

Geological engineering in Colombia, importance and applications

La ingeniería geológica en Colombia, importancia y aplicaciones

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ABSTRACT

This article examines, from a documentary perspective, the development and importance of Geological Engineering in Colombia, highlighting its evolution from the Industrial Revolution to becoming an independent discipline globally. The need for a deeper understanding of geological processes in engineering projects was driven by disasters such as the Malpasset dam collapse and the Vaiont dam landslide, which led to the professionalization of this discipline. In Colombia, Geological Engineering was consolidated in 1956 with the creation of the first-degree program at the Universidad Nacional de Colombia (UNAL), followed by other universities such as the Universidad Pedagógica y Tecnológica de Colombia (UPTC), Escuela de Ingeniería de Antioquia (EIA) and the Fundación Universitaria del Área Andina, Valledupar (AREANDINA). The academic training of geological engineers includes everything from basic sciences to specialized techniques in geotechnics, applied geology, hydrogeology, seismic engineering, among others, with an emphasis on environmental management and sustainable development. Currently, there are 2,918 professional registrations in Colombia, with UNAL and UPTC standing out for having the highest number of graduates. Colombian geological engineers face a growing job market, with demand in areas such as natural resource management, geological risk mitigation, and infrastructure projects. The importance of associations such as the Colombian Society of Geology, the National Association of Geological Engineers, and the Colombian Society of Engineers is emphasized, as they support research and the defense of professional interests.

Keywords: Geological Engineering, applied geology, Colombian universities.

RESUMEN

Este artículo aborda desde un punto de vista documental el desarrollo y la importancia de la Ingeniería Geológica en Colombia, destacando su evolución desde la revolución industrial hasta convertirse en una disciplina independiente a nivel global. La necesidad de una comprensión más profunda de los procesos geológicos en proyectos de ingeniería fue impulsada por desastres como el colapso de la presa de Malpasset y el deslizamiento en la presa de Vaiont, que llevó a la profesionalización de esta disciplina. En Colombia, la Ingeniería Geológica se consolidó en 1956 con la creación de la primera carrera en la Universidad Nacional de Colombia (UNAL), seguida por otras universidades como la Universidad pedagógica y Tecnológica de Colombia (UPTC), Escuela de Ingeniería de Antioquia (EIA) y la Fundación Universitaria del Área Andina, sede Valledupar (AREANDINA). La formación académica de los ingenieros geólogos abarca desde ciencias básicas hasta técnicas especializadas en geotecnia, geología aplicada, hidrogeología, ingeniería sísmica, entre otras, con un énfasis en la gestión ambiental y el desarrollo sostenible. Actualmente, se registran 2,918 matrículas profesionales en Colombia con la UNAL y la UPTC destacándose por el mayor número de egresados. Los ingenieros geólogos colombianos enfrentan un panorama laboral en crecimiento, con demanda en áreas de gestión de recursos naturales, mitigación de riesgos geológicos y proyectos de infraestructura. Se resalta la relevancia de asociaciones como la Sociedad Colombiana de Geología, la Asociación Nacional de Ingenieros Geólogos y la Sociedad Colombiana de Ingenieros, que apoyan la investigación y defensa de los intereses profesionales.

Palabras clave: Ingeniería Geológica, geología aplicada, Universidades Colombianas.

1. INTRODUCTION

Geological Engineering as a discipline began to take shape during the industrial revolution in the 18th and 19th centuries, with the rise of mining, the construction of railroads and the development of large infrastructure projects, where the need for a deeper understanding of the properties of the terrain and natural materials became evident. Geology began to be applied systematically to solve engineering problems, such as slope stability, tunnel construction and groundwater management [1].

Formal recognition of Geological Engineering as a separate discipline began in the late 19th and early 20th century [1]. This development was driven by a series of engineering disasters related to the lack of adequate geological understanding where engineering projects were undertaken, such as dam collapses, mine collapses and structural failures in major infrastructure works [2], [3]. This led to an increased awareness of the importance of integrating geology into project design and construction. One of the key events that marked the development of Geological Engineering were the collapse of the Malpasset dam in France in 1959 that resulted in the death of more than 400 people [4]–[7] and the landslide at the Vaiont dam in 1963 that resulted in the death of 2000 people in several villages located in the valley downstream [8]–[14].

These disasters prompted the need for a detailed understanding of the underlying geology in engineering projects and led to a greater formalization and professionalization of the field, for that reason since that time several universities worldwide have incorporated this discipline in their academic programs, such as TU Bergakademie Freiberg (Germany), École des Mines de Paris (France), Colorado School of Mines (USA), Imperial College London (UK), Universidad Nacional de Ingeniería (Peru), among others.

In Colombia, Geological Engineering was integrated into the field of engineering, sharing space with disciplines such as Geology, Civil, Mining and Petroleum Engineering. Currently, this career is taught in four universities in the country and has a duration of five years, which is equivalent to ten semesters. This research seeks to show the importance and applications of Geological Engineering in Colombia.

The concept of Geological Engineering, and therefore that of Geological Engineering, varies from country to country. According to [15], Geological Engineering consists of applying geological principles to practical engineering, or, in other words, it is the discipline that analyzes all the geological factors involved in the location, design, construction and maintenance of engineering works. On the other hand, the International Association of Geological Engineering [16] defines this discipline as the one in charge of investigating, studying and solving engineering and environmental problems derived from the interaction between geology and human activities, as well as predicting and proposing preventive or corrective measures for geological hazards. Similarly, González de Vallejo et al., [1] describe engineering geology as an applied science that focuses on solving engineering and environmental problems.

These appreciations become much clearer if we consult the meaning of the terms Engineering and Geology:

Engineering: Engineering is understood as any application of the physical, chemical and mathematical sciences; of industrial technology and, in general, of human ingenuity, to the use and invention of matter [17].

Geology: Science that studies the history of the Earth, as well as the nature, formation, evolution and present disposition of the materials that compose it [18].

From all these definitions a common body emerges that allows defining Geological Engineering as the discipline that studies and deals with the resolution of problems related to the direct and indirect interaction of man with the geological environment, understanding this as the support of human activities [19]. Therefore, Geological Engineering is a hybrid discipline that combines aspects of both Geology and Engineering, with a balance between both areas that varies according to the labor needs of the country or region where the training is offered. In some countries, such as England, Poland and the United States, the degree is known as Engineering Geology. On the other hand, in other countries such as Spain, Portugal, France, Canada, Japan, Mexico, Colombia and Peru, the degree is called Geological Engineering [19].

Sometimes, different names for the same profession, such as "Geological Engineering" or "Engineering Geology", are used to fill job vacancies that other careers do not cover. However, these terminological differences are nothing more than semantic details that sometimes generate confusion about the same profession. In order to better understand the role of the Geological Engineer in the global environment, we offer a broader perspective on this professional figure [20]–[24].

2. LOCATION

In Colombia there are four universities where the professional career of Geological Engineering is taught, these are: Universidad Nacional de Colombia (UNAL), Universidad Pedagógica y Tecnológica de Colombia (UPTC), Escuela de Ingeniería de Antioquia (EIA) and Fundación Universitaria del Área del Andina (AREANDINA), which are located in Medellín, Sogamoso, Las Palmas (Envigado) and Valledupar, located in the departments of Antioquia, Boyacá and Cesar (Figure 1).

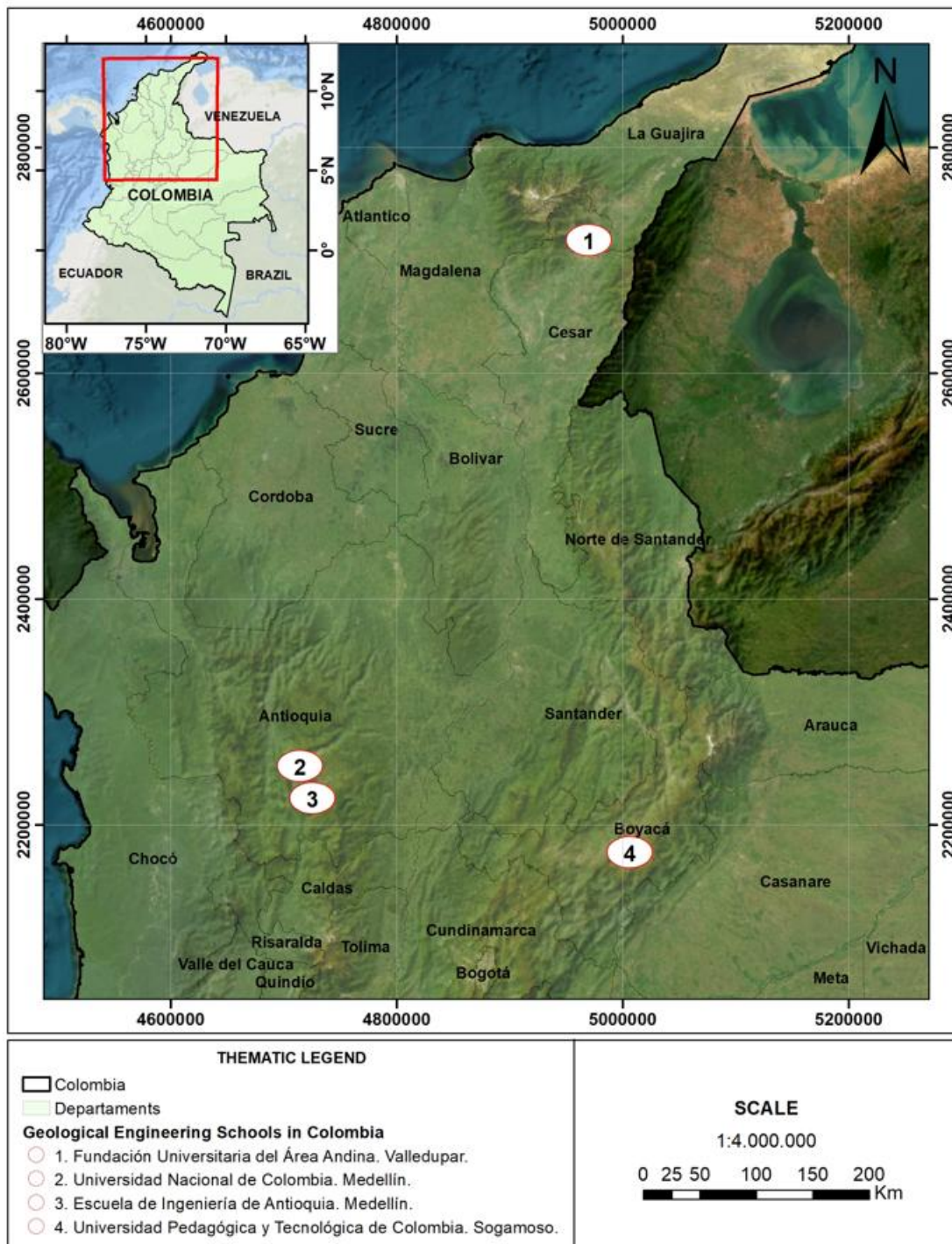


Figure 1. Geographical distribution of universities where Geological Engineering is taught in Colombia.

3. METHODOLOGY

This article addresses from a documentary point of view the development and importance of Geological Engineering in Colombia, based on the compilation, analysis and synthesis of secondary information from various academic and historical sources, highlighting its evolution from the industrial revolution to become an independent discipline at a global level.

The procedure was structured in several stages, based on the methodology of [19], first the main purpose was to analyze the evolution of Geological Engineering in Colombia, highlighting its historical development, the current academic and professional landscape, as well as the challenges and opportunities faced by the discipline. Subsequently, relevant sources such as scientific articles, official documents, academic databases [25]–[28] and the National Professional Council of Engineering [29] were identified and selected.

Historical and contemporary data were reviewed to identify development patterns, important milestones and current trends. The information gathered was organized into thematic sections, including historical background, educational background, professional landscape and key partnerships.

4. ACADEMIC TRAINING OF THE GEOLOGICAL ENGINEER

Geological Engineering has been known in Colombia since 1939 as a competency associated with Civil Engineering, Mining Engineering and Geology, within the Basic Core of Knowledge of Civil Engineering and related subjects, as of Law 94 of 1937, which was replaced by Law 842 of 2003, which regulates the practice of engineering in the country [30], [31].

The significant demand in the public and private sectors for geological engineers in areas such as risk management, environmental aspects, prospecting and sustainable exploitation of natural resources, led the National University of Colombia to propose to the Ministry of National Education the creation of the first professional career in Geological Engineering in 1956, followed by the School of Engineering of Antioquia in 1982, the Pedagogical and Technological University of Colombia in 1983, and the University Foundation of the Andean Area in 2011 [29], [32].

4.1 Universities with a professional career in Geological Engineering

Currently in Colombia (October 2024) there are a total of 3147 professional license plates issued by COPNIA, which date back to 1939, since then the career has had an exponential growth trend (Figure 2). Something important to mention is that 7.3% (229) correspond to validation of professional degrees from foreign universities and 2918 professional registrations correspond to graduates from Colombian universities.

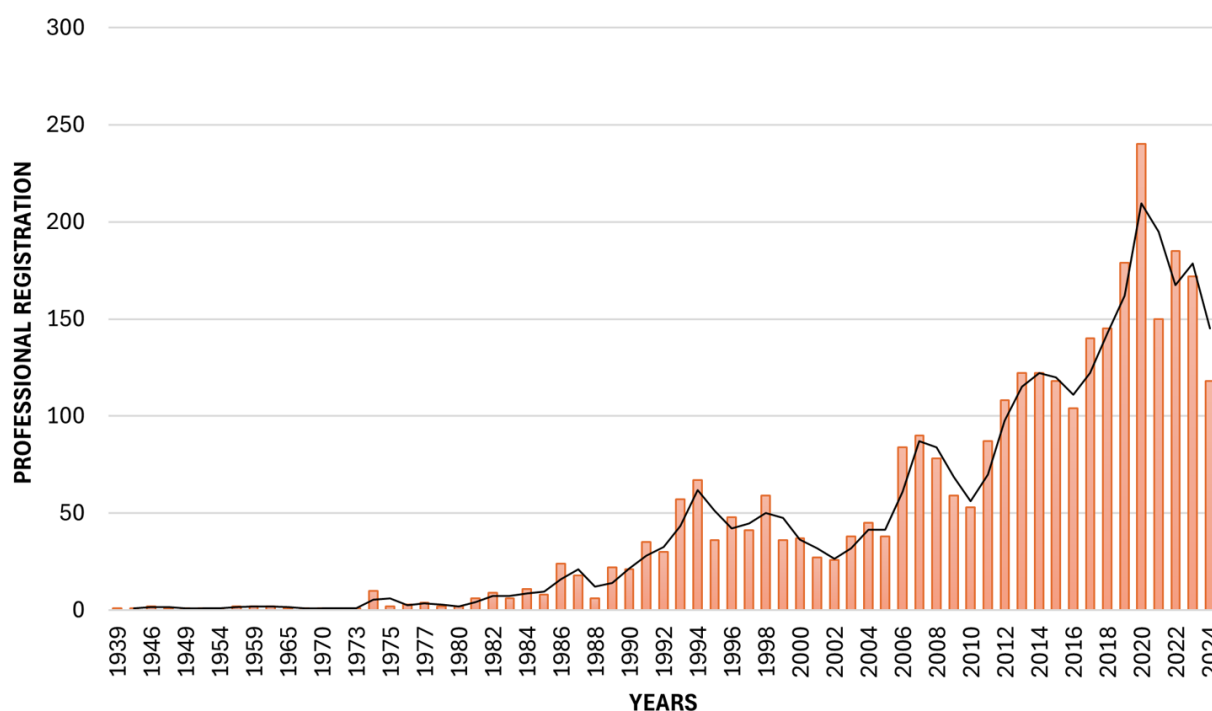


Figure 2. Professional licenses issued in Colombia for Geological Engineers. Source: [29].

4.2 Evolution of Geological Engineering in Colombia

Figure 3 shows the evolution of the career in Colombia. There is an upward trend of enrollments registered in the National Professional Council of Engineering (COPNIA), reaching a figure of 2918 Geological Engineers graduated from Colombian universities by October 2024 [29].

Something important to mention is that the highest number of graduates correspond to the years 2019 and 2020 in which 409 professional enrollments were registered, possibly due to the methodological changes that universities underwent due to the global crisis caused by Covid-19 in that period.

Another relevant indicator is the one shown for the School of Engineering of Antioquia, where fluctuations are observed in different periods, highlighting a very low record for the years 2000 to 2018.

In this regard, it is important to take into consideration that such demand may be related to the economic and energy growth not only of the country, but also at the international level, since it allows a greater demand for these profiles or, on the contrary, when presenting different crises or socio-political uncertainties that may negatively affect the supply and demand of the same, it may also be due to institutional policies, academic quality, infrastructure and costs that may affect the competitiveness of each university and, therefore, its number of enrollments.

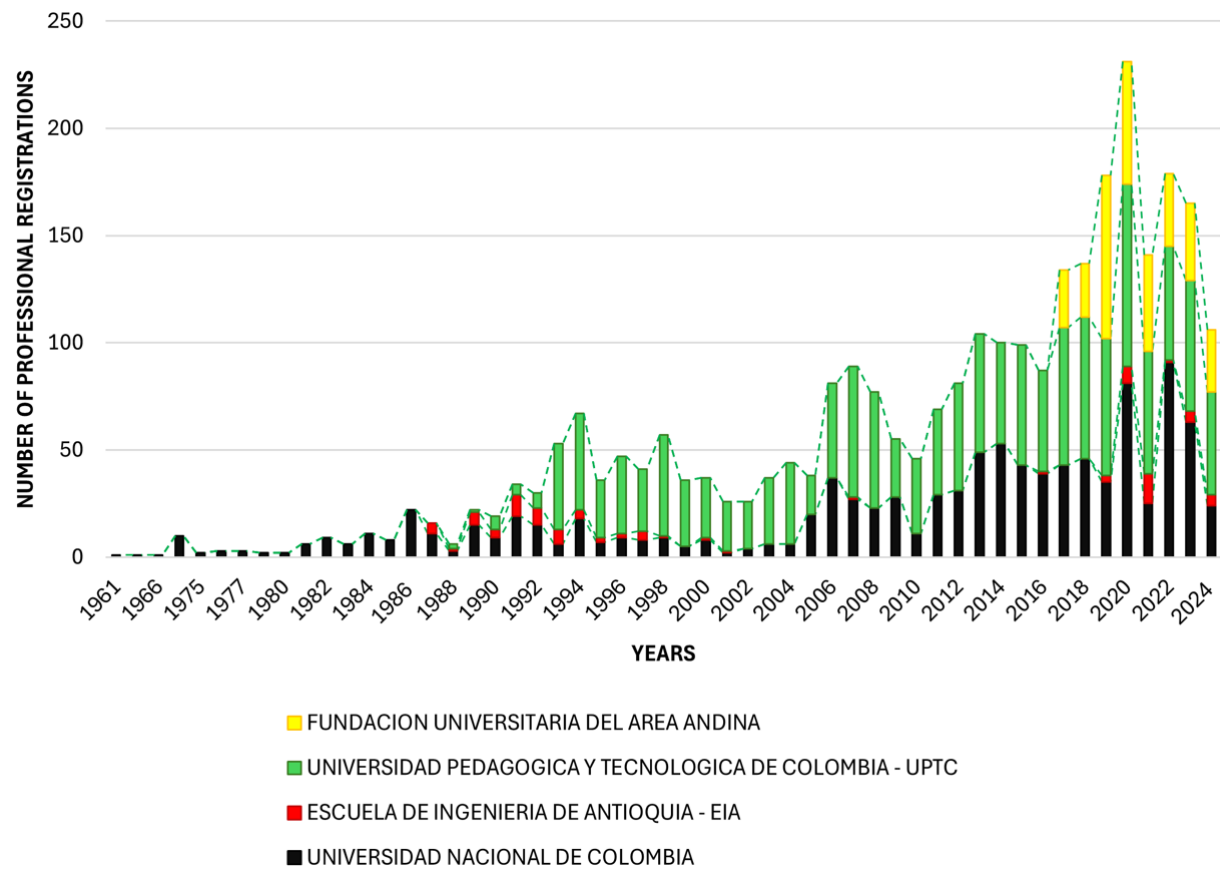


Figure 3. Evolution of Geological Engineering in Colombia and cumulative number of professional enrollments Source: [29].

Geological Engineering programs in Colombia show a historical and current impact of each university in the training of professionals. UPTC and UNAL stand out for their high number of registered graduates (1450 and 1045 respectively), which confirms their leadership in this field, while AREANDINA and EIA represent growing options with promising prospects, although with a lower volume of registered graduates to date (329 and 94 respectively; Figure 4).

In all universities, students are required to complete a degree project, which can take different forms such as thesis, monograph, internships or internships. These activities allow students to demonstrate technical skills and competencies acquired during their engineering education.

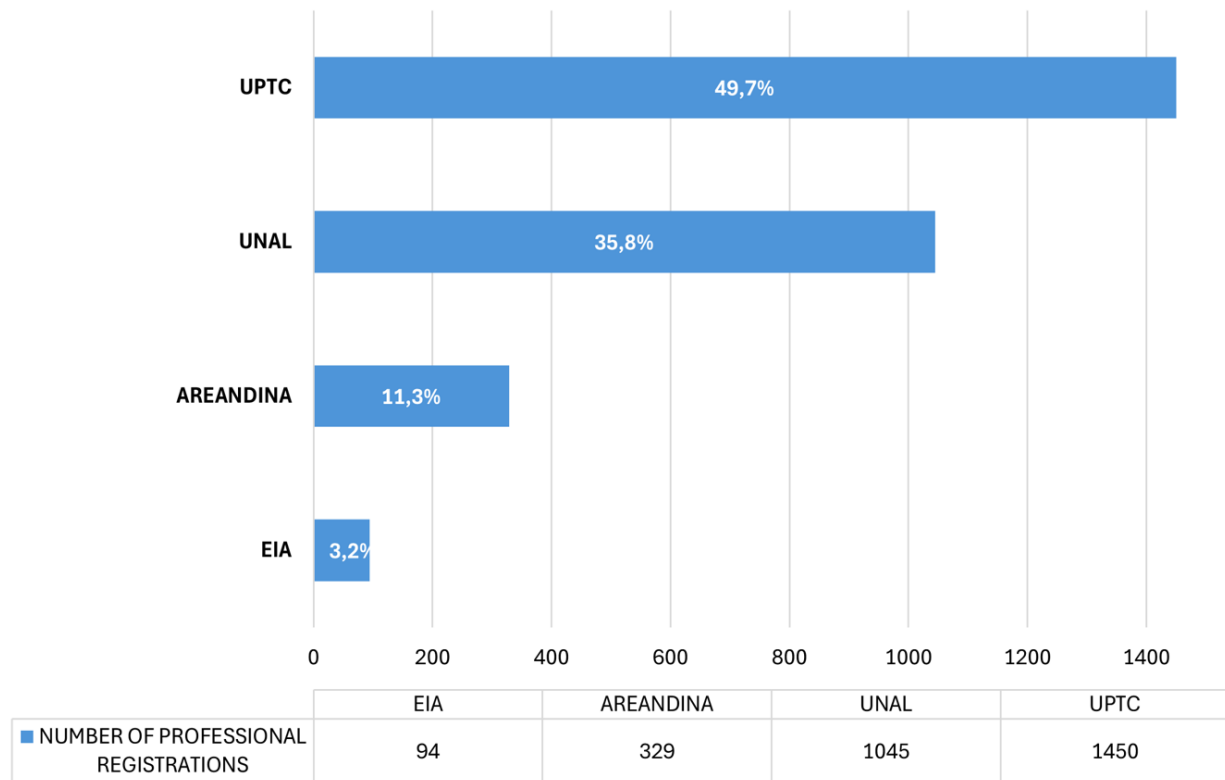


Figure 4. Characteristics of Geological Engineering in Colombia by universities. Source: [25]–[28].

4.3 Geological Engineering Education

The Geological Engineering curriculum consists of ten semesters, structured according to the focus of each institution, with certain similarities between higher education institutions.

The Geological Engineer receives a solid training in basic sciences, such as mathematics, physics, chemistry and geometry, which is the basis of his academic and professional development. In addition, he/she acquires a comprehensive knowledge in applied sciences and techniques, including disciplines such as soil and rock mechanics, hydraulics, hydrology, structures, construction techniques, topography and cartography. This knowledge is complemented by specific training in the different branches of geology, which allows him to competently address the challenges of his field.

Thanks to this multidisciplinary preparation, the Geological Engineer is able to work in a wide variety of areas, such as geomechanics, hydrocarbons, mining, environment, natural risk management, exploration and management of natural resources, hydrogeology and geophysics, energy transition, GIS, among others. This versatility allows it to adapt to the needs of diverse sectors and contribute significantly to sustainable development and the solution of complex geological and engineering problems.

In Colombia, the subjects of these programs can be grouped into common subjects, which are all those that are characterized by having a common, basic, general or foundation training within engineering; specific subjects, which are all those specific, applied or in-depth professional subjects; and elective or free-choice subjects. Following this general scheme, the subjects of all the curricula of the universities in Colombia have been analyzed.

Tables 1 and Figure 5 show the distribution of subjects in the curricula of the universities where Geological Engineering is taught in Colombia. These subjects were grouped into three categories: common, specific and elective. It can be observed that the common subjects show a significant variation among the institutions. EIA registers the highest percentage with 54.24%, followed by AREANDINA (47.83%) and UPTC (45.45%). UNAL, on the other hand, has the lowest percentage of common subjects, representing only 22.64% of its curriculum.

In the case of specific subjects, UNAL leads with 54.72% of its subjects focused on technical and disciplinary training. This suggests a particular emphasis on specialized content in geology and engineering. The other institutions have similar percentages: UPTC (47.27%), AREANDINA (46.38%) and EIA (42.37%), indicating a balanced distribution between basic and specific training.

Elective subjects represent the lowest proportion in all programs, which could be related to a more structured approach in the main contents. UNAL has the highest percentage in this category (22.64%), suggesting greater flexibility in its curriculum. On the other hand, EIA shows the lowest proportion of elective subjects, with only 3.39%, while UPTC (7.27%) and AREANDINA (5.80%) maintain moderate figures.

Table 1. Number of subjects in geological engineering universities according to their classification.

SUBJECTS	UNAL	EIA	UPTC	AREANDINA
Common	12	32	25	33
Specify	29	25	26	32
Elective	12	2	4	4

Source: [25]–[28].

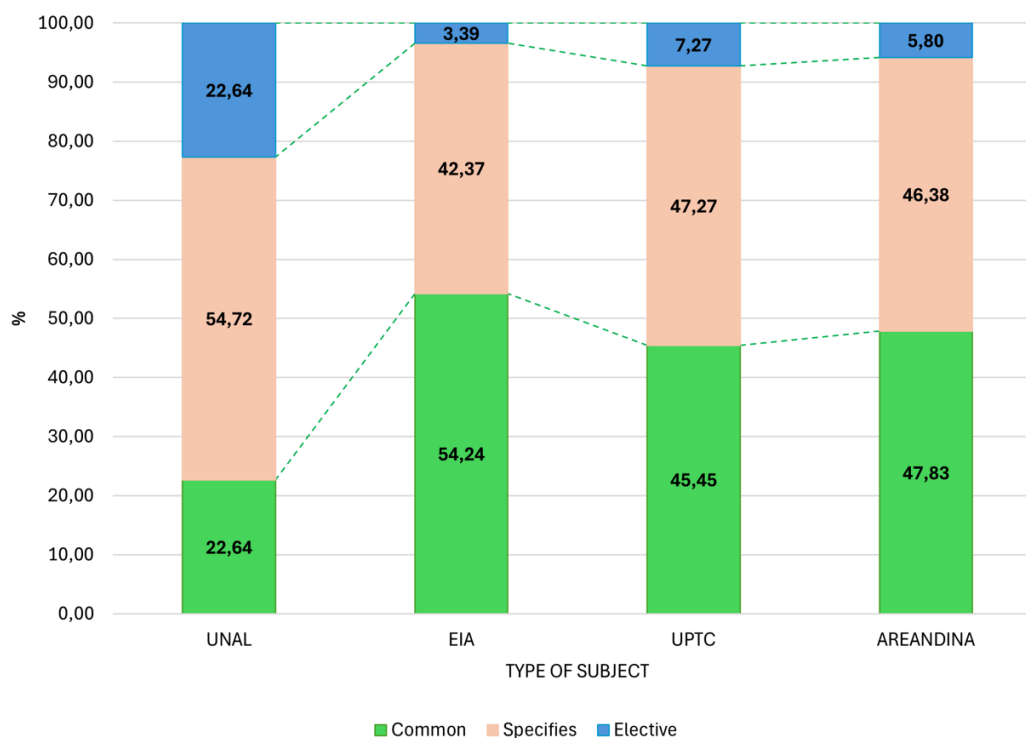


Figure 5. Percentages of contents of types of Geological Engineering subjects in Colombia. Source: [25]–[28].

The distribution of subjects reflects differences in the pedagogical approaches of the universities. While UNAL prioritizes a more specific and flexible training, EIA gives greater weight to common subjects, which could be oriented to a more engineering training. UPTC and AREANDINA present a balance between the three types of subjects, ensuring a comprehensive and technical training.

This analysis highlights the diversity in the curricular organization of Geological Engineering programs, allowing students to choose according to their preferences and career goals.

A common aspect in all universities is the solid training that Geological Engineers receive in Geology and Applied Geology, which gives them the ability to interpret and comprehensively understand the geological environment where infrastructures are developed. Areas such as geological risk management, territorial planning, environmental engineering, geological resource management and engineering are fundamental pillars in their professional profile.

Thanks to this preparation, the Geological Engineer becomes an expert capable of analyzing and recognizing the geological environment from an engineering perspective. This allows him/her to design and propose effective technological solutions to address problems associated with the interaction between terrain and structures, contributing significantly to sustainable development and risk mitigation in engineering projects [19].

4.4 Status of geological engineers in Colombia

Colombian geological engineers play a fundamental role in the sustainable development of the country. To date, 2918 professional registrations have been registered with COPNIA (Figure 2).

Although geological engineering in Colombia has experienced remarkable growth in recent decades, there are still challenges and opportunities to be explored. Despite having a solid academic background, Colombian geological engineers face a diverse and constantly evolving labor landscape.

The demand for professionals in this field has increased significantly due to the growing need to exploit, evaluate and manage natural resources, mitigate geological risks and develop sustainable infrastructure projects, understanding the geological environment and the mechanical response of the terrain to different loads or stresses and how these influence the performance of structures.

At present, there are no precise statistics available on the professional activities carried out by practicing geological engineers. However, it is known that most of them work independently or in construction and consulting companies specialized in civil works, geotechnical engineering, risk management and exploration of mineral resources, and others in state and multinational companies. In addition, some are engaged in teaching and academic research, while others work in the public sector, contributing in various areas related to their professional training.

5. CAPABILITIES AND COMPETENCIES

The capabilities of the Geological Engineer come from the knowledge acquired during their academic training, while the competences are related to the activities that, according to the regulations, they can legally perform. In the Colombian context, the academic training of Geological Engineers provides them with a wide field of knowledge, both geological and technical, covering different areas that can be related to other professions offered in Colombia, as is the case, for example, of geology, civil engineering and mining. Among these areas are:

- Geotechnics and geomechanics: Design, correction and stabilization of structures such as slopes, embankments, cuttings and slopes, which makes its participation in civil works indispensable. It also studies the mechanical behavior of rocks and soils under different loads, stresses and environmental conditions, in order to predict their response and design safe and durable structures.
- Design of foundations and retaining structures: Evaluation of geotechnical parameters and ground conditions for the design of appropriate structural solutions.
- Mapping: Analysis and mapping of the characteristics of the land, to determine its distribution, use and define what activities or infrastructure can be developed in the area.
- Earthquake engineering: Seismic risk management and planning, seismic hazard studies and design of earthquake-resistant structures.
- Land use planning and risk management: Assessment of geological risks and potential damage caused by natural processes, as well as infrastructure design to prevent or mitigate such risks, including risks such as mass movements, floods and torrential floods.
- Environmental engineering: Analysis of the impact of human activities on the physical environment and development of corrective and preventive measures.
- Hydrogeology: Study of groundwater dynamics and quality, management of water resources and development of groundwater prospection and collection systems.
- Mineral and energy resources: Exploration, exploitation and management of resources such as natural gas, oil, coal, metals, stone materials and minerals necessary for the energy transition, as well as the use of sources such as geothermal, solar and wind energy.
- Management of degraded environments: Recovery of areas affected by human activities, such as quarries and landfills.
- Geographic Information Systems: Processing and analysis of geographic data in an efficient and effective manner, its application in multiple fields has revolutionized the way we analyze and understand our environment, with a better understanding of geological processes for more informed and sustainable decision making.
- Geological modeling: Interpretation and creation of detailed 3D geological models from geophysical, geological and geochemical data. These models are essential for mineral resource exploration, geohazard assessment and engineering project planning.
- Medical geology: They study the migration of contaminants in soil and groundwater, which is crucial to identify and remediate sources of contamination that can affect human health, due to exposure to toxic elements present in soil, water and air, such as arsenic, lead and cadmium, among others.
- Public policy: they provide fundamental technical knowledge for the formulation of effective and sustainable public policies.
- Geophysics: Uses physical methods to investigate the interior of the Earth.
- Structural geology and tectonics: Fundamental for understanding the Earth's history and for assessing geologic hazards, tectonics studies the endogenous and exogenous processes that deform the Earth's crust.

It is clear that thanks to this comprehensive training, the Geological Engineer is a professional with a solid background in Geology and mastery of engineering tools, is able to face challenges in multiple technical and scientific areas, solving problems related to the field in a comprehensive and efficient manner. Its

differential value lies in the ability to apply geological knowledge to engineering projects, considering both theoretical and practical aspects. Unlike other professionals, the Geological Engineer has a broader and more specialized vision of geological processes, which allows him/her to offer innovative and sustainable solutions to the challenges posed by the interaction between human beings and the environment.

6. ASSOCIATIONS OR SOCIETIES IN ENGINEERING GEOLOGY IN COLOMBIA

Associations are non-profit organizations whose purpose is to defend the interests of a certain group jointly (Unidad Administrativa Especial de Organizaciones Solidarias, 2024). Since the constitution of the profession in Colombia, the group of students and professionals of earth sciences (Geology, Geological Engineering, Geosciences, etc.) have promoted the creation of several associations that seek to promote the study, development, research and dissemination of the disciplines of earth sciences and engineering, as well as to defend their interests before public agencies that could intervene on it. Thus, in the country there are the Colombian Society of Geology (SCG), Colombian Society of Engineers (SCI), Colombian Society of Geotechnics, Colombian Association of Geologists and Energy Geophysicists (ACGGP), National Association of Engineering Geologists (ANIG), Colombian Association of Hydrogeologists (ACH), Colombian Association of Engineers (ACIEM), Colombian Association of Oil and Gas (ACP), American Association of Petroleum Geologists (AAPG), Colombian Association of Geologists and Miners (ACGM), and student chapters of these associations, research groups, among others. These associations and guilds promote through the organization of courses, conferences, congresses, publications and other related activities.

6. CONCLUSIONS

Geological Engineering in Colombia was born with the purpose of training professionals specialized in studying and solving problems related to the direct and indirect interaction of man with the geological environment, understanding this as the support of human activities. Undoubtedly, this implies the occupation of a part of the field of action currently performed by other professionals according to the international schemes of competence distribution of other developed countries.

Colombian universities offer high quality academic programs that train competent professionals capable of facing the challenges of geological engineering in a national and global context.

In the country, Geological Engineering is offered at four major universities and has seen a growth in the number of professional enrollments since 1939. The training stands out for including a solid foundation in basic and technical sciences, as well as a strong orientation towards applied geology and engineering.

The Geological Engineering degree is taught in a ten-semester plan and covers a range of common, specific and elective subjects, with variations in the approaches of the universities. The Universidad Nacional de Colombia (UNAL) emphasizes more on specific and flexible subjects, while the Escuela de Ingeniería de Antioquia (EIA) prioritizes more on common subjects, and the Universidad Pedagógica y Tecnológica de Colombia (UPTC) and the Fundación Universitaria del Área Andina (AREANDINA) present a balance between the three types of subjects.

Geological engineers in Colombia are trained to work in areas such as geotechnical engineering, hydrogeology, seismic engineering, environmental geology, and natural resource management, among others. Their training allows them to apply their knowledge to complex engineering and environmental problems, contributing to sustainable development and mitigation of geological risks.

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