PHYSICAL AND ENGINEERING GEOLOGY

S.K. GARG

PHYSICAL AND ENGINEERING GEOLOGY

[Textbook meant for B.E. (Civil), B.E. (Mining), B.E. (Metallurgical), B.Sc. (Geology), Civil Services (IAS) Competitions and A.M.I.E. Section B. Exam.]

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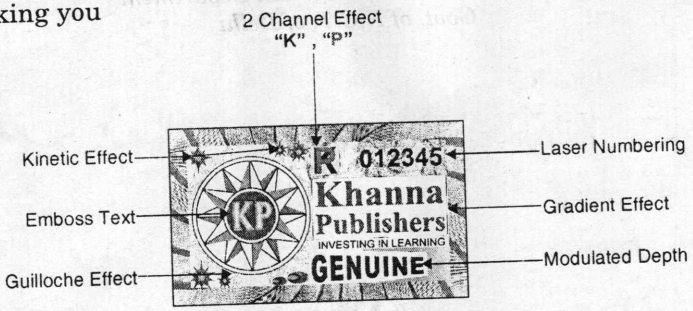

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PREFACE (7th Revised Edition)

Geology, as you will read in this book, is the science of the Earth. It is the science of that Earth, on which you, I, and all of us are living. It is the science of that Earth, on which all of us were born and on which all of us will die. It is the science of that Earth, which is the mother of all living beings. It is the science of that Earth which provides us life and resources to eat and live, thereby sustaining life.

When the Earth enjoys such a great importance, then who among us will not like to know about it ? Who among us will not be curious to know as to how the Earth originated, and what is its past, present and future too ? This information about the Earth shall be provided to us only through the study of Geology. Geology will not only tell us about the history of Earth, but will also tell us about the various physical processes that are occurring on Earth. Say for example, it will tell us about the reasons for the eruption of spectacular volcanoes and the devastating Earthquakes, about which you must have read in the print media, or which you must have seen on your television sets, if not seen in your actual life. It is the science which tells us the reasons for the formation of great mountains or deep valleys, and of beautiful shapes and scenries around us. It is this science which explains to us, the several astonoshing facts about the processes, that have occurred on Earth during its long history of more than 4000 million years. **Some of such startling facts about the Earth and Earth's processes** are indicated below :

(*i*) All the continents into which the today's world is divided, used to exist as a single land mass. These continents have drifted, and are moving even today.

(*ii*) *The Earth had been totally engulfed in ice, six times during its historical past*. Such an intense cold period, known as **glaciation**, last occurred as recently as around 20,000 B.C.

(*iii*) Only 9 out of more than 100 known elements, constitute more than 99% of the Earth's crust (rocks made of minerals).

Had the remaining scarce elements like gold, silver, platinum, chromium, manganese, copper, lead, zinc, etc., been uniformly distributed, there could have been no ore deposits at all. That would have meant, no

industries and no civilisation. But the nature has concentrated this small percentage of valuable elements in workable ore deposits.

(*iv*) The fossils present in rocks of different geological ages provide us enough proof about the evolution of life on Earth, at minimum of about 3600 Million years ago. This life originated in the sea and then extended to the land. The trend was as follows :

Unicellular organisms → *Trilobites* → *Fish* → *Amphibians* → *Reptiles* → *Birds*, *Mammals*

The mammals, including the man, presently dominating the world today, were infact non-existent for nearly 80% of the initial years of the Earth's history, at which time, the presently insignificant lizard-like creatures dominated the Earth, and were represented by the physically well developed giant creatures, like *dinosaurs*. You might have seen such creatures in the english movie, "Jurassic Park".

(*v*) The north and the south poles were not at their present positions in the past. They were at some different places, which eventually means that the climatic conditions had changed repeatedly in different parts of the world.

(*vi*) The Indian land mass, at present, does not have even a single active volcano ; but the same country had experienced very intense volcanic activity nearly 60 Million Years ago, when lava flowed far and wide, leading to the formation of volcanic rocks over an area, as large as 8 lakh sq. km.

(*vii*) The great Himalayas, the tallest mountains of today, have been formed in the recent past, over the place, where a sea, named **Tethys**, used to exist.

(*viii*) For thousands of millions of years, *the natural external forces*, like winds, rivers, glaciers, etc., have been relentlessly eroding the hills and mountains. Inspite of such a large scale erosion, balance has been maintained, because the *internal tectonic forces* are uplifting the Earth's crust, thereby creating hills and mountains again and again.

Contents

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Introduction to the Subject of Geology

1.1. Definition and General Introduction

We live on a wonderful planet, called the Earth, yet how little most of us really know about its composition and history. We consume the products of soils which have been formed by the weathered rocks ; we use coal, natural gas and oil formed from the remains of pre-historic plants and animals ; we enjoy the beauty of precious stones. But these are only a fraction of the valuable materials, which have been bestowed on us, by the Earth. Think of the importance of the Earth's products in the development of modern industry. Our vast mineral resources, such as lead, iron, coal and petroleum are derived from the Earth, and these basic products have been made available to us easily, by the application of a science, which deals in the study of the Earth. *This science, which deals with the study of the Earth, is known as Geology*. The term "Geology" has been derived from the Greek words *Geo* + *logos*. *Geo* means Earth, and *logos* means discourse or study or science. The subject of "Geology", therefore, deals with the study of the wonderful planet 'Earth', on which we are living. The science of Geology tells us about the origin, structure and history of the Earth and its inhabitants, as recorded in the rocks. Without its study, one remains ignorant about the same planet on which one is living.

The Earth has not only provided us with the minerals and other products, which are used and consumed by us ; but has also provided us with so many scenic things, which we call as the products of 'nature' or 'God'. The areas of exceptional beauty, like the great mountains, the deep awesome gorges, the fascinating lakes, the charming springs, the marvellous coral reefs, the spectacular volcanoes, the stupendious water falls, and what not. Even the man itself is a product of Earth and its surrounding environment. All these and many more things are the results of *geological processes* that are still at work within and on the Earth, even today. They are

the same processes which began to shape the Earth soon after its birth some four or five billion* years ago.

The event of July 1969 took Geology out of its original sphere, and plunged it into *space Age* : man had set foot on the moon and brought back samples of moon rocks for the geologist—the Earth scientist, to study. Who knows to what such studies will lead ? Shall we have a clearer picture of the origin of both moon and Earth ? Shall we find on the moon, rich mineral deposits, or minerals as yet unknown to us.

Perhaps, we will be visiting other planets within our solar system in the coming years ; this too, will create fascinating new branches of geology.

But now, let us return to our own planet. To a geologist, the Earth is not a simple globe, upon which we live ; it is an ever-present challenge to learn more about such things as *earthquakes, volcanoes glaciers*, and the meaning of *fossils*. How old is the earth ? Where did it come from ? Of what is it made of ? What will happen to it in future ? To answer such questions, the Earth scientist (geologist) must study the evidence of events that occurred millions of years ago. He must then relate his findings to the results of similar events that are happening today. He tries, for example, to determine the location and extent of ancient *oceans* and *mountains*, and to trace the evolution of life as recorded in the rocks of the different ages. He studies the composition of the *rocks* and *minerals* forming the crust of the Earth, in an attempt to locate and exploit the valuable economic products that are to be found there.

In persuing his study, a geologist heavily relies upon other basic sciences, such as *astronomy, chemistry, physics, biology, zoology, botany*, etc. For example, **astronomy**, which deals with the study of the nature and movements of planets, stars and other heavenly bodies, tells him as to where the earth fits into the universe, and has also suggested several theories as to the origin of our planet. **Chemistry**, for example, deals with the study of the composition of substances and changes which they undergo, helps a geologist in analysing and studying the rocks and minerals of the Earth's crust. The science of **physics**, which deals with the study of matter and motion, again helps a geologist to interpret and explain the various physical forces affecting our Earth, and the reactions of the Earth's materials to these forces.

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*1 billion = 10^9 = 1000 million = 100 crore.

Similarly, to understand and interpret the per-historic plants and animals, a geologist takes the help of **biology**, which deals with all living forms. Similarly, **Zoology** provides him detailed information about the animals ; and **botany** gives insight into the nature of ancient plants. By using all these sciences as well as others, a geologist is better able to cope with the many complex problems that arise in the study of the Earth and its history.

1.2. The Scope of Geology

The *scope of geology* is so broad that it has been split into two major divisions : (1) *Physical geology* ; and (2) *Historical geology*. Each of these divisions, have for convenience of specialised study, been further sub-divided into various branches or sub sciences, as shall be discussed a little later. The term **Earth science** is commonly used in conjunction with the study of the Earth ; although Earth science includes the study of geology, and also encompasses the sciences of *meteorology* (the study of the atmosphere), *oceanography* (the study of the oceans), and astronomy of course.

1.2.1. Physical Geology. Physical geology deals with the Earth's composition, structure, the movements within and upon the Earth's crust, and the geologic processes by which the Earth's surface is, or has been changed. This division of geology includes in itself, the following branches :

(*i*) *mineralogy* ;
(*ii*) *petrology* ;
(*iii*) *structural geology* ;
(*iv*) *geomorphology* ; and
(*v*) *economic geology*.

These branches are defined below :

(*i*) **Mineralogy.** The *mineralogy*, obviously deals with the study of minerals. Minerals are the basic constituents of rocks, and thus, influence the properties of the rocks. Hence, inorder to know the properties of the rocks, one has to study the properties of the minerals. In mineralogy, therefore, the mode of formation, composition, occurrence, types, association, properties, uses, etc. of the minerals, shall be studied in details. This study will help the civil engineers to know as to why the rocks like Quartzite and Marble, which though resemble in shine, colour and appearance, yet differ widely in their behaviour ; Quartzites being very tough, strong and durable ; while Marbles disintegrate and decompose in a shorter period. This happens so, because of the differences in their mineral compositions.

(*ii*) **Petrology.** The term Petrology is derived from the Greek word, *Petro + logos*. Petro means rocks and logos means study. *Hence, petrology means the study of the rocks*. Since the Earth's crust, also called **lithosphere**, is composed of different types of rocks, their study is done under this branch, which deals with the study of mode of formation, structure, texture, composition, occurrence, types, etc. of the various rocks of the Earth's crust.

(*iii*) **Structural Geology.** The rocks which constitute the Earth's crust, have undergone and continues to undergo various deformations, dislocations under the influence of tectonic forces ; causing formation of *geological structures* like *folds, faults, joints, unconfirmities* etc., in the rock masses. The details of their mode of formation, causes, types, classification, importance, etc., are studied in this branch of physical geology. Since the structural features of rocks do affect the strengths and behaviours of the various rocks rendering them more suitable or unsuitable for engineering uses, their study to the engineers becomes as important as that of petrology. Say for example, sedimentary rocks at a dam site become suitable when their beds dip in the upstream direction ; whereas the same rocks become unsuitable when their beds dip in the down stream direction.

(*iv*) **Geomorphology.** This branch of geology explains and studies the origin of various surface features of the Earth.

(*v*) **Economic Geology.** This is a specialised division of Mineralogy and Petrology, wherein the products of the Earth's crust having good economic value, are studied. Valuable *Ores*, containing metals, like diamond, gold, etc., *economical minerals like coal, petroleum*, etc., do come under the domain of this specialised study. It includes the study of their occurrence, search, and exploitation for commercial and industrial uses.

1.2.2. Historical Geology. Historical geology deals with the study of the origin and evolution of the Earth and its inhabitants. Like physical geology, this division of geology has also been bifurcated into several branches, due to the variety and vastness of this field. Each of these branches is actually a science in its own right, and one may devote a lifetime to study the specialised subject in any one of them. The various sub divisions of this branch of geology includes :

(*i*) *stratigraphy* ;

(*ii*) *palaeontology* ; and

(*iii*) *palaeogeography.*

These branches are defined below :

(*i*) **Stratigraphy.** These studies help in working out the geologic history of an area, and is concerned with the origin, composition, proper sequence, and correlation of the rock strata. The term stratigraphy has been derived from the Greek words : *strata* + *graphy*. *Strata* means the sets or beds of sedimentary rocks ; while *graphy* means the description. Hence, this branch of science deals with the study of the beds of the sedimentary rocks. The study of such rocks give an indication of the time that has passed since their formation ; thereby indicating the life history of the rocks and of the Earth and its inhabitants. The study of these rocks will also involve extraction of fossils, *i.e.* the remains of plants and animals of the past geological Eras. These fossils, are so important, that specialists are now a days examining them in another branch of historical geology, called palaeontology. This study, thus helps in identifying the ages of the rocks of the various regions and areas, thereby assisting in delineating their general civil engineering uses.

(*ii*) **Palalentology.** Palalentology deals with the study of the ancient organisms, plants, and animals, etc ; as revealed from their remains and remnants (*i.e. fossils*). This study helps in providing a background to the development of life on Earth, over the past geological eras.

(*iii*) **Palaeogeography.** This branch of science deals with the study of the geographic conditions of the past times. It, thus deals with the reconstruction of the relations of the ancient lands and seas, and the organisms that inhabited them.

These branches of historical geology are, infact interconnected with each other, and overlap also in various respects ; as is the case with the various branches of physical geology.

1.3. Geology Around us

If we start thinking in terms of geology, we will always find geology around us. Whether we are walking through the fields ; or driving through the country ; or standing near a temple or a building ; or sitting at a place, we will always be incontact with the processes and materials of geology. For example, pick up a piece of Limestone rock. There will probably be fossils in it, which may well represent the remains of the animals that lived in some prehistoric sea, which once covered the area.

Similarly, say for example, we are walking along a river bank, and notice the silt, which has been left on the bank by the river floods. This should, in geological parlance, remind us of the ability

of the running water to deposit sediments—sediments that may on a later date be transformed into rocks. At the same place, if we notice, we can find the scoured river banks, which have been eroded by the swift water currents. This will indicate, as to how the soil has been removed by *erosion*—a geological process, which is so very important in shaping of various features of our Earth's surface.

Sometimes, you may notice a field of black fertile soil supporting a fine crop of corn. You may be surprised to know that this dark rich soil may have been derived from an underlying chalky white Limestone—still another reminder of the importance of Earth's material in our every day life.

Sometimes, you may be sitting or standing near a building or a temple, where you will notice various types of stones used in flooring ; or in face work ; or in structural members. Will you not like to know as to what rocks are they, where are they found, and what are their strengths and costs ? *All these details shall indeed be provided by the study of geology.*

Geology, therefore, concerns with our daily life, and is the most interesting and useful subject for a layman as well as for knowledgeable people like you. One must know, if not in a specialised manner, then atleast in a general way, something about geology. The engineers, particularly the *civil engineers*—who have to use the rocks for construction purposes, and the grounds (soils and rocks) for supporting their engineering structures like dams, roads, bridges, railway tracks, docks and harbours, tunnels, etc ; must have a good and a thorough knowledge of the subject. Similarly, the *mining engineers*, who have to mine the rocks, to take out ores and other rocks for their various economic and building uses, must be well aware of this subject.

Here is a book, which explains this fascinating science in a simple and lucid manner, as to make it easily understandable, even with average callibre and intelligence. The study of the subject may also take you amidst the mountains, rivers and oceans to study their rock types, geological features, and other phenomena, which you will really enjoy, since it will bring you in close vicinity with the finest scenery that the world provides.

—2

The Earth on Which We are Living

2.1. The Universe and the Solar System

The earth on which we are living is a 'remarkable' astronomical body in the entire universe, even though it is neither the largest or the heaviest, nor the fastest or the slowest member of our *solar system*. It is, infact, a very insignificant component of our solar system, which consists of nine major planets (including the earth) moving around a central body—the Sun. Besides these nine major planets, there are 32 *moons* or *satellites*[1], vast number of *asteroids*[2], thousands of *comets*[3], and innumerable *meteors*[4], which constitute the integral part of our solar system. The nine major planets and their moons are revolving in nearly the same plane around the sun. In addition to this movement around the sun, these planets are undergoing constant rotation about their own axis. [The times taken by different planets to complete the full revolution around the sun, and rotation about their own axis are shown in column (6) and (7) of table 2.1]. The *inner* four planets, in the order of increasing distance from the sun are (1) Mercury ; (2) Venus ; (3) Earth ; and (4) Mars. The *outer* group consists of (5) Jupiter ; (6) Saturn ; (7) Uranus ; (8) Neptune ; and (9) Pluto.

The four inner planets are also known as **terrestrial planets** because they are about the same size, and their density suggests a composition of iron and stone. They are, thus, characterised by relatively smaller mass, much higher average density (above 4.2)

1. **Satellites** or **Moons** are those celestial bodies, each of which are revolving around any of these nine planets.

2. **Asteroids** are the minor planets, generally situated between the orbits of Mars and Jupiter, as shown in Fig. 2.1. The largest of these bodies probably exceeds 700 km in diameter, and the smallest visible ones are 2 to 3 km across.

3. **Comets** are the heavenly bodies having a long tail pointing approximately away from the sun, and a brighter head section (coma) that contains a small bright nucleus.

4. **Meteors** are smaller solid bodies moving through the space, and getting illuminated while entering earth's atmosphere.

and faster speeds of rotation. These four planets have also been referred to as *minor planets*. The five outer planets are the *major planets* which resemble the terrestrial planets, but are usually treated as a separate group. They are characterised by heavy mass, much lighter in average density (below 2.4), and sluggish in speeds of rotations.

Astrologers agree that all the major planets have already been discovered. The latest and the most recent discovery was that of the

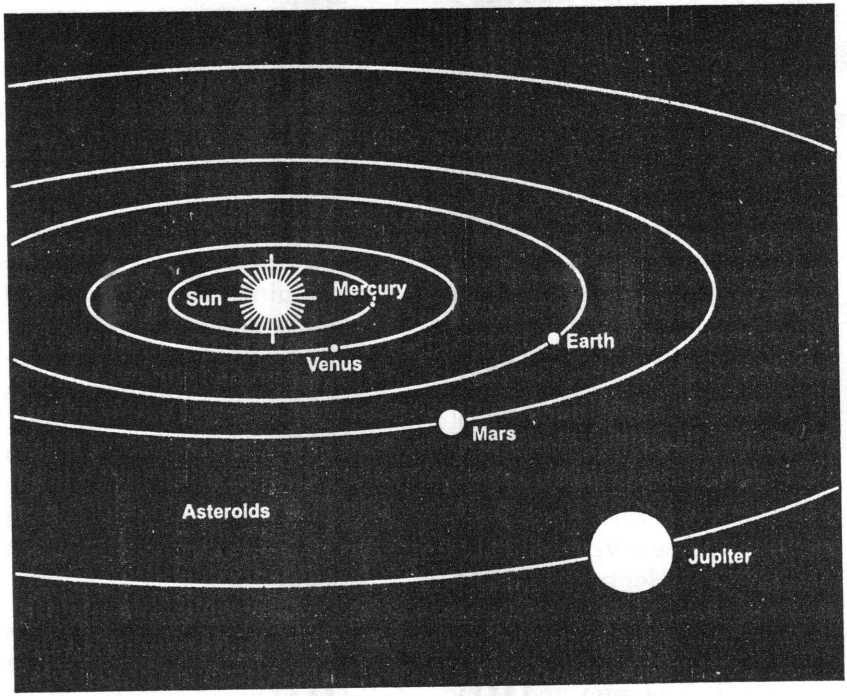

Fig. 2.1. Figure showing a part of the solar system in space. The sun is in the centre and the observer is located beyond Jupiter.

planet Pluto, the farthest planet from the sun, and whose position in space was predicted by astronomers more than a decade before the actual discovery in 1930. The only planet, for which no moons are known, are Mercury, Venus and Pluto. The Earth has only 1, whereas Saturn has 10, and Jupiter has 12 ; Mars and Neptune have 2 each, and Uranus has 5.

Even inspite of the fact that the earth is a very insignificant component of our solar system, and much more insignificant part of

our universe*, it has been termed as 'remarkable', mainly because of the fact that out of billions of celestial objects in the universe, it is the only body which is certainly known to support life, as we know it today**. It also becomes important to us because it is our home and we live on it. So let us now study this planet in details.

Table 2.1. Certain Important Facts about the Solar System

S. No.	*Name of the Planet or the Celestial body*	*Average Distance from the Sun in Million km*	*Equatorial Diameter in km*	*Density (water 1)*	*Length of time for one trip around the sun (earth unit)*	*Length of time for one revolution about the own axis (earth unit)*
(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
1.	Mercury	57.91	4878	3.80	88 days	59 days
2.	Venus	108.2	12100	4.85	224 days	243 days (Retrograde)
3.	Earth	149.6***	12,756—12,714	5.52	365 ¼ days	23 hrs. 56 min. 1 sec
4.	Mars	227.94	6,793—6,753	4.01	1.9 years	24 hrs. 37 min
5.	Jupiter	778.33	1,42,880—1,33,540	1.33	11.9 years	9 hrs. 50 min.
6.	Saturn	1,426.98	1,20,000—1,06,900	0.73	29.5 years	10 hrs. 14 min
7.	Uranus	2,871	50800—49400	1.22	84 years	10 hrs. 49 min
8.	Neptune	4,497	48,600—47,500	1.41	164.9 years	15 hrs. 48 min.
9.	Pluto	5,914	5500	(?)	248 years	6.4 days
	Sun	—	13,83,740	1.41	—	25 days
	Moon	150	3,480	3.34	—	28 days

*Previously it was thought that the universe consists of only the *milky way*—a galaxy containing the sun and the planets of our solar system. But now it has been established that the universe contains billions of galactic systems and each galaxy consists of billions of individual stars. In this way, our solar system becomes a very insignificant fraction of our universe, in the astronomical sense.

**The recent studies have shown that the possibility of life on Mars cannot be entirely ruled out.

***This distance equals one astronomial unit (A.U.).

2.2. The Planet No. 3 (The Earth)

From the above discussion, it becomes obvious that the Earth's place in the universe is indeed small, and compared to other planets, it is not too large in size. Even inspite of that, Earth is a sizeable body, with a polar diameter of about 12,714 km, and equatorial diameter of 12,756 km, and thus has an equatorial bulge. The circumference of the earth is about 40,000 km, and its **surface area is about 510 million square km**. Its volume is about 1042 billion cubic km, and its mass is about 5.97×10^{21} tonnes. In shape, the earth is like an oblate spheroid. That is, with the exception of a slight flattening at the poles, the earth is nearly spherical or ball shaped (see Fig. 2.2). This minor flattening or earth's equatorial buldge is caused by the centrifugal force of rotation. This midriff bulge of earth is very minor in the sense that on a model earth of 8 metre in diameter, one could hardly see it, for this slight protuberance would amount to less than 2 cm. On the same scale, our highest mountains would rise to about $\frac{1}{2}$ cm above the sea level.

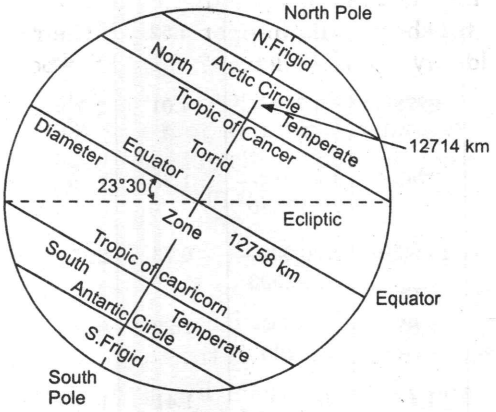

Fig. 2.2. The spheroidal Earth.

But despite its relatively unassuming statistics, ours is a most fortunate planet that seems "just right" in many ways. Its general size, composition, daily rotation, and its distance from the sun perhaps provides optimum conditions for the development and continuation of life. The fact that Earth is the only planet that appears to have a large supply of water, has undoubtedly had much to do with this. Earth's No. 3 position is also very important, for at about 150 million km from the sun, it is neither too near it, nor too far off it. Has it been very near to the sun like mercury, the heat and temperatures would be enormously high (*i.e.* 330°C) and seas would have literally boiled away. On the other hand, if it would have been

PHYSICAL AND ENGINEERING GEOLOGY

Geology, as you will read in this book, is the science of that Earth on which all of us were born and will die. It is the science of that unique planet of our solar system, which alone survives life in different forms.

Physical Geology will not only deal with the past, present and future of the Earth, but also with the various physical processes that are occurring on Earth including ***Volcanoes and Earthquakes.*** It will also explain the forces that cause the ***formation of mountains*** and the ***shifting of continents.*** This subject will take you closer to the natural beauty of this world.

Engineering Geology will cover safe and sure mining operations through the body of the Earth to extract minerals, metals and other building materials. Thorough geological subsurface investigations would be of paramount importance in the design of all the civil engineering structures, like dams, reservoirs, bridges, buildings, harbours, etc.

This book provides comprehensive details of the entire subject, including the ***historical geology*** and ***stratigraphy of India***, in lucid language. It is expected to be of immense use to the students of science and engineering courses, besides being able to serve as an excellent study material for Civil Services (I.A.S.) Competition, wherein this simple and interesting subject can be offered as one of the optionals.

The author, **Mr. Santosh Kumar Garg**, is a veteran in the field of Civil Engineering, and has eight widely acclaimed books to his credit. His books on **Environmental** and **Irrigation Engineering** are being followed in various Engineering Colleges in India and abroad. His two new publications, titled **Geotech Engineering** and **International and Inter-state River Water Disputes,** have already gained immense popularity within a short span of their publications.

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