

A new occurrence of bassanite in recent evaporitic environments, Kuwait, Arabian Gulf

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ABSTRACT

A significant occurrence of the metastable mineral bassanite ($\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$) is reported here from the continental sabkha zone pans and gypsum dune complexes of Al-Khiran, Kuwait. This is the first known occurrence in the Arabian Gulf of this evaporite mineral outside the Abu Dhabi sabkha complex. The bassanite is probably partially topotactic after gypsum and occurs as a dissolution-precipitation product after gypsum. Scanning electron microscope (SEM) investigations show that the bassanite crystallites are approximately 5–30 μm in length, with a clearly identifiable hexagonal crystal morphology (illustrated here for the first time) which is only rarely observed in nature. The surficial layers of bassanite from Al-Khiran prevail only during the hot, dry summer season (April–October); during the wet winter months it reverts to gypsum fairly rapidly and hence a very significant climatic control is suggested for its genesis.

INTRODUCTION

Bassanite has been reported as arid zone efflorescences from many parts of the world (De La Hunty & Low 1958; Moiola and Glover 1965; Kinsman 1967, 1974), and also as an evaporite mineral from the coastal sabkhas of Baja California and Abu Dhabi (Kinsman 1967, 1974). It has been studied experimentally as part of the gypsum \rightleftharpoons anhydrite equilibrium in the system $\text{CaSO}_4\text{--H}_2\text{O}$ (Zen 1965; Gay 1965). The metastable equilibrium gypsum \rightleftharpoons anhydrite in CaSO_4 solutions lies at 96–98°C and in saturated NaCl solutions at about 70–76°C. The above equilibrium in the dry state requires that bassanite be an intermediate phase. The dehydration of gypsum \rightleftharpoons bassanite \rightleftharpoons β or insoluble anhydrite in nature does not appear to fit with the available experimental data, which suggests that the 'dry' dehydration sequence should be gypsum \rightleftharpoons bassanite \rightleftharpoons α or soluble anhydrite (Kinsman 1967).

Bassanite is always a metastable phase under all earth surface conditions. Also, it appears that bassanite is not a very common evaporite mineral in supratidal sediments. This may be due to its extreme instability and transitory nature in Recent environments. In Kuwait, it is found within evaporite pans and gypsum dune complexes in the continental sabkha zone. Outside of Abu Dhabi (in the United Arab

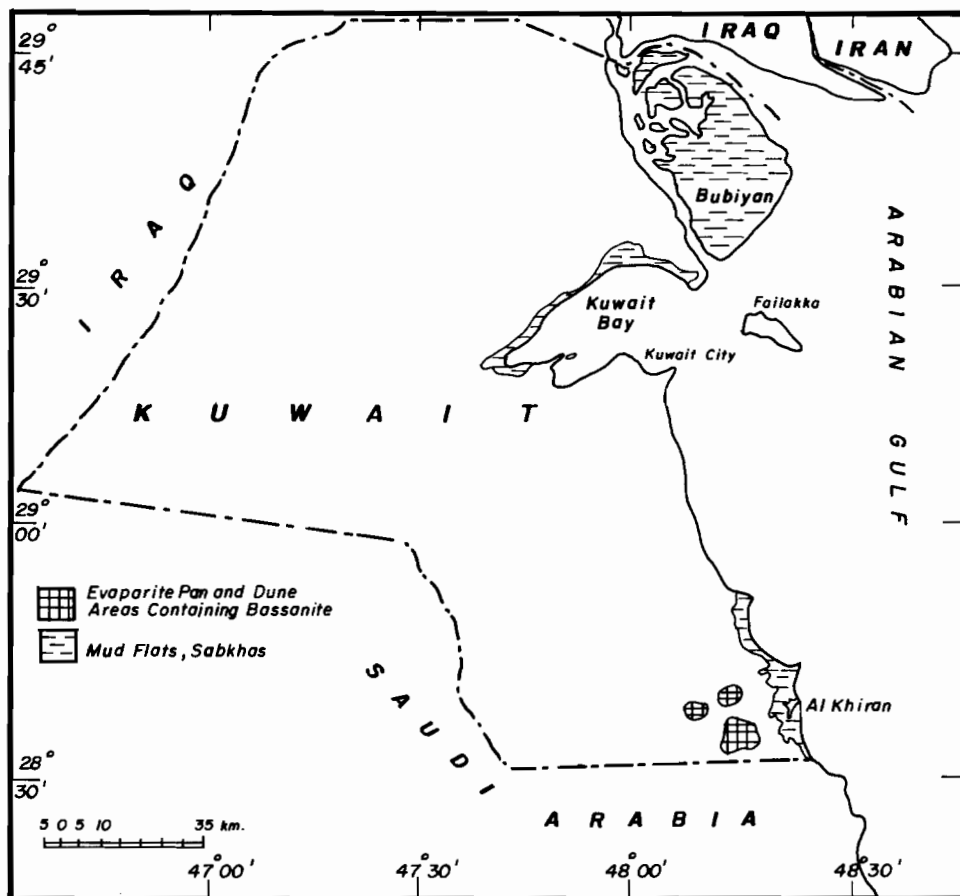


Fig. 1. Regional setting and location of study area in Kuwait.

Emirates), this is the only known occurrence in the Arabian Gulf. Kinsman (personal communication) has also found bassanite in the very extensive Sabkha Matti in western Abu Dhabi, that appears to be very similar to the Al-Khiran occurrence. Because of its crypto-crystalline habit, it can best be studied under the scanning electron microscope.

All samples were identified as bassanite by standard X-ray diffraction methods (Table 1). The location of the bassanite occurrences is shown in Fig. 1. The purpose of this study is to understand the environmental conditions of bassanite formation in the supratidal regions of Kuwait and investigate its crystal morphology in nature.

CLIMATE

The climatic control of evaporite mineral facies in Recent supratidal environments appears to be a critical factor in their distribution (Kinsman 1976; West *et al.* 1979). The average rainfall in Kuwait is about 120 mm yr^{-1} falling mostly between November and April inclusive. While rainfall values of over 200 mm yr^{-1} and ground surface

Table 1. X-ray diffraction data for bassanite* from Al-Khiran

$dA^{0\dagger}$	I/I^*	hkl^*
6.00	95	100
4.37	2	101
3.46	45	110
3.21	2	002
3.03	6	111
3.00	100	200
2.81	50	102
2.71	4	201
2.34	2	112
2.27	4	210
2.18	2	202
2.13	10	211
2.12	2	002
1.99	2	103
1.91	4	301
1.85	12	212
1.84	6	—
1.74	4	220
1.69	8	302
1.66	8	310

[†] Average of 12 samples. The d -spacings are for $2\theta = 4^\circ$ to 60° . Radiation CuK_α , $\lambda = 1.5418$, Ni filter.

* Inferred from ASTM data.

temperatures as high as 62°C have been recorded from the evaporite pan areas of Al-Khiran, the distribution of the relative humidity (RH) pattern is less clear as it changes from year to year. In the dry summer months daytime RH values vary from 30–90% and evaporation rates are moderately high, depending on the wind regime. The salinity of the groundwater table in these pans is never more than 25‰ (ppt).

The surface bassanite within the pans changes to gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) every year with the advent of the rainy season, and subsequently starts reverting back to bassanite by the end of April of each year (or within 4 to 6 weeks after the end of the rains). The rainy season 1983/84 was one of the driest on record. A rain gauge installed at Al-Khiran recorded a total of less than 10 mm. The bassanite survived through the winter period without any perceptible change in mineralogy. An important climatic-biological control of anhydrite (CaSO_4) genesis has also been reported for the Al-Khiran region of Kuwait (Gunatilaka *et al.* 1980).

Bassanite has not been reported from the supratidal zone of the more humid Mediterranean sabkhas of Egypt (West *et al.* 1979), where the average rainfall is 180 mm yr^{-1} and average summer air temperatures are about 30°C . In the Trucial Coast (UAE), the air temperatures in the sabkha areas average 47°C in summer and occasionally rise as high as 57°C , while the rainfall averages less than 50 mm yr^{-1} . Presumably, the bassanite here is less prone to frequent seasonal alteration, unlike in Kuwait.

BASSANITE OCCURRENCES IN KUWAIT

AL-KHIRAN AREA

In the Al-Khiran area (Fig. 1), bassanite is found locally in significant quantities in the evaporite pans of the continental sabkha. These are areas of lower elevation surrounded by higher ground constituting the sand sheets. Gypsum masses lie exposed at the surface of the evaporite pans. Here the groundwater table is less than 1 m below the surface and bassanite occurs as thin sheet-like masses, 5–30 cm thick within some of these pans (whose average dimensions are 1000–1500 m long and 700–800 m wide). It is not easily observed at the surface, as a thin layer of desert sand covers the deposits. Some sparse halophytic vegetation covers the pan surfaces.

The bassanite occurs as a crumbly, crustose layer with a surface texture resembling pumice. It disintegrates between the fingers easily, giving a very fine powder. Impregnated thin sections show that it is too fine grained to be identified under the microscope. At depth within the sediments, it grades into a pure gypsum crust. No anhydrite was detected within the pans. This fine grained bassanite is probably very similar to the powdery alteration product (hemihydrate) that is locally called *kopi* in Western Australia (De La Hunty & Low 1958); *kopi* is formed *in situ* as alteration layers by the exposure of large gypsum deposits to the atmosphere.

X-ray diffraction analysis shows that the pumice-like crust is made up of 100% bassanite (Table 1). Scanning electron micrographs confirm that the deeper bassanite is probably partially topotactic after gypsum, while at the surface it occurs as multiple sheets or bundles and sometimes shows a 'ghost' gypsum crystal outline (Figs 2–5).



Fig. 2. SE micrograph of bundles of needle-like bassanite crystals (B) showing hexagonal morphology. Surface sample collected at the beginning of the dry season after the rains, Al-Khiran pans.



Fig. 3. SE micrograph of bundles of bassanite crystals (B). Sample collected after a very humid spell. The crystals are probably undergoing local dissolution on their surfaces due to collection of moisture and dew on the pan surfaces, Al-Khiran area.

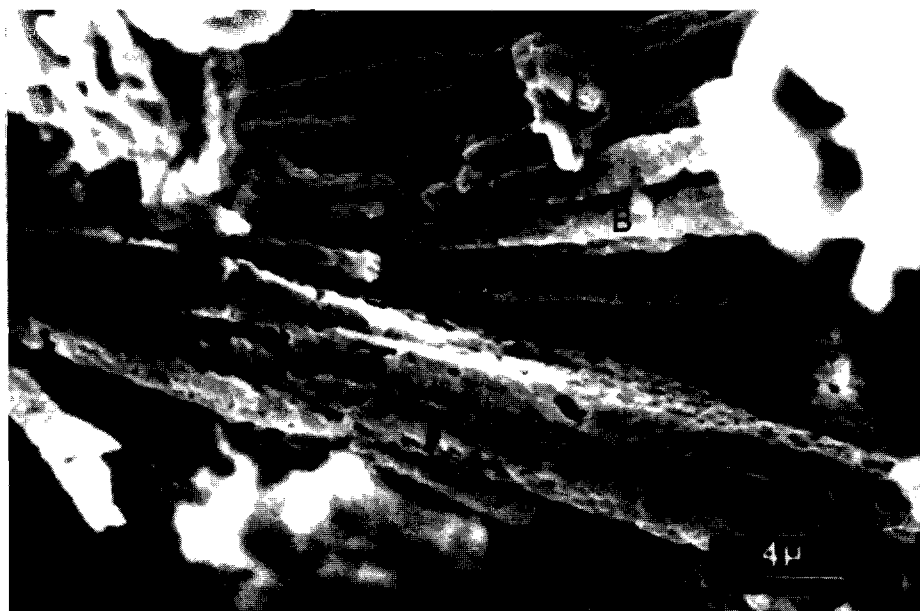


Fig. 4. SE micrograph of bassanite bundles (B) collected during the dry season from 5 cm below the surface. Note solution pits on the surface of the crystallites. This is the most common aspect of the bassanite crystals observed under SEM, Al-Khiran area.

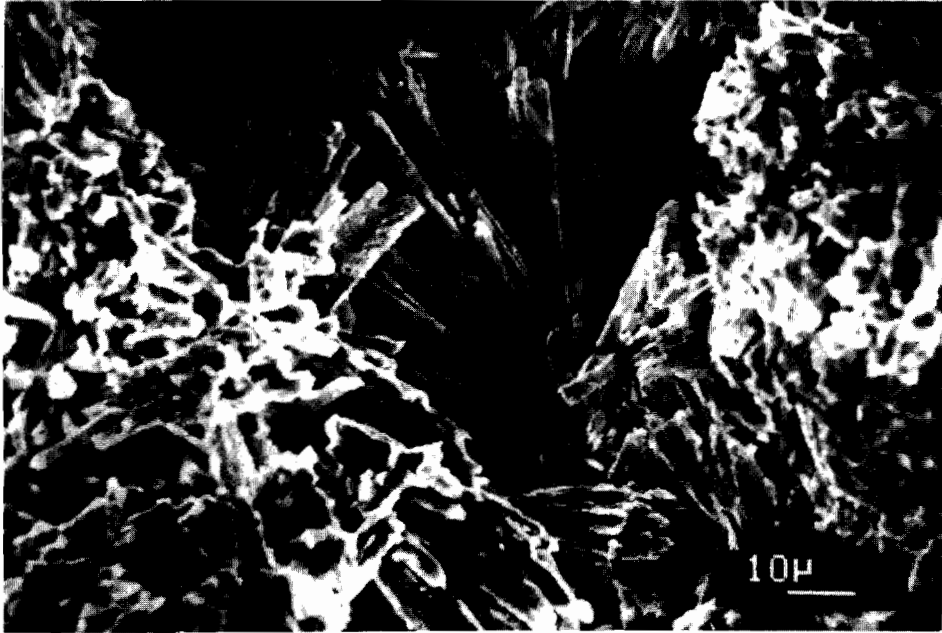


Fig. 5. SE micrograph of radiating crystallites of bassanite in a sample taken at 20 cm depth, Al-Khiran area.

Each bassanite crystal is about 5–30 μm long and 1–3 μm wide and may occasionally show a hexagonal crystal morphology (Fig. 2). It is a very difficult mineral to deal with under the SEM as it appears to disintegrate when exposed to the electron beam (a cooling stage was not available for this study).

The last three seasons' field work (1980–83) in Al-Khiran also indicates that the gypsum \rightleftharpoons bassanite transformation occurs every year at the onset of the dry and wet seasons, with the surface layers undergoing alteration as the environmental conditions change. In fact, this bassanite crust can be converted to gypsum in the laboratory when left in contact with rainwater for 24 hours (Fig. 6). Evidence from both scanning electron microscopy (Figs 2–6) and the geochemistry of the two solid phases involved indicates that the gypsum \rightarrow bassanite transformation is essentially a dissolution–reprecipitation reaction. The $^{87}\text{Sr}^{++}/^{44}\text{Ca}^{++}$ ratio of the gypsum varied from $1.6\text{--}2.2 \times 10^{-3}$ and that of bassanite from $0.9\text{--}1.4 \times 10^{-3}$ (based on five samples of each phase analysed by standard atomic absorption techniques). Hence, the dehydration and rehydration changes are not isochemical in nature, which rules out a solid state transformation of gypsum \rightarrow bassanite. A largely topotactic replacement would show a constant or very similar $^{87}\text{Sr}^{++}/^{44}\text{Ca}^{++}$ ratio. It is not known whether the bassanite in Abu Dhabi undergoes a similar change with the seasons. The chemical data appears to be in agreement with crystal chemical considerations of the gypsum (monoclinic) and bassanite (hexagonal) structures. With increasing crystal symmetry, it would be more difficult to accommodate large ions such as Sr^{++} (1.12 \AA) in a given structure. Hence, the lower $^{87}\text{Sr}^{++}/^{44}\text{Ca}^{++}$ ratios in the bassanites are accounted for by chemical theory.

More than 10 km inland from coastal Al-Khiran the evaporitic pans develop so

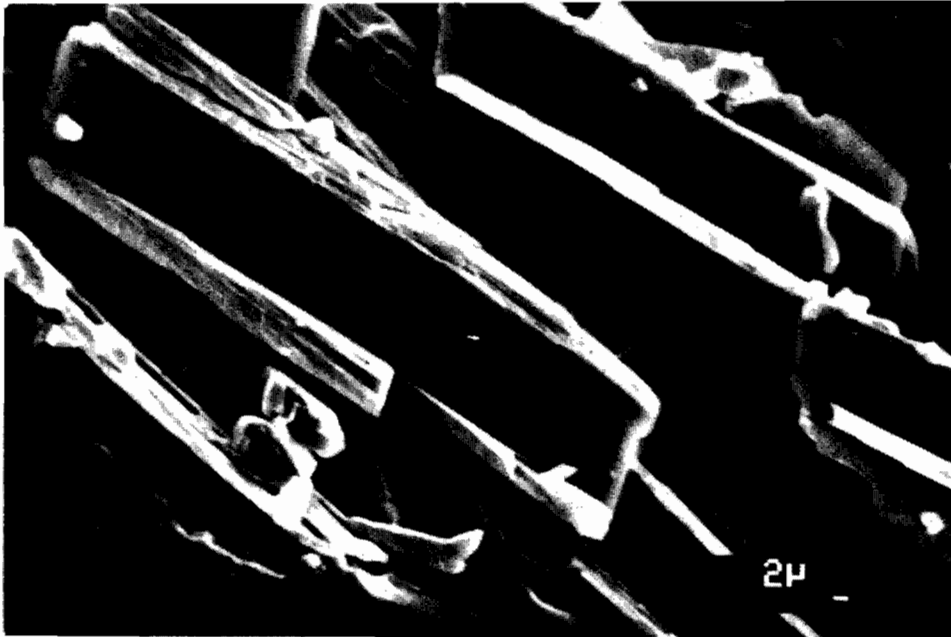


Fig. 6. SE micrograph of gypsum crystals formed after bassanite was left in contact with rainwater for 24 hours.



Fig. 7. An evaporitic pan with well developed nebkha dunes, 11 km from the coast. The plant colonising the dunes is *Nitraria*. The pan itself is floored with gypsum-rich sediments.

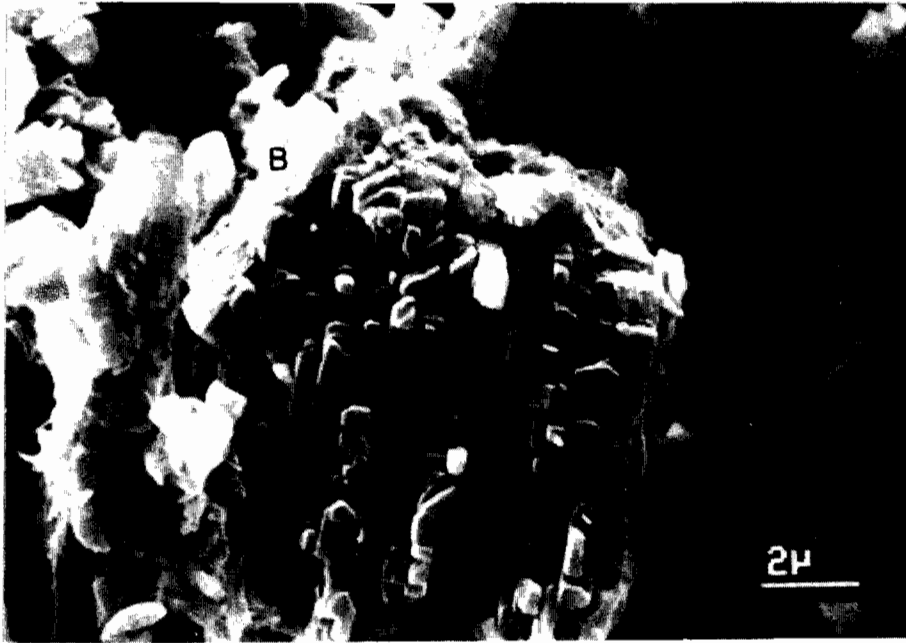


Fig. 8. SE micrograph of gypsum crystal undergoing alteration to bassanite (B) on the outer surface and showing partial topotaxy. X-ray analysis of a smear sample on a glass slide indicated approximately 55% bassanite and 45% gypsum. Sample grains from a dune in Al-Khiran.



Fig. 9. SE micrograph of a broken surface of a partially altered gypsum grain. Note cryptocrystalline bassanite (B) on the left and the still unaltered core of the gypsum crystal, an evidence that the transformation proceeds centripetally from the outside to the inside of the crystal. Al-Khiran.

called *nebkhas* or shrub coppice dunes through the trapping of moving sand and gypsum grains by the halophyte *Nitraria retusa* (Fig. 7). Here, bassanite occurs within the gypsum-rich dunes up to a depth of one metre from the surface. In the upper layers of the dunes, bassanite partially or more rarely completely pseudomorphs gypsum crystals of approximately 0.7–3 mm in length (Fig. 8). With depth, the gypsum shows only an outer alteration layer of bassanite (Fig. 9). Here too, the mechanism appears to be one of dissolution–reprecipitation, resulting in replacement ($^{87}\text{Sr}^{++}/^{40}\text{Ca}^{++}$ ratios were not determined in this case due to the difficulty in obtaining a pure bassanite phase). To the authors knowledge, scanning electron micrographs of bassanite showing its crystal morphology and diagenetic changes are not known in the literature.

It is very likely that the high porosity-permeability of the gypsum dunes and the rapid downward percolation of rainwater precludes a wet state in the dunes for any significant length of time. In addition, the plants colonising the dunes probably have some role to play in bassanite formation by partially dehydrating the gypsum. Such a plant control has been recognised in the formation of anhydrite from gypsum in Al-Khiran (Gunatilaka *et al.* 1980). Interestingly enough, in the pans and dunes this 'dry dehydration' of the gypsum never proceeds beyond the bassanite stage to form anhydrite. Gypsiferous, vegetated dunes where gypsum is undergoing alteration to bassanite are also present in Bubiyan Island in the extreme north of Kuwait (Fig. 1), where there are several halophytic species colonising the dunes.

DISCUSSION AND SUMMARY

This short study reports the first major occurrence of bassanite in Kuwait and outside of Abu Dhabi in the Arabian Gulf region. Its crystal morphology has been observed for the first time by scanning electron microscopy. As an important mineral phase in the $\text{CaSO}_4\text{--H}_2\text{O}$ system, its conditions of formation contribute to the better understanding of this system. In the conversion of gypsum to anhydrite and vice versa in the wet sabkhas, bassanite was never identified as an intermediate phase. This is in agreement with most published data which describes its formation only during dry transformation of gypsum to anhydrite (Kinsman 1967). However, the physico-chemical conditions for anhydrite formation are not even marginal in the pan and dune environments of Kuwait.

It is possible that beside the thermodynamic factors, climatic and biological controls are also significant in evaporite mineral transformations in sabkhas, and this may perhaps explain the discrepancies between the natural and experimental systems. Experimental data includes consideration of metastable phases and thus one cannot emphasise the thermodynamic aspects only; kinetic factors too are important. It may well be that climate and biology control the rates of certain physical and/or chemical processes (such as evaporation rates, supersaturation rates and nucleation aspects) in these evaporite systems.

Outside the Arabian Gulf (and also Baja California) bassanite is very rare in supratidal environments. In the much wetter and humid Egyptian sabkhas (which are also covered by halophytes) neither bassanite nor anhydrite has been detected (West *et al.* 1979). Consideration of climatic aspects would suggest that it should be fairly widespread in continental interiors in continental sabkha/playa environments. As coastal environments even in subtropical areas are generally fairly humid, the development of bassanite in coastal sabkhas is likely to be more restricted. The

occurrence of bassanite reported in this short note is a good illustration of the climatic control on the distribution of evaporitic minerals in modern sabkhas.

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تواجد معدن البازنيت في البيئات التبخرية لمنطقة الخيران في جنوب دولة الكويت

انا قوناتيلاكا و علي التميمي و عباس صالح و نصرى نصار
قسم الجيولوجيا بجامعة الكويت

خلاصة

تم التعرف على كميات لا بأس بها من معدن البازنيت النادر المعروف بقلة ثباته والمكون من كبريتات الكالسيوم (مع نصف جزيء من الماء) ، وكان البازنيت متواجدا في نطاق السبخات القارية لمنطقة الخيران حيث تكثر الاراضي الواطئة المغطاة بكتيبيات من حبات الجبس ، وهذه هي المرة الأولى التي يكتشف فيها هذا المعدن التبخري في الخليج العربي خارج نطاق سبخات أبو ظبي في الامارات العربية المتحدة .

ان معدن البازنيت هو في الغالب شكل كاذب جزئيا لمعدن الجبس ويتكون نتيجة عملية الازابة والاحلال للجبس . ان دراسة هذا المعدن بواسطة المجهر الالكتروني تظهر ان بلورات معدن البازنيت ذات اشكال سداسية واضحة يبلغ طولها من 5-30 ميكرون ، وتنتشر هنا لأول مرة ، وهي نادرا ما تشاهد في الطبيعة .

ان تواجد الطبقات السطحية لمعدن البازنيت في منطقة الخيران يكثر فقط خلال فصل الصيف الحار الشديد الجفاف (ابريل الى اكتوبر) اما خلال فصل الشتاء الممطر فان معدن البازنيت يتحول بسهولة الى جبس ولذلك يمكن القول ان منشأ معدن البازنيت يخضع مباشرة للعوامل المناخية .

