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ENGINEERING GEOLOGY ON THE THREAD OF MEMORY

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EXTENDED ABSTRACT

L'invito a tenere per i miei 80 anni un discorso al Dipartimento di Scienze della Terra dell'Università di Roma "La Sapienza" mi ha dato l'opportunità di riflettere su come la progressiva evoluzione della Geologia Applicata abbia accompagnato la mia intera vita accademica. Nel passato, questa disciplina rappresentava l'applicazione delle conoscenze strettamente geologiche alla soluzione dei problemi posti dalle attività umane e dalle loro interazioni con l'ambiente naturale, senza che ciò comportasse la conoscenza e l'utilizzazione di metodi allora considerati di esclusiva pertinenza ingegneristica. Oggi si intende una disciplina che fornisce le basi per una più completa conoscenza della natura e del comportamento dei mezzi geologici e della loro interazione con l'ambiente naturale e umano.

I concetti di base della moderna Geologia Applicata erano presenti già nell'antichità a partire dal terzo millennio A.C. Le opere realizzate comportano conoscenze di base dell'idrogeologia (i 'qanats' degli antichi Persiani) e delle tecniche di costruzione delle dighe (diga di Ma'ribin dei Sabei nello Yemen). Gli Egizi, nella produzione di blocchi di dimensioni e forma adeguate e di obelischi, applicano i principi della propagazione delle fratture, mentre principi di meccanica delle rocce e degli ammassi rocciosi sono applicati nello stabilire la pendenza delle piramidi (piramide di Bent). Nella realizzazione delle fondazioni di grandi edifici, Greci (Tempio di Giunone, Agrigento) e Romani (Colosseo) mostrano di conoscere le basi della meccanica delle terre. Il trattato di Vitruvio ("De Architectura", 1° secolo d.C.), un ampio compendio sui materiali naturali, i metodi di costruzione, l'idraulica e la pianificazione urbana, ne è una conferma. Nel contesto europeo e fino agli albori della rivoluzione industriale, criteri e tecniche delle fondazioni si sviluppano molto lentamente. Molto significative sono, tuttavia, le tecniche adottate nelle fondazioni dei palazzi storici di Venezia (1200-1600 d.C.) dove fu considerata la presenza, in ambiente salino, di terreni superficiali di elevata compressibilità e bassa resistenza al taglio presenti al di sopra di un livello più consistente (il caranto).

Lo sviluppo della Geologia Applicata come disciplina indipendente può essere fatto risalire agli inizi del XX secolo. I disastri dell'inizio secolo, quali le frane del Canale di Panama, i terremoti di San Francisco (1906) e di Messina (1908), hanno forse incoraggiato i lavori di Karl Terzaghi, un ingegnere con una formazione geologica, che hanno segnato una prima fusione tra le scienze geologiche e quelle allora considerate solo ingegneristiche. Solo nel 1970 il 1° Congresso dell'International Association of Engineering Geology fornisce un esplicito quadro di riferimento della Geologia Applicata: essa deve necessariamente includere la conoscenza delle basi della meccanica dei terreni e degli ammassi rocciosi, della geofisica, dell'idrogeologia e dell'idrologia. Alcuni di questi aspetti si sono progressivamente differenziati dando vita a discipline indipendenti (Idrogeologia, Idrologia, Geofisica e Geologia Ambientale) ma sempre legate alla Geologia Applicata.

Agli inizi degli anni 1960 il corso di Geologia Applicata della laurea in Scienze Geologiche, tenuto dal Prof. R. Signorini e dai suoi assistenti C.F. Boni e R. Mortari, si basava sul testo di Ardito Desio, dedicato quasi esclusivamente ai concetti generali della Geologia di base e mineraria e della Geomorfologia. Il concetto informativo di partenza del Prof. Desio era che le conoscenze di ingegneri e geologi fossero molto diverse: fisico-matematiche per gli ingegneri e naturalistiche per i geologi. Oggi, con Geologia Applicata si intende per lo più lo studio delle caratteristiche e del comportamento dei terreni, delle rocce e dell'acqua, e delle loro interazioni con l'ambiente naturale e umano.

Nella seconda metà degli anni Sessanta, all'Istituto di Geologia e Paleontologia dell'Università di Roma Marcello Zalaffi, docente del corso di Rilevamento Geologico, era convinto della necessità di integrare le conoscenze dei geologi con quelle di base della meccanica che governa i processi geologici. Propose così a me ed a un mio compagno di università, Luciano Rossi, una tesi che comportava lo studio della genesi e delle caratteristiche fisiche e meccaniche di una cosiddetta "dolomia sfarinata", largamente presente nell'area di studio. Iniziò così lo studio da autodidatti della meccanica dei terreni sui testi di K. Terzaghi e W. Lambe-R.V. Withman. Una conferma di questo indirizzo delle Scienze Geologiche venne quando l'Istituto di Geologia e Paleontologia fu incaricato della caratterizzazione geologica e geotecnica dei terreni del delta del Tevere per la progettazione delle nuove piste dell'aeroporto di Roma-Fiumicino. I problemi e le difficoltà affrontati furono notevoli per un gruppo di persone alle prime armi (Roberto Mortari, Pietro Iuzzolini, Paolo Belletti ed i tecnici Grillanda, Pepa, D'Arpino e Ronconi), dall'esecuzione di sondaggi e di prove penetrometriche statiche in terreni anche allo stato fluido ed in presenza di sacche di gas in pressione all'esecuzione delle prove di laboratorio. Gli incontri con il Prof. Arrigo Croce, ingegnere considerato uno dei padri della Geotecnica in Italia, e con il Prof. Jean Kerisel, ingegnere responsabile della parte geotecnica del progetto, furono molto intensi e di grande aiuto e stimolo. Fu così possibile progettare, costruire e monitorare un rilevato sperimentale per il controllo dei cedimenti e dei tempi di consolidazione, utilizzando drenaggi di sabbia verticali collegati a un sistema di pompe a vuoto. Il successivo incarico dello studio del tracciato della Ferrovia Alta Velocità nel tratto Roma-Orte condusse agli studi sul comportamento delle argille sovra-consolidate e dei terreni a comportamento extrasensibile per la presenza in percentuali molto elevate di gusci silicei di diatomee. La partecipazione alla progettazione di una diga in terra in Algeria fu l'occasione di riconoscere da un lato la rilevanza della geologia strutturale e dall'altro di avvicinarsi ai metodi di analisi della stabilità dei pendii in terra, grazie anche agli incontri con il Prof. Franco Esu, ingegnere geotecnico dell'Università di Roma.

Queste esperienze portarono ad un ampliamento delle conoscenze teoriche e pratiche delle proprietà e del comportamento dei terreni, che condusse al riconoscimento della Geotecnica come disciplina propria delle Scienze Geologiche. Tuttavia, le difficoltà della loro interpretazione resero evidente da un lato l'incompletezza delle conoscenze sino ad allora acquisite da autodidatta e, dall'altro, l'assenza di un consistente gruppo omogeneo di discussione e confronto. Ho frequentato, quindi, brevi corsi come quello sull'esecuzione e l'interpretazione delle prove di taglio diretto semplice, tenuto presso il Dipartimento di Ingegneria dell'Università di Cambridge da Peter Wroth, un pioniere della meccanica dei suoli. L'arrivo di Alberto Prestininzi creò le condizioni per lo sviluppo delle ricerche in altri settori sino ad allora non considerati e, soprattutto, per la pubblicazione dei risultati, sino ad allora scarsamente perseguita. Si iniziò a studiare il comportamento degli ammassi rocciosi e la stabilità di pendii in roccia, applicando con Roberto Romeo e Gabriele Scarascia Mugnozza anche i metodi probabilistici per tenere conto della naturale dispersione delle discontinuità. Furono condotti studi sperimentali sul comportamento reologico di graniti a diverso grado di alterazione. Le ricerche nel campo della stabilità dei pendii furono sollecitate anche dalla partecipazione al progetto di ricerca del CNR–Gruppo Nazionale per la Difesa dalle Catastrofi Idrogeologiche, grazie al quale insieme a Leandro D'Alessandro ed Alberto Prestininzi iniziarono le prime ricerche sulle colate di fango. L'arrivo di Giovanni Valentini, un ingegnere con un approccio interdisciplinare alle scienze ingegneristiche e geologiche, confermò il percorso didattico e di ricerca scientifica che a Roma la Geologia Applicata aveva fino ad allora intrapreso.

Nel 1986 mi trasferii all'Università di Ferrara per un breve ma intenso periodo durante il quale ho conosciuto Enzo Vuillermin e Giovanni Masé, discutendo sugli acquiferi carbonatici e sulle problematiche della cartografia tecnica in ambito urbano. L'incontro con Edoardo Semenza mi ha portato al primo contatto con la frana del Vajont e ha rafforzato la consapevolezza della straordinaria rilevanza dei modelli concettuali di base (geologico, stratigrafico e geomorfologico) nell'analisi delle grandi frane. La collaborazione si è estesa alla tesi di dottorato di Monica Ghirotti che ha costruito il primo modello geo-meccanico della frana del Vajont ed utilizzato, tra i primi in Italia, il codice agli elementi distinti UDEC. Fu anche progettato e realizzato sul versante opposto alla frana del Vajont un sistema di monitoraggio, poi abbandonato a causa delle difficoltà nell'acquisizione manuale dei dati. La consulenza tecnica richiesta per il crollo nel 1985 di due dighe di sterili a Stava (Italia settentrionale) portò allo studio dei flussi granulari e ad approfondire quello sulla stabilità delle dighe in terra.

Nel 1990 mi fu conferita la cattedra all'Università di Bologna, dove le ricerche proseguirono con la partecipazione di Monica Ghirotti, Matteo Berti ed Alessandro Simoni, stimolate anche dalle discussioni con gli altri membri del Dipartimento, in particolare con il Prof. G. B. Vai. La partecipazione al progetto europeo "Debris Flow Risk Project" coordinato dal Prof. Alberto Lamberti (Dipartimento di Ingegneria Civile, Università di Bologna) portò alla realizzazione, in collaborazione con il Cascades Volcano Observatory (Vancouver,USA), di una stazione di monitoraggio sulla colata detritica di Acquabona (Cortina d'Ampezzo). I risultati ottenuti, discussi anche con il Prof. Aronne Armanini (Università di Trento) ed il Prof. Roger Cojean (Ecole des Mines, Parigi), hanno segnato un passo in avanti nello studio e nella definizione dei meccanismi di innesco. La progettazione geologica ed idrogeologica della nuova stazione ferroviaria di Bologna della linea ad Alta Velocità confermò la necessità di pensare alla Geologia Applicata come parte integrante nella progettazione delle strutture e nello studio delle loro interazioni con l'ambiente naturale.

Nel 1998 fui chiamato dall'Università di Padova dove sono restato sino al pensionamento. Un lungo periodo caratterizzato dalla presenza, fra gli altri, di Paolo Fabbri, Antonio Galgaro, Paolo Scotton e Mario Floris.

Sulla base all'esperienza acquisita negli anni, fu concepito un nuovo corso di laurea magistrale in Geologia Tecnica, inserendo nel piano di studi materie fino ad allora considerate proprie dell'ingegneria, ritenute però necessarie per una migliore comprensione dei fenomeni naturali e per una più completa interazione con gli ingegneri. Il coordinamento del progetto europeo THARMIT consentì di manutenere ed implementare la stazione di Acquabona, di realizzare in collaborazione con l'Università di Salta una stazione di monitoraggio nel nord-ovest dell'Argentina e di effettuare sperimentazioni in canaletta in collaborazione con Pia Rosella Tecca e Andrea Deganutti (CNR-IRPI, Padova). Nuove ricerche furono indirizzate all'utilizzazione del Terrestrial Laser Scanning per il monitoraggio delle frane. La convinzione della necessità della collaborazione tra settori scientifico-disciplinari culturalmente differenti (geologi applicati, geologi strutturali, geomorfologi, idrogeologi, geofisici, idrologi e matematici) costituì l'idea di partenza del progetto di ricerca GEORISK, coordinato dal settore di Geologia Applicata, con il quale sono stati ottenuti risultati significativi come, ad esempio, la definizione di un nuovo modello strutturale e idrogeologico della frana del Vajont. Fu anche realizzato un laboratorio di meccanica delle rocce integrato con alcune strumentazioni appositamente progettate per prove di creep. In questo periodo, con la collaborazione di Alberto Prestininzi, sono stati organizzati, con successo, due congressi internazionali: la '5th International Conference on Debris-Flow Hazards Mitigation' (2011) e la 'International Conference on Vajont, 1963-2013' (2013).

Il mio viaggio in questa disciplina, dai tempi del testo di Ardito Desio fino ai giorni nostri, è stato lungo ed a volte difficile ma sempre coinvolgente. Ho insegnato - e spero trasmesso ai miei studenti - tutto ciò che avevo via via studiato, imparato e sperimentato. Credo che l'evoluzione dei contenuti e del significato stesso di Geologia Applicata abbia portato questa disciplina ad essere quella indicata dalla IAEG nel lontano 1970.

Un grande musicista, Ezio Bosso, scrisse: “Si dice che la vita sia composta da dodici stanze, dodici stanze in cui lasceremo qualcosa di noi, che ci ricorderanno. Dodici stanze che ricorderemo a nostra volta quando arriveremo all’ultima, quella della consapevolezza e dei ricordi”. Quattro delle mie dodici stanze le ho attraversate con tutte le persone che mi hanno accompagnato nelle quattro Università che mi hanno accolto. A tutte le persone con cui ho lavorato e studiato, a tutti i miei studenti ed a voi che siete qui oggi voglio esprimere la mia gratitudine per la vicinanza e l’amicizia ricordando il detto di Leonardo da Vinci che da studente leggevo nell’aula di chimica: “Triste è quel discepolo che non avanza il suo maestro “. Tutti voi, con mia grande fortuna e soddisfazione, lo avete fatto e spero che continuerete a farlo.

ABSTRACT

The invitation to deliver a talk on his 80th birthday gave Prof. Rinaldo Genevois the opportunity to look back on his life in the light of the evolution of what Applied Geology meant and what it means today. The thread of memory runs over a period of more than 40 years through four different universities where he studied, researched and taught this discipline, progressively changing its content and participating in the continuous expansion of its fields of application. After a brief historical excursus, his journey begins in the late 1960s and ends with his retirement. At the same time, Applied Geology was transformed from a strictly naturalistic science, as defined by Ardito Desio, to a complex and structured discipline as defined by the IAEG in 1970, which can best be denoted by Engineering Geology. The story looks above all at that people who has directly participated in this long journey largely first as students and later as passionate researchers.

Keywords: *Engineering Geology, Applied Geology, Geotechnics*

INTRODUCTION

The invitation to deliver a talk about my academic life has come ten years after my retirement, giving me the opportunity to reflect on my relationship with the discipline to which I have devoted so much of my life. Life is a collection of reminiscences, of fragments linked to a given event or person that, together with the experiences acquired and the information gathered, constitutes our own memory. Gabriel García Márquez said ‘Life is not what is lived, but what is remembered and how it is remembered in order to tell it’. Therefore, the critical aspect of remembering is how we remember, since in the course of life we change while basically remaining ourselves. Thus, in all of us there is a fundamental structure, which remains constant over time, but which is, at the same time, prompted by the changes that boundary conditions impose. In other words, there is a kind of dynamic contrast between continuity and change, where continuity is the thread that accompanies us throughout our life. This concept includes the memory of the past, thanks to which we can experience changes in a stable context without them becoming irremediable failures.

My journey through Engineering Geology did not necessarily begin at the time I started my academic career, nor did it end when I reached retirement. I would like to retrace the path of my life through the evolution of Engineering Geology, which began much earlier, bearing in mind that it will never end, since the thread of memories continues to flow. I have split my journey into four parts, corresponding to the four universities in which I worked (Rome, Ferrara, Bologna and Padua). The key reference points of my journey are all the people I met there, and who have accompanied me throughout my life, in particular those who have been closest to me for the longest time.

Before I begin my lifelong journey, I think it would be appropriate to make some comments on the meaning of terms on which there is still no agreement today and, in particular, Applied Geology and Engineering Geology. The fields of direct interest of Applied Geology, an integral part of general Geology, should be understood as the application of any field of Geology to the solution of a given problem posed by human activities, and their interactions with the natural environment, but without implying the knowledge and use of engineering geological methods. Engineering Geology is the branch of Geology that is mainly devoted to the translation of mechanical and hydraulic properties of geo-materials into practical knowledge to inform decision making for the safety and well-being of people and their infrastructure. On the other hand, civil engineers have traditionally regarded engineering geologists as some kind of inadequate pretenders in their own world, considering many geological disciplines as essentially, if not exclusively, qualitative sciences, and to some extent they still do. This was because certain disciplines, such as Soil and Rock Mechanics, Hydrogeology, and Hydrology, have not been considered to be core subjects in Geology degree courses for many years. The first effective definition of the areas pertaining to Engineering Geology dates back to 1970, when the 1st Congress of the International Association for Engineering Geology and the Environment (IAEG) provided the framework for its promotion and development. However, some significant disagreements regarding the concept, definition, and consequently the real scope of this discipline, arose especially in academic environments, and they have persisted at least in part to this day. Today, the two terms tend to be wrongly interchangeable, but Engineering Geology must be understood as the study of the behaviour of soils, rocks, and water, together with the interaction between them and the natural and human environment.

To understand what I mean, and what I believe should be understood as Engineering Geology, it is worth looking at the application of its basic principles throughout human history.

The Dawn of Engineering Geology

The first evidence of the application of what will later become Engineering Geology principles can be traced back to the second-third millennium BC. The ancient Persians, Egyptians, Greeks, and Romans built important hydraulic structures (dams, water tunnels, catchment works, and aqueducts) and very tall infrastructure (pyramids and temples) on the basis of empirical methods only, and with the aid of some mathematics, geometry, and basic elements of physical sciences. The starting point could hence be traced back to the great dams of antiquity.

When building the Sadd el Kafara dam (Fig. 1), the ancient Egyptians had formulated the concept of a water reservoir around 2600 BC. However, as they lacked the necessary knowledge of hydrology, the dam collapsed, probably due to overflowing. The dam of Ma'ribin (Yemen), around 750 BC, (Fig. 1) shows how the Sabeans, an ancient group of South Arabians, had advanced notions of soil compaction (core of the dam) and erosion protection (rip-rap). The Persians 'qanats' (Fig. 2) had the function of both tapping aquifers and collecting rainwater, carrying water along underground tunnels, often with a length of many kilometres.

The Egyptians, who built pyramids as long ago as the 4th millennium BC, implicitly took into account the basic principles of rock mechanics. Producing blocks of suitable shape and size for the construction of pyramids and obelisks necessarily involved the application of the principles of fracture propagation in rock masses. Applications of the basic principles of rock mechanics may also be found when observing the gentle sloping faces of the Unas pyramid (around 2400 BC), the catch bench criteria in the Djoser pyramid (around 2630 BC), and the face slope flattening in the Bent pyramid (around 2600 BC) (Fig. 3), all showing that they understood the existence of some relationship between height and slope angle in rock masses.

Fig. 1 - Ruins of Ma'ribin (top) and Sadd el Kafara (bottom) dams

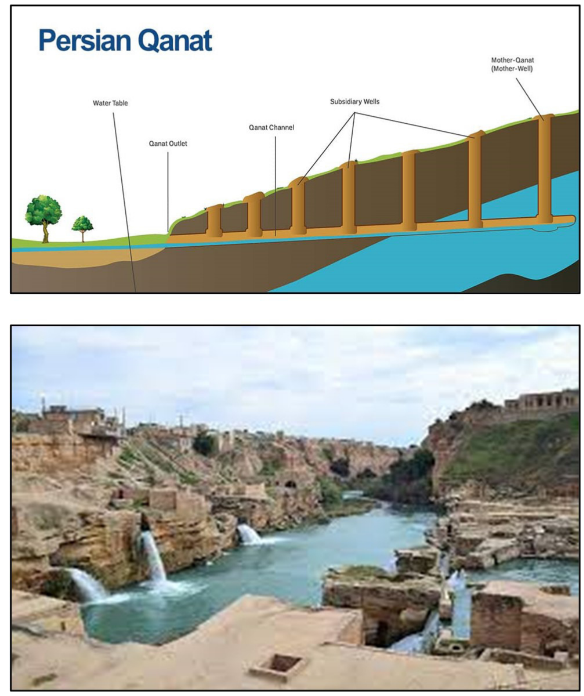

Fig. 2 - The ancient Persia 'qanat' system and reservoir: 'qanat' scheme (top) and reservoir example (bottom)

The foundations of large buildings show the care taken by ancient Greeks and Romans in their construction and the implicit application of the principles of geo-mechanics. The foundations of the Temple of Juno (450 BC) (Fig. 4) were deep enough (more than 7 m) to bypass the Pliocene clays and thus rest on the underlying calcarenites. To find soils with characteristics suitable for the Coliseum foundations (70 AD) (Fig. 4), the area was completely drained and a 6 m pit, later filled up with Roman cement, was excavated as far as the stiffer clays, and then foundations were raised by another 6 m and reinforced on both sides by 3 m wide brick walls. Vitruvius' treatise "De Architectura" (Rome, 1st century AD) is an extensive compendium of natural materials, construction and measurement methods, hydraulics and city planning.

In the European context and until the dawn of the industrial revolution, the evolution of criteria and foundation techniques was very slow. However, some improvements were associated

Fig. 3 - The ancient Egypt pyramids: the Unas pyramid in the foreground and the Djoser pyramid in the background (top);Bent pyramid (right)

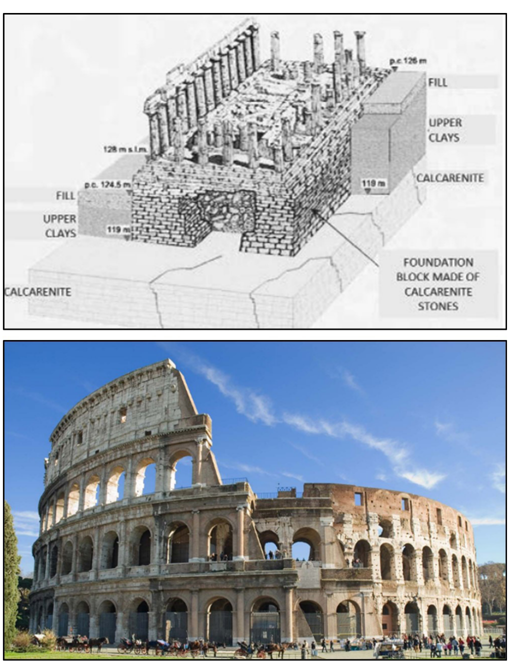

Fig. 4 - The building foundations of Ancient Greeks and Romans: foundations of the Temple of Juno in Agrigento, Italy (top) and the Coliseum, Rome (bottom)

with the construction of important buildings on poor soils. Examples include the foundations of historical palaces in Venice (1200-1600 AD) where (Fig. 5), by applying the principles of Soil Mechanics, the Venetians adequately considered the very poor shear strength and high compressibility of surface soil (a layer only few metres thick but overlying a more consistent level), and the presence of salt water.

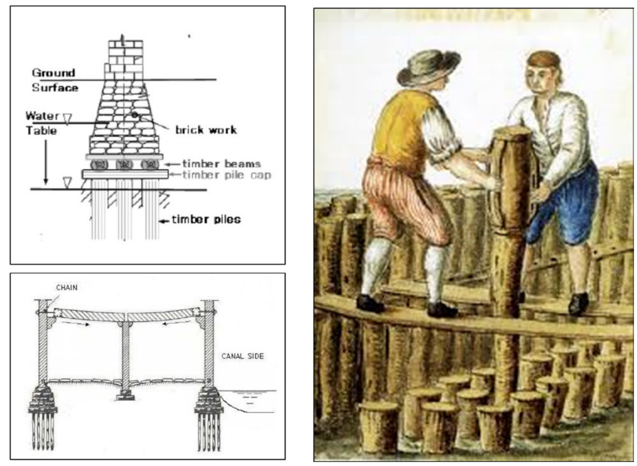

Fig. 5 - Foundations of Venetian buildings in the Middle Ages: pile foundations and deep–shallow combination (left); wooden driven pile installation (right)

Engineering Geology in the 20^{th} century

The development of Engineering Geology as an independent discipline can be traced back to the early 20^{th} century, although Leonardo da Vinci could perhaps be considered to be an ante litteram engineering geologist (The Heritage of Engineering Geology, by G. A. Kiersch, 1991). Natural and anthropogenic disasters in the early 20^{th} century (e.g., the Panama Canal escarpment failures, the 1906 San Francisco and the 1908 Messina earthquakes, and many others) focused public attention on the relationships between natural environment and human presence. The same events very probably encouraged the research work of Karl Terzaghi, an early 20^{th} century mechanical and geotechnical engineer with a geological background, which marked an early merger between geological and engineering sciences.

It was only in 1970 that the 1^{st} IAEG Congress described the 'Engineering Geology' discipline on the global scale, providing a clear framework for it. Based on the definition given by the IAEG, there was no doubt that Engineering Geology needed a deeper knowledge of geological media (soils, rocks, and water) and of the processes taking place within them. It was necessary to improve geologists' knowledge about the types and methods of investigations that were required to understand how these processes influenced human structures and activities, and a more comprehensive geomorphological evolution of the Earth's surface with reference to man-made works. From this point of view, Engineering Geology must necessarily include the knowledge of the basics of soil and rock mechanics, geophysics, hydrogeology, and hydrology. It must be emphasised that, right from the beginning, some aspects of Engineering Geology have become progressively differentiated, giving rise to separate disciplines, albeit remaining closely related to Engineering Geology: in particular. Hydrogeology, Hydrology, Geophysics, and Environmental Geology.

Engineering Geology in Rome in the 1960s

In the 1960s, the then Geological Sciences four-year degree curriculum included a course of Applied Geology at the end of the fourth year. The term 'Applied Geology' undoubtedly derives from a simplification of the title of Ardito Desio's text "Geologia applicata all'Ingegneria" (Geology applied to Engineering), which was mainly devoted to the general concepts of basic Geology, Mining Geology, and Geomorphology. The parts strictly concerning practical applications were descriptive and limited to a few dozen pages out of almost 1000. On the other hand, Prof. Desio said: "The scientific and technical educational backgrounds of engineers and geologists have fundamentally different bases: physical-mathematical for engineers and primarily naturalistic for geologists". It was however the only text available, and it was regarded as excellent for students of Geological Sciences.

At the end of the 1960s, this text was adopted for the Applied Geology course taught by Roberto Signorini and his assistants Carlo Felice Boni and Roberto Mortari. It was focused on the stratigraphy of the Tuscany region with elements of geological exploration of the subsoil, of hydrogeology, and of natural building materials; these subjects were very different from those that the IAEG indicated a few years later. Therefore, the basic issue was what was meant and what should have been meant by Applied Geology in the late 1960s. An indication could have come from the consideration that in Great Britain, at the same time, the Engineering Geology Unit and the Overseas Geological Survey merged to form a single institute called "Institute of Geological Sciences", whose main interests were above all geological–technical mapping, geotechnical and geophysical properties of geological media, and slope stability.

Only two years later, in 1970, the IAEG published and disseminated the following definition at international level:

Engineering Geology is defined in the statutes of the IAEG as the science devoted to the investigation, study and solution of engineering and environmental problems which may arise as the result of the interaction between geology and the works or activities of man, as well as of the prediction of and development of measures for the prevention or remediation of geological hazards. Engineering Geology embraces: the applications/implications of the geomorphology, structural geology, and hydrogeological conditions of geological formations; the characterisation of the mineralogical, physico-geomechanical, chemical and hydraulic properties of all earth materials involved in construction, resource recovery and environmental change; the assessment of the mechanical and hydrological behaviour of soil and rock masses; the prediction of changes to the above properties with time; the determination of the parameters to be considered in the stability analysis of engineering works and earth masses."

With respect to this definition, the Geological Sciences curriculum of the time lacked essential elements, such as the physical-mechanical and hydraulic characterisation of geological media, and the evaluation of their behaviour. Today, the expression Applied Geology mostly refers to the study of the properties and behaviour of soils, rocks, and water, and the interactions between them and with the natural and human environment; therefore, the English expression Engineering Geology is perhaps more appropriate.

Progressive changes in the scientific and professional content of Engineering Geology, from the late 1960s to the present, have accompanied my entire academic and professional life.

The University of Rome period (1968-1986)

In the second half of the 1960s, a new direction was emerging at the Institute of Geology and Palaeontology under the impetus of Marcello Zalaffi, lecturer of the Geological Survey course. Marcello had sensed that disciplines forming the central framework of university courses in Geological Sciences needed to be integrated with basic knowledge of the mechanics governing geological processes. He suggested a thesis topic to me and one of my university classmates, Luciano Rossi. The thesis would consist of a standard geological survey of half of a 1:25000 topographical map, to be associated with the study of the nature and origin of a natural "dolomite flour" present there, and with the related physical and mechanical characterisation. The first soil mechanics laboratory was a small room located on the terrace that existed at the time at the Institute. To carry out our work, we were supposed to learn at least the basic principles of soil mechanics, which we did by self-studying the fundamental texts by Terzaghi and Lambe-Withman.

Further impetus to these initiatives came in the early 1970s, when the Institute of Geology and Palaeontology was entrusted with the study of the soils of the Tiber delta for the Fiumicino airport runways. For this purpose, the Institute purchased rotary drilling equipment and a static penetrometer (among the very first in Italy) and expanded its geotechnical laboratory to accommodate triaxial equipment, direct shear boxes, and some oedometers. We faced and solved many operational problems both in the field and in the laboratory, when dealing with low consistency soils, which made borehole drilling and penetrometer tests problematic, and complicated the preparation of specimens for laboratory tests. Of significant help in the field was the presence of the technicians Grillanda, Pepa, and D'Arpino. Physical and mechanical tests were carried out with the help of Roberto Mortari, Pietro Iuzzolini, Paolo Belletti, and others for shorter periods, assisted by the technician Ronconi, but all of them only had an elementary knowledge of soil mechanics. The first tests were repeated several times, gradually correcting the errors made and at the same time learning from them. Some administrative problems arose from the use of condoms in the preparation of specimens for triaxial tests. We found that they performed the same function as the much more expensive standard membranes. However, at the time, it was quite difficult to convince first the pharmacy to authorise the purchase of 100-piece boxes, and then the administrative secretary of the Institute to reimburse the costs.

The results obtained and our difficulties in interpreting them made it clear that our self-taught knowledge of soil mechanics and behaviour was not sufficient. Meetings and discussions with Professor Arrigo Croce, Director of the Special Office of Public Works for Fiumicino Airport, considered as one of the fathers of Geotechnics in Italy, were of great help and a significant stimulus, thanks in particular to his willingness to talk about geotechnical problems with all young geologists. Meetings with Jean Kerisel, a geotechnical engineer in charge of the geological and geotechnical part of the project, were very intense. He expected us not only to build the stratigraphic model of the area, but also to actively participate in geotechnical aspects, such as calculation of settlements, consolidation, and hydraulic safety of the runway embankments, and evaluation of the effectiveness of drainage systems designed for speeding up consolidation times. Those were days of learning, of nights studying his text (A. I. Caquot and J. Kerisel, Traité de Mécanique des Sols), and of anxiety when submitting the findings from our calculations. However, we consequently learned how to design, build, and monitor an experimental embankment to control settlements and consolidation rate, by using vertical sand drains connected to a vacuum pump system. This experience led to an important improvement of theoretical and practical knowledge on the properties and behaviour of soils, in particular soft clays.

The commission to study the line of the high-speed railway in the Rome-Orte section led to studies on the behaviour of over-consolidated clays and of soils with extra-sensitive behaviour due to the presence of very high percentages of siliceous diatom shells. Participation in the design of an earth dam in Algeria was an opportunity to recognise the relevance of structural geology on the one hand and, on the other, to approach methods for analysing the stability of earthen slopes, thanks also to meetings and discussions with Prof. Franco Esu, a geotechnical engineer at the University of Rome. All the results achieved so far led finally to the recognition of Geotechnics as a discipline of the Geological Sciences.

I integrated my training (mostly self-training) by attending short courses, such as the one on execution and interpretation of direct simple shear tests, delivered at the Engineering Department of Cambridge University by, among others, Peter Wroth, a world pioneer in Geotechnical Engineering and Soil Mechanics.

However, only a small part of the results achieved by participating in the above projects resulted in scientific publications, since I lacked the support of a permanent research and discussion team and dedicated financial resources. My first two publications date back to the 1st Symposium on Penetrometer Testing (Stockholm, 1974). Alberto Prestininzi's arrival in the group created the conditions for the growth of the sector through what have always been the fundamentals of research: discussion of data and comparison of ideas. Thus, papers began to be written and accepted at international conferences on soil mechanics. Research and studies thus developed, broadening the horizons of Engineering Geology and, in general, of Geological Sciences to other fields as well. We started studying the mechanics of rock masses using methods described in the first text by Hoek and Bray and developed research on the stability of rock slopes, reaching conclusions that were confirmed decades later. Thanks to the fundamental contribution given by Roberto Romeo and Gabriele Scarascia Mugnozza, we completed the latter research by applying probabilistic methods to take into account the scatter of discontinuities data in assessing landslide probability. We also carried out investigations on the rheological behaviour of granites with different alteration grade and on the arrangement of mountain basin protection structures, which also required some studies in the hydrology field.

The overall situation, just as in the rest of Italy, improved with the first research programme, funded by Consiglio Nazionale delle Ricerche-Gruppo Nazionale per la Difesa dale Catastrofi Idrogeologiche (CNR-GNDCI, National Research Council-National Group for Prevention of Hydrological Hazards), on 'Prediction and prevention of high-risk landslide events' thanks to Prof. Paolo Canuti. The knowledge acquired by all geologists in the previous years was absolutely necessary to pursue these research projects. Together with Leandro D'Alessandro and Alberto Prestininzi we initiated studies on the behaviour of mudflows, which could be considered to be among the first research studies on the rheology of these phenomena.

The advent of Giovanni Valentini - an engineer with a basic interdisciplinary approach to engineering and geological sciences - as the Chair of Applied Geology confirmed and further strengthened the teaching and scientific research path that Applied Geology had taken until then.

The University of Ferrara period (1986-1990)

This was an extremely short but intense period during which I met and collaborated with Edoardo (Edo) Semenza. Those were the years of discussions with Enzo Vuillermin about carbonate aquifers and of the first attempts, together with Gigi Masé, to build a engineering geology map of the city of Ferrara.

But those were mainly the years when, together with Edo, I was confronted with the Vajont landslide, finding that, despite 25 years of study and research, an exhaustive explanation of its triggering and dynamics had not yet been provided. Edo strengthened my awareness of the extraordinary relevance of conceptual models of geology, stratigraphy (continuity and existence of clayey levels in limestone sequences), and geomorphology for the analysis of large landslides

The collaboration with Edo extended to Monica Ghirotti's PhD thesis on the Vajont landslide. Thus, the first geomechanical model of the landslide was built on the basis of engineering geology field surveys, carried out under precarious and even dangerous conditions. As part of her thesis work, use was made, I think for the first time, of the Universal Distinct Element Code (UDEC) in Italian engineering geology, thanks to the construction of a geomechanical model of the landslide. Research was also carried out on the stability and kinematics of rock slopes, designing and implementing a monitoring system equipped with wire strain gauges. Unfortunately, this system was abandoned owing to operational difficulties arising in data acquisition. Indeed, at the time, data was collected on site, as automatic transmission systems were not so easily available as they are today.

An incentive to study natural granular flows came from technical consulting services that we were required to provide after the 1985 collapse of two twin tailings dams at Stava (northern Italy). The issues to be solved were fairly complex, since they involved both geotechnical (stability of tailings dams under construction) and rheological (flow of silty clays and silty sands down the valley) aspects. As we were aware of our poor theoretical bases to address the above issues, we decided to take a long trip to the US, in order to discuss them with academic researchers and experts in this field. We also needed an improved understanding of fluid rheology to identify the different types of flow and assess their speed (up to 120-130 km/h).

Ultimately, Ferrara's experience led to important stimuli in geomechanical characterisation of rock masses, numerical modelling, and analyses of rock slope stability, and represented one of the first approaches to debris flows studies undertaken subsequently.

The University of Bologna period (1990-1998)

In 1990 I was appointed to the Chair of Applied Geology of the University of Bologna, the oldest university in Europe, with the task of reorganising its engineering geology sector, starting with the existing soil testing laboratory. Prominent was the presence, among many, as PhD students first and Assistant Professor later, of Matteo Berti, Alessandro Simoni, and Monica Ghirotti, whose main research activity was focused on debris flows and slope stability under dynamic conditions, and on the integration of Engineering Geology as an integral and essential part of large projects.

I continued my research on slope stability, namely on the relationship between epicentral distance and seismically induced landslides, especially within the framework of the European Commission for Geomorphological Hazards. In this field, my discussions with Gian Battista Vai were particularly significant. To determine how the recurrence of minor earthquakes affected progressively increasing mass displacements, we carried out static and dynamic analyses of landslide phenomena in structurally complex formations.

A further development in engineering geology occurred as part of my early participation in the European Debris Flow Risk Project, which gave me the opportunity to study debris flows and, in particular, their dynamic aspects and behaviour. The project led to the idea of setting up a monitoring station (a project implemented jointly with the Cascades Volcano Observatory, Vancouver, US) on the debris flow of Acquabona, near Cortina d'Ampezzo. A key factor in taking the first effective steps in physical and numerical modelling of flows and defining the mechanisms of flow initiation was my collaboration with Aronne Armanini (Hydraulic Engineering Department of Trento University) and Roger Cojean (Ecole des Mines de Paris), respectively. I addressed the topic of hazards related to the triggering of debris flows in conjunction with Professor Alberto Lamberti, considering the geomorphological and hydrological characteristics of the area and path evolution defined by numerical models calibrated on the basis of data collected from real events.

My participation in the design of the underground railway station in Bologna and of its long access tunnel is an example of the recognition of the key role of modern Engineering Geology in the design of large-scale structures. This period of time marked the expansion of the fields of interest of Engineering Geology, their effective recognition, and the establishment of new scientific cooperation relationships with other national and international universities.

The University of Padua period (1998-2012)

In 1998, I was given the opportunity to move to Padua University to join the already existing Applied Geology sector, with a mandate to develop studies and researches in the field of slope stability and rock mass mechanics. This change came with some regrets, as I had always felt at ease in Bologna, in spite of sometimes heated discussions with colleagues from other sectors. However, I was starting to feel the burden of long daily commutes from Padua, where I had been living since before 1990 for family reasons. This period was marked by the presence of Paolo Fabbri, Antonio Galgaro, and, at a later stage, by Paolo Scotton and Mario Floris.

Given the increasing demand for engineering geologists, a new two-year Master's degree course in Engineering Geology was created. Thus, subjects that had been hitherto typical of engineering were included in the curriculum, as they were deemed necessary for a better understanding of natural phenomena and for a more complete interaction with engineers. This was possible thanks to the arrival of Paolo Scotton, a hydraulic engineer, in charge of teaching Elements of Hydrology, Hydraulics, and Structural Mechanics. These years were mainly dedicated to development of the new Master's degree course, implementation and maintenance of the Acquabona monitoring station project, monitoring of landslides by using Terrestrial Laser Scanning (TLS), and construction of a rock mechanics laboratory.

I continued my studies and research on debris flows as part of the coordination and management of the European THARMIT project jointly with French, Austrian, Dutch, and Swiss researchers. I also continued the implementation and maintenance of the Acquabona monitoring system, initially with Antonio Galgaro and then with Paolo Scotton, broadening my studies on the rheology of debris by using experimental data. A new monitoring station, although instrumentally simpler given the distance of the site and the size of the flow canal, was also installed in Argentina in collaboration with the University of Salta. Physical and numerical models of debris flows were also created in collaboration with Pia Rosella Tecca and Andrea Deganutti (Consiglio Nazionale delle Ricerche-Istituto di Ricerca per la Protezione Geologica, CNR-IRPI, National Research Council-Hydrogeological Protection Institute, Padua) by building a flume and using a distinct element numerical code (Particle Flow Code, PFC).

Other research that was carried out regarded the analysis of stability conditions of underground quarries with a three-dimensional distinct element numerical code (3DEC) based on their characteristics obtained from geomechanical surveys, seismic tests on circular sections of a sample pillar, and laboratory tests. The rock mechanics laboratory was also supplemented with some specially designed machines for creep tests.

The GEO-RISK project, coordinated by the engineering geology sector, was one of the first 10 strategic projects of the University of Padua. It arose from the idea of a project that would bring together the skills and knowledge of researchers belonging to different academic fields in a multidisciplinary environment (engineering geologists, structural geologists, geomorphologists, hydrogeologists, geophysicists, hydrologists and mathematicians). The Engineering Geology sector consequently achieved significant results, in particular in the study of the dynamics of masses in slow or rapid movement, in the definition of a new structural and hydrogeological model of the Vajont landslide, as well as in the setting up of the first rock mechanics laboratory. All these activities made it possible to organise the 5th International Conference on Debris-Flow Hazards Mitigation (2011) and the International Conference on Vajont 1963-2013 (2013) in Padua, jointly with Alberto Prestininzi. Both of these events were successful, and they attracted researchers from all parts of the scientific world.

From the text of Ardito Desio to date

My journey through this discipline has been a long one, from the days of Ardito Desio's text to the present days. I taught - and hopefully passed on to my students in Geological Sciences in the Applied Geology courses - all what I had gradually studied, learned, and experienced.

The evolution of the content and meaning of Applied Geology, which I directly experienced and accompanied, has led this discipline to be the one indicated by the IAEG in 1970. Today, its fundamental scope is the study and understanding of how natural processes influence human structures and activities. Ultimately, today's engineering geologists can and must provide an essential support to the complex development of human projects and structures and of environmental preservation

The broadening of the skills of engineering geologists implies not only an improved knowledge of the scientific fundamentals of the discipline, but also increased responsibilities, as they have moved from the initial merely qualitative phase to the current quantitative one. These responsibilities are enhanced by two non-negligible features that make our discipline fairly difficult and at the same time fascinating: variability, inherent in geological systems; and uncertainty, deriving from an inevitably incomplete knowledge of the characteristics and behaviour of a given geological system. Nonetheless, this uncertainty, arising from the awareness of one's own ignorance and limitations, has a significantly positive value: it represents the key quality of every researcher, leading one to always wonder what is round the corner.

"It is said that life consists of twelve rooms, twelve rooms in which we will leave something of us, which will remember us. Twelve rooms that we will in turn remember when we get to the last one, the one of awareness and memories" (Ezio Bosso). After being at four different universities, working with many different people, in particular with those that I have mentioned here, I have walked through four of these rooms, each one a part of a larger whole. I would like to express my gratitude to you for your presence here and friendship, and to all those who are not here today. However, I also want to thank the people with whom I worked and all my students by recalling the saying of Leonardo da Vinci that I once read as a student in the chemistry classroom: "Poor is the pupil who does not surpass his master". To my great fortune and satisfaction, you all did, and I hope you will continue to do so.