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Rocks in Arab-Islamic scientific heritage

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Abstract

Jabir ibn Hayyan (8th century) is considered one of the first to divide rocks according to their origins. he clearly distinguished between three categories of rocks. Al-Jahidh (9th century) spoke about the volcanoes and fire rocks, wondering about some interpretations of these rocks'diversity of characteristics wich accord it to the ratio of terrestrial, water or air component, but do not consider the fire component. The brothers of al-Safa (9th century -10th century), also distinguished Smoothy solid magmatic rocks with Few plants, from soft superimposed sedimentary rocks (layer over layer), with many caves and a lot of plants, grasses and threes. Ibn Sina (11th century) also distinguished between sedimentary rocks (consisting of the essence with terrestrial predominant substance) and the igneous rocks (consisting of the essence with water predominant). It seems that Al-Al-Dimashqui (8th century) was well aware that the formation of some rocks, is due to their exposition to very high temperature (such as white marble), where Extensive fire changes its shape and its original stone appearance to take on a completely new look. Al-Jahidh said: "And tell me about the jewels of the Earth.. are they Something definitly created or earth turned to it (transformed)?". May be it is the first reference to metamorphic rocks. It is a statement that the rocks containing the gems, are not the "land" created by God, and then remained on their first creation; But they are rocks that can be changed and transformed. Muslim naturalists were fully aware of the many origins and categories of rocks. It may be possible to consider them as the founders of petrology in general and sedimentary rocks Science in particular. Especially In the works of Al-Bairouni (10th century -11th century), Al-Karkhi (11th century), the brothers of Al-Safa and Ibn Sina, witch presente a precise scientific speech, describing the processes of weathering, transport, sedimentation and what follows.

Keywords: Arab Islamic Heritage**,** Rock formation, sedimentary cycle.

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1. Introduction

The Earth Sciences are considered modern sciences. They are largely attributed to Western Scientists and their efforts since the Renaissance and especially since the second half of the 19th century. In deed, there is a common belief among various Sciences historians that the first lines of geology were drawn by the pioneers of the Enlightenment, such as George Bauer (Agricola), Bernard Palissy, and George Owen, who were the first ones to execute the initial foundations and writings on Geology.

The distinguishion between different types of rocks in Europe, was first proposed in the middle of the eighteenth century. This classification was little developed by Italian scientists at the end of this century.

In this paper, we will try to show that Arab-Muslim scholars have indeed participated in the development of some of the disciplines of Earth Sciences. We limited ourselves to the interst of Arab-Muslim naturalists to observe and study rocks, their awarness to different categories of rocks and their attempts to classify rocks and to explain their formation.

2. An early attempt to distinguish and to classify Rocks.

Jabir Ibn Hayyan divides the rocks according to their origins, as he says: "The rocks are divided into three classes: the first class, which is like the first creation of stones, and has a balance singular of all scales; And a second class, which is the one who is influenced from the first stone and simulates it and runs its course, but its decay is closer than the time of the first, although it is extended as if it were in the world for thousands of years; and the third of the classes, which is constituted for us with one intention, behind the ranks" [1].

In this text, Jabir Ibn Hayyan clearly distinguishes between three categories of rocks. We can discern that with the first category he means magmatic rocks (ignous or volcanic); with the second category, he means metamorphic rocks "influenced from the first rock", which are close to igneous rocks (similar to it), but less resistant than it (they decay faster). The comparison of the resistance of igneous rocks and metamorphic rocks with similar chemical (and mineral) compositions supports this observation; and he perhaps intended with the third category, which is "constituted for us with one intention," sedimentary rocks.

Al-Nakkach stated that Jabir Ibn Hayyan was the first Muslim scholar to distinguish igneous rocks, sedimentary rocks, and metamorphic rocks, "where he said: sedimentary rocks are separate from igneous rocks" [2].

Al-Jahidh talked about volcanoes (eyes of fire) and fiery rocks, asking about some people's interpretation of these rocks' diversity of properties, according to the different proportions of the presence of the terrestrial, watery, or air component in them, and not considering the fiery component,

he said: "..If we see a position from the ground from which water comes out, we said: this is one of the pillars; what about our mind if we see a position from the Earth from which a fire comes out and we did not say that on it?. Is that because of the mixture of the parts of the air lifting him?; And if we find it more gummy and more durable and farther than decaying, we attributed it to the part of water in it. And if we find that it pushes the sparks and shows the fire, we attributed it to its part of air?; And why if something diminished by the extent of his body, we referred it to its part of air, and we do not refer it, in the same way, to the parts of the fire in it?. Especially if the eye finds it sparking with sparks, and parts of the air in it were not visible. Why did they deny this while this story corresponds to the origin on which they built their analysis?" [3].

Ikhwane Al-Safa distinguished between hard smoothy magmatic rocks and soft sedimentary (stratified: layer over layer) rocks. This was done by distinguishing between the mountains that make up these rocks, they say: "Be aware that among the mountains that we mentioned, some have hard rock, hard stones, and smooth rocks, and only a few plants grow on it like the Tihama Mountains; in some others there are soft rocks, soft mud, soil, sand, and various flocculated (aggregated) pebbles, in coherent parts, layer over layer; they are nevertheless with many caves, grottos, valleys, airs, springs, streams, and rivers; there are plenty of plants, weeds, and trees, such as the mountains of Palestine, the mountains of Lukkam and Tabaristan, and others" [4].

And it is well known that the Tihama Mountains (Makkah Region) are dominated by igneous rocks; While the mountains of Palestine, Lukkam and Tabaristan, consist mainly of limestone rocks.

Ibn Sina (Avicenna) also distinguished between sedimentary rocks (consisting of the predominantly terrestrial substance) and igneous rocks (consisting of predominantly aquatic essence), he says: "The rocks are formed in the most, on two ways: by an explosive way, or by stiffening. Many rocks are composed of the predominantly terrestrial substance, and many of them consist of the predominantly aqueous essence" [5]. In another paragraph, he affirms that some rocks consist of fire when they cool and stiff, he says: "And there may be types of rocks from fire if they cool down and and are extinguished" [6].

As for Al-Dimashqui, it seemed that he was well aware that some rocks -like white marble- form by being subjected to temperatures, at very high levels. In fact, strong fire that exceed the standards, changes its shape and its original stony appearance, to take a new look completely different from the previous, as he says: "And that is because the glass did not leave the stone substance; rather, it only acquired clearance and transparency and was kindled by the fire, until it melts and solidifies. It is a stone, if the fire is applied on it more than its limits, it burns and is transformed to a white opaque stone" [7]. This is a clear indication that the white marble rock came from another rock, which was

overburned. This conclusion is consistent to the fact that marble is a metamorphic rock that derive from a clay rock, due to high temperature and pressure.

Al-Jahidh said: "And tell me about the jewels of the earth and all metals, are they something for granted from his creation or a land that was transformed to?" [8], this citation might be the first reference to metamorphic rocks: it is stated that the lands (rocks) containing the gems are not lands created by God, and then fixed on the original first creation; rather, they are rocks that can evoluate and transform.

It is worth noting the German J.G. Lehman, was the first scientist to distinguish between different types of rocks in Europe, he proposed in 1756 to classify rocks into crystalline primary rocks; Stratified secondary rocks; and inconsistent surface rocks. At the end of the eighteenth century, the Italian scientist Giovani Arduino and the German scientists G. G. Fuschsel and A. G. Werner, developed this classification without reaching what Muslim scholars established, centuries before [9].

3. Sedimentary rocks: Their formation and their cycle.

If the Ikhwane Al-Safa and Al-Bairouni had already mentioned the sedimentary rocks (layer over layer), then Avicenna provided a practical and reasonable explanation of the succession of layers and their deposit on each other. Indeed, he says about the formation of mountains of sedimentary rocks: "And it is possible that land is exposed from the sea, and each level is a layer, and some mountains can be seen as tabular: a layer then a layer. It seems that their mud, at a given time, was also a layer then a layer: A layer had accumulated first, then in a given duration, another layer had accumulated. An object of different essence flowed over each layer, and it became a barrier between it and the other layer, and when the material was harden, the barrier fractured and spread over what was between the two layers. The paste from the land of the sea's barrier can be sedimentary, it can be old and non-sedimentary also, it seems that the mountains where the blocks stand out are sedimentary mountains, and this how the mountains form" [10].

This discourse about the law of superposition and about the formation of the successive sedimentary layers and the stratification surfaces that separate them, can be considered as founder of sedimentology, which only appeared in Europe in the last half of the 17th century, with Nicholas Steno, to which one wrongly attributes the law of superposition*, wich states that in undeformed stratigraphic sequences, each strata of sedimentary rock is more recent than the strata which is below and older than that above.

* The law of superposition was first proposed in Europe by the Danish scientist Nicolas Steno in 1669.

For sedimentary rocks to form, Ibn Sina requires an appropriate environment. In this environment, the Land must not emerge above the surface of the water, because firm land does not harden; It is rather a space of fragmentation and not of cohesion; he says: "Let us start first by examining the state of mountains' formation, and the investigations that you need to know about it: so we say: in most time, pure earth does not harden, because dryness does not benefit it more cohesion ; but makes it more ready for fragmentation" [11]. While the formation of sedimentary rocks requires that their materials be viscous and saturated with water, because the formation of stones is often done in two ways: "by explosive route, or by stiffening. Many rocks are composed of predominantly terrestrial substances and many of them are made of predominantly aqueous material. many clays dry and first become something between a clay and a stone, it is a soft stone, which becomes a stone. The most worthy clays to become stones, are viscous clays, if the clay is not viscous, it crumbles most of the time before becoming hard" [12].

This viscosity state requires that the material subjected to the induration operation be immersed in sedimentation basins such as seas: "It seems that this populated land, was a long time ago not populated; but well immersed in the seas, and it was hardened, either by exposing itself little by little, in durations that datations cannot define; either under the effect of the waters because of the intense heat congested under the sea ; but it is rather due to the exposure of the sea.. and it cannot be excluded that the mineral force which was generated there, also helped, and that some waters transformed into stones also. But the formation of the mountains is done rather in this way and the abundance of their stones is due to the great quantity of muds which the sea contains, and which the sea subsequently expose" [13]. Ibn Sina deduced the induration of the mud and its transformation into a soft stone, from his observations at the banks of the *JIHOUN* river (AMOU DARIA), where the process took about 23 years, he says: "And we saw at during our childhood, the clays with which we wash our heads, in places at the level of the shores of *JIHOUN*; we then saw them indurate a soft induration, and the period is close to twenty-three years" [14]. So Ibn Sina tries to explain what happened in the distant past, by what he sees in his present: This is nothing other than an application of the principle of Uniformitarianism (or Actualism), according to which the present is the key to the past and that the processes which have taken place throughout the history of the Earth are not different, and that the processes which controled geological phenomena and events, of the past are indeed those which still coltrol them nowadays.[†]

[†] This principle is attributed to James Hutton, one of the most prominent earth scientists in the eighteenth century (1726-1797); It was published and promoted by a number of European scholars in the nineteenth century, such as Charles Lyle (1767-1849) and Constant-Prevost (1787-1836); but it is to be attributed to Al-Bairouni (973-1048), who mentioned it very clearly in the introduction to his book "Determining the Ends of Places to Correct Home Spaces".

He also deduced that the sedimentary rocks must be viscous and soft at the pre-induration stage, by logical proof explaining the presence of the remains of animals that live in an aquatic environment, inside the rocks after their compaction‡ and their hardening. He says: "its mud must help it to become petrified, because its mud is viscous. And this is why one finds in many stones if they are broken, parts of aquatic animals, such as bivalves and others" [16]. Indeed it is impossible for these animals to penetrate hard rocks and settle there. There is no way to do it, except that these rocks were once viscous at a stage before their solid state, which allowed these aquatic animals to be inside (fig.1).

If the process of transformation of the mud into a soft stone, can take a short duration (23 years in the case of the clay used to wash the hair); the process of the complete induration requires a very very long time, which "the datations cannot define" [17].

Besides compaction in marine sedimentary basins, Ibn Sina states that sedimentary rocks can be formed by flowing waters "in two ways: one consists of a total precipitation of water as it percolates or as it flows; In the second, this water deposits something, in connection with the flow mode, wich indures. And water has been seen to flow, then what percolates towards a known site, precipitates to stones or pebbles of different colors. And we have seen that the percolating water, if it was taken, did not harden, and if it had fallen on a stone ground near its thalweg, it immediately precipitated to a stone. So we also knew that this ground had a mineral force which transforms what flows into a rigid body" [18]. He thus speaks about two aspects of sedimentation and compaction, in continental environment:

● A compaction by precipitation of flowing waters, "as it percolates" or "as it flows": in the first case, he speaks of stalagmites and stalactites inside the caves; in the second, he speaks of travertines, which precipitate at the level of resurgences emanating from the limestone rocks within which water saturated with calcium carbonate flows.

Al-Dimashqui has a very interesting text on the precipitation of stalagmites and stalactites in karst environments, in which he says: "It is a strange wonder that from a cave in the Levant emerges a stream which does not exceed the heels of the one who is running through. If someone enters, he finds it wide and long, about four thousand steps below the ground surface and water percolates from its sides. like a long building and a built cellar; but it is a sculpted cave. We find there, under all that percolates from its roof, stones of different shapes and colors, from the precipitation of the waters percolating. Among them, some are honey colored, fruit shaped, meat shaped, human body members

‡ **Compaction** ocurswhen the weight of overlying material, which continually accumulates in a sedimentary environment, compresses the sediment buried beneath into a tight, coherent mass. Wet mud consists of 60 to 80% water, most of wich is driven out during compaction, (HAMBLEIN & CHRISTIANSEN, 2001) [15].

shaped, grain shaped, clover shaped and a variety of shapes. They are all stones precipitated from percolating water and their colors are pure: red, black and others. And that's why it was called "the cave of wonder" [19].

● And it imperatively forms, from what deposited from running water, during its flow. It is a clear reference to the deposition of sediments at the bottom of river beds and their compaction in sedimentary river basins. In this regard, Al-Bairouni speaking about Earth and the natural phenomena which occur there, says: "Of its state, we only know traces we observe, which require long periods of time to be produced, like the high mountains composed of smooth gravel of different colors, cemented by mud and sand. He who thinks about the question from the front and comes to it by the door, knows that the blocks and the gravels are stones that break from the mountains by fracturing and clashes, then the water flows over it and the wind blows and their friction lasts, then they wear and wear on the corners and angles until they dull; and that the detrital elements from which they differ, are sand and soil. And that these gravels when they were gathered in the rivers' beds and interpenetrated with sand and soil, kneaded with and buried, and the torrents overcame them. they settled at the bottom and in the slingers after being above the surface of the earth. They were hardened by the cold because the mountains were hardened by the cold. This is why the stones melt by fire, Indeed what precipitates by cold is dissolved by heat, and what precipitates by heat is dissolved by cold. And if we find a mountain formed by these smooth stones -which is very common in our environment- then we will know that its formation is as we have described. and that it was repeatedly at the top and then at the bottom" [20].

In this text, Al-Bairouni clearly speaks about the sedimentary cycle, where the rocks of the exposed high mountains, are subjected to fracturing and fragmentation, after their wear under the action of flowing waters and blowing winds; the resulting detrital elements are then transported in the rivers's beds, where they are compressed, kneaded and compacted then indurated then buried at the bottom; thus the sedimentary rocks are formed, they are then lifted upwards and exposed in the form of mountains. There is a very good perception of the phenomenon of Lithification,[§] essential to the formation of sedimentary rocks, in fact the process of lithifaction of the rocks, requires the compaction of soft sediments, in order to expel the large quantities of water present in the pores and prepare them, after their burial, to transform into a hard rock. The detrital elements are cemented by a precipitated mineral cement,[**] this gives cohesion and hardness to these rocks (**Fig 1**).

[§] **Lithification** is the term used to describe a number of different processes that take place within a deposit of sediment to turn it into solid rock, (EARLE, 2019) [21].

[**] **Cementation** occurs when dissolved ions, carried by water seeping through pores, is precipitated, (HAMBLEIN & CHRISTIANSEN, 2001) [22].

Al-Karkhi (10th century -11th century) made the lithification a primordial process and an imperative natural law, he said: "within the Earth there are permanent movements, including the buildings' demand to fall and collapse, and to tilt from the azimuth of verticality; just as mountains and uplands gradually wich collapse and disintegrate, seeking the center; and within soft earth there a is a permanent movement, which is the claim of hardness by its parts by leaning on each other" [23].

Note the reference of Ibn Sina to the role of high temperatures (due to the withdrawal of the sea), in the process of rock induration, because the heat increases the susceptibility of soft debris to induration. This has been demonstrated by a practical experience, he says: "It may be that the sea gradually overflows on a land composed of a plain and a mountain, and it recedes.

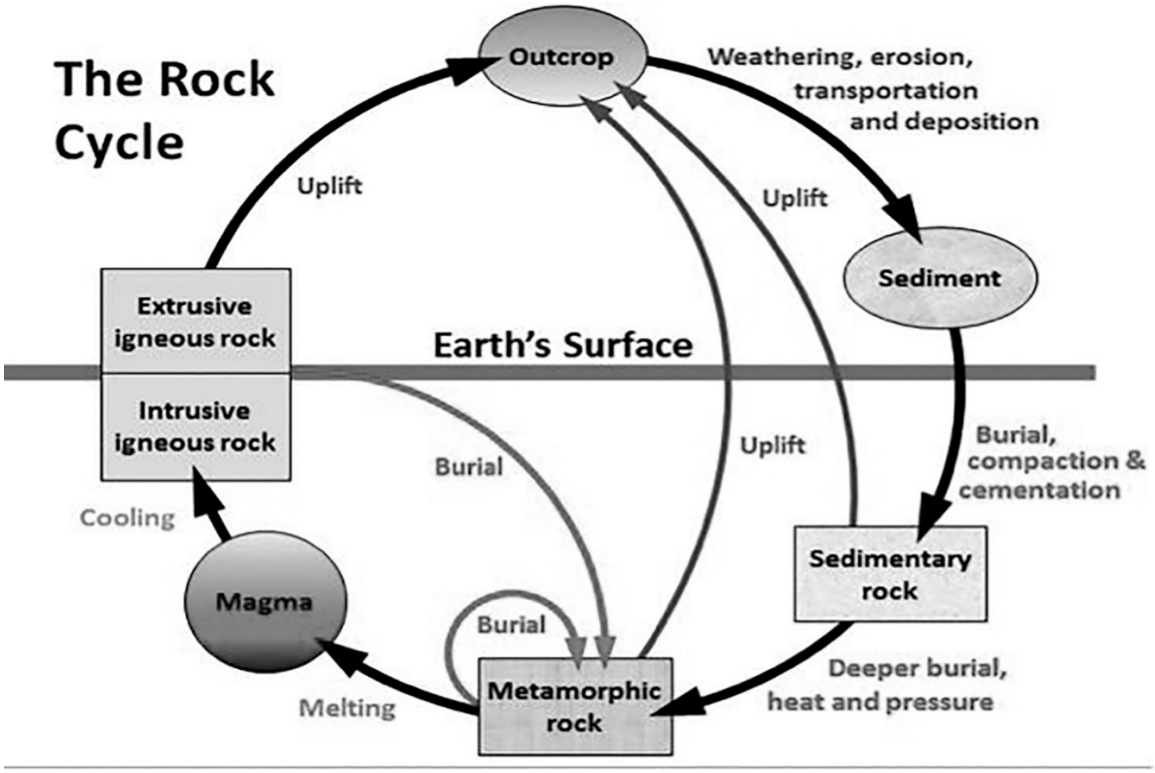

Fig 1. The rock cycle, showing the processes related to sedimentary rocks on the right-hand side (EARLE, 2019).

Then it happens that parts of the plains turn into mud, which does not happen in the mountains, and what turns into mud, is ready to harden when exposed. If what has just hardened is exposed, the old hardened may have been somewhat prepared to fragment; and it may happen the opposite of what happened for the soil, that this one moistens and softens and becomes a soil, and that the other one prepares for induration. As if you soak in water, a brick, some mud and soil; then, you expose the brick, the mud and the ground to fire, the brick becomes more and more ready to fragment by fire, while the mud and the soil are more and more ready to harden" [24].

4. The diversity of sedimentary rocks and their variations.

Ikhwane Al-Safa say about the diversity of sedimentary rocks and their variations: "And that is that the terrestrial globe as a whole, in all its parts, its depth, on its surface, in its interior, is formed of strata, layer upon layer, flocculated and precipitated, of different composition and facies. There are hard rocks and mountains, resistant pebbles and blocks, smooth gravels, coarse sands, soft clays, not very resistant soils, and sebkhas; they are mixed with each other or juxtapposed, like Almighty God described it by saying: "And in the Earth are tracts (diverse though) neighboring" (Chaptre 13; Verse 4) [25]; They are of different colors, baits and smells. From its soil, its clay and its stones, there are reds, whites, blues and yellows, as Almighty God said: "And in the mountains are tracts white and red, of various shades of color and black intens in hue"(Chaptre 35; Verse 27) [26]; among its soils and clays is that which is sweet in taste, bitter, salty, sour or sweet; and what is pleasant to smell and whose smell stinks. Because in the whole Earth, there are many permeations, holes, cavities, veins, streams and rivers, inside and outside, with lots of air, caves and grottos; and all these are filled with water and vapor, and the taste, the smell, the roughness, the smoothness, the heaviness and the lightness of this water, depend on the soil of the locations, the clay of the places and the stagnations of its swamps" [27].

In this text, Ikhwane Al-Safa evoke:

*/- Differences in resistance of rocks: resistant, soft, hard, soft, smooth and rough;

*/- Differences in the size of the elements: pebbles, blocks, gravels, sands and clays, mixed with each other or adjacent to each other;

*/-Differences in other properties, which can be used for the distinction and the classification of rocks, such as: color, taste and smell.

Al-Quazouini also explains the variety of sedimentary rocks, by the diversity of environments (places), in which these rocks were formed: "If they are in areas of soils and clays, all the rocks then precipitate; And if they are in Sebkhas'places, then some types of salts, boraxes and alums are generated; And if they are in acid and bitter regions,[††] then forms of red, yellow, green and other oxides are generated; each placement has a characteristic that only Almighty God knows" [28].

5. Magmatic rocks formation.

Ibn Sina says: "The principles of rock formation are either a viscous clay essence, or an essence in which water is predominant; this type can be hardened because of a hardning mineral force, and it may be dominated by the earthy component, in the way of how salt precipitates, so that the earthiness

[††] He uses the word *Afsia* wich means acid and bitter and means oak trees and their fruits as well.

in him, dominates by force without quantity; even if it is not with the manner of the earth, where there is salt; but in another way, which helps it to dominate using heat; and when exposed to heat, it precipitates; or another force, that we are unaware of. It can happen the opposite, and that earthiness dominates by a cold and dry force, which helps it" [29].

Ibn Sina attributes the formation of magmatic rocks (whose essence is dominated by the aqueous component) to a first cause which consists of an indurating mineral force; the second cause is related to a part of the earthiness present in these rocks, which correspond to a precipitation comparable to the precipitation of salt under the effect of heat (evaporation), but which differs from it; plus other possible causes, but which he ignores.

Beside the sedimentary rocks precipitated from the water, Al-Quazouini thinks that, certain rocks (volcanic rocks) can be generated in the open air (outside the water), from smokes parts, dominated by earthy characteristics, and which are extinguished by the drop in temperature, when they exit into the air. This causes them to harden, so they transform into rocks [30]. This is what Ibn Sina underlines by saying: "And some types of rocks form from fire, when it is extinguished" [31].

Conclusion

From the above, we can conclude that Muslim naturalists might be considered as the founders of petrology in general and sedimentary petrology in particular, since it is clear that they were aware of the variety of origins of rocks and of their great diversity (sedimentary rocks: clay, pelitic and evaporitic; magmatic rocks: volcanic and ignous; and metamorphic rocks).

The works of Al-Bairouni, Al-Karkhi, Ikhwan Al-Safa and Ibn Sina, show a precise scientific language:

*/- They described the processes of alteration, transport, sedimentation and the following;

*/- They described the processes of stratification and formation of sedimentary rocks (layers of rock superimposed on each other), and they showed that this goes through several stages, requiring long and prolonged times.

*/- They stressed that a sedimentation basin is necessary and that the sediments must be in a viscous state and saturated with water, which confers them an aptitude for induration and lithification;

*/- They also evoked other factors contributing to the lithification process, such as:

- The increase in pressure and temperature, following the accumulation of sediments at the bottom of seas or rivers and burial;
- And the exposure of newly formed rocks, in relation to the exposure of the sedimentation basin, following the withdrawal of water or its drying.

Conflict of Interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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