

SALINE DEPOSITS AND ALKALINE MAGMATISM: A GENETIC MODEL

M. Momenzadeh

Geological Survey of Iran, P.O. Box 13185-1494, Tehran, Iran

Keywords: Saline Deposits, Alkaline Magmatism, Evaporites, Rifting

Abstract

The temporal-spatial coincidence of saline deposits with rifting and alkaline magmatism has now become a commonly accepted fact. The congruency of these three phenomena implies logically, their trilateral genetic interrelation. The conventional concept for the formation of saline deposits, i.e. an "evaporation process" can not be properly applied to giant saline deposits. The proposed "Volcanogenic Model" offers a genetic explanation for problems encountered. The role of alkaline and calc-alkaline magmatism in producing saline and sulfate deposits and the application of the proposed model in each case is discussed. The term "saturites" is proposed instead of "evaporites".

Introduction

The temporal-spatial coincidence of the 1)- giant saline-sulfate deposits, 2)- alkaline magmatism, and 3)- rift systems and their associated mineral resources, like sulfides (Fe, Cu, Pb, Zn,), sulfates (Ca, Ba, Sr.....), oxides (Fe, Mn,.....) and fuels (hydrocarbons) inclines one to search for a possible genetic relation between these three phenomena. It is considered that the formation of thick and extended halite, gypsum and anhydrite deposits in marine environments, for instance in the Mediterranean, the Red Sea, the Circum-Atlantic etc. can not be justified by a conventional evaporation model. In the present paper a genetic model, named here "Volcanogenic Model" is presented, which gives a genetic explanation for the temporal-spatial coincidence of the three phenomena.

Evaporation model; its defects.

It is more than a century since Ochsnius [29] first stated that the origin of fossil evaporites must be explained through a comparison with modern occur-

ences, despite their difference in scale. Usiglio's experiment in 1849 showed the successive precipitation of different salts in an evaporite environment. Now, after about a century, the observations, data and facts, collected from land and submarine localities indicate that the conventional evaporation model is unable to explain many of the cases encountered in nature. The "deepwater evaporite" model of Schmalz [31] and the interpretations of the association of calcium sulfates in Kuroko type sulfides [17, 40] and Black Smokers in the East Pacific Rise can be considered as attempts to surmount the defects of an evaporation model. Regrettably the passage of time and lack of any other alternative for the evaporation model has made a "dogma" of this model and this has become a barrier for more realistic interpretations about such observations in nature. In order to gain a general impression of the defects of the conventional evaporation model some notes are reviewed:

1. Precipitation of salts without an evaporation process.

Precipitation of a salt, experimentally, is achieved

when its concentration in a given solvent exceeds its saturation limit (other parameters assumed constant). But saturation can be obtained in either of two processes; 1)– By reducing the amount of solvent via an evaporation while the total amount of dissolved salt is constant; 2)– By addition of more salt while the total amount of solvent is constant. In nature we can theoretically expect both processes. In the last century when Usiglio [41] and Ochsenius [29] developed the evaporation model as a concept for the interpretation of the genesis of saline deposits they used the data available at their time to build up the model. Despite the popularity of evaporation hypothesis and its monopoly and dogmatic power in genetic interpretations of saline deposits it is logical to consider also the second process.

2. Coincidence of rifting-alkaline magmatism-saline deposits; evaporation model?

The temporal-spatial coincidence of continental rifting, alkaline magmatism and saline deposits is a well accepted fact [23, 36]. This suggests the possibility of a temporal-spatial trilateral genetic relationship, since the evaporite model does not offer a convincing explanation for such coincidence. Extensive attempts have been carried out to explain the genetic interrelations between rifting-alkaline magmatism and rifting-saline deposits [23]. It is astonishing however that there has apparently not been any attempt to explain the genetic relationship between alkaline magmatism and saline deposits until the present time (Figure 1).

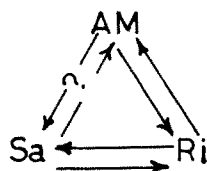


Fig. 1: Scheme showing the possible genetic interrelation between Alkaline magmatism (AM), Rifting (Ri) and Saline deposits (Sa).

Concerning the genetic interrelation of rifting and alkaline magmatism numerous studies in different rift systems offer a quite convincing genetic explanation [1, 2, 3, 7, 6, 12, 14, 22, 35] whereas the genetic relation between rifting and the formation of saline deposits, despite many attempts, is not satisfactorily resolved. Explanations to date are more descriptive than genetic [5, 11, 18, 19, 20, 34, 35, 37, 38] and an encompassing model which can give a convincing explanation and genetic justification for the time-space congruency of

the three phenomena is missing.

3. Evaporation model and large dimensions of saline giants.

The geographical dimensions, thickness, monotony and purity of saline deposits, in all of the relevant marine basins (Red Sea, Mediterranean, Zechstein etc.) are difficult to explain by the conventional evaporation model. The total thickness of some saline deposits exceeds 2,000 meters. Considering that the deposition of only 0.75m of gypsum and 13.7m of halite demands about 1,000m water with the composition of normal modern marine water, the precipitation of 2,000m of halite and gypsum would consume more than a 150,000m of water. The thickness, purity and monotony of monomineralic saline beds, across the stratigraphic column, are such that they minimize the value of an assumption of a periodical change of the sedimentary basin with open marine water. The accumulation of huge amounts of saline deposits, in relatively short intervals of time, for example the Upper Miocene salts of the Mediterranean and Red Sea basins, in less than two million years and thick annual varves [10] has been explained by very hypothetical interpretations. The hypothesis, which considers the saline sedimentary basins as closed basins, with a charging connecting sill to the open sea [31] is based on several variables, which can only with difficulty be justified by available facts and observations.

The total volume of saline deposits of the Earth, formed in some periods, like Upper Miocene, is anomalously high. The elimination of such amounts of material from the whole hydrosphere, in relatively short intervals, would cause a decrease of several percent of the salinity of the whole hydrosphere. There is no direct criterion indicating such a periodical decrease in the salinity of hydrosphere in such critical periods. The explanations are more hypothetical than realistic.

4. Saline deposits with incomplete, inverse or chaotic superposition.

According to the evaporation cycle one expects a normal cyclic precipitation successively of carbonates, calcium sulfate, halite, potash salt etc. [41]. There are many examples in nature which contradict this precipitation by turn. De Ruiter [9] notes the absence of sulfates and carbonates and the high proportion of carnallite in the saline deposits of the Congo basin. According to Belmonte, and others [4] the basic salt

cycle of the Congo basin begins with halite directly on a thin black shale bed. Inverse salt deposition is reported over a large part of the Congo basin by the same author. The cycles are made up of a nearly pure carnallite layer at the base, overlain by an increasingly halitic section capped by pure halite. The uppermost salt unit consists of halite at the base, overlain by shale, anhydrite and dolomite, and is a cycle of decreasing solubility.

5. No modern evaporite basin is known analogous to ancient marine saline deposits.

At the present time no modern mega-basin, analogous to Miocene or Permian etc. saline depositional basins is known in which the salinity of brines exceeds that of saturation and precipitation limit of salts. The Red Sea, in spite of its suitable climatic situation and available charging possibilities from salt producing continental sources, both from outcrops surrounding the Red Sea and under water saline deposits of Upper Miocene has no reported modern halite deposition. The salinity of brines in the lowermost layers of water in some modern basins, like the Red Sea and the Dead Sea, is excessively higher than in the upper layers. [38, 39]. Though the phenomenon has been interpreted in different ways, especially with the fact that there is a higher density of brines in comparison with normal marine water, but there is no evidence that the brines are the products of an evaporation process.

6. Evaporation process and the depth of a sedimentary basin.

The depth of ancient saline basins is still a matter of controversy. If the deep-water model of Schmalz is accepted, the descent of salt crystals, from the water-air surface to the bottom of the basin, without dissolving enroute, is still an open question. According to evaporation processes the saturation and forming of salt crystals take place at the water-air surface, where sun energy is available. The resultant crystals ought to traverse the undersaturated water layers before they reach the bottom of the basin. The crystals will then be completely dissolved if the basin is deep enough. Schmalz states in his model, that the thickness of undersaturated water layer equals the depth to the input-output sill, and the lower shells can be saturated. Even in this case their traverse to a "safe depth" can be much longer than the depth by which any crystal may be dissolved. In other words, the greater the depth of sill the lesser the chance of salt crystals reaching the safe depth.

7. "Kuroko and Black Smokers"- type sulfates and the evaporation model.

Calcium and barium sulfates, in association with sulfide ores, both with Miocene calc-alkaline volcanic pyroclastic rocks of Kuroko type ore and with recent hot springs on the crest of the East Pacific Rise are now well known [17, 40, 30, 21]. Due to quite different environments of formation, such sulfates are not considered as products of an evaporation process, by any of the authors. In the case of Kuroko calcium sulfates, the SO_4^{2-} anions, as well as the Ca^{++} cations are assumed to be supplied by the ocean water. Only the Ba^{++} cations are assumed to be supplied by the ore forming volatiles. A similar explanation is given for the sulfates of the Black Smokers [21].

It is astonishing that the phantom of the dogma of considering an exogenous source for SO_4^{2-} and Ca^{++} ions; for calcium sulfate, in contradiction with the source for Ba, S, Fe, Cu, Pb, Zn etc., i.e. volatiles, is so prominent in the genetic interpretations. Why are the Ca^{++} and Ba^{++} ions assumed to be obtained from two different sources?

Volcanogenic Model: General statement

The development of this model, like any model, is fundamentally based on available observations and data. Therefore its precision and correctness are not absolute. Its value and preference to the conventional evaporation model are probably its better and universal fitting to the criteria concerning the saline-sulfate deposits and their associated features, especially their coincidence with rifting, alkaline magmatism, and stratiform base metal sulfides in red beds.

The hypothetical pre-requisites and the concept for the development of the model are discussed elsewhere [24, 27] and the first field observation and criteria for development of this model were collected in the early 1980's [25, 26], and are briefly noted below: Any type of volcanism exhausts its materials in gaseous, (volatiles), solid (pyroclasts) and fluid (lava flows) states. Some portions of magma, which may not approach to the surface (plutons) may exhaust only their volatile products. The quantity and chemical composition of exhausting materials are functions of the nature of volcanism. For example, alkaline volcanism (or rather, magmatism) usually is richer in volatile content than other types [36, 2, 13]. The ratio of each element comprising the volatiles is also a function of the type of magmatism. For example in alkaline magmat-

ism, the volatiles are exceptionally rich in CO₂, Na, K, Cl, and P. Therefore, when extended magmatic activity, like alkaline magmatism in rift systems, erupts into a subaqueous or subaerial environment, it is logical to expect the presence of volatiles. The exhaustion of volatiles may substantially take place in advance of the solid and liquid states of any individual pulses of volcanism, but it may continue, with less intensity, during and after the solid and liquid states. In the case of plutons the volatiles may reach the surface, whereas the solid and liquid states do not. Since each cycle of magmatic activity, including alkaline magmatism, usually occurs along an extended belt, like a rift zone, and runs for a long time, it is obvious that in any given moment the exhaustion of volatiles, related to the initial stage of volcanism may be in its paroxysm in one location, whereas at the same time in another place the solid and/or liquid states may be more active. With time, the intensity, type and composition of each physical state may gradually change.

These temporal-spatial variations in the physicochemical and quantity of the three aspects of magmatism, (volatiles, lavas and pyroclastics) affect essentially the physicochemical conditions of the invaded sedimentary environments. This fact has to be considered in interpretations and reconstruction of sedimentary basins, where the saline deposits are formed. In shorter intervals of time and in shorter dimensions, due to local subsurface differentiations of magma, just before approaching the surface, some physico-chemical and quantitative changes (ratios) may take place in the magma itself. In the case of alkaline magmatism in the intracontinental rift zones, the petrogenetical composition of magma may vary to the carbonatite, per-alkaline under-saturated or over-saturated extremes. The composition of volatiles, as well as their quantities can vary as a function of these variations. For example it is logical to expect different ratios of CO₂, Na, K, Cl, SiO₂, H₂S and Ca in correspondence with variations in the composition of the erupted alkaline magma. In other words, wherever the manifestations of an alkaline magmatism exist, it is logical to expect a proportional amount of materials originated from its volatiles. Otherwise there is a "deficit" in the "materials balance".

Volcanogenic Model

The intracontinental rifts are amongst the important tectonic and economic features of the earth, and

much of the essential fuels (hydrocarbons, radioactive ores and some coals), fertilizers (phosphates and potash), base metals and iron, as well as some important non-metallic mineral resources (halite, bauxite and some refractories) are restricted to rift systems [23]. The accumulation of saline-sulfate sediments in rift zones and the association of alkaline magmatism, especially its submarine volcanic manifestation, with rifts are well known phenomena. The temporal-spatial coincidence of the three phenomena implies a genetic interrelation among them. The present model explains, in a way, their genetic interrelations.

The rift axes, either in accordance with the geosynclinal concept [15, 8] or the plate tectonics concept [42, 43, 44, 7] are considered to be phenomena related to the splitting of a continental crust. According to the Wilson concept [42, 43] the process of splitting of continental crust, begins with hot spot domes and hot spot magmatism on an axis. i.e., the rift axis. Each hot spot, being the site of arising mantle plume [28], makes a triple junction [16, 6]. Two of the three arms may develop and produce the Red Sea type ocean, whereas the third arm may fail and make up a failed rift or an aulacogen [6, 32, 33]. By extension of the continental crust an initial depression will be formed along the developing arms. The appearance of depression is accompanied by transform faults along the margins of the depression. The extension of two parts of the split proto-continent causes more successive parallel faults and gradual deepening of the depression, as well as thinning of the continental crust along the rift zone. The extension of two parts of the proto-continent will continue until the complete splitting and separation of the continental crust. In this stage the first window of the oceanic crust appears at the bottom of the central trough of the rift zone. The free ocean water may find its way to the initial rift depression. In this case a shallow, narrow long basin will be formed. This will become a Red Sea type sedimentary basin, during the period of rifting process.

The alkaline magmatism associated with hot spot doming and rifting, either as plutons, underneath the rifting zone and the failed arm of the trilete, or as extended alkaline volcanism coming up along the transform parallel faults during the rifting period, introduces tremendous amounts of volatiles into the sedimentary basin (or parallel basins, in the case of disconnected water in parallel depression along the rift system). If the failed rift, which strikes at a high angle into the developed rift zone makes up a shallow

depression before its stagnancy the alkaline magmatism may not be able to manifest as volcanism but the plutons may exist underneath the failed arm. i.e. the aulacogen. In this case the volatiles will emanate and charge the basin with fumaroles in the absence of alkaline volcanism.

The quantity and the intensity of exhaustion of volatiles, is greater in the initial stage of the formation of depression in the rift zone, than in the main stage of rifting. Since the volatiles of magma, which has been differentiated during updoming, will emanate before the exposure of magma, as effusives, in the rift zone. The intensity of emanation of volatiles will gradually become less as the rifting develops. The emanation of volatiles, as well as the alkaline volcanism itself, ceases with the first exposure of the oceanic crust, i.e. at the initial stage of oceanization. The rifting processes along the rift axis may migrate, in one direction or another, during time, so that the successive stages of updoming, subsidence, magmatism, emanation of volatiles and finally the splitting of the crust take place, with time shifting, along the rifting axis. If, due to the tectonic setting of the fractured protocrust, the splitting episode is delayed, the alkaline magmatism and the emanation of its volatiles may continue, probably due to reactivation of the already *in situ* existing materials (East African and Dead sea rift systems?). The reactivation may be periodic during the history of the rift system. The petrology of the alkaline magmatism, and the ratio of the volatile constituents may vary during the development of the rift system. The magmatic differentiation may produce per alkaline, carbonatitic, alkaline to subalkaline products [22,1,2,23].

The introduction of volatiles, in great quantities and short intervals, with or without the eruptive products of alkaline magmatism, in pulsative manner, into the sedimentary basin along the rift depression, in association with the terrigenous materials from the already elevated edges of the rift zone, constitute the raw materials for up to several kilometers of sediments in the rift basin. The extraordinarily rapid and frequent introduction of volatiles (especially rich in CO₂, Na, K, Cl, Ca, SO₂, H₂S, etc.) into the limited volume of water of the basin, will cause an *in situ* saturation of water and precipitation in the bottom of the basin, producing massive saline-sulfate accumulations. The dispersion of ions, in the basin, will take place with a moderate velocity in three dimensions (in accordance with the Brownian movement principle). If the sedimentary basin is energetic, the displacement of water loads

(subbasinal currents, tides, waves etc.) will accelerate the dispersion of ions. It is obvious that the topography of the basin floor will minimize the effect of basinal currents on the velocity of dispersion. Those emanation foci which occur at the bottom of subbasinal troughs, may be safe from the currents. In this case the currents cannot disperse the emanated brines. The greater density of brines compared with water retains them at the trough's bottom (for instance in the Red Sea). Therefore the additional ions emanated will be trapped and cause the gradual increase of the salinity with subsequent saturation, precipitation and accumulation of salt-sulfate loads.

The number and size of emanation foci and their emanation rate can be unlimited. One may expect millions of tiny foci as well as giant ones, widespread on the bottom of the rift basin. Since a great part of salts will be precipitated *in situ*, due to *in situ* saturation, i.e. near the emanation foci, one can expect that the distribution of salt masses on the basin's floor at a given time is heterogenous. The thicker and more extended masses will be formed around larger foci whereas only tiny heaps can be expected around the small foci. This will probably cause a characteristic topography on the basin's floor. The gradual dispersion of salt producing ions in the basinal water will enrich water in saline content. A final enrichment to the degree of saturation and precipitation of salts by evaporation process may take place in these parts of the basin, where shallow water and sabkha condition exist. The enriched waters may find their way to the open ocean and cause abnormal salinity of the ocean water on a regional, even global scale, and for a geological period. The process of accumulation of saline-sulfate masses, goes on as long as the alkaline magmatic activity and rifting continue. The gradual subsidence of the basin allows the saline-sulfate deposits to accumulate and to produce loads up to several kilometers thick. The duration of accumulation is a function of the duration of emanation of ions. The rate of accumulation is a function of the rate of emanation. The type of salts and sulfates, which will be formed on the bottom of the basin, is a direct function of the chemical composition of emanating volatiles and the proportion of different elements in them. The local and short termed variations in the composition of volatiles can cause local and short termed variations in the chemistry of salt precipitates. The long termed periodical and regional changes in the chemistry of volatiles, which can be due to magmatic differentiation, will cause the successive accumulation of different types

of salts and sulfates (halite, potash salts, gypsum, barite, etc.). In longer times and at larger distances along the rift zone, the type of salts-sulfates, still being a function of the type of volatiles, depends on the gradual changes of the type of magma, along the rift zone. Hence, when and where the magma products are more alkaline (being rich in Na, K, Cl, etc.) more saline precipitation is expected, whereas in the case of calc-alkaline and subalkaline (being rich in Ca, S, etc.) more sulfate precipitation is to be expected (Kuroko, Black Smokers and modern Red Sea sulfates). The sedimentary basin can have a limited or unlimited connection with the open ocean. Larger connections reduce the chance of the evaporation process but do not affect the *in situ* accumulation of the main saline-sulfate masses. If the connection is large, considerable amounts of dispersed brines will have a chance to escape from the basin into the open ocean.

In a rifting episode, when the initial depression is formed in the rift lineament, a tentative sedimentary basin is available. If the oceanic water, for any reason, does not find its way into the basin, or fills it only partially, or the basin becomes later on desiccated partly or completely, the volatiles may partly encounter the atmosphere and partly be emitted into the intrabasin lakes (East African Rift system and Dead Sea?). In these cases the lakes will become hypersaline and can obtain brines from subbasinal emanations, as well as from subaerial salts, obtained by subaerial (active or/and fossil) volatile foci.

The volatiles of alkaline magmatism, beside the mentioned components, may contain variable amounts of Fe, Mn, P, Cu, Pb, Zn, Ag, Au, W, Ba, Sr, F, U, SiO₂, Al₂O₃, etc.). The precipitation of these components, in different environments and in different periods, can produce corresponding mineral resources in the sedimentary basin.

Characteristics and implications

The proposed Volcanogenic Model can explain almost all the problems associated with the tectonic setting and sedimentary environments of the formation of huge saline-sulfate deposits. In comparison with the conventional evaporation model, as well as the deep-basin model of Schmalz no contradictions exist, and the proposed model is much more encompassing and universal. Some characteristics, implications and comparison with conventional evaporation model are listed below:

1. A clear genetic explanation is given for the temporal-

spatial interrelation of alkaline magmatism and saline-sulfate accumulation in the rift zones. (Figure 1)

2. The unusual gigantic dimensions, thickness, rapid precipitation, thick annual varves, purity of thick individual beds (monomineralic beds), are explainable by the emanation of large quantities of salt-producing ions, in short periods, due to alkaline magmatism, gradual subsidence of the basin, *in situ* saturation and precipitation and changes in the chemical composition of volatiles.

3. The incomplete, chaotic and inverse precipitation cycles, which are frequent in nature, are the results of changes in the chemical composition of the emanating volatiles in a broad spectrum of scales. The cyclic and "in turn" precipitation of Usiglio [41] is not necessarily encountered in the case of giant deposits, applying this model.

4. The depth of a sedimentary basin, which is so problematic in terms of the explanation by conventional evaporation model, has no significant effect on the process of accumulation of saline-sulfate deposits in this model. *In situ* saturation, just at the bottom of the basin, provides the acceptable explanation for deep sea precipitation. Even the defect in the Deep-Basin Model of Schmalz is well explained with the proposed model.

5. The association of red beds, black shale with sulfides, and saline-sulfate accumulation, as well as phosphorites, uranium bearing sediments and some other associates in the rift zones, have a meaningful genetic explanation with the proposed model. (The author has given a genetic model for this case elsewhere; [24, 26, 27]).

6. The model implies a special chemical composition of volatiles for each type of salt or sulfate sedimentary member in the given basin. This means that the petrology and geological setting of the saline and sulfate deposits, which are the subject of the model, can eventually characterize the related volcanism, at least in large dimensions.

7. As the model gives little value to the evaporation process in producing massive salt-sulfate giants, the paleoclimatical and to a certain extent, the paleogeographical conclusions can not, anymore be made merely on the basis of the presence of saline-sulfate deposits in

an area, since they are not necessarily evaporites. The restriction of giant saline deposits to low latitudes (if so) is not therefore a function of paleoclimate. This conclusion can be very determinative in the methodology of exploration for mineral resources and hydrocarbons.

9. Due to the introduction of volatiles, from the bottom of a basin, limited velocity of dispersion, and the higher specific gravity of brines in comparison to normal marine water the lower layers of basin are more saline than upper layers.

10. The model implies that the genetic interrelation between the formation of saline-sulfate giants and alkaline magmatism is closer than that with rifting.

11. The model does not exclude the feasibility of the evaporation process in producing salt-sulfate sediments in sabkha and desert, or limited scale closed shallow water environments.

Conclusion

If the Volcanogenic Model, is considered to be a feasible concept in the formation of saline deposits, a sequence of substantial questions, problems and new genetic conclusions will be set forth for discussion. At the present stage of development of this model it is difficult to predict precisely the consequences. Some conclusions and predictions are as follows:

1. The huge saline deposits of the world are principally originated from, and related to, alkaline magmatism. Therefore their temporal-spatial coincidence with rift systems, wherever they are, is due to the coincidence of rifts with the alkaline magmatism.
2. The precipitation of salts and sulfates is not necessarily the function of an evaporation process. The saturation and forming of salt and sulfate crystals can theoretically occur at any depth, but is dominant on the bottom of the basin. Therefore the saline and sulfate deposits in a sedimentary basin can not be considered as a criterion for shallow water and dry-hot climate environment in paleogeographical and paleoclimatological interpretations.
3. The Volcanogenic Model implies that the variations

in the chemical and petrogenetical nature of alkaline volcanism, in time and space dimensions, in regional scale, are the first and major causes for successive precipitation of chlorides and sulfates and for the variations in their chemical composition. Volcanism, including its volatiles, with an alkaline tendency, being rich in Na, K, Cl in comparison with that of the calc-alkaline tendency produces more salt deposits, whereas, that with calc-alkaline tendency produces more sulfate products. The sedimentary environments affect the precipitation processes as a subordinate parameter after volcanism. Therefore when studying the petrogenesis and origin of saline deposits and saline basins the study of magmatism in the same time-space dimension is essential. This means that a quantitative approach to the problem of saline masses and the extension of alkaline magmatism, in rift systems, is essential in working on the genesis of saline deposits.

4. The earth's hydrosphere, as a whole, or a definite sector of it, if confined in a semi-closed or closed sedimentary basin, operates as an agent in transformation, transportation and preservation of salt-sulfate forming ions between the volcanism and sedimentation time-space intervals. This implies the heterogeneity of the hydrosphere during its geological history, and in its geographical and vertical dimensions in different scales. In other words during some periods of the earth's history, like Infracambrian-Lower Cambrian, Devonian, Permian-Triassic, Jurassic-Cretaceous and Miocene-Pliocene, due to extended alkaline magmatism, in vast areas of the earth's hydrosphere the salinity has been abnormally high.

5. As the evaporation process, according to the Volcanogenic Model, is not the main process for precipitation of salt-sulfate deposits, the term "evaporites" is not a proper name for such sediments. Hence, we may use the term "saturites" or "massive saline-sulfate deposits" instead of evaporites for these sediments.

References

1. Bailey, D. K. Lithosphere control of continental rift magmatism. *J. Geol. Soc. Lond.* **133**, 103-106 (1977).
2. Bailey, D. K. Volatile flux, geotherms, and the generation of the Kimberlite-Carbonatite-alkaline magma spectrum. *Min Mag.* **43**, 695-699 (1980).
3. Baker, B. H., Mohr, P.A., and Williams, L.A. Geology of the eastern rift system of Africa. Spec. Pap. *Geol. Soc. Am.*, 1-136 (1972).

4. Belmonte, Y., Hirtz, P., and Wenger, R. The salt basins of the Gabon and the Congo, in salt basins around Africa; London, Inst. Petroleum, 55-74 (1965).
5. Burke, K. C. Atlantic evaporites formed by evaporation of water spilled from the Pacific, Tethyan and southern oceans. *Geology* **3**, 613-616 (1975).
6. Burke, K.C. Aulacogens and continental break-up. *A Rev. Earth Planet. Sci.* **5**, 371-396 (1977).
7. Burke, K. C. and Dewey J.F. Plume-generated triple junctions: Key indicators in applying plate tectonics to old rocks. *J. Geol.* **81**, 406-433 (1973).
8. Dana, J. D. On some results of the earth's contraction from cooling, including a discussion of the origin of mountains and the nature of the earth's interior. *Am. J. Sci.* **5**, 432-434, 6, 6-14, 104-115, 161-171 (1873).
9. De Ruiter P. A.C The Gabon and Congo basins salt deposits. *Econ. Geol.* **75**, 419-431 (1979).
10. Dott, R. H., and Batten R.L. Evolution of the earth. McGraw-Hill Book Co. 1-573 (1981).
11. Evans, R. Origin and significance of evaporites in basins around Atlantic margin. *Amer. Asso. of Petrol. Geol. Bull.* **62**, 223-234 (1978).
12. Falvey, D. A. The development of continental margins in plate tectonic theory. *Aust. Petroleum Explor. Ass. J.* **10**, 95-106 (1974).
13. Fisher, R. V. and Schmincke, H.U. Pyroclastic rocks, Springer-Verlag, Berlin, Heideberg, New York, Tokyo. 1-744 (1984).
14. Garson, M. S. and Krs, M. Geophysical and geological evidence of the relationship of Red Sea transverse tectonics to ancient fractures. *Bull. Geol. Soc. Am.* **87**, 169-181 (1976).
15. Hall, J. Description and figures of the organic remains of the lower Helderberg Group and the Oriskany Sandstone, In: "Natural History of New York" Palaeontology. New York **3**, 1-544 (1859).
16. Hoffman, P. F., Evolution of an early Proterozoic continental margin: The Coronation Geosyncline, and associated aulacogens of the N.W. Canadian Shield. *Phil. Trans. R. Soc. Lond.* **273A**, 547-581 (1973).
17. Horikoshi, E.L. Volcanic activity related to the formation of the Kuroko-type deposits in the Kosaka District, Japan. *Mineral. Deposita* **4**, 321-345 (1969).
18. Hsu, K. J. Origin of Saline giants: A critical review after the discovery of the Mediterranean evaporites. *Earth Science Rev.* **8**, 371-396 (1972).
19. Hutchison, R. W. and Engels, S.G. Tectonic significance of regional geology and evaporite lithofacies in northeastern Ethiopia. *Phil. Trans. R. Soc. Lond.* **267A**, 313-329 (1970).
20. Kozary, M.T., Dunlap, J.C. and Mumphrey, W.E. Incidence of saline deposits in geological time. *Geol. Soc. Am. Spec. Pap.*, **88**, 45-57 (1968).
21. MacDonald, K.C., Becker, K., Spiess, F.N. and Ballard, R.D. Hydrothermal heat flux of the "black smoke" vents on the East Pacific Rise. *Earth Planet. Sci. Lett.* **48**, 1-7 (1980).
22. McConnell, R. B. Geological development of the rift system of eastern Africa. *Bull. Geol. Soc. Am.* **83**, 2549-2572 (1972).
23. Mitchell, A. H. G. and Garson, M.S. Mineral deposits and global tectonic settings. Academic Press Geology Series. Third printing, London. 1-450 (1984).
24. Momenzadeh, M. Syngenetic ore deposits; A provisional classification, and the main syngenetic metallogenesis periods in Iran, *Geol. Surv. of Iran, int. rep.* 1-37 (1982).
25. Momenzadeh, M. Baleghlu Gypsum deposit (Gharghabad-Saveh, W-Central Iran; A new genetic interpretation. *Geol. Surv. of Iran, Int. rep.* 1-12. in Persian (1982 a).
26. Momenzadeh, M. Temporal-spatial distribution of gypsum, barite, lead, iron, manganese, copper and turquoise in Eocene sequences, north and northeast Iran: A new genetic model; presented in second symposium. Geological Survey of Iran, Winter 1983. *Geol. Surv. of Iran, int. rep.*, 1-52, 1 map, in Persian (1983).
27. Momenzadeh, M. Contribution of submarine volcanism in the formation of major stratiform synsedimentary ores: A hypothetical approach. *Geol. Sur. of Iran. int. rep.* 1-19 (1986).
28. Morgan, W. J. Plate motions and deep mantle convection. In «Studies in Earth and Space Sciences (Hess volume)» (R.R.Shagam and other eds.) *Mem. Geol. Soc. Am.* **132**, 7-22 (1972).
29. Ochsensius, C. Die Bildung der Steinsaltzlager und ihrer Mutter langensaltze, Pfeffer, Halle, 172p (1877).
30. Ohmoto, H. and Skinner, B.-The Kuroko and related volcanogenic massive sulfide deposits, Skinner, B. ed., *Eco.Geol. Monograph* **5** (1983).
31. Schmalz, R. F. Deep water evaporite deposits: A genetic model. *Amer. Assoc. of Petroleum. Geol. Bull* **53**, 798-823 (1969).
32. Shatski, N. S. Structural correlations of platforms and geosynclinal folded regions. *Akad. Nauk SSSR Izv. Geol. Sec.* **5**, 37-56 (1947).
33. Shatski, N. S. On the origin of the Pachelma trough. Mosk. 0-va. Lyubit. Prir. Byull. *Geol. Sec.* **5**, 5-26 (1955).
34. Sheridan, R. E. Atlantic continental margin of North America. In «The Geology of Continental Margins» (C.A. Burke and C.L. Drake, eds), 391-407. Springer-Verlag, New York. (1974).
35. Sillitoe, R. H. Strata-bound ore deposits related to Infracambrian rifting along northern Gondwanaland. Proceedings of the Fifth quadrennial IAGOD Symposium, Vol. I. Edited by E. Schwazerbart'sche Verlagsbuchhandlung (Nagele U. Obermiller) Germany. Stuttgart. 163-171 (1980).
36. Sorensen, H. The alkaline rocks, pub. by A Witer. Interscience Publication, John Wiley and Sons, Chichester, New York, Brisbane, Toronto. 1-622 (1979).
37. Stöcklin, J. Possible ancient Continental margins in Iran, in «The Geology of Continental margins». C.A. Burke. and C.L. Drake, Springer-Verlag. N. Y., 873-887 (1974).
38. Theisse, Y., Guennoc, P, Pouit, G. and Nawab, Z.A. The Red Sea: A natural geodynamic and metallogenic laboratory. *Episodes* **1983**, **3**, 3-8 (1983).
39. Twenhofel, W.H. Principles of sedimentation, Sec. Ed. McGraw-Hill Book Company (1950).
40. Urabe, T. and Sato, T. Kuroko deposits of the Kosaka Mine, Northeast Honshu, Japan-Products of submarine hot springs on Miocene Sea floor. *Econ. Geol.* **73**, 161-179 (1978).
41. Usiglio, J. Analyse de l'eau de la Mediterranee sur les cotes de France. *Ann. phys.*, 3 rd. Ser., **28**, 92-107, 172-191 (1849).
42. Wilson, J. T. A possible origin of the Hawaiian Islands. *Can. J. Phys.* **41**, 863-870 (1963).
43. Wilson, J.T. Evidence from ocean islands suggesting movement in the earth. In «Symposium on continental drift» *Phil. Trans. R. Soc. Lond.* **258A**, 145-167 (1965b).
44. Wilson, J. T. Static or mobile earth: The current scientific revolution. *Proc. Am. Phil. Soc.* **112**, 309-320 (1968).