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DARWIN's influence in the development of the igneous petrology

"I cannot avoid the conviction that some great law of nature remains to be discovered by Geologists"
(Darwin, unpublished red notebook)

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DARWIN hatása a magmás kőzettan fejlődésére

Összefoglalás

DARWIN korának nagy tudósa volt. Habár lényegében a biológia tudományában elért eredményeiért közismert, ugyancsak hozzájárult a geológia, egyebek mellett a magmás kőzettan fejlődéséhez, miközben bekapcsolódott a korában a témakörben zajló heves vitákba. Érdeklődését a petrológia iránt a Beagle expedíció során megtett megfigyelései váltották ki. A „magmás differenciálódásról" szóló elmélete erős befolyással volt a kőzettan fejlődésére. A tárgybéli elmélet kidolgozásához használt módszere meglepően hasonlít ahhoz, amit a fajok evolúciója elméletének a megalapozásához használt.

Tárgyszavak: Darwin, magmás kőzettan, geológia

Abstract

DARWIN was one of the truly great scientists of his epoch. Although essentially known for his contributions to biology, he also promoted the development of geology — especially in the field of igneous petrology — by his active involvement in the controversies of his days. His interest in petrology was based on the observations he made during the Beagle expedition. His theory on "magmatic differentiation" had a strong positive influence on the development of petrology. The method he used for the development of this theory is very similar to that he propounded for the origin of species.

Keywords: Darwin, igneous petrology, geology

Introduction

At the beginning of the 19th century, science was in a state of turmoil due to the important social and economic changes. DARWIN was a great scientist of that epoch who contributes to the development of science in general, but he is mostly known as the author of "The origin of Species by means of Natural Selections". Less acknowledged is his contributions to geology despite the fact that in his youth he was devoted more to geology then to other sciences. During his voyage on the Beagle he was employed as a naturalist and practiced as both a geologist and a biologist.

DARWIN established a number of new ideas for the development of petrology which were suggested to him by the construction of oceanic islands or by the theory of gravitational differentiation and hydraulic pressure leading him to the conclusion that the distinct rock types have a common origin in melting processes in the Earth's interior. However, this fundamental theory for the development of petrology has not usually been attributed to DARWIN.

The evolution of DARWIN'S areas of investigation and ideas led us to consider that the methods used in his geological studies were valorized in his later works, and there is a likely link between the theory on the origin of the species and his results on the origin of igneous rocks.

His geologic formation

DARWIN (1809–1882) was born when the French revolution brought changes in the society, religious radicalism was losing impact, and the emerging liberal society was clamoring for the end of slavery. Considering the industrial revolution with its growing necessity for row materials to this social turmoil, one would find the place and social environment of his early studies. These circumstances were complemented by the level of geological knowledge present at that time in university teaching. DARWIN took classes in Geology at Edinburgh University when he started his studies in Medicine and at Cambridge University when he studied Theology.

The scientific controversies of that period were saturated by religious thinking, since not all scientists were able to reject the biblical paradigm. According to HALLAM (1983) that period was dominated in the geological community by the debate between the 'plutonists' (HUTTON) and 'neptunists' (WERNER) having its climax in Britain at the beginning of the 19th century. It was the place where these theories were argued about with the greatest ardor, but another decade passed to the point when both treatises of these fundamental theories were published. The "volcanists" were situated in between by recognizing that the origin of the basalts is associated with volcanoes. However, the puzzle remained as for what the basalts actually represent. Were these melts formed in the Earth's interior or did they rather result from an effect of underground burning of carbon-bearing sediments? In order to solve this problem there was a rush for observing European volcanoes, then to study the volcanic oceanic islands.

Other controversy of that epoch was that between the 'Catastrophists' (ELIE DE BEAUMONT) and the 'Uniformitarists' or 'Actualists' (LYELL). At the beginning DARWIN was influenced by 'neptunism' due to his professor JAMENSON in Edinburgh, but later he turned to plutonism connected to actualism. DARWIN conclusively followed LYELL's theories from the Principles of Geology.

It is possible that 'actualism' has considerably influenced DARWIN's concepts of the biologic evolution that will establish the basis of his concept of historical evolution of Earth.

The Beagle expedition

DARWIN was selected for the expedition on the Beagle because his geological knowledge. His grandfather ERASMUS, a neptunist, together with his teachers during the university years in Cambridge, HENSLOW and SEDGWICK, had a considerable influence on the geological knowledge of DARWIN after his bitter experience in Edinburgh with the 'neptunis' JAMENSON. The selection of DARWIN for the Beagle expedition was determined by his practical experience in Geology, recognized following his work undertaken in North Wales with SEDGWICK (SCORD 1991). According to his sister Carolina, he was so dreamy for the expedition to the "tropics" that he started to learn Spanish and to read geological information about the islands.

DARWIN was recommended by HENSLOW to Captain FITZROY to be accepted on the Beagle expedition to South America that started in December 1831 and finished in 1836. The endeavor, beyond its scientific purpose, also had a military mission to find the most important ports to be acquired for the English army. The relationships between DARWIN and the Captain have not been friendly, since the captain was conservator while DARWIN was a liberal in their respective scientific and social ideas.

Before embarking, possibly influenced by his grandfather, DARWIN already had in mind the idea to write a book about his geological findings during the expedition. He wished to follow LYELL's 'Principles of Geology' (1830–1833) and the writings of two former 'neptunists' — von BUCH and HUMBOLDT — who had changed their ideas after visiting oceanic islands.

BOWLER (1990) considered that DARWIN had many more geological ideas ('huttonian' and 'actualistic') than biological at the time when he embarked on the Beagle. During the months spent in Plymouth before embarking, he performed some fieldwork to get familiar with geological mapping.

HERBERT (1991, 2005) has divided the field notebooks of DARWIN completed during the Beagle campaign as follows:

1. The field notebooks.
2. The specimen notebooks.
3. The proper geological notes, generally organized according to locality, and running to 1383 pages, in contrast to 368 pages for the zoological notes. The physical appearance of these notes suggests DARWIN's method of composition. The notes are written on one side of the page only, specimen numbers keyed into the notes and usually appearing in the left-hand margin. Versos are left empty for footnotes, which are plentiful and give the manuscript a dense and almost prematurely scholarly appearance. Throughout the geological notes there is an evidence of later annotations, some dating from the voyage as DARWIN revised and enhanced his own earlier work, and some dating from after the voyage as DARWIN reworked his material for publication.
4. Several synthetic essays written towards the end of the voyage including 'Coral Islands', 'Recapitulation and concluding remarks' on the geology of South America, and a set of 36 folio pages on cleavage.
5. Two notebooks, 'Santiago Book' and 'RN' or the 'Red Notebook', which DARWIN used partly to prepare for publication

This long journey was used by DARWIN for writing a large amount of scientific notes and for collecting various types of samples to help him later to write publications. Some of those publications were specifically geological in nature, the geological information being superior to the biological one.

Geologist in London

After returning from the expedition on the Beagle he was privileged as he owned a huge amount of scientific material and he understood that its study had to be connected with the scientific life in London, therefore he decided to be located there. Later on he moved in the small town of Down, close to London. He started to perform an intensive geological activity, more than he has done in the biological field which was addressed at a lesser extent in that period.

In his autobiography he wrote that he felt himself a geologist after reading 'The Principles of Geology" (SÁNCHEZ RON 1997). Although he did not entirely share LYELL's ideas, he always supported them. He was confirmed as a geologist when he visited the volcanic island Santiago in the Cape Verde archipelago (*Figure 1*). In a letter to HENSLOW he wrote about Santiago: *"The geology was pre-eminently interesting & I believe quite new: there are some facts on a large scale of upraised coast ... that would interest Mr Lyell ... St Jago is singularly barren & produces few plants or insects — so that my hammer was my usual companion & in its company most delightful hours I spent ... Geology & the invertebrate animals will be my chief object of pursuit through the whole voyage"*.

Figure 1. Landscape on the volcanic island of Santiago (Cape Verde archipelago), Post Hill area, probably as it was seen by DARWIN when visited it as a geologist. Photo credit: Eumenio ANCOCHEA

1. ábra. *Tájkép Santiago szigetén (Zöldfoki Szigetek), a Post Hill környékén, ahogy azt DARWIN láthatta, amikor geológusként meglátogatta a szigetet. Eumenio ANCOCHEA fotója*

DARWIN's zest for geology is vividly captured in a letter to his cousin, W. D. FOX, written from Botafogo Bay, near Rio de Janeiro in May 1832. *"But Geology carries the day; it is like the pleasure of gambling, speculating on first arriving what the rocks may be; I often mentally cry out 3 to one Tertiary against primitive; but the latter have hitherto won all the bets"*.

His activity was not focused only on writing books; he was also a very active member of the Geological Society of London founded in 1807. He was nominated a member of it on 30th of November 1836 at HENSLOW's proposal. In 1838 he presented a memoir published in 1840 — collecting his ideas about the theory of Earth and improving in some aspects LYELL's theories — which was very well received. The Society was the centre of geological investigation in 1830's, and the elected President considered that year as "The Heroic Age of the Geology". In 1837 the Society had 709 members, although not all of them attended the scientific meetings. Among others, the names of LYELL and DARWIN have been included in the Directory of Council. Several years later DARWIN was nominated as Secretary, which he gave up due to health problems; he was vice-president for two years and member in the Directory of Council for 14 years.

DARWIN's influence in the Geology of those years was enormous. RHODES (1991) considers him as the most recognized geologist. If we consider this statement in terms of present-day criteria of scientific impact, the citation of DARWIN was superior to any other geologist's. According to the speech of the president WHEWELL in 1838, the citations of VON HOFF (7), TURNER (6), OWEN, LYELL, and SEDGWICK (5 each) have been inferior to those of DARWIN who had been cited 14 times.

Darwin: Contribution to Petrology

At the beginning of 19th century, it was a huge interest for understanding the origin of the granites and basalts and for the classification of rock types, since the recognition of large rock variety is at the base of development in Petrology (PEARSON 1996).

The treatises of WERNER (1787) and HUTTON (1788) and the fiery debate they generated surely was the starting point of the rapid advancement of Petrology as it is considered today. Becoming aware of these disputes, a scientific group from other disciplines added their contributions. The mathematician Playfair, for instance popularized HUTTON's theories and refined them in 1802. The chemist HALL, a friend of HUTTON, started in 1790 to experiment the fusion of materials in crucibles in order to reproduce the natural phenomena; for this reason he can be considered the father of experimental petrology. According to YODER (1993), the development of petrology is marked by a number of milestones such as HUMBOLDT'S (1810) idea that volcanoes are aligned along fractures and earthquakes are associated with volcanism, or that of VON BUCH (1825) who defined the concept of Caldera in La Palma Island (Canary Islands). All these ideas, as well as others associated with magmatic processes, were in DARWIN's mind when he embarked on the Beagle, hence there is no exaggeration to say that he was impregnated by petrologic ideas.

According to YOUNG (2003), his biographers — notably BOWLBY (1990), BOWLER (1990), DESMOND & MOORE (1991) — did not consider him as a volcanologist. DARWIN has never visited the European volcanic areas, or the Canary archipelago, since the Spanish authorities have not allowed Beagle to disembark in Puerto de la Cruz, apparently by health precautions since at that time cholera was raging in England. This was a big disappointment to DARWIN who idealized the Canary archipelago after reading HUMBOLDT. According to VIRGILI (2003), LYELL was later obliged to travel in these islands in 1853–1854, to analyze the popular book of VON BUCH (1825) "Physical Description of the Canary Islands" since DARWIN, his friend, was not able to offer information about them.

One of DARWIN's concerns in order to complete the expedition was to classify and preserve the sample material collected during the expedition. The rock samples went into the custody of the Cambridge University. Apparently this collection has not benefited from a detailed petrographic study, although it has been classified with the rock names of the epoch which considered the volcanic rocks as being divided in two families: 1) the dark ones including the basalts containing pyroxenes and olivine, and 2) the light-coloured rocks, such as trachytes, defined by the presence of feldspars. Also, at that time the first chemical analyses were performed on basalts showing their low SiO_2 content as compared with the bright rocks richer in this oxide, with some exceptions such as obsidians. This collection consisting of more than 2000 rock samples (*Figure 2*) was used later by HARKER (1903) to produce his variation diagrams and to understand the ideas underlying the rock classification by considering the wide variability of rock types shown by DARWIN's collection.

DARWIN's petrologic ideas cannot be considered as being isolated; they have been mixed with other ideas of his geological conception. Considering the whole of his work — field notebooks, maps, autobiography, articles presented at the Geological Society, books and articles based on his field observations and synthesis of his knowledge — the following idea emerges. The lectures of his theories on Earth's formation presented at the Geological Society of London in 1838 and published in 1840 with a modified title ("On the Connection of certain Volcanic Phenomena in South America and the Formation of Mountain Chains"), his other works "Volcanoes as the Effect of the same Power by which Continents are elevated", "Coral Reefs" (DARWIN 1842), "Volcanic Islands" (DARWIN 1844), and "Geological observations on South America" (DARWIN 1846) allow us to consider his global perspective on Earth evolution. The global thesis of DARWIN related to the formation of Earth structures states a connection between earthquakes, volcanism and formation of the cordilleras as related to continental uplift, as a result of slow and continuous changes in the Earth interior. This conclusion was innovative enough in an epoch in which the general point of view was that the formation of the volcanoes is a result of water percolation and reaction with metals which strongly warms up the rocks in Earth's interior (RHODES 1991).

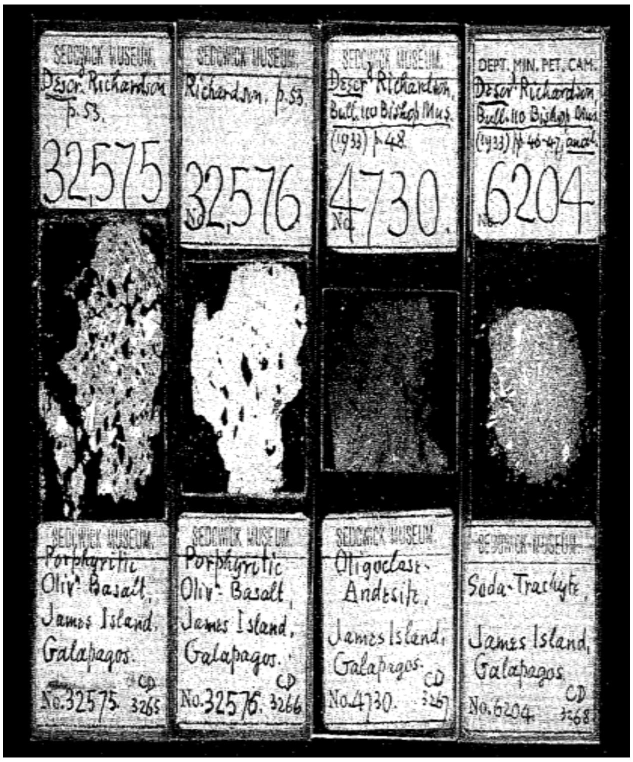

Figure 2. Thin sections from Darwin's petrological collection preserved at the University of Cambridge, used later by HARKER (reproduced in HERBERT 2005, p. 117)

2. ábra. *Vékonycsiszolatok DARWIN Cambridge-ben őrzött kőzettani gyűjteményéből, amelyet később Harker is használt kutatásaiban (HERBERT 2005, könyvéből, 117. oldal, átvéve)*

Geological observations on volcanic islands

DARWIN's book "Geological Observations on the Volcanic Islands" has the most petrologic focus of all his writings, but maybe it would have had no value for him if he had not include chapter VI, where his theoretical considerations to all his observations made during the expedition are presented. The first five chapters describe the visited islands, including field descriptions, where he compared his observations with the previous knowledge of other authors, whose books were taken with him during the journey. The visited islands are: Santiago (Cape Verde), Fernando Noronha, Terceira, Tahiti, Mauricio, San Pablo, Ascensión, Santa Helena, Galapagos Archipelago. The seventh chapter deals with the geology of Australia and Cape of Good Hope.

From the descriptions of these islands it is obvious that he had a particular interest in dikes. At that time it was a controversy related to dike generation: one (neptunist) theory involved their formation via water infiltration and the precipitation of dissolved salts in fissures, while the other (plutonist) view related the dikes to melts coming from the Earth's interior and solidified in fractures. DARWIN was concerned with this problem, using the word "dike" 75 times in his book "Geological Observations on the Volcanic Islands", always describing the characteristics of dikes and their relationships with the country rocks, reflecting his numerous detailed observations performed during the journey.

The sixth chapter "Trachytes and basalts. Distribution of the Volcanic Islands" can be divided into two parts: in the first part he describes how the rocks are generated, while in the second part he discusses how the volcanic islands are formed.

DARWIN presumed that volcanic islands of small size are either coral reefs or are constituted by volcanic rocks at a certain distance from the continents, which means that the majority of the active volcanoes are generated in these islands, or within the ocean close to the shore of these islands. These islands have been formed by a large central volcano and an alignment of small-sized volcanoes. Although this finding was documented previously in VON BUCH's writings, DARWIN suggested that there are no compositional differences between different volcanic islands. Also, he considered that the oceanic volcanic islands are aligned following a simple, double or triple direction, sometimes slightly curved, trying to explain that the internal forces that helped the generation of the mountain chains in general are similar to those found in the volcanic archipelagos. For DARWIN the island groups of Galapagos and Canary are similar, and Cape Verde is slightly different since one of the alignments is curved at its extremities. In his opinion the generation of a volcanic island starts with submarine volcanism recorded by sediment intercalations within the volcanic rocks, then continues with subaerial volcanism and strong erosion processes in the final stages.

Darwin and the processes of crystallization–differentiation

YODER (1993) considers that DARWIN made an important contribution to igneous petrology by theorizing on the differentiation and pressure filtration processes. There have been circumstances to expound this theory, since studies on the rock and mineral densities have already been performed. CAVENDISH (1798) has determined Earth's density, HALL (1805) melted natural rocks, reproducing their textures, making also observations on the mineral distribution in the melt. DARWIN with his 'actualistic' formation and knowledge on the crystallizations of minerals in the melts and their separation considered that the diversity of igneous rocks was not a result of a singularly catastrophic situation, but they have a unique origin being separated one from another. The place where magma with a unique composition was generated is the interior of the Earth. How was this magma able to produce rocks of different composition? Different kinds of crystals have been formed from the melt by crystallization, so the remaining liquid (melt) has changed its original composition. The produced crystals have different densities than the melt; hence they will be distributed according to their densities. For developing this idea DARWIN (1844) considered three sorts of feldspar with densities between 2.4–2.7, hornblendes and augites between 3.0 and 3.4, olivine at 3.3– 3.4, and oxides at 4.8 to 5.2. Therefore, the feldspar crystals have the tendency to ascend, whereas the other crystals descend in the evolved magma. In this way, along the volcanic conduit the trachytes (density of 2.5 g/cm^3) formed mainly of feldspars are overlying the basalts (density of 3.0 g/cm^3) located in the lower part. During an eruption trachytes will erupt first, than followed by basalts covering the trachytes as a rule. Developing this theory DARWIN has cited different authors, and recognized that he already described this situation in his notebooks. However this was not validated in Tenerife where VON BUCH (1825) described basalts covered by trachytes in the upper part of the volcano. To solve this issue DARWIN considered that in evolved trachyte volcanoes basalts can also be generated in the marginal parts of the edifice. Afterward, DARWIN has generalized his theory developed for the volcanic rocks by interpreting the formation of intrusions such as SKAERGAARD, where his ideas have been refined. In supporting his theory he refers to dikes that intrude granites, met during his fieldwork in England, arguing that all have more basic compositions, suggesting that they belong to the lower part of a crystallizing magma body.

Was not DARWIN's theory so important for the development of the petrology, since it was not acknowledged afterwards? PEARSON (1996) answered to this question very simply: one of the most influential people in the development of the igneous petrology during the 19–20th centuries was BOWEN and his work who and all his followers never cited DARWIN, therefore his contribution was forgotten. DARWIN's contribution to geology has been not anymore revealed at the end of 19th century and even DARWIN, although he always loved geology, has abandoned this interest in time.

DARWIN returned from his Beagle journey with an immeasurable amount of data for proving his early launched geological theories. However, improving them would require further expeditions that he never undertook. The main causes that obliged him to renounce to travel were his family and his poor health. For this reason he was then focused on biology where the experimental field was local and open, and he had control on creatures from the different farms.

Darwin's unitary thinking

DARWIN is better known for his theory of the natural selection, than for his geological theories. PEARSON (1996) wondered whether there is any relationship between his geological theories and the biological ones and concluded that the methodologies he used are comparable, following the same type of analogism and the development of one (biological) after another (geological) was performed in succession during the same time period.

In 1835 he collected samples in the Galapagos Islands and took notes that have been used in his both theories and when approaching the end of the journey he was prepared to realize the conclusions for both.

The development of his geological theory started in 1837 and the book "Geological observations of the volcanic islands" was published in 1844. The development of his biological theory started also in 1837, when GOULD (the ornithologist), communicates that chaffinch of Galapagos is not only one species, but manifold. DARWIN revised his notebooks and opened a new one titled Transmutation (book B), that was parallel to book (A) where he sensitized his geological notes. Later on he wrote books C and D where he outlines the ideas related to the two theories. In a letter to LYELL (1838) he wrote that his book of Geology was going well and he believed it to be revolutionary in Volcanology, and additionally he was working on animal species. The book 'Origin of the species' was written only in 1858–1859.

The mechanisms that he proposed in both theories are similar. If in a magma we remove one mineral containing a group of elements from the melt, this melt will be depleted in those elements, provoking a change by diminution, a process similar with that he invoked in his biological theories, as the extinction of the weak species.

The variation of species in the biological selection or the rocks resulted in magmatic differentiation will depend of the mutations in the selection of species, and by composition change and amount of fractionation in magmatic differentiation. If the differences in composition of the initial melt and of the new minerals that are generated are small and there is only insignificant crystallization, the new extracted melt will be very similar to the initial composition. In contrast, if the difference is large, the composition of the new melt will be significantly changed.

A specific difference between the two theories is that the biological theory can discuss on the reproduction and heredity, which in the geological theory does not exist, and consequently the only requirement is to adapt to the closed environment.

Evolutionists such as DAWKINS (1988) admit two types of simple selection: one which has no implications in the heredity and another, accumulative with reproduction. The first case refers to the formation of a crystal in a saline medium, followed by the separation of minerals by gravity, in the very same way DARWIN firstly proposed to generate different types of magmatic rock from a common melt source.

DARWIN developed these two theories — one for magmatic rocks another for species — without explicitly considering the relationships between them, but it is obvious that for both kinds of evolution the separation of minerals and animals, respectively, from a common 'source' (parent) was a natural outcome of selection, a line of thinking deriving from his starting idea of uniformity.

Conclusion

DARWIN is known as the father of the theory of the 'Origin of the Species', but doubtless his contribution is comparably important in other fields of sciences, such as in petrology, where he is largely ignored. In the year of bicentenary from his birth it is our duty to reconsider and acknowledge his influence and merits that he never achieved during his life. With his ideas DARWIN greatly helped the development of the petrologic knowledge, that is not really reflected in handbooks and treatises of igneous petrology in which he is not recognized as the initiator of the theory of fractional crystallization and gravitational differentiation of magma.

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