Chapter

A View to Anorthosites

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Abstract

It seems anorthosites are by far interested by geologists because they give us great information about Earth history and how it was evolved in planetary geology. Planetary geology is subject the geology of the celestial bodies such as the planets and their moons, asteroids, comets, and meteorites. It is nearly abundant in the moon. So, it seems studying of these rocks give us good information about planetary evolution and the own early time conditions. Anorthosites can be divided into few types on earth such as: Archean-age (*between 4,000 to 2,500 million years ago*) anorthosites, Proterozoic (*2.5 billion years ag*o) anorthosite (also known as massif or massif-type anorthosite) – the most abundant type of anorthosite on Earth, Anorthosite xenoliths in other rocks (often granites, kimberlites, or basalts). Furthermore, Lunar anorthosites constitute the light-colored areas of the Moon's surface and have been the subject of much research. According to the Giant-impact hypothesis the moon and earth were both originated from ejecta of a collision between the proto-Earth and a Mars-sized planetesimal, approximately 4.5 billion years ago. The geology of the Moon (lunar science) is different from Earth. The Moon has a lower gravity and it got cooled faster due to its small size. Also, it has no plate tectonics and due to lack of a true atmosphere it has no erosion and weathering alike the earth. However, Eric A.K. Middlemost believed the astrogeology will help petrologist to make better petrogenic models to understand the magma changing process despite some terms geological differences among the Earth and other extra-terrestrial bodies like the Moon. So, it seems that these future studies will clarify new facts about planet formation in planetary and earth, too.

Keywords: Anorthosites, Archean, Proterozoic, the Moon, plagioclase

1. Introduction

Anorthosites can give us great information about Earth history and how it was evolved. They can be divided into few types on earth such as: Archean-age (between 4,000 to 2,500 million years ago) anorthosites, Proterozoic (2.5 billion years ago) anorthosite (also known as massif or massif-type anorthosite) – the most abundant type of anorthosite on Earth, Anorthosite xenoliths in other rocks (often granites, kimberlites, or basalts). Furthermore, Lunar anorthosites constitute the light-colored areas of the Moon's surface and have been the subject of much research. So, these studies will clarify new facts about planet formation in planetary, too.

Magmatic rocks or Igneous rocks are the dominant rock type that the other two main type rocks (I, e sedimentary and metamorphic rocks) are originated them. These Igneous rocks are formed through the cooling and solidification of magma or lava.

Magma is a natural semi-molten material is existed inside the Earth and magmatism is a commonplace phenomenon in terrestrial planets like the Mars and the Venus and some natural satellites such as the Moon. The high internal heat of planets (more than 700°C) like the Earth causes the volcanism phenomenon in which solid rock are formed by cooling magma which are called lava. Definitely, lava is a viscous material but it can be flowed at great distances before cooling as igneous rocks. It should be reminded that melting is not caused by rising temperature, it can also be generated by pressure decreasing or changing in composition, too.

Magma solidification can occur either below or on the surface of the Earth (Planet surface) which are called as intrusive rocks and extrusive rocks, in turn. Moreover, these Igneous rocks can form via crystallization or without crystallization which are called natural glasses. Intrusive rocks which are formed within Earth's crust can be observed as diverse forms even such as dikes (Magmatic dikes are created by flowing magma into a pre-existing fracture of rock body) or even great Batholiths (Large mass of intrusive igneous rock more than 100 square km in area get formed through cooling magma in the depth of Earth.

Petrologists try to find good information about the conditions of igneous rock formation by study them, for example, Plagioclases are really important to identify the origin and evolution of igneous rocks. Fortunately, Anorthosites are dominantly contained Plagioclase minerals and it seems it would be possible to find the answers of suggested questions about how the earth was at own early history and how other extraterrestrial bodies like the Moon get formed, although, Phanerozoic (The eon from the Cambrian Period to the present) rocks are dominantly exposure in the earth as a more evolved planet and Anorthosites are not abundant in the Earth. In a simpler language, these studies will help scientists to make a good planetary formation model which will be vitally important at space exploration time within the solar system or beyond it through the galaxy, or even in astrobiology studies.

2. What are Anorthosites?

Anorthosites are a fascinating type of igneous rocks which are composed predominantly of calcium-rich plagioclase feldspar and mostly formed during Precambrian times. It has to be reminded that all found anorthosites on Earth are contained coarse crystals (See **Figures 1** and **2**) but moon anorthosite samples are finely crystalline which were collected from The Moon highlands (See **Figures 3–5**).

Lunar anorthosites within the light-colored areas of the Moon's surface are subject of investigations to understand the history of moon evolution. It seems the light coloured lunar highland crust was formed by the crystallization and floatation of plagioclase from a global magma ocean, although the actual generation mechanisms are still debated [5].

Additionally, Lunar anorthosites are known for displaying a limited range of plagioclase (~94 to 98) and basis nearly recent studies at 2019 [6, 7], the plagioclase trace-element variations from Apollo ferroan anorthosites (FAN) samples (collected by the Apollo 15 and 16 missions) display more significant chemical heterogeneity and it can give us a better illustration about the timing and formation mechanisms of the Moon's crust. This study clarified a chemical heterogeneity within the LMO[1] as a global moon feature in the crustal formation. It seems that maybe during mantle overturn, the act of exhuming deep mafic-rich cumulates to the base of the lunar crust would have triggered decompression

[1] The lunar magma ocean (LMO).

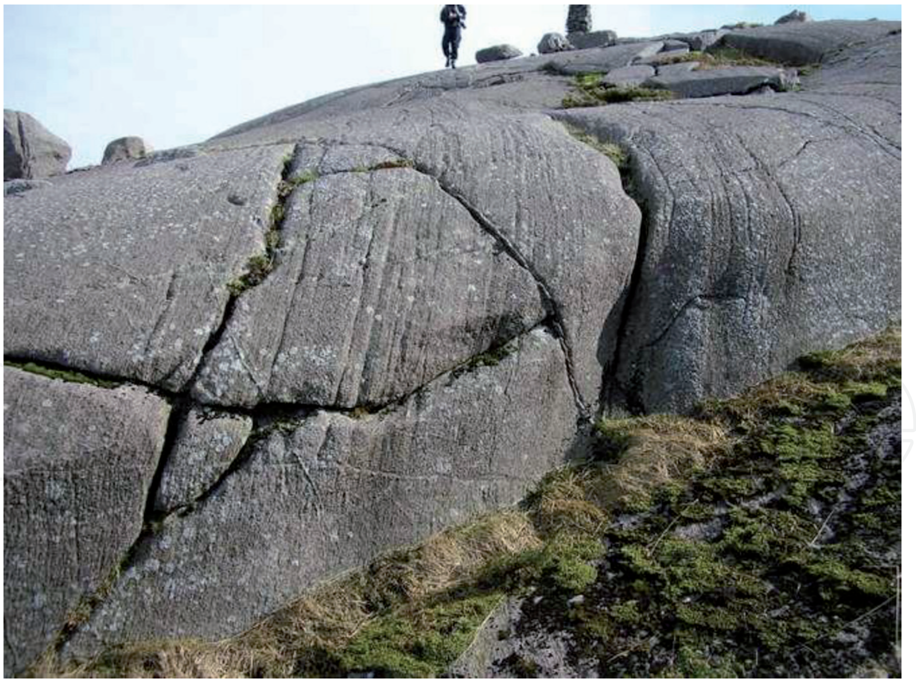

Figure 1.
Large outcrop of anorthosite in the Helleren massif, Jibbeheia, Rogaland-Norway [1].

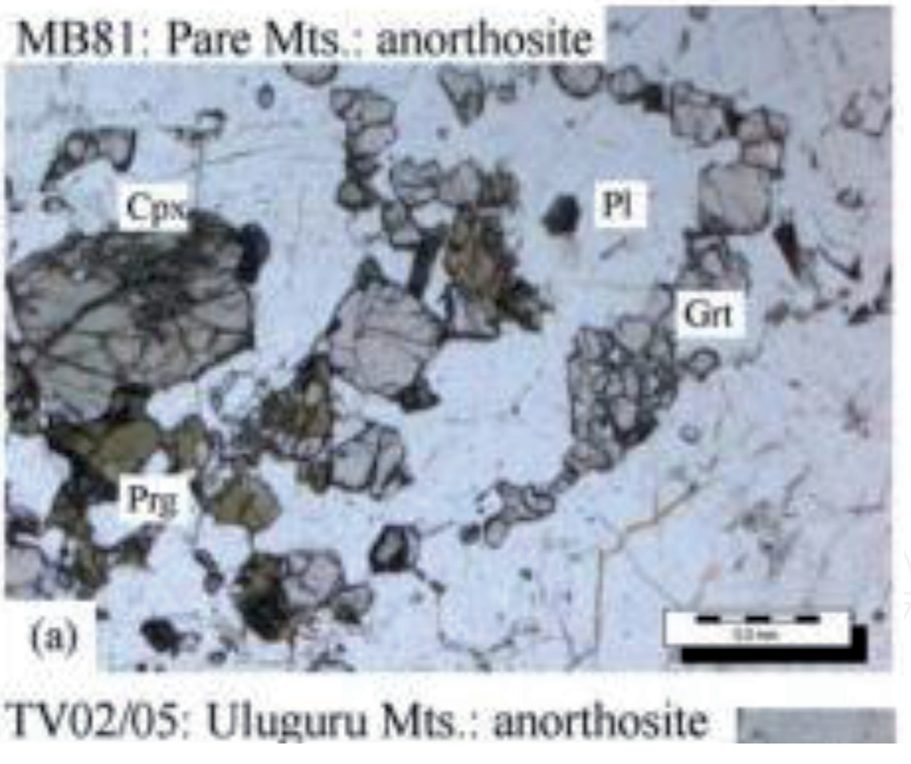

Figure 2.
Anorthosite from the Pare Mountains with mafic lense and Grt (spell out) corona [2].

melting. These are likely to be small degree (<10%) partial melts[2], which are typically enriched in incompatible elements[3]. It is not contradict with the idea of

[2] Partial melting is the transformation of some mass solid rock fraction into a liquid as a result of heat input, decompression or flux addition. This resulting liquid is nominated either magma or lava as if eruption from a volcano.

[3] Incompatible elements own difficulty in entering cation sites of the minerals, so they get concentrated in the melt phase of magma.

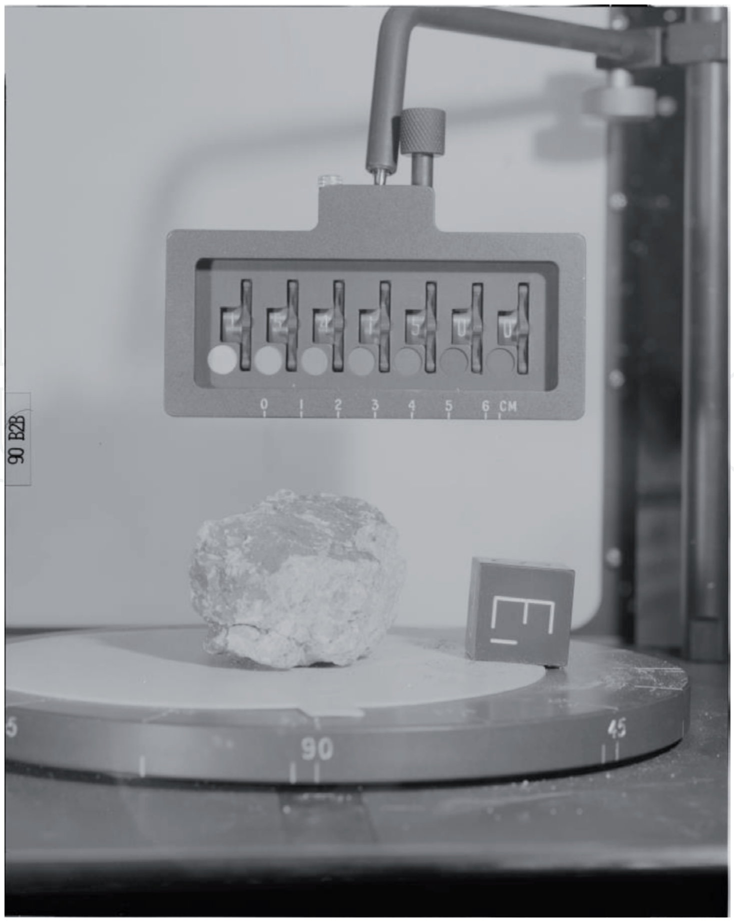

Figure 3.
Black and White Photograph of Apollo 15 Sample (s) 15415-Nasa - Lunar Samples [3].

60025
Ferroan Anorthosite
1836 grams

Figure 4.
Ferroan Anorthosite (1836 grams)- 60025. NASA #S72–41586. Cube and scale are 1 cm. Note the thick black glass coating and numerous micrometeorite pits [4].

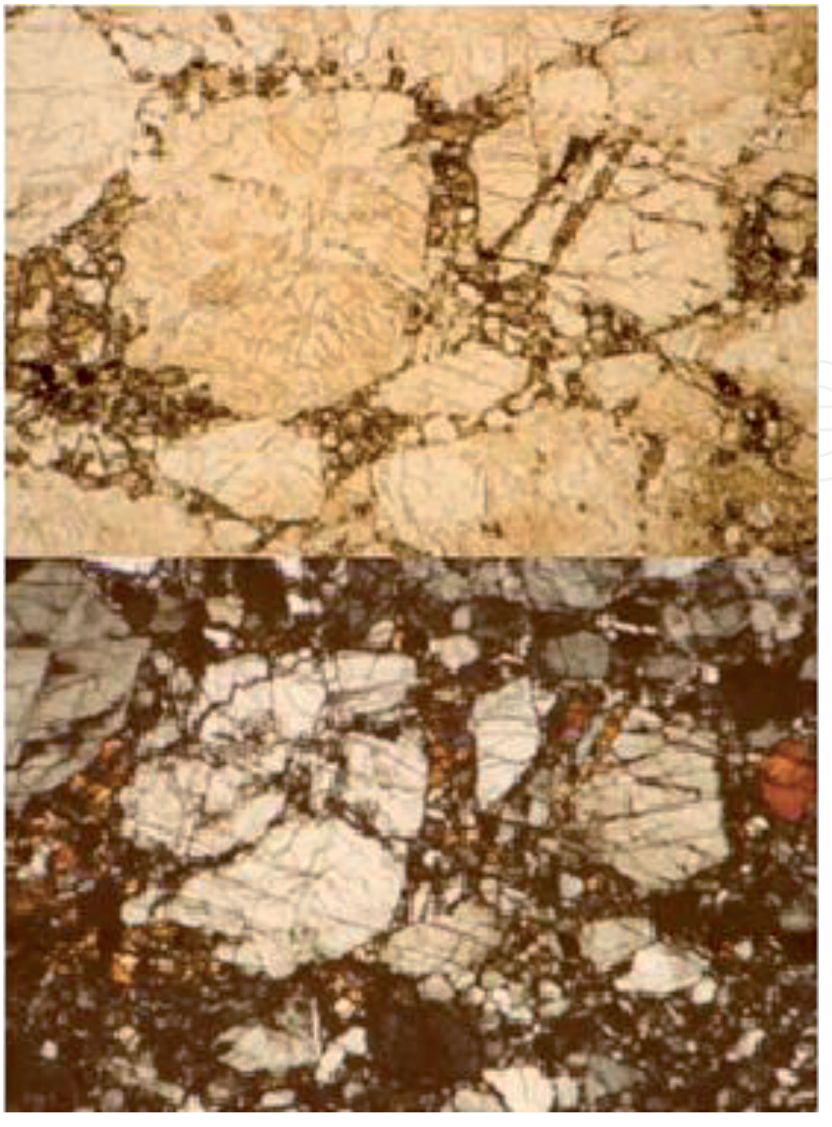

Figure 5.
Plane-polarized and cross-polarized photos of thin Section 60025,21. Field of view is 2.5 mm. S79–27300 and 301 [4].

local LMO magmas infiltration[4] by more evolved liquids through metasomatism[5] process, too.

The terrestrail anorthosites can be divided into five types: Archean-age anorthosites, Mid-ocean ridge and transform fault anorthosites, Anorthosite xenoliths in other rocks, Layers within Layered Intrusions and Proterozoic anorthosite as the most abundant anorthosite kind. Lunar geological studies also clarified that the light areas of the moon also consist of very old anorthosite. The dark areas of the moon, many of which are circular, consist of the black volcanic rock basalt. In fact, the primary pre-Nectarian lunar highlands are contained light-grey anorthosites which are caused at the early moon crust formation.

3. Anorthosites- geologic timescale

The geological history of Moon is categorized into six major epochs which is called the lunar geologic timescale. The boundaries of this time scale are subject to

[4] Infiltration is defined as the flow of liquid such as water from aboveground into the subsurface.

[5] Metasomatism is replacing one mineral with another that mineral dissolution and minerals deposition are occurred at the same time.

large impact events which affected the lunar surface through time as crater formation and their absolute ages got determined by radiometric dating of obtained lunar samples. The lunar surface is generally modified by impact cratering and volcanism, so, it is possible to define the lunar geological events in time basis on stratigraphic principles [8–10].

In the moon history, the Nectaris Basin and other major moon basins were formed by large impact events at the Nectarian Period (from 3920 million years ago to 3850 million years ago). Also, the pre-Nectarian period of the lunar geologic timescale is between 4.53 billion years ago to 3.92 billion years ago. It is extended between the initial Moon formation time to Nectaris Basin by a large impact. During this time, these light anorthosites came from the cooling of the surface lunar magma ocean (LMO). The impact event is subject the collision of astronomical objects like asteroids, comets or meteoroids on the surface of planets and moons, and they have a significant role in the evolution of the Solar System like the Earth and the Moon. For instance, approximately 4.5 billion years ago the Moon created from the ejecta of a collision between the proto-Earth and a Mars-sized planetesimal and it seems a giant hit causing from this hit at both parent bodies (I, e the earth and moon) [11].

The pre-Nectarian system was characterized by the formation of an anorthositic crust and its subsequent brecciation by large basin- forming impact events [12]. In fact, it contains the minerals that were emplaced at the lunar surface over the period extending from the moon formation to the excavation of the Nectaris impact- basin. According to studies, the lunar highlands being compose of anorthositic gabbros and gabbroic anorthosites, but the pre-Nectarian terrain are now probably breccias (rather than pristine igneous rocks) produced during the excavation of the basin cavities.

During the Nectarian Period (*from 3920 million to 3850 million years ago*), the Nectaris Basin and other major lunar mare or sea basins (Volcanic-basaltic lava as the dark spots of moon) were formed by large impact events that Ejecta from Nectaris forms the upper part of the densely cratered terrain found in lunar highlands. In the following of Nectarian Period, along with the Late Heavy Bombardment of the Inner Solar System, the huge Mare Imbrium basin was formed at 3850 to 3800 million years ago (The Early Imbrian epoch), then, this basin and other formed basins get filled with basalt mostly during the subsequent Late Imbrian epoch (3800 to about 3200 million years ago) (See **Figure 6**).

The lunar geological timescale went away on with *Eratosthenian* (from 3,200 million to 1,100 million years ago) and the massive basaltic volcanism of the Imbrian period tapered off and ceased during this long span of lunar time. In the following, impact craters lost their bright ray systems (thrown out radial streaks of fine ejecta at the formation of impact crater) due to space weathering processes[6] and It ends up to *The Copernican period* (From 1.1 billion years ago to the present day) in which light freshly excavated lunar surface has been growing to become darker over time due to space weathering processes.

This lunar geologic time scale is based on the recognition of few geomorphological markers, but it is practical to correlate the geological events at the solar system, in specific too much far distant early Earth time. The Hadean eon of Earth between 4.6 to 4 billion years ago which it begun with the Earth formation and ended up before the earliest-known rocks on Earth. According to the Lunar geologic timescale, this eon can be subdivided to *Pre-Nectarian* (the formation of the Moon's crust, 4533 to 3920 million years ago) and Nectarian (the Late Heavy Bombardment, from 3920 to 3850 million years ago). Some Hadean rocks as the oldest Earthen rocks

[6] Including, bombardment surface planetary bodies like the Moon or the Mercury by different sizes of meteorites, coalition of solar cosmic rays, solar wind and galactic cosmic rays.

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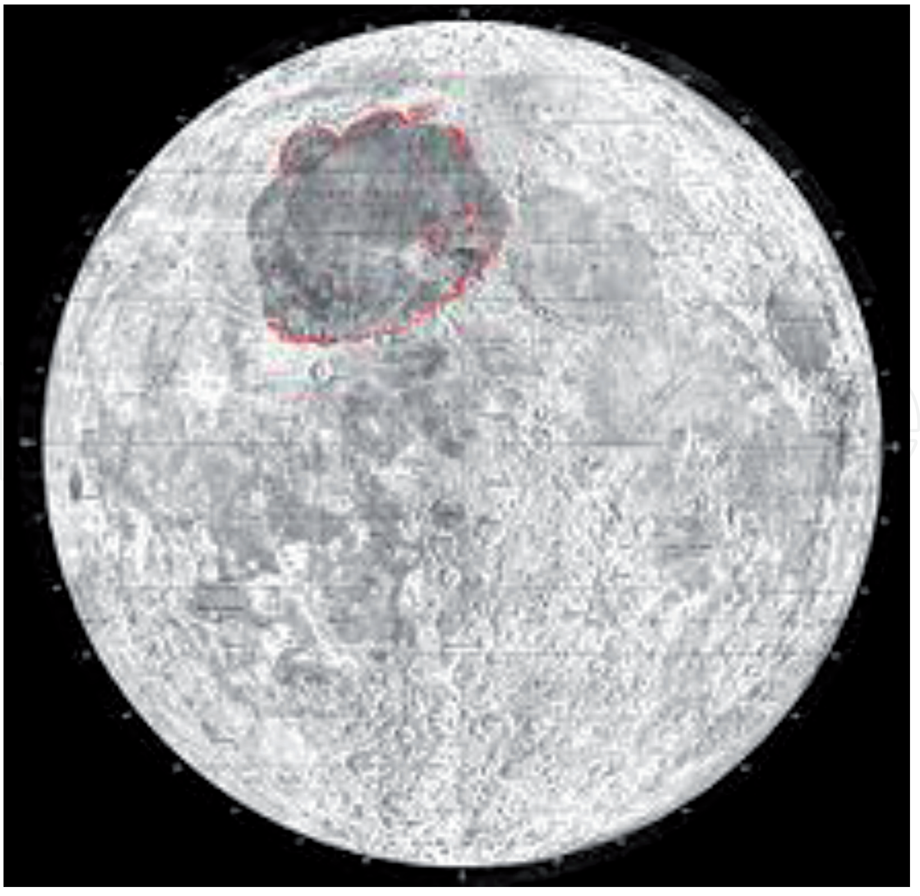

Figure 6.
The location of lunar Mare Imbrium [13].

were found out at western Greenland, northwestern Canada, and Western Australia with the oldest dated zircon crystals in a metamorphosed sandstone conglomerate in the Jack Hills of Western Australia which these xenocryst zircons formed after 200 million years after Earth formation.

The Earth history can be subdivided to few Eons which are the Hadean, the Archean, the Proterozoic and the Phanerozoic (See **Figure 7**). Each eon can be divided into eras, which are in turn divided into periods, epochs and ages. The Phanerozoic (541 million years ago to the present) is the current geologic eon with abundant animal and plant life and it begun at the Cambrian Period when the first hard shells of animals developed and have been preserved as fossil record. The time before the Phanerozoic Eon which is the Hadean, Archaean and Proterozoic eons are called the Precambrian, too.

During the Archean eon (between 4,000 to 2,500 million years ago), the Earth's crust had cooled enough in forming continents and also the emergence of life. At the early Archean, the Earth's heat flow was nearly three times as high as it is today and also it was still twice the current level at the transition from the Archean to the Proterozoic (2.5 billion years ago) due to the heat remnant of planetary formation and the decay of radioactive elements.

Therefore, it can be assumed that these volcanic activities at the Precambrian had great role in The Cambrian explosion at 541 million years ago to rapid emergence life diversification at a short period time between 13 to 25 million years and this trend has being continued. It owns to say the life was mostly simple unicell organisms at the Precambrian, but it got suddenly was turned into colonies as multi-cellular life after the snow earth period.

There is a lot of exposed rocks relevant to this eon which can be observed around the globe such as Greenland, Siberia, the Canadian Shield, the Baltic Shield, India,

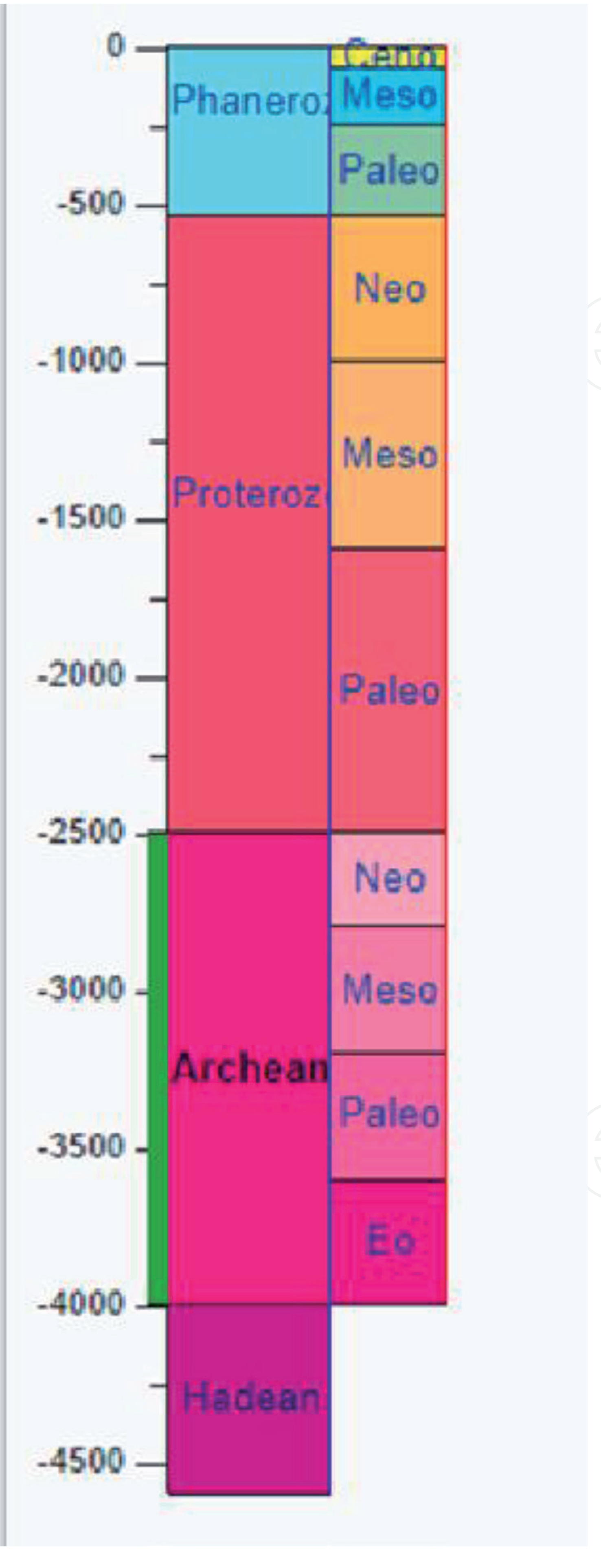

Figure 7.
Earth geologic time scale- Scale: millions of years [14].

Brazil, western Australia, and southern Africa. For example, granitic rocks have been significantly observed from the crystalline remnants of Archean crust, and also other rocks like monzonites (An igneous intrusive rock with equal amount of plagioclase and alkali feldspar and less than 5% quartz) anorthosites (*mostly plagioclase feldspar (90–100%)*) and, too.

4. Petrological specifications of Anorthosites

Plagioclase is a major constituent mineral which is really important to identify the composition, origin and evolution of igneous rocks and it is observed at different parts of the Earth and even other parts of world such as the highlands of the Moon or the Martian crust. Johann F. C. Hessel showed at 1826 that plagioclase feldspars are solid solutions of albite (the sodium (Na^+) endmember of the plagioclase solid solution series) and anorthite (the calcium (Ca^{2+}) endmember of the plagioclase feldspar mineral series) that the formula of pure albite and pure albite endmembers are NaAlSi3O8 and CaAl2Si2O8, in turn.

General speaking, Anorthosites are dominantly contained Plagioclase minerals that the first researchers such as Thomas Sterry Hunt at 19 centuries understood this fact. These pioneer geologists tried to explain the origin of Anorthosites like the granite. For instance, there is a lot of anorthosite lenses within Archean gneisses around diverse parts of world such as Africa, Greenland or even the Scotland. So, it is supposed that they get formed like Gneiss. Gneisses are metamorphic rock with foliated texture that they get made by heating and squeezing previous igneous and sedimentary rocks during mineral recrystallizations and The Lewisian complex with the Archean age at the north of Scotland is a typical example and these granitic gneisses form the basement of later deposited sediments. Therefore, these pioneers tried to illustrate the origin of huge massif anorthosites basis on this natural procedure.

A lot of Archean anorthosites are lenses within Archean gneisses. Moreover, it is clear that the ambient temperature of the Archaean mantle (1500–1600°C) was 200–300°C higher than today's mantle (1300–1400°C) [15, 16], so, the higher mantle temperatures under the Archaean oceanic spreading means more 7–10% partial melting than present-day and it was caused thicker oceanic crust was made in comparison to modern ocean ridges. In a simple language, there was more voluminous basaltic magma with generating large, shallow magma chambers. In fact, higher geothermal gradients in the Archaean oceanic crust let shallow magma chambers cool slowly and it was caused more differentiation and stratification to produce cumulates of dunite, peridotite, chromitite, pyroxenite, gabbro and anorthosite (See **Figure 8**).

As far as, lithological and geochemical characteristics are concerned, it seems that these Anorthosite-bearing layered intrusions in the southern West Greenland and Canada are subject Archaean subduction-related ophiolites. The changes of anorthosites can reflect the thermal evolution of the Earth. Furthermore, the presence of water at these magma zones had played great role in the formation of plagioclase mega crystals due to rising cooling time.

In one hand, the major difference between the Earth and Moon and their influence on the formation of anorthosite is the presence water, and in first glance it seems that anorthosite could not form on the Earth if the terrestrial magma ocean was saturated with the water. By considering lunar anorthosites, it can be interpreted that the early earth - terrestrial magma was not saturated with water as the moon [17], so, it is possible that these plagioclases crystallized from the dry terrestrial magma ocean, so the Earth and the Moon were maybe both dry just after the formation.

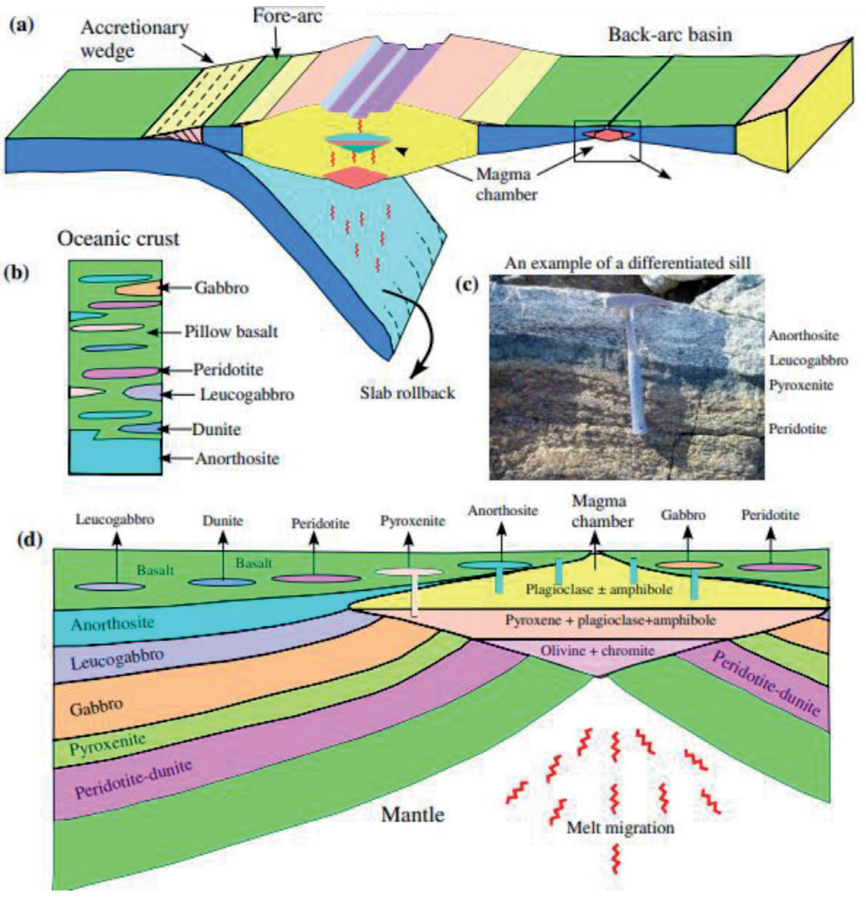

Figure 8.
Simplified geodynamic model for the origin of Archaean anorthosite-bearing layered intrusions. (c) shows an example of mineralogically stratified sill, representing a small version of Archaean magma chambers [16].

It should be mentioned that the origin of the water on the Earth is still debated, one of the scenarios is the "late-veneer" hypothesis[7] in which the Earth and the Moon were dry just after the formation of the Moon, and late-accretion of volatile-rich carbonaceous chondrites beyond the asteroid belt supplied water to the "dry" Earth. In this case, it is possible that plagioclase crystallized from the "dry" terrestrial magma ocean and anorthosite formed on the Hadean Earth [17].

Geological records of anorthosite crusts of the Hadean[8] have been erased by tectonic erosion on the Earth, or reprocessed by impacts. Once the anorthosite is subducted to a depth of 30 km, the plagioclase changes to garnet due to the phase transition, and the density of the garnet-composing "meta-anorthosite" becomes higher than the pyrolite. The result suggests that the meta-anorthosite could easily be transported into the mantle due to the density difference. Future works should be focusing on the detection of the geophysical evidences of meta-anorthosite buried in the deep interior of the Earth [17].

On the other hand, at the end of Hadean around 4 billion years ago, Earth changed from having a hot, molten surface and atmosphere full of carbon dioxide to being very much like it is today. Furthermore, the abundance of large anorthosite massifs in the Proterozoic[9] (2.5 billion years ago up to 500 million years ago) are good indicators of other the early Earth history and inherits and

[7] Basis on late-veneer hypothesis, it seems nearly all earth water were formed by impacts with icy comets, meteorites and other passing objects at the Late accretion (about 4.5 billion to 3.8 billion years ago).
[8] It began with the formation of the Earth about 4.6 billion years ago and ended at 4 billion years ago.
[9] It began from the appearance of oxygen in Earth's atmosphere (2.5 billion years ago) to just before the proliferation of complex life at 500 million years ago.

it point outs a specific condition of earth-crust evolution and the Proterozoic magmatism.

It seems the Archaean—Proterozoic boundary represents a transitional period during which the Archaean-thickened continental crust was uplifted and eroded to give rise to abundant clastic debris [18]. A Continental rift is a too much deformed continental lithosphere which can lead to form new ocean basins that the East African Rift System is a typical example of this type of tectonic valley. Even, it is possible that, some parts of this old crustal component may be derived either by direct erosion of Archean rocks. It is clear that the Earth's heat flow had been nearly three times as high as it is today in the beginning of the Archean and it was still twice the current level at the transition from the Archean to the Proterozoic (2,5 billion years ago).

It owns to say that, magmatic differentiation (Igneous differentiation) owns important role in making these old anorthosite rocks. It should be reminded that is an umbrella term to describe the natural processes such as partial melting process, cooling, emplacement, or even eruption in which magmas undergo bulk chemical changing. The composition of magma (Parental-primitive magma) can be different into diverse composition magma due to these factors. For example, basis on diverse cooling rate, the various crystallize minerals get created from the melt or liquid portion of the magma. Also, contamination is another cause of magma differentiation which made by mixing other wall rocks of magma chambers.

The anorthosites are even observed at younger the Phanerozoic rocks as xenolith or Layers within Layered Intrusions as in Africa and Nigeria. Finally, it seems anorthosites can be caused from each basaltic magma mass as if the opportunity of accumulation and sorting of plagioclase crystals get provided, as if it was occurred at the lunar surface or early earth crustal evolution time.

5. Conclusions

Anorthosites are very much interested by geologists because they give us great information about Earth history and how it was evolved. They are able to be classified as Archean-age anorthosites, Proterozoic anorthosite in the Earth and Lunar anorthosites which are constituted the light-colored areas of the Moon's surface.

Petrologists try to find good information about the conditions of igneous rock formation by study them and anorthosites (As an igneous rock which are dominantly contained Plagioclase minerals) are good rocks in this regard to find out more than about early history and how other extraterrestrial bodies like the Moon get formed.

It seems that the light-colored areas got formed by the crystallization and floatation of plagioclase from a global magma ocean with a significant chemical heterogeneity. Furthermore, the Earth was remarkably hotter than to day in the Archean (4 to 2.5 billion years ago) and the Proterozoic (2.5–0.5 billion years ago) nearly three and two times as today, respectively. The Archean anorthosites are more than as lenses within other Archean rocks due to high mantle temperature at this time and let more differentiation and stratification to produce cumulates. Furthermore, Proterozoic anorthosite are massif-type anorthosite which are the most abundant type of anorthosite on Earth. So, it can be assumed that these volcanic activities at the Precambrian probably had great role in The Cambrian explosion. Definitely, these studies will help scientists to make a better planetary formation model to study extraterrestrial bodies within the solar system or other star systems through the galaxy, or even in astrobiology studies.

Future works should be focusing on the detection of these ideas to confirm or on contrary suggesting new ideas. Definitely, by considering new astro -geological studies like the Moon, our knowledge about the earth early condition and developing planetary formation modeling will be remarkably developed as an important science to study in the space exploration era.

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References

[1] Available from: https://www.britannica.com/science/anorthosite [Accessed July 2020]

[2] V. Tenczer a, C.A. Hauzenberger a, H. Fritz a, M.J. Whitehouse b, A. Mogessie a, E. Wallbrecher a, S. Muhongo c, G. Hoinkes: Anorthosites in the Eastern Granulites of Tanzania—New SIMS zircon U–Pb age data, petrography and geochemistry. DOI: i:10.1016/j.precamres.2006.03.004.

[3] Available from: Nasa- Lunar Samples- https://curator.jsc.nasa.gov/ , [Accessed July 2020].

[4] Lunar Sample Compendium- C Meyer 2011- https://www.researchgate.net/publication/234491909_Lunar_Sample_Compendium, [Accessed July 2020].

[5] Makiko Ohtake, Tsuneo Matsunaga, Junichi Haruyama, Yasuhiro Yokota, Tomokatsu Morota, Chikatoshi Honda, Yoshiko Ogawa, Masaya Torii, Hideaki Miyamoto, Tomoko Arai, Naru Hirata, Akira Iwasaki, Ryosuke Nakamura, Takahiro Hiroi, Takamitsu Sugihara, Hiroshi Takeda, Hisashi Otake, Carle M. Pieters, Kazuto Saiki, Kohei Kitazato, Masanao Abe, Noriaki Asada, Hirohide Demura, Yasushi Yamaguchi, Sho Sasaki, Shinsuke Kodama, Junya Terazono, Motomaro Shirao, Atsushi Yamaji, Shigeyuki Minami, Hiroaki Akiyama & Jean-Luc Josset : The global distribution of pure anorthosite on the Moon.DOI: 10.1038/nature08317.

[6] Eric A.K. Middlemost, Magmas and Magmatic Rocks: An Introduction to Igneous Petrology-1985.

[7] John F.Pernet-Fisher, EtienneDeloule, Katherine H.Joy: Evidence of chemical heterogeneity within lunar anorthosite parental magmas- 22 April 2019- https://doi.org/10.1016/j.gca.2019.03.033.

[8] R. F. Emslie: Proterozoic Anorthosite Massifs. In: The Deep Proterozoic Crust in the North Atlantic Provinces. 1985. pp 39-60. DOI: https://doi.org/10.1007/978-94-009-5450-2

[9] SA Bowring, JP Grotzinger, CE Isachsen, AH Knoll, SM Pelechaty, P Kolosov: Calibrating rates of early Cambrian evolution-1993- DOI: 10.1126/science.11539488

[10] Don Wilhelms : Geologic History of the Moon, U.S. Geological Survey Professional Paper 1348, –1987.

[11] Edward D. Young1 , Issaku E. Kohl1 , Paul H. Warren1 , David C. Rubie2 , Seth A. Jacobson2,3, and Alessandro Morbidelli3- Affiliations: Oxygen isotopic evidence for vigorous mixing during the Moon-forming Giant Impact- 15 Mar 2016. DOI: 10.1126/science.aad0525.

[12] J.L.Whitford-stark : Lunar surface morphology and stratigraphy, a remote sensing synthesis-Department of geological science, Brown university, Providence Rhode Island 02912, USA- This paper presented at the BAA(British Astronomical Association) lunar symposium held at Keel University on 1979 July 7-8.

[13] Avialable from: Mare Imbrium- Wikipedia- https://en.wikipedia.org/wiki/Mare_Imbrium, [Accessed July 2020].

[14] Avialable from: Archean- Wikipedia- https://en.wikipedia.org/wiki/Archean, [Accessed July 2020]

[15] Keith A. Milam, Harry Y. Mc Sween Jr. Jeffrey Moersch and Philip R. Christensen: Distribution and variation of plagioclase compositions on Mars- 2010. DOI: 10.1029/2009JE003495.

[16] Ali Polat, Fred J. Longstaffe & Robert Frei: An overview of

anorthosite-bearing layered intrusions in the Archaean craton of southern West Greenland and the Superior Province of Canada: implications for Archaean tectonics and the origin of megacrystic plagioclase-2018. DOI: 10.1080/09853111.2018.1427408.

[17] Tatsuyuki Arai, ShigenoriMaruyama: Formation of anorthosite on the Moon through magma ocean fractional crystallization-2017. DOI: 10.1016/j.gsf.2016.11.007

[18] Brian F.Windley : Developments in Precambrian Geology- Volume 4, Chapter 1 Precambrian Rocks in the Light of the Plate-Tectonic Concept-1981, Available online 21 April 2008.