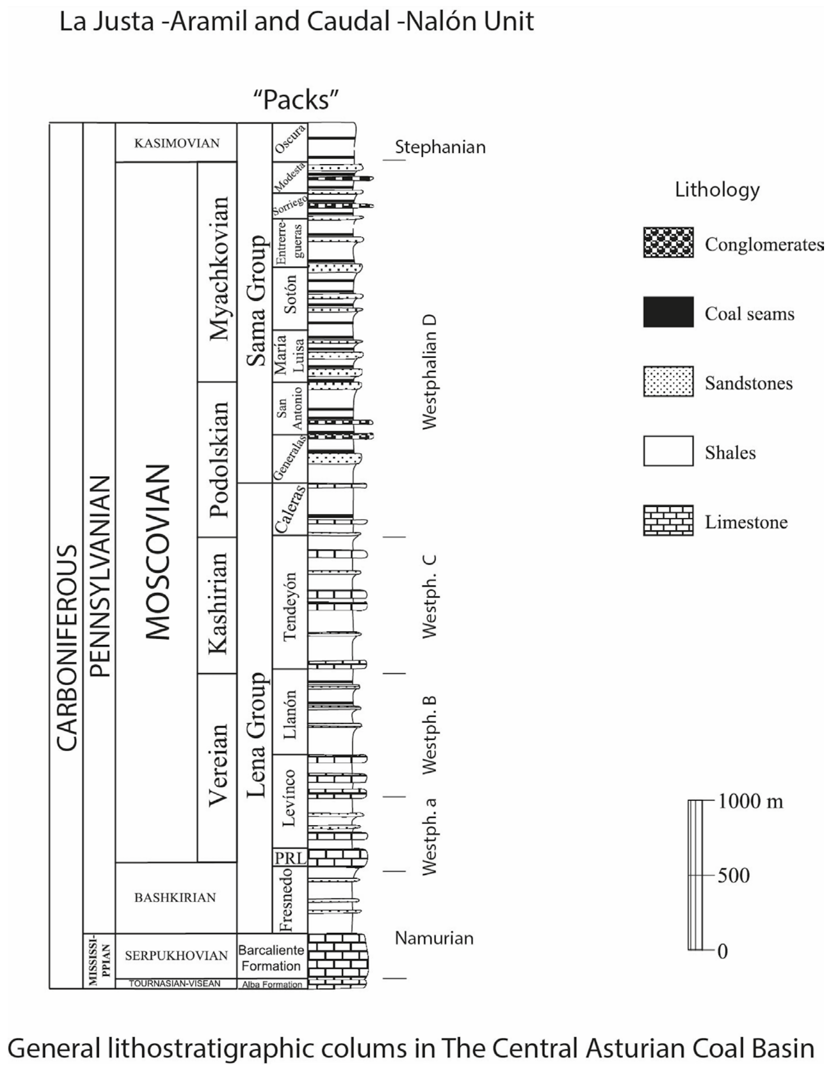

Figure 3: General stratigraphic columns in the Central Asturian Coal Basin (Sáenz de Santa María et al.*, 1985)*

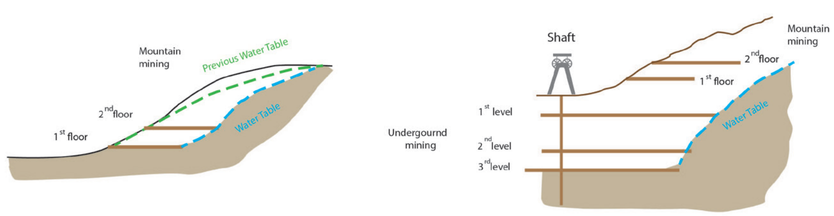

Figure 4: Drift mining and shaft mines (based on González and Rebollar, 1986).

is directly related to the degree of fissuring within the rock mass. Research carried out in areas surrounding the El Entrego and San Mamés mining works obtained transmissivity values of 6.5 m^2/day and permeability values of 3.92 x 10^{-5} m/s (Fandos *et al.,* 2004).

Variable permeability materials due to fissuring and/or karstification: Thin layers of limestone and dolomites randomly distributed between the series of shales and siltstones. These materials have developed a secondary permeability due to fissuring and/or karstification, even though their primary permeability is near zero.

4. Relief and Climate

The CCAB climate is included in the Western Europe Oceanic zone. Mild temperatures and elevated amounts of rainfall spread throughout the year are its main characteristics. Average yearly rainfall ranges from 1100 to 1300 l/m^2, the annual average maximum temperature ranges from 16 to 20 °C and the average minimum is from 4 to 9 °C.

The relief is especially uneven, the lower valley floors being at an average altitude of 280 m and the high mountains to the south of the basin rising to 1500 m. Height differences of 300 to 500 meters are very common on the steep slopes of the valleys in the mining zone, and have influenced the mining techniques used.

5. Mining Method

Mining operations have been carried out in the CCBA for the last 200 years. Drift mining or "mountain mining" was the mining method used during the mid-nineteenth century. Mining was carried out by digging tunnels at different levels from the surface (***Figure 4***) on the slope of a hill, driven horizontally into the coal seam. Coal was mined manually, in exploitation zones or panels ("talleres") with a steep slope connecting the upper and lower galleries. An inverse stair was created while mining the coal seam, and timber supports were used for protection against falls or collapse of the immediate roof. Slopes and ramps were opened to connect levels, usually in a downward direction, and were used for haulage of coal, supplies and waste.

Mining activities moved to the bottom of the valley as the coal layers worked by "mountain mining" or drift mining were depleted. Exploitation of coal seams at lower depths continued in shaft mines, underground mines in which the main entry or access is by means of a vertical shaft (called "El Pozo"). Most of the underground workings of the vertical shaft mines were finally connected with each other through galleries and some working faces, thus creating a vast network of underground galleries.

The rock mass containing the mined coal was modified substantially as a consequence of this intensive mining activity. It induced fracturing and fissuring of the rock mass, caused enlargement of existing voids, and created new man-made voids as the galleries and vent shafts were opened and other mining work was carried out. These changes allowed rain water to infiltrate the rock mass and drain through the different levels, especially through the mining voids, requiring the discharge of these waters by means of pumping to lower the piezometric level of the area. Such pumping activity had to be maintained throughout the working life of the mine shaft.

When the mining work ends and pumping is stopped, all the voids previously created gradually flood. This groundwater flow raises the piezometric watertable level, whose position may not coincide with the initial one (Younger *et al.*, 2002) making it necessary, in some cases, to maintain permanent pumping in order to avoid flooding connected active mining zones or populated areas.

The Barredo-Santa Bárbara system coal mines comprise the Barredo, Figaredo (which has two shafts: San Inocencio and San Vicente), San José and Santa Bárbara shaft mines (***Figure 5***). They are connected at a number of locations (***Figure 6***).

6. Barredo-Santa Bárbara Water Reservoir

In order to determine the volume available in the Barredo-Santa Bárbara system (***Table 2***), both the volume corresponding to the mine galleries and the corresponding voids generated by the coal operation (exploited coal seams, backfill zones, etc.) have been taken into account. The mine gallery volume was obtained from the plans of the mining work in the different mines, supposing an average section of 10 m^2. The voids volume generated by coal mining (exploiting the coal seam) has been estimated from coal production data. Estimates consider that 40% of the volume of coal exploited is void space that allows water flow, and that the remaining 60% has been filled by backfilling or controlled roof collapse, depending on the coal mining method used.

7. Assessment of Mine Water as a Geothermal Resource

The Barredo-Santa Bárbara system coal mines have an average usable flow rate of about 6.2 hm^3/year (pumping average flow rates), a regulation volume (mining voids) of more than 10 Mm^3 with a stable all-year-long temperature above 20 °C (***Figure 7***). The mine water is usable for energy purposes (Gutiérrez *et al.*, 2016) and its quality is suitable for public water supply after being treated. Nevertheless, the elevated hardness of these mine waters is a drawback; this prevents its direct use in the heat pump, and therefore the use of heat exchangers is necessary.

8. Vital Álvarez Buylla Hospital Heating and Air Conditioning

This hospital serves more than 70,000 inhabitants, mostly from the Caudal River Basin, including the nearby urban settlements of Mieres, Aller and Lena. The hospital facilities have 120 rooms for patients and 28,000 m^2 floor space.The stable temperature and high available pumping flow of the mine waters allowed them to be used for geothermal heating and air conditioning.

The water flow to meet the demands of the hospital facilities, which varies due to the heating exchange demand, is pumped from the drainage system of the Barredo-Santa Bárbara system coal mines. The pumping station facility comprises four submersible pumps, each with a nominal flow of 215 m^3/h and a head of 60 m.

The heat exchange system is located at the Barredo vertical mine shaft. It has a tubular heat exchanger, with three circuits and three manifolds made of AISI 316 stainless steel, designed for a flow rate of 400 m^3/h in the primary circuit and 520 m^3/h in the secondary circuit. It performs a heat exchange of 3500 kW, as the mine water transfers its energy to a closed loop circuit of "clean" water, which is piped to the hospital, located 2 km from the mine shaft (***Figure 8***).

The 2-km closed loop circuit is made of 400 mm diameter high density polyeth-

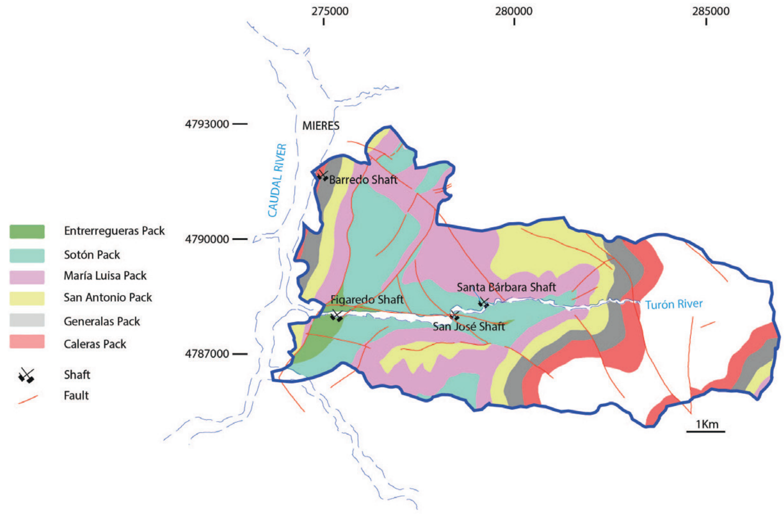

Figure 5: Delimited study area.

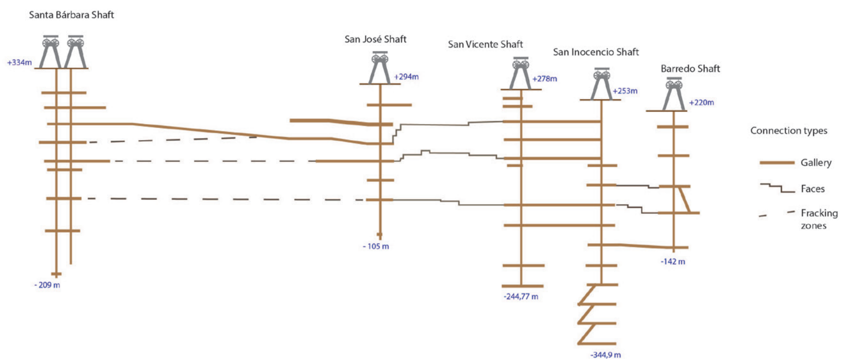

Figure 6: Connecting locations in the Barredo-Santa Bárbara system coal mines.

Table 2: Barreo-Santa Bárbara Water Reservoir.

MINE SHAFT	GALLERY VOLUME (Mm^3)	MINED VOLUME (Mm^3)	TOTAL VOLUME (Mm^3)
Barredo	1.48	0.47	1.95
Figaredo	2.54	0.42	2.96
San José	1.71	0.45	2.15
Santa Bárbara	3.47	0.42	3.90
	9.20	1.76	10.96

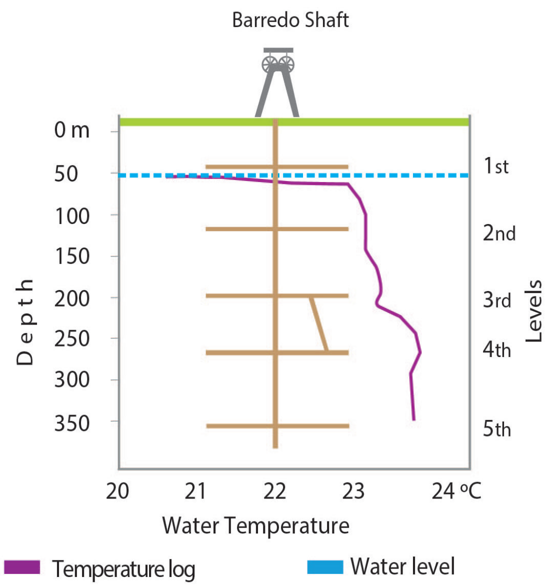

Figure 7: Water temperature vs. depth below surface.

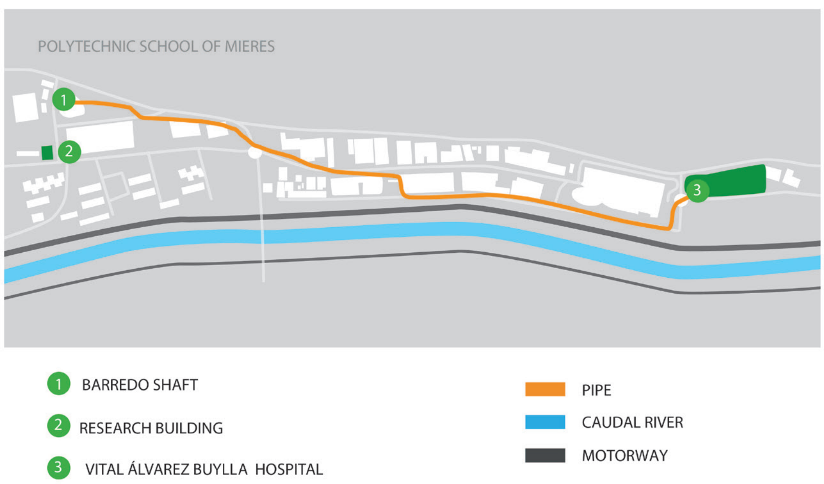

Figure 8: Map of the pipeline to the hospital.

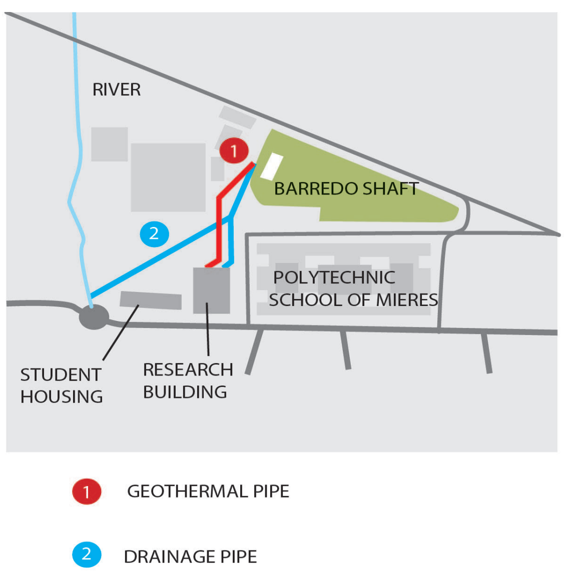

Figure 9: Pipeline layout.

ylene pipes, and 2+1 pumps that supply a 260 m³/h flow rate with a head of 55 m to the hospital facilities. These pumps are equipped with variable frequency drives to regulate the water flow and therefore the energy that is transported to the hospital.

The hospital machine room comprises three heat pumps, two of which can work either in heating mode or refrigerating mode (1509 kW power each) and another one can operate in both modes simultaneously, generating both heat and cold at the same time (1298 kW).

Whenever the demands for heating and refrigerating are unbalanced, mine water is used as a compensation fluid, i.e., when the cooling demands exceed the heating demands, mine water is used to lower the temperature of the returned hot water by means of a plate heat exchanger. In the opposite case, during the winter the building is not able to consume all the refrigerated water that the heat pump requires to operate in equilibrium, so the mine water provides the necessary heat (using a second plate heat exchanger), allowing the heat pump to operate at the optimal temperature difference.

During 2015 the total useful energy supplied (heating and refrigerating) totalled 7,654,862 kWht (5.5 MWht of heat and 2.15 MWht of cold). In order to provide all this energy, there was a consumption of 1,343,780 kWh of electric energy (operation of heat pumps + closed loop circuit pumps).

A resulting reduction in CO_2 emissions of more than 80% and an economic saving of 10% (Gutiérrez *et al.*, 2016) is achieved compared with the traditional heating and refrigeration systems originally planned in the hospital.

9. Heating and air conditioning of the Research Building of the University Campus of Mieres

The drainage system of the Barredo-Santa Bárbara system coal mines provides the water flow demanded (120 m³/h), as in the case of the Vital Álvarez Buylla hospital facilities. A multilayer polypropylene pipeline transports the mine water to the Research Building (***Figure 9***), where it gives up some of its energy, and then leads it to the nearby stream.

The building is equipped with two heat pumps, each with 362 kWt capacity and capable of producing hot water at 45 °C and cold water at 7 °C at the same time. A four-pipe fan coil system is used for heating and air conditioning. In 2015 the heat pumps required 61,605 kWh of electric energy and produced 235,747 kWht, used mainly for heating purposes. The use of this system results in important economic savings and a reduction of up to 70% in CO_2 emissions.

10. Conclusions

The Central Coal Basin of Asturias contains a large number of closed and flooded underground mines that make up "underground reservoirs" capable of being reused as water energy resources. Until now, mine water was being wasted but through the heat pump technology it can be successfully reused, reactivating the economy of the mining areas and allowing us to carry out a sustainable cessation of the traditional mining activity.

Mine water has enormous geothermal potential, with a stable all-year-long temperature and flow. Heat pump technology is now being applied to singular buildings located in Mieres using water from the Barredo-Santa Bárbara mine reservoir, reducing energy consumption, CO_2 emissions and contributing to economic savings when compared with a conventional system.

References

Bastida, F., Aller, J. (1995). Rasgos Geológicos Generales (General geological features). In: Aramburu, C., Bastida, F., (Eds.) *Geología de Asturias.* Editorial Trea: Gijón, Spain. pp. 27–33.

García-Loygorri, A., Ortuño, G., Caride, C., Gervilla, M., Greber, C., Feys, R., (1971) El Carbonífero de la Cuenca Central Asturiana (The Carboniferous of the Central Coal Basin of Asturias). *Trabajos de Geología* (Universidad de Oviedo), 3. 101–150.

González, J., Rebollar, A. (1986). Interrelaciones de la minería y las aguas subterráneas en el Carbonífero de la Cuenca del Nalón (Sector Pola de Laviana-Olloniego) (Relationship between mining and groundwater in the CCBA: Pola de Laviana-Olloniego sector). Spanish Geological Survey Report, Spain.

Gutiérrez, I., Lara, L.M., Viesca, J.L. (2016). La Innovación Geotérmica. Nuevos Usos del Agua de Mina (Geothermal Innovation: New Uses of Mine Water). Editorial Universidad de Oviedo: Spain.

ITGE (Instituto Tecnológico GeoMinero de España). 1995. Estudio de la repercusión del abandono de los pozos Entrego y San Mamés sobre la variación del nivel freático del entorno (A review of the mine water rebound in the San Mamés-Entrego system). Centro documental del IGME: Madrid.

Julivert, M. 1967. La ventana del río Monasterio y la terminación meridional del Manto del Ponga (The tectonic window of the Monasterio River and the southern tip of the Ponga nappe). Trabajos de Geología (Universidad de Oviedo, Spain), 1. 59–67

Jullivert, M. 1971. Décollement tectonics in the Hercynian Cordillera of NW Spain. *American Journal of Science*, 270. 1–29.

Lotze, F. 1945. Zur Gliederung der Varisziden der Iberischen Meseta. *Geotektonische Forschungen*, 6. 78–92.

Fandos, P, Rodríguez, F., Gutiérrez, A.M., Álvarez, J.J. 2004. El yacimiento de Hunosa en la Cuenca Carbonífera Central (The Hunosa´s coal basin in the CCBA), Servicios de Geología del Caudal y del Nalón). HUNOSA Report, Spain.

Pendás, F.; Loredo, J. (2006). El agua en los procesos de cierre de minas en Asturias. Proceedings de la Reunión Científico-Técnica (Closed coal mines and water evolution in the Asturias coal basin). "Gestión del Agua en los Procesos de Cierre de Minas". E.T.S. Ingenieros de Minas. Universidad de Oviedo, Spain.

Saénz de Santa-María, J.A., Luque, C., Gervilla, M., Laveine, J.P.,Loboziak, S., Brousmiche, C., Coquel, R., Martínez-Díaz, C., 1985. Aportación al conocimiento estratigráfico y sedimentológico del Carbonífero productivo de la Cuenca Central Asturiana. Compte Rendu du Dixième Congrés International de Stratigraphieet de Géologie du Carbonière 1983, Madrid. Vol. 1, pp. 303–326.

Younger, P.L., Banwart, S.A., Hedin, R.S. (2002). *Mine Water: Hydrology*, Pollution, Remediation. Springer: Dordrecht, Netherlands.