Engineering geology challenges at the Politecnico di Torino

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The Engineering Geology area studies the physical geography and geomorphology of the "Environment system". In particular, Engineering Geology deals with the defense of the soil, territory and civil protection, with attention to landslides, hydrogeology, the study of underground water circulation, the geological-technical survey, geological exploration of the subsoil and thematic cartography, geological and hydrogeological risk; interpretation of aerial photos and satellite images, topographical analysis on digital models of the survey, study of climate changes and their influence on erosion, sedimentation and pedogenesis processes, the study of geothermal systems, the analysis of geological systems related to hydrocarbons and minerals. Research methods include field and laboratory experiments and appropriate numerical modeling software is often used. In conclusion, the aim of this paper should be a review of all engineering geology tematics analysed and studied by Applied Geology Group in Politecnico di Torino.
Keywords: *Engineering geology, hydrogeology, Springs analysis, DSGSD, GWHP, raw materials.*

Le sfide della geologia applicata all'ingegneria al Politecnico di Torino. *Il settore della geologia applicata, della geografia fisica e della geomorfologia studia il "Sistema Ambiente". In particolare, la geologia applicata si occupa della difesa del suolo, del territorio e della protezione civile, con particolare attenzione alle frane, all'idrogeologia, allo studio della circolazione delle acque sotterranee, al rilievo geologico-tecnico, all'esplorazione geologica del sottosuolo e alla cartografia tematica, all'analisi di rischio geologico e idrogeologico. Rientra tra le competenze del geologo applicato l'interpretazione e lettura di foto aeree e immagini satellitari, analisi topografiche su modelli digitali di rilievo, studio dei cambiamenti climatici e loro influenza sui processi di erosione, sedimentazione e pedogenesi. Tematica appartenente al settore è lo studio dei sistemi geotermici, analisi dei sistemi geologici legati a idrocarburi e minerali. I metodi di ricerca includono esperimenti sul campo e in laboratorio e spesso viene utilizzato un software di modellazione numerica appropriato.*
In conclusione, l'obiettivo di questo articolo vuole essere una revisione di tutte le tematiche di geologia applicata analizzate e studiate dal Gruppo di Geologia Applicata del Politecnico di Torino.
Parole chiave: *Geologia applicata, idrogeologia, analisi di sorgenti, DGPV, GWHP, materie prime.*

1. Introduction

In the age of human activities, Engineering Geology plays a key role in the sustainable development of our societies: scientists, regulators, and practitioners of Engineering Geology are called to confront themselves with the purposes, methods, limitations, and findings of their works (AA. VV., 2014).

Engineering Geology is traditionally a discipline that is strongly related to practice and practical applications of broad geological knowledge. Engineering geology as an established professional practice has been in existence for some 70 years, although some may argue that the practice has been around for as long as man has been carrying out engineering works in and on the ground. As the industry grew it became increasingly clear that the meanings of words, observations, and results were too often being misunderstood, making effective work increasingly difficult.

The development of these various specialized fields reflects the complexity of modern engineering design and construction, especially those designs involving the interface between naturally occurring earth materials and the engineered structure, or the use of naturally occurring materials within the constructed facility.

Geological engineering is primarily a reflection of legal and technological conditions within the USA and in the other part of world. Technological developments in Canada, western Europe, and elsewhere generate very similar demands for individuals with appropriate technical skills. A brief historical review of the relationships between engineers and geologists over the past 200 years provides some insight into the current situation surrounding the accepted professional stature and roles for geologists and engineers (AA.VV., 2014).

Individual practitioners are increasingly likely to become involved in litigation, professional liability has become an important concern for many professions in many countries, and the engineers and the geologists are not immune from this condition. These concerns have led to increased professional registration options for both geologists and engineers, although the exact methods of achieving this vary from country to country.

Geological engineering has developed as a relatively small and unique specialization within the broader engineering profession. The skills of a geological engineer are becoming more desirable than ever as the technologies involved in construction continue to evolve.

The Applied Geology group (AGg) of Politecnico di Torino, explain the engineering geology: in particular deals with the defense of the soil, territory and civil protection, with attention to landslides, hydrogeology, the study of underground water circulation, the geological-technical survey, geological exploration of the subsoil and thematic cartography, geological and hydrogeological risk; interpretation of aerial photos and satellite images, topographical analysis on digital models of the survey, study of climate changes and their influence on erosion, sedimentation and pedogenesis processes, the study of geothermal systems, the analysis of geological systems related to hydrocarbons and minerals. Research methods include field and laboratory experiments, and appropriate numerical modeling software is often used.

2. Engineering geology in Department of Environment, Land and Infrastructure Engineering at Politecnico di Torino

Large engineering projects were constructed all over the world; however nowadays in general more developed countries tended to be more sensitive to their environmental impacts and engineering geological arguments (Oliveira, 2014). In DIATI – Department of Environment, Land and Infrastructure Engineering at Politecnico di Torino the geology is explained through a perspective applied to engineering and numerous aspects are developed.

2.1 Hydrogeology, protection and planning of groundwater resources.

Firstly, the Hydrogeology: in the sense of protection, monitoring and planning of groundwater resources (Lo Russo, Taddia 2009; Vigna *et al.*, 2010), assessment of water flows and matter, management and protection of groundwater resources (Fig.1). In order to contribute to the solution of the problems concerning groundwater the conceptual model for the groundwater flow system, the schematization of the aquifers boundaries and the estimation of basic hydrogeological parameters are among the main issues which

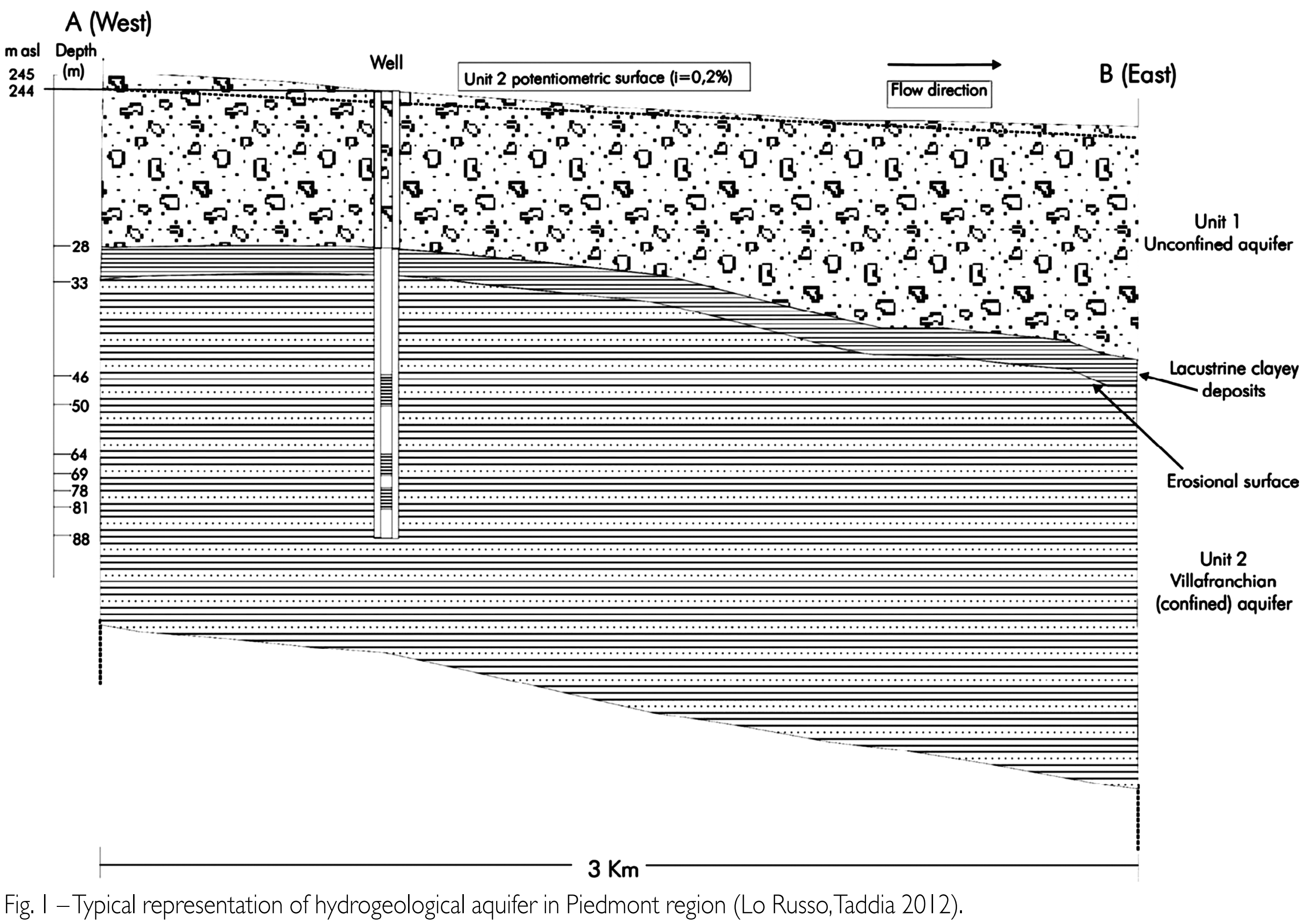

Fig. 1 – Typical representation of hydrogeological aquifer in Piedmont region (Lo Russo, Taddia 2012).

should be investigated.

Artificial tracers for to analysed the path of groundwater is a technologies that study on the hydrogeological use of fluorescent markers (fluorescein and tinopal) to testing in different hydrogeological context the reconstruction of the tracer arrival curve.

With regard to the analysis of water flow and transport of substances in the unsaturated zone the research focused on the application and comparison of methods for assessing the average annual recharge of the unconfined aquifer by means of chlorides concentration profiles and different water balance methods. The research has produced original results both in relation to geographical areas of application (Turin plain) and to the operational acquisition and processing of field data (Lo Russo *et al.*, 2011). If we transfer in mountain areas the hydrogeology aspect also concerns the springs analysis: monitoring and implementation of conceptual models relating to the operation of numerous springs fed by aquifers in carbonate and massive rocks with different degree of fracturing, karst and type of land fields (Vigna 2014). In a typical Alpine context, aquifers in high-mountain carbonate rock supply springs at the foot of mountains (Vigna *et al.*, 2014). Their main recharge areas are at high altitudes. These areas are present above the forest-line, where soil is very limited, and are characterized by signs of Quaternary glaciations. They are supplied by pluvial and snow precipitation (Vigna, Banzato 2015). This type of research in particular examined the geomorphology, caves, the fillings and the paleoclimatic data of high Alpine karst areas for example Bossea Caves. The karst degree in these aquifers can be different: some of these aquifers can be very karstified (high permeability), others can have a very dense fractures network (relative low permeability) (Fig.2) (Vigna, Banzato 2015; Filippini *et al.*, 2018).

Fig. 2 – The karst spring, this particular spring is named "Pis Spring" in Cuneo area near Turin and this is a very famous Piedmont spring.

The research also focused on the protection of water supply sources and on potential interference with anthropogenic land uses both for wells than for springs. In particular, a novel method aimed to quantify the springs vulnerability to pollution (VESPA method) has been tested and validated basing on monitoring data of water discharge, electrical conductivity and temperature (Galleani *et al.*, 2011; Banzato *et al.*, 2017). Further developments were focused on the use of time-series analysis techniques to analyze and model recession hydrographs of mountain springs (Cerino Abdin *et al.*, 2021).

On the other hand, several Alpine springs are located in correspondence at massive rocks, their location appears strongly influenced by the tectonic discontinuities developed in the bedrock and by the morphostructures related to Deep Seated Gravitational Slope Deformations (DSGSDs) (Fig. 3) (Gizzi *et al.*, 2019).

Optimizing the present and future management strategies of mountain groundwater resources has become increasingly necessary. The accuracy and frequency of the flow rate (Q) measurements determine and restrict the processes that can be studied using spring hydrograph and recession curve analysis (Cerino Abdin *et al.*, 2021).

Another aspect of research is hydrogeological flow in gypsum karst areas.

Although largely underexploited, karst aquifer systems often deliver large amounts of high-quality drinkable water and already serve about a quarter of the world's population. Gypsum crops out in almost all Italian regions, but the most significant evaporite karst areas are located in Piedmont, Emilia-Romagna, Marche, Tuscany, Calabria, and Sicily.

The gypsum aquifers in Piedmont region, on the contrary, are sandwiched between sediments with low to very low permeabilities. The waters flowing in these evaporite aquifers derive from slow recharge from the upper and lower aquitards. These gypsum aquifers are, thus, generally characterized by the presence of an extensive saturated zone, along a karstic network that is heavily

Fig. 3 – Typical fracture spring in Germanasca Valley near Turin (Gizzi *et al*., 2019).

influenced by the fractures in the host rock. In the area of Moncalvo and Calliano the surface topography is characterized by a series of gentle hills mostly carved into the post-evaporitic sediments (marls and clays) (Fig. 4A). The evaporite beds are inclined 10-20° and are mostly buried underneath the Late Miocene-Pliocene sediments (Fig. 4B). The underground quarries in this gypsum follow the overall geometry of these evaporite bodies and intersect different aquifer levels. A series of boreholes with piezometers, together with kilometers of quarry galleries excavated in the gypsum have allowed reconstructing the hydrogeological structure of this area with great accuracy (Vigna *et al*., 2010; 2017).

2.2 Underground Karst Laboratory of Bossea

Understanding flow dynamics in karst systems has many implications on water quality assessment and storage estimation. Karst aquifers are vulnerable to contamination and it is fundamental to assess how contaminants are transmitted from the surface to the karst springs (Nannoni *et al*., 2020).

In this perspective, two underground laboratories have been installed in the Bossea Cave, aimed respectively at the study of karst hydrogeology and the study of the effects of climate change in the subsoil.

Bossea is a show cave attracting about 30,000 visitors each year, located in the Ligurian Alps of Southern Piedmont (Northern Italy) within a strongly deformed zone comprising metamorphosed carbonate rocks (marbles) of Jurassic to Cretaceous age and Permian meta-volcanics. The downstream part of the karst system, open to tourists, developed mostly by erosion and collapse whereas dissolution speleogenesis is secondary and important mainly in the inception stage. Bossea is an important geosite where, in a scenic underground environment, unique Quaternary paleontological findings are displayed to the public and two state-of-the-art laboratories record continuously environmental, hydrologic, and hydrochemical parameters (Antonellini *et al*., 2019). This laboratory, located inside the cave environment, has been equipped over the years with increasingly sophisticated instruments and works in four different scientific fields: hydrogeology, meteorology, natural radioactivity, and biospele-

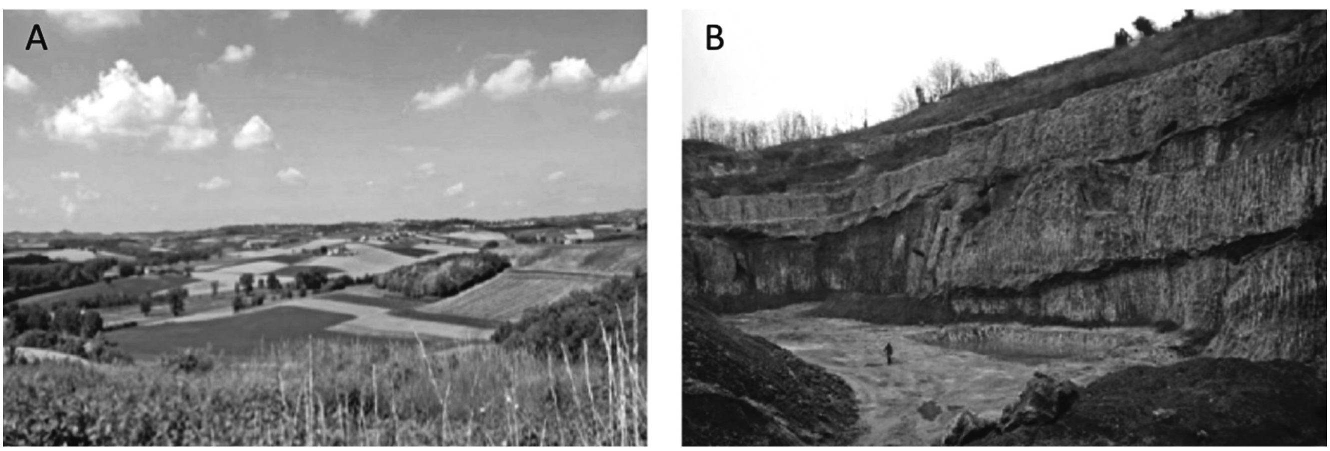

Fig. 4 – The gypsum area in Piedmont region [A]: The hilly landscape around Monferrato mostly carved in the Post-evaporitic sediments of Messinian age; [B]: The main macrocrystalline gypsum beds exposed at the surface in the open pit quarry at Moncalvo (Modified by Vigna *et al*., 2017).

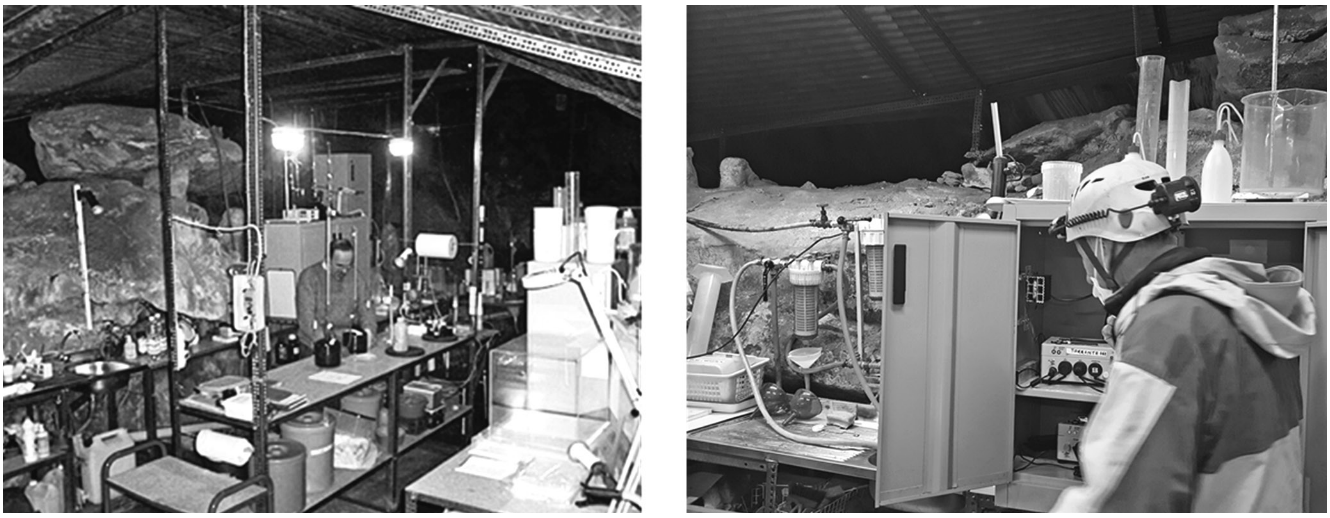

Fig. 5 – Underground Karst Laboratory of Bossea with sophisticated instruments.

ology. Several tracing experiments and the continuous monitoring of the dye tracer arrivals in different spots have enabled to build an increasingly detailed map of the different zones that recharge the Bossea karst aquifer.

The meteorological monitoring comprises air temperature and relative humidity variations, evaporation and condensation, and CO_2 levels. Rainfall and snowmelt are also measured above the cave, and the response of these infiltration events are recorded inside Bossea in different sites.

The study of the natural radioactivity of the underground environment is very interesting, because the cave is developed at the structural contact between the underlying Permian volcanic rocks and the covering Mesozoic carbonates. Radon (222Rn) deriving from the radioactive decay of 238U diffuses rapidly into the cave atmosphere and also into the percolating and flowing waters.

The research relates to the dynamics of gas exchange between rock, water and atmosphere. Different types of instruments and dataloggers are tested in the cave for the detection of Rn in the water. The biospeleological investigations have lead to the discovery of over 100 different species of cave dwelling fauna, making Bossea one of the most important biological hotspots in Italy.

The Underground Karst Laboratory of Bossea (Fig. 5) is one of the most important National Laboratory in Italy and is managed by the Alpine Club of Cuneo (CAI Cuneo) and the Central Scientific Committee of CAI in collaboration with the Diati department by Applied Geology group (AGg) of Politecnico di Torino (Vigna *et al*., 2017).

2.3 Digital photo-interpretation and interaction groundwater and slope stability

Another aspect developed by AGg is the Interaction with groundwater and slope stability: studies relating to the Langhe hilly slopes (Bottino *et al*., 2011; Vigna 2014) and to Deep Seated Gravitational Slope Deformations (DSGSDs) in Germanasca Valley (Gizzi *et al*., 2019) and Susa Valley. This particular aspect is continuous monitoring throughsprings and drainages. This aspect is very important because often the slope stability has been influenced by the groundwater flow and shallow aquifer.

As reported in Bottino *et al.* 2011, many flooding phenomena have occurred in the hilly Langhe region (NW Italy), causing damage to properties and loss of life. In this work has been demonstrated that severe water pressure conditions can drive slope instability, provided that the operational strength on the slip surface attains the residual value. Back analysis results suggest also that, for a number of slopes, the onset of instability requires a further loss of shear strength, which can be associated with decalcification phenomena that can result from the particular hydrogeochemical conditions of the region (Fig. 6).

Another aspect related to the slope instability concentrated on the development and the application of new techniques of digital photo-interpretation in hydrogeological and engineering geology surveys. In particular the Deep Seated Gravitational Slope Deformations (DSGSDs) with hydrogeology is described in Gizzi *et al.* (2019). The continuous expansion of urban areas has caused an increase interest in finding new potable water sources and led to consider mountain aquifers as an increasingly more strategic resource.

In this contest, the mountains water resources management is a topic that has become increasingly important. As mountain aqui-

Fig. 6 – Planar landslide immediately after failure. Typical landslide body displaced by a planar sliding mechanism (modified by Bottino *et al.* 2011).

fers can be particularly vulnerable from qualitative and quantitative point of view, they need a high degree of protection: it is important to understand their recharging system, from both geological and hydrogeological perspective, in order to protect and optimize its present and future management.

In the past years, several authors in collaboration with Diati AGg (Forno *et al.*, 2011; Forno *et al.*, 2012; Piras *et al.*, 2016) have conducted detailed survey, identifying the geological and geomorphological characters and resulting in the production of a new morphological and quaternary geological map of the area. A lot of peculiar morphologies connected to DSGSDs (Fig. 7) phenomena as scarps, depressions, transversal trenches, ridges elongated parallel to watersheds has been recognized and described in Forno *et al.* (2011).

In addition, some water mountain sources, many of which potentially exploitable for drinking purposes, have been identified along the longitudinal trenches mapped in the upper sector of Rodoretto Valley: by mean exclusive geological investigations it was therefore possible to demonstrate how the pattern of the hydrographic network is strongly affected by the recognized gravitational features (Forno *et al.*, 2012).

2.4 Rock-fall risk analysis and mitigation

The research activities of Diati AGg have been aimed at the development of analytical tools able to quantify the risk to road infrastructure subjected to rock-fall. In particular, it has been developed and validated an innovative operating procedure (RO.MA) that, starting with an analysis of the rock mass conditions, through a trajectory computation, and then with a risk analysis based on the event tree method, can provide a quantification of the risk condition on the road users. This procedure has been tested and applied on many field test-sites (Mignelli *et al.*, 2014).

2.5 Tunneling and groundwater

Fundamental aspect for the Applied Geology Group is the interaction between tunnelling and groundwater, this is an important element to be considered in any underground work. This is another aspect of the hydrogeological studies, in fact the research through continuous flow monitoring systems, mineralization of water temperature for the evaluation of interferences of underground works (tunnels) on aquifers cha-

Fig. 7 – Deep Seated Gravitational Slope Deformation (DSGSD) in Rodoretto Valley in Germanasca Valley near Turin.

racterized by different levels of permeability is developed in Diati department.

Groundwater can represent a major constraint for many technical decisions related to the tunnel construction and, at the same time, a fundamental valuable natural resource to be preserved quantitatively and qualitatively during and after the tunnel completion. The knowledge of the geological subsurface system, the hydrogeological mechanisms of groundwater infiltration and circulation, the degree of the aquifers connection with the river network as well as the chemical composition of the circulating groundwater are some of the more important topics that should be analysed in the early phase of the tunnel design, as it happens for the Tenda tunnel and Euralpin Lyon Turin tunnel (Western Alps).

In the Tenda tunnel was intercepted a carbonate aquifer that feeds a series of important flow of groundwater, named Tenda Spring. This source was discovered during excavation of the railway tunnel (1889-1898). In 1990 the spring was tapped in the tunnel by the Langhe and Alpi Cuneesi Aqueduct; this infrastructure is very important for the social-economic development of a vast area, which has few other water resources suitable for human consumption and which supplies, along with some other sources, a population of over 100.000 (Banzato *et al*., 2011) (Fig. 8). This source is actually monitoring by Diati Applied Geology group.

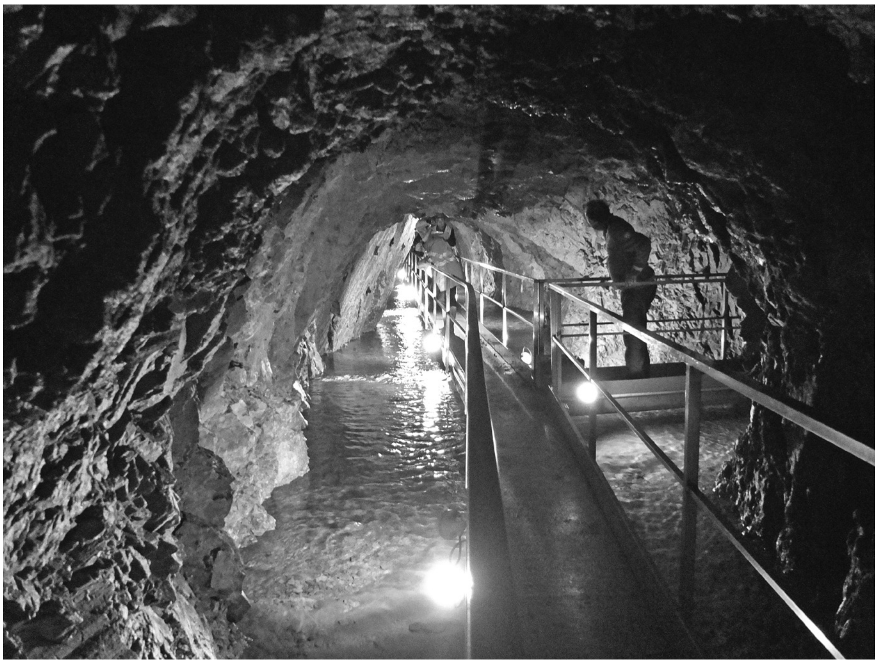

Fig. 8 – Hydrogeological monitoring of Tenda tunnel.

The second important project that developed by Diati AGg regarded the "La Maddalena" exploratory tunnel. "La Maddalena" exploratory tunnel, located in Chiomonte (Italy Western Alps – Susa Valley), is one of the four exploratory adits, three in France, completed in 2010, and one in Italy, whose realization is related to Turin-Lyon high-speed rail project (Fig. 9).

During the tunnel construction several monitoring data have been recorded in order to assess geological parameters important for the future Base tunnel realization. In fact, one of the main task in the optimization of the final design of a Tunnel has been represented by the hydrogeological monitoring. This activity has

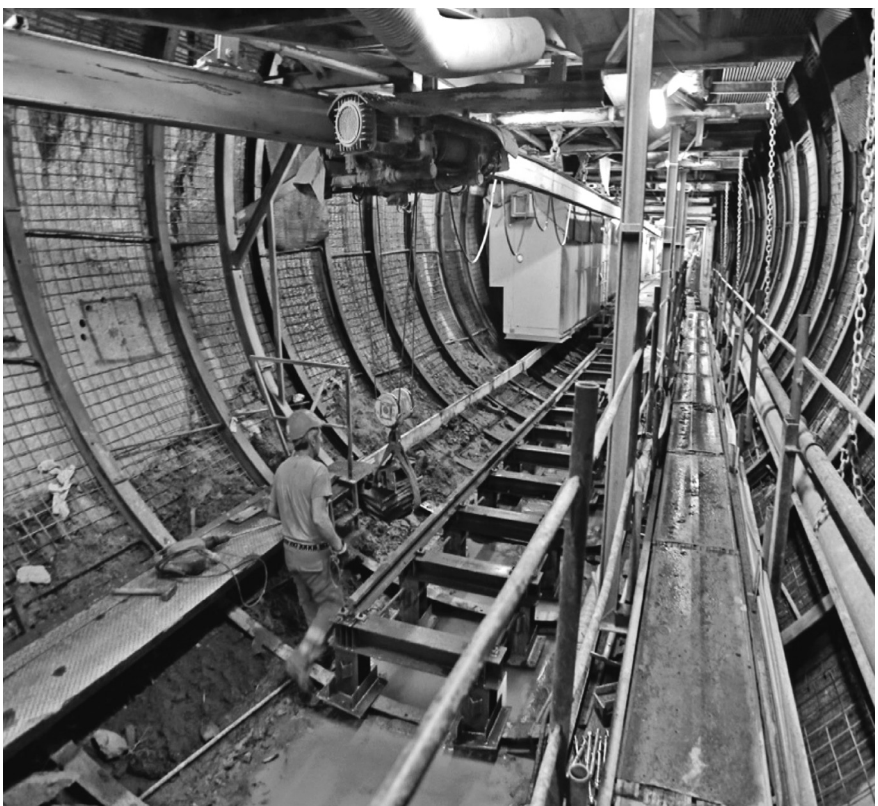

Fig. 9 – Realization phase of "La Maddalena" exploratory adit (Lo Russo *et al.*, 2019).

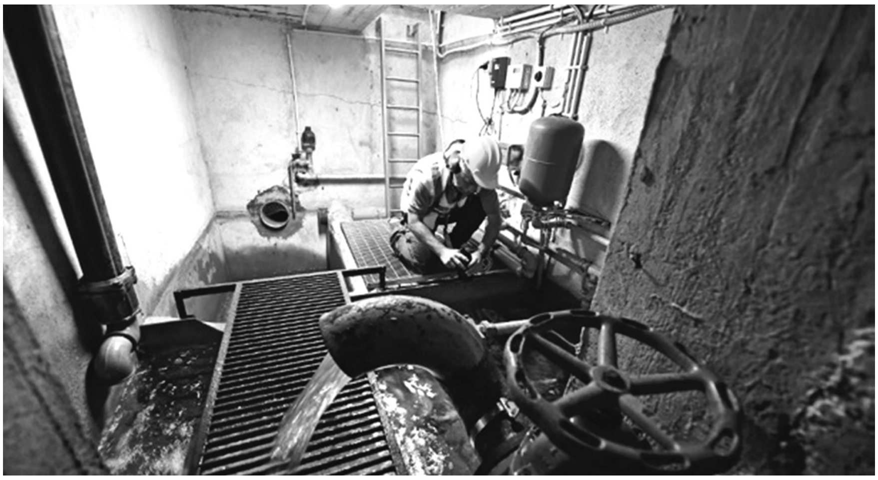

Fig 10 – Hydrogeological monitoring in "La Maddalena" exploratory tunnel.

been aimed to verify the correctness of the project hypothesis and specially to evaluate the inflow forecast in term of discharge rate and distribution, temperature and chemical facies of groundwater. The hydrogeological monitoring has proved extremely valuable not only in checking the reliability of the tunnel design forecast but also in underlining the importance of the realization of exploratory tunnels prior to the excavation of a main tunnel. Thanks to the hydrogeological and temperature monitoring of the main water inflow "La Maddalena" exploratory adit can also represent in perspective a very interesting possibility to exploit the related geothermal potential (Fig. 10).

2.6 Relationship between chemism of water and human health

Another important aspect developed by the AGg at Diati, concerns the in-complexity study of the chemism of water in relation to human health (Tiwari *et al*., 2021).

In particular in Civita *et al*., 2001, is analyzed as aluminum was determined in surface and groundwater in the Alba city (NW Piedmont Region) to provide information on natural and anthropogenic sources of contamination. Thanks to the Water Lab in Diati department it was possible to find out as aluminum is not an essential element for the biological cycle, its high concentration in both water and soil could have toxic effects both on plants and animals.

The presence of aluminum in drinkable water is of particular interest, because suggest the connection between high levels of this metal and Alzheimer's disease (Civita *et al*., 2001). This is a very important study developed by Diati AGg.

2.7 Temperature of the air and of the rock in various natural cavities

Recently the research of engineering geology has led to the analysis of the temperature of the air and rock in various natural cavities in the sector of the Ligurian and Maritime Alps. In these karst cavities there are ice deposits (Fig. 11) in the phase of evident melting due to the increase in surface temperatures (Vigna and Paro 2020).

This research activity is still under investigation.

2.8 Renewable energy: geothermal heat pump

Thanks to the international political response to climate change the past five years have been a period of unprecedented growth and development for renewable energy worldwide and according to Sustai-

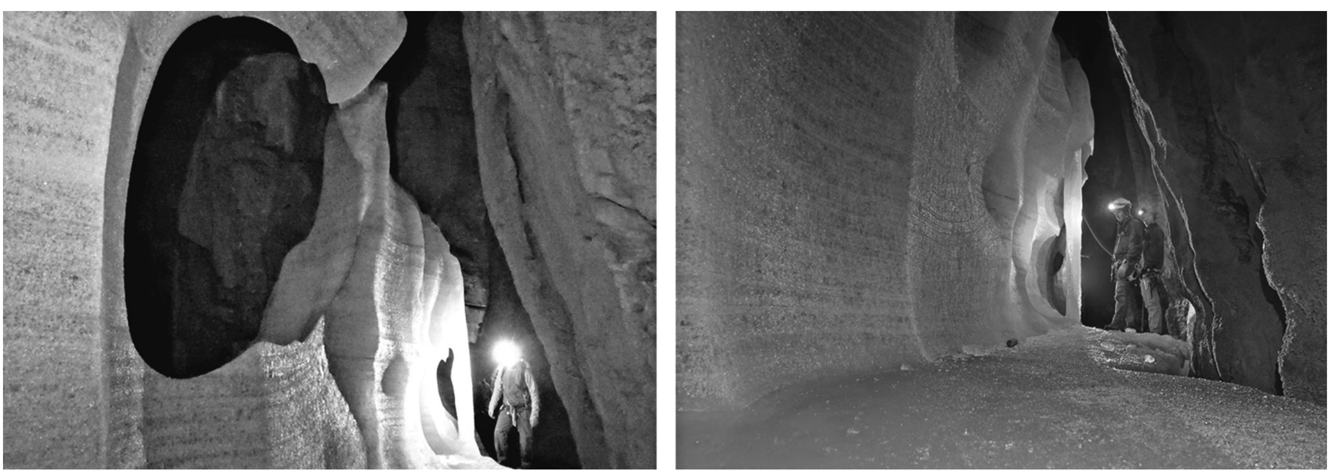

Fig. 11 – Ice-deposits in karst cavities.

nable Development Goals (SDGs) adopted by United Nations Member States in 2015 there has been a further increase in renewable energy and geothermal energy in particular.

The AGg at Diati began to deal with the renewable energy issue starting from 2009, focusing the studies on geothermal energy and its development in Italy (Lo Russo and Taddia, 2009; Taddia *et al.*, 2018).

Geothermal heat pumps represent an interesting technology expected to contribute significantly to the reduction of primary energy use for heating and cooling. Additional benefits of this technology, which also meets the European Union targets, are the possibilities of integration with discontinuous energy resources, in particular wind, combining heat and power.

The replacement of conventional heating systems such as boilers, with general heat pump systems allows the de-localization of emissions of micropollutants from urban centers to the sites in which thermal power stations are operating. Furthermore, the use of distributed production systems based on the use of renewable sources reduces also CO_2 emissions (Baccino *et al.*, 2010; Lo Russo *et al.*, 2011). Thanks to the continuous monitoring of the Politecnico di Torino geothermal plants, it was possible to develop detailed research in renewable energy fields in urban contexts.

In fact, this research, some fundamental aspects related to the development of open-loop heat pumps have been explored in a typical urban contest (Politecnico di Torino in Turin city, NW Italy). In particular, appropriate hydrogeological investigations and simulation modelling were performed for the characterization of the main hydrogeological parameters of the subsoil at the considered site. The results of the work have allowed to define several fundamental aspects in order to optimize the design choices of Groundwater Heat Pump (GWHP) systems and the importance of geological and hydrogeological surveys (Taddia G. 2018).

2.9 Energy security and transition and Raw materials in mining sustainability

According to renewable energy, recently the engineering geology developed also the energy transition strategies: the research focuses on raw materials, their identification and economic and environmental impact analyses related to their primary extraction, transformation and transport on a global scale. In the energy sector, further research focuses on numerical risk modelling and national and international energy security, with particular regard to the supply of hydrocarbons (Oil & Gas) (Gizzi *et al.*, 2021; Lo Russo *et al.*, 2020).

In the field of raw materials, research is carried out on the assessment of the potential of deposits and the environmental impacts associated with mining activities at both regional and site-specific scale (Lo Russo *et al.*, 2021).

In particular, the impacts on the environmental matrices of traditional extraction programs but also of those necessary for the extraction of raw materials necessary for the energy transition policies towards electric mobility technologies and electricity storage on a global scale are analyzed.

3. Conclusion

In conclusion, as we have seen an increase in the incidences of extreme weather events end environmental risks, there is a greater need for geoscience professionals who can assist communities in planning mitigation efforts for future flooding and landslides. There are also many current and future development projects being undertaken in landslide prone areas and in relationship at renewable energies, which requires careful consideration and planning by expert applied geoscientists. In this perspective, the group intends to continue the studies of engineering geology with great enthusiasm and professionalism.

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