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ORIGIN OF CHERT NODULES IN KOMETAN FORMATION FROM DOKAN AREA, NORTHEAST IRAQ

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ABSTRACT

Kometan Formation, in most localities, contains sporadic and rare chert nodules, but in Dokan area, these nodules become widespread and associated with well-developed and high amplitude stylolites. They are mainly distributed along or around the bedding planes. The long axes of nodules and stylolite surfaces are aligned parallel to the bedding plane. Field observations and statistical analysis (rose diagram of long axes) showed that nodule elongation and stylolite peaks have no any relation with the known tectonic stress directions of the area. Therefore, the growth of the nodules and stylolites are attributed to deep burial diagenesis of the rocks of the formation under vertical lithostatic pressure and not due to tectonic stress. This result contradicts with the previous studies, which supposed that stylolite peaks have directions of North – South and East – West.

Microscopic studies showed that nodules are developed by both displacement and replacement during deep burial. The microscopic criteria for emplacement are: **1-** The limestone around nodules shows exceptional crowding of planktonic forams due to the dilatational relations with country rock. **2-** They are associated with stylolites, this mean that the nodules compressional environment is favored by nodules and stylolites on expense of host limestone. While the criterion for replacement includes presence of partially dissolved and replaced forams directly at the contact between the chert and limestone. The local accretions of silica for replacement and displacement growth are assisted by diffusion and moving of watery solutions. The presence of widespread chert nodules and stylolites in Dokan area and their absence in other areas is attributed to exertion of the vertical lithostatic differential pressure at Dokan area. While the surrounding areas were performed as pressure shadow or the pressure was hydrostatic type (equal in all direction). The load pressure is estimated indirectly by comparing with calcite compensation depth (CCD) pressure under which limestone dissolve and silica increases in deep oceans.

أصل الدرنات السليكاتية داخل تكوين كوميتان فى منطقة دوكان، شمال شرق العراق

شيرزاد توفيق البرزنجي

المستخلص

يحتوي تكوين كوميتان على درنات سليكاتية ولكنها تكثر في بعض المناطق مثل منطقة دوكان وبصورة قليلة في مناطق أخرى. تكون هذه الدرنات منتشرة وممتدة على سطوح إذابة عالية القمم أو على امتداد أسطح الطبقات.

أظهرت الدراسات الحقلية والإحصائية (مخطط روز) بأن امتداد هذه الدرنات وقمم أسطح الذوبان لاتظهر أية علاقة مع الاتجاه العام للحركات التكتونية المعروفة في المنطقة، لذلك يعزى نمو الدرنات وأسطح الذوبان إلى الدفن العميق للتكوين مع ضغط الرسوبيات. هذه النتيجة ظهرت معكوسة لنتائج الدراسات السابقة والتي تشير الى أن اتجاه قمم أسطح الذوبان موازية لاتجاه الحركات التكتونية المعروفة في المنطقة وهو شمال – جنوب وشرق – غرب.

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أظهرت الدراسات المجهرية بأن الدرنات تكونت ونمت بواسطة الإزاحة والإحلال خلال الدفن العميق. وان الشواهد المجهرية للإزاحة هي: **1-** يظهر الصخر الجيري الحاوي للدرنات السليكاتية تجمع أستثنائى للفورامنفرا بسبب العلاقة غير المنتظمة مع الصخور المجاورة. **2-** هذه الدرنات تكون متحدة مع أسطح الذوبان، وهذا يعني تكوين الدرنات بمساعدة الإجهاد الحصري على حساب الصخور الكلسية المظيفة. تذكر هذه الدراسة عدد من مصادر السليكا داخل التكوين ولكن المصدر المحلي يعزى الى تجمع السليكا بواسطة انتشار وحركة المحاليل المائية. ان وجود هذه الدرنات وأسطح الذوبان بكثرة في منطقة دوكان وقلتها في مناطق اخرى، يعزى الى زيادة الضغط العمودي للطبقات في منطقة دوكان. أما المناطق الأخرى المحيطة، فان الضغط قد يكون على شاكلة ظل الضغط (pressure shadow). ان ضغط الرسوبيات قدر بصورة غير مباشرة وبالمقارنة مع ضغط CCD حيث تحتها تذوب الصخور الجيرية ويزداد ترسيب السليكا.

INTRODUTION

Kometan Formation (Cretaceous) is extensively exposed along both limbs and plunge areas of some major anticlines of northeastern Iraq, such as: Piramagroon, Sara, Azmir and Goizha Anticlines. According to Buday (1980), this formation was first described by Dunnington, (1953) at Kometan village near Endezah, in the contact between the Imbricated and High Folded Zones. It consist of (100 – 200) m white weathering, light gray, thinly to thickly bedded limestone. Karim (2004) attributed the formation to the transgressive system tract of Late Cretaceous. Petrographic analysis shows that it has fine grained texture with many planktonic forams, mainly including Oligostegina and Globigerina species. The present study is concerned with the area around Dokan Dam site (Figs.1 and 2.4) where the northwestern plunge of Sara Anticline is dissected by Lesser Zab River. In this area, spectacular large size and high frequent chert nodules occur with large scale stylolites in the Kometan Formation. This type of occurrence is not observed elsewhere and is unique in the area of occurrence.

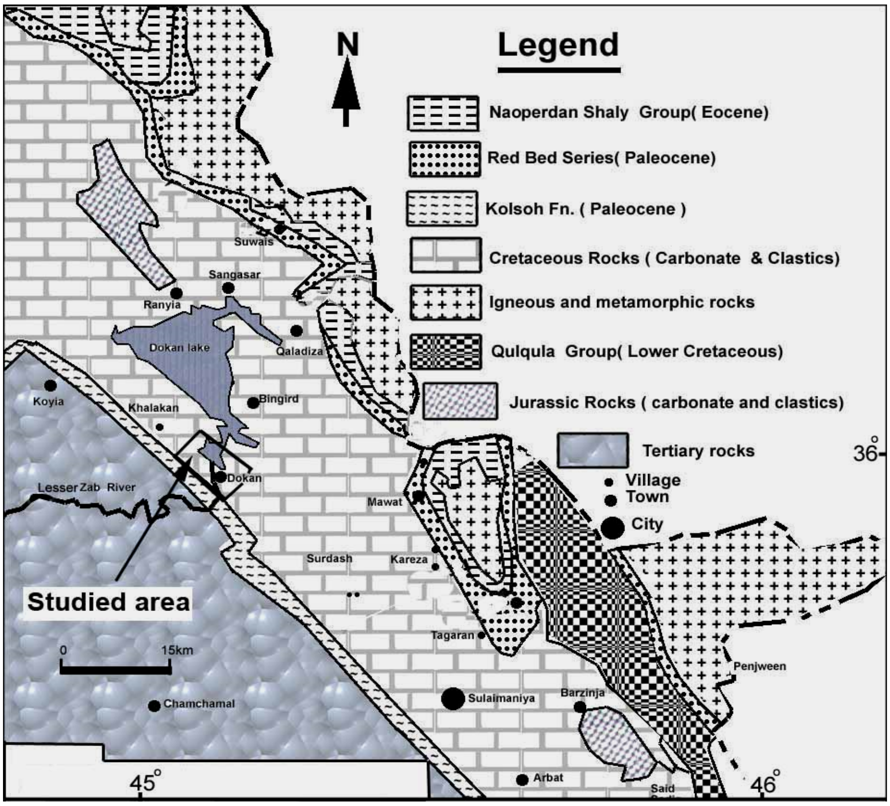


Fig.1: Geological map of the studied area (modified from Sissakian, 2000)

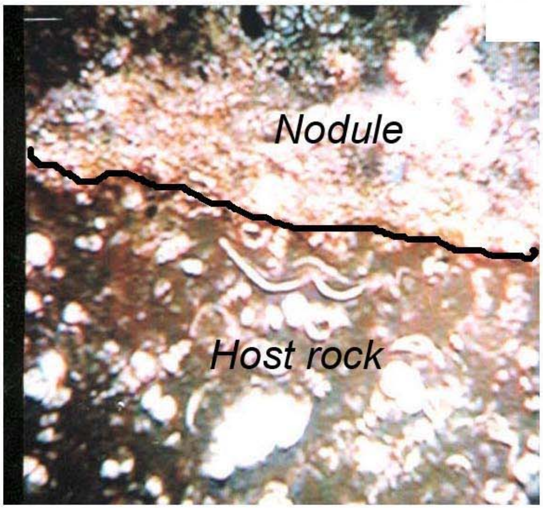


Fig.2.1: The boundary between a chert nodule and limestone showing crowding of forams due to nodule displacement

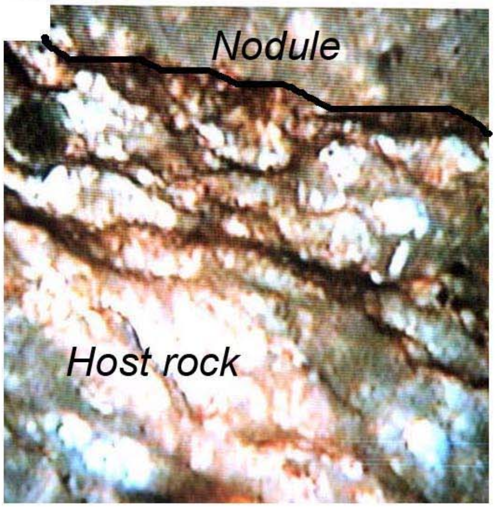
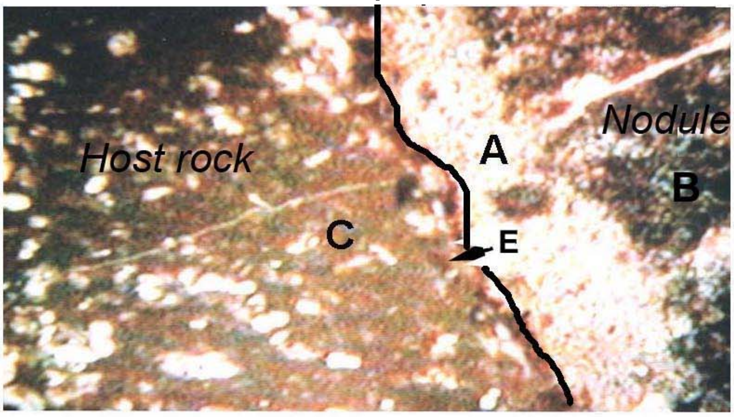


Fig.2.2: Stylomottling in the limestone of Kometan Formation near a chart nodule



Flig.2.3: Thin section photo of the chert boundary with the limestone (host rock) shows the replacement of limestone by silica.
A) partially replaced
B) totally replaced
C) fresh limestone (not replaced)
E) Clay seam

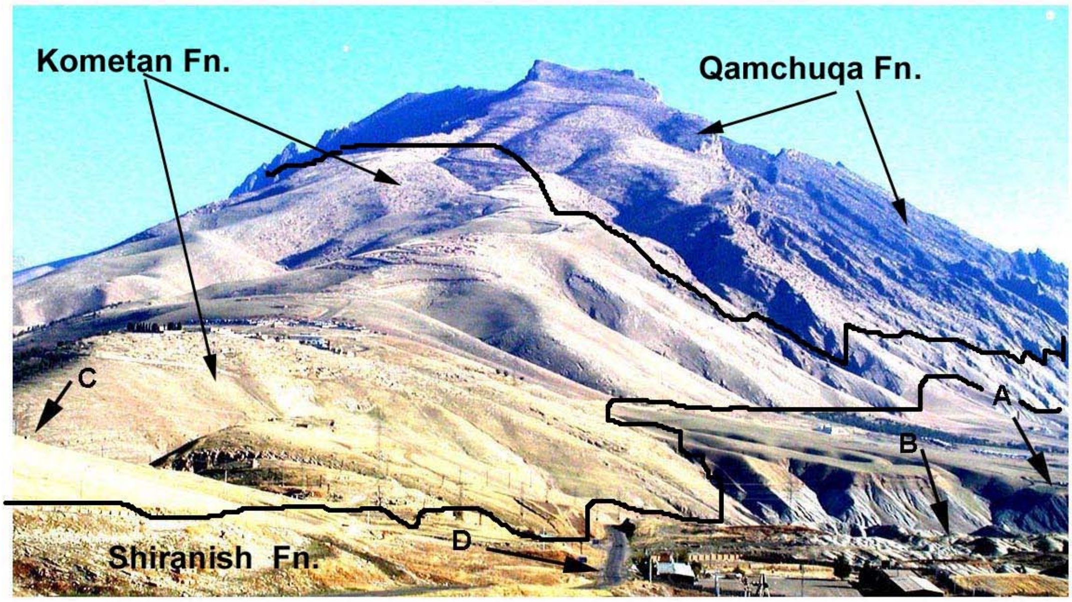


Fig.2.4: Northwestern plunge of Sara Anticline where the chert nodules and styloites occurrence is studied. A) Dokan town, B) Little Zab River, C) Dokan dam site, D) Sulaimaniya – Erbil main road
(All the smooth light color surface are covered by Kometan Formation)

In the studied area the lower and upper contacts of Kometan Formation are represented by glauconitic limestones (Bellen *et al*., 1959). The upper boundary, with Shiranish Formation, is noticeable where a bed of 1.5 m thick exists between the two formations. Karim *et al*., (2000) studied this boundary in detail, a hardground and an omission surface was found. Qamchuqa and Shiranish formations are conformably underlying and overlying the formation, respectively. However, the nature and position of the lower boundary is slightly variable. Because near the Dokan Dam site, Gulneri Formation (1.5 m black bituminous shale) is underlying Kometan Formation, while 2 Km to the east of the dam site, the formation seems to pass to Qamchuqa Formation and the glauconite of the lower boundary in the studied area is not found.

The nodules are distributed through light gray limestone of Kometan Formation. They can be seen clearly on bedding planes, cutting the beds vertically such as surface of joints, road cut and erosional cliffs (Fig.3.4). They exist as oblate or irregular bodies and range in size from cobble to pebble. They are occasionally joined together laterally through neck-like connection. Their surfaces are light brown and generally smooth or may be knobby. The internal color is black or greenish gray and shows no internal organization. However, the color becomes darker towards the center of the nodules. Their longitudinal axes are arranged parallel to bedding plane (Fig.3.1 and 3.2) but they have no preferred azimuthal direction (as measured in horizontal plain). Occasionally, the nodules join together and form net-like structures. Nodules are more frequently associated with stylolites and both generally concentrated along or near bedding plains (Fig.3.3 and 3.4). The stylolites are well developed and appear in sections cut normally to the bedding planes, as an irregular zigzag high amplitude lines but, in sections parallel to bedding (in this case can be seen in three dimensions), they are similar to rough file surface and their peaks are perpendicular to the bedding surface (Fig.3.1).

PETROGRAPHY

Thin sections for petrographic study are prepared from the nodules and the host rock (limestone), in addition to the margins between the nodules and the limestone. These sections showed that there is a clear relation between both, which indicate diagenetic origin for the growth of the nodules. The diagentic growth occurred by two processes, these are:

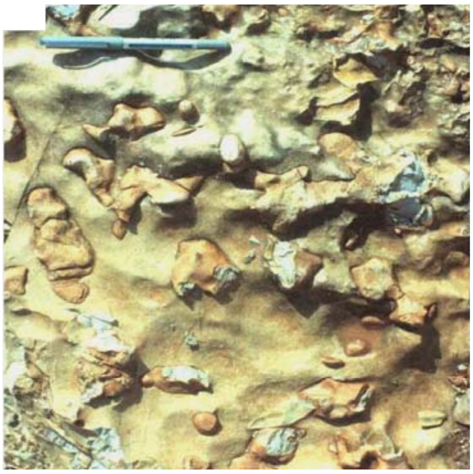
- **Replacement growth**

This type of growth is manifested by the following four features. **First**, the host rock is composed of calcareous test of planktonic forams embedded in micritic matrix (Fig.2.1). **Second**, the nodule's interior is made up of very small radiating crystals of chalcedony, while dark materials (clay and iron oxides) increase near the outer boundary. **Third,** there is crowding of planktonic forams in the host rock, surrounding the nodules. Some of these tests exhibit breakage and deformation (Fig.2.1). **Fourth**, the boundary is not completely sharp but contains a thin layer or zone of transition between the limestone and the chalcedony. In this zone the forams are partially corroded and replaced by silica, therefore they appear as ghosts (Fig.2.3 and 2.2).

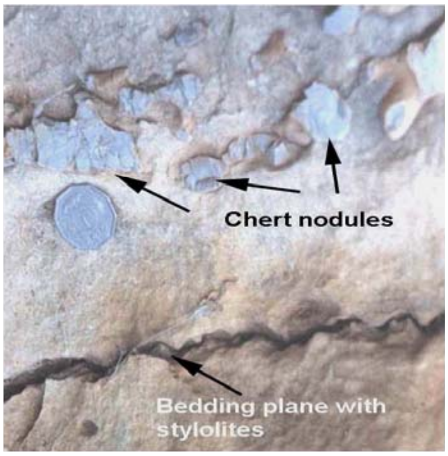
- **Displacive growth**

This type of growth is indicated by the following two features**. First**, in addition to replacement, there are many evidences for displacive growth, including arrangement of long axes of forams parallel to nodule boundaries (Fig.3.1). **Second**, the existence of very thin smooth solution seams surround and bend around the nodules exactly at the contact. According to Walness (1979), these seams are formed by pressure solution in impure limestone. Although Kometan Formation is relatively “pure limestone” but the nodules boundary is rich in claystone. The claystone is most possibly formed at the expense of dissolved limestone, when overburden stress produces pressure, which forces the large volume of limestone to dissolve. The soluble materials (dissolved $CaCO_3$) are carried away by vertical or lateral movements of intrastratal solution.

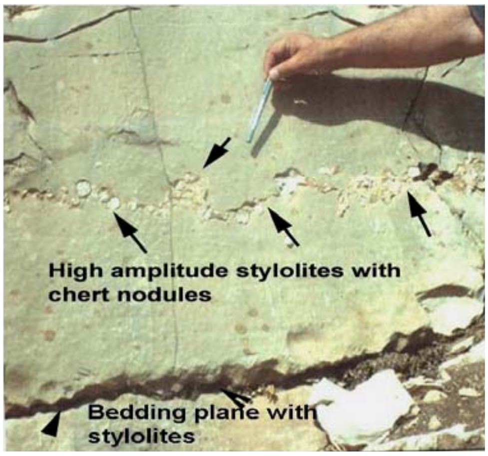
(3.1) Surface of bedding plane showing high amplitude stylolite peak in three dimension. These peaks show no preferred direction.



(3.2) Surface of bedding plane showing crowding of chert nodules. These nodules show no azimuthal preferred direction.



(3.3) Vertical surface of a joint showing growing of chert nodules nearly parallel to bedding planes (lower zig-zag line).



(3.4) Vertical surface of a joint showing growing of chert nodules along with stylolite (upper arrows).

Fig.3: Four field photographs showing stylolites and chert nodules

Replacement and displacive origins of chert nodules are confirmed from the aforementioned two points, both are diagenetic processes. The first one, is dissolution of a rock or mineral and concurrent deposition of other mineral of different chemical composition. The second one contains the process of nucleation and growing of a mineral by shouldering aside the host rock. This does not mean that there is no early diagenrtic chert nodules, as Al-Rawi (1988) found (in his study in the Iraqi Western Desert) clear thin section photos of chert nodules, which contain distinctive nummulites. Unlike nodules of Kometan Formation, these are certainly of early diagenetic origin. Recently, Sharp *et al*. (2002) studied the origin of isotope cyclicity in the bands (rings) in the chert nodules. They attributed this cyclicity to the thermal changes due to convection system.

SOURCES OF SILICA OF CHERT NODULES IN KOMETAN FORMATION

Replacement and displacive growth of nodules, considered in present study, require concentration of silica anions in certain locus within the limestone. The diffusion and movement of intrastratal solutions are the most important dynamic factor for transferring silica from direct or round about neighboring areas. The diffusion is the movement of silica ions in stationary pore solutions. While ions carried and transported by moving water are called metasomatism, high silica concentration sites are the reservoir for supplying silica for diffusion and metasomatism. The moving silica is in the form of H_2SiO_4 (Pettijohn *et al*., 1972). This was the proximate source of silica, but what were the ultimate sources of silica in Kometan Formation?. This question is answered through the following four points:

- As Kometan Formation is environmentally open marine sea (Buday, 1980, and Jassim and Goff, 2006) so it may contain some biogenetic siliceous radiolarians and diatoms, which easily dissolve in presence of limestone prevalence. This dissolution is returned to high surface energy of these fine and disseminated silica grains, as they are most stable and have less free energy, if these grains occur in clusters, hence aggregates will be formed during long times (Ramberge, 1952 in Pettijohn, 1975). McBride *et al*. (2006) showed that the chert nodules of Drunka Formation (Early Eocene) in Egypt are mostly formed after moderate alteration of limestone by meteoric water and the replacement of carbonate mud by microcrystalline quartz was the dominant chertification process. They attributed the source of silica to secreting marine organisms.
- According to Blatt *et al*. (1980), silica is precipitated in low pH environment and needs concentration of silica more than 100 ppm. In these circumstances primary silica precipitation is possible, when silica-rich cold upwelling current flows to the basin of Kometan Formation from deeper oceanic basin.
- According to Karim (2004) and Karim and Surdashy (2005), Qulqula Formation is compressed to accretionary prime during Conacian and Santonian in a basin in which Kometan Formation was deposited. Then the accretionary is uplifted during Campanian forming positive land in the area near Iran – Iraq border. Therefore, the basin included siliceous rock, so it is possible that the silica ions are carried by submarine currents (upwelling currents) and mixed with the deposited lime mud, before lithification.
- According to Cecil (2004), eolian dust is an important source of chert in marine environments in the warm and arid climates. He referred to quartz as main constituent of eolian dust, which has small grain size (less than 60 micron). He added that the dust grains have relatively high solubility, as compared to coarse grains due to high surface area. In Kometan Formation, it is possible that it received dust from terrestrial area located at the present position of Iraqi Western Desert (Rutbah Uplift), which is more than 300 Km far from the basin of Kometan Formation, at that time. The evidence for this is the occurrence of many quartzose sandstone units during Late Cretaceous in this area (Jassim and Goff, 2006).

INDIRECT ESTIMATION OF LITHOSTATIC PRESSURE

As mentioned before, the relations of bedding with nodules and stylolite surfaces are parallel arrangement of both nodules and stylolite surfaces. According to these relations, it is evident that the lithostatic (overburden) pressure is the only stress for development of stylolites and parallel arrangement of nodules long axes, in Kometan Formation. Relative degree of vertical stress can be known from the size of stylolites. Large-scale stylolite in Dokan area reveals relatively high stress. But, how can the absolute values of this pressure be measured?. To answer this question, it is necessary to review the value of pressure under which calcite (limestone) dissolves and silica precipitates.

In present deep oceans, this value is 300 Kg/ cm^2 and under this pressure limestone partially dissolves, while in less than 400 Kg/ cm^2 it totally dissolves (Nichols, 1999). The latter pressure is equivalent to 4000 m depth, which is called calcite compensation depth (CCD). Below CCD the skeleton of radiolaria can form the main biogenetic component of the pelagic sediment (Stow *et al*., 1996). Finally, a question may arise, why these pressures are mainly restricted only to Dokan area? The answer of this question needs the following argument:

The presence of widespread chert nodules and stylolites in Dokan area and their absence in others is attributed to exertion of the vertical differential lithostatic pressure in Dokan area, while the surrounding areas were performed as pressure shadow or the pressure was, possibly, of hydrostatic type (equal in all directions). When the strain diagram is drawn, it shows oblate spheroid in which maximum principle stress (σ^1) acts in vertical direction and other two axies are equal (σ^2 and σ^3) and act in horizontal direction (Fig.4).

In Dokan area, the lithostatic pressure of Maastrichtian and Tertiary formations was exerted on the Kometan Formation before total lithification. This exertion may be due to presence of a fault, which removed the lateral support for the lithologic column of the Dokan area. The total thickness of this column (all post Campanian formations) in the Dokan area and surroundings exceeds 2500 m (considering the removed intervals), which might have been responsible for a stress more than 5000 Kg/ cm^2.

PLOTTING OF COMPUTER DATA

The directions of 324 (elongated) chert nodules are measured randomly in different localities using Brinton Compass. The original quadrant compass readings are converted to their equivalent azimuthal readings (Table 1). Then the data was used for drawing rose diagram through Window-based Rock Ware Program. The options asked by the program are accurately selected according to the characteristics of the nodules. The most important options are Bidirectional, Full rose and Activated filters options. These options are critical for accurate drawing of the rose diagram, as they belong to the nature of the nodules.

The drawn diagram by the program shows nearly random azimuthal alignments distribution of the elongated nodules (Fig.4A). This proves that the nodules are developed by diagenetic processes during deep burial before the folding of the area .The diagram shows slight polarity in the directions of Northeast – Southwest and Northwest – Southeast, this possibly is attributed to very late deformation of nodules (stretching) by tectonic stresses.

The random distribution of the stylolite peaks (as seen in three dimensions) can be seen in the studied area (Fig.3.2). So both stylolites and chert nodules are developed (grown) together in a late diagenetic environment of high load pressure (lithostatic pressure) before folding of the area and devote any shear (directional) stress in their original growth. But, Taha *et al*. (1995) have recorded opposite conclusion to the present one. They found that stylolite peaks are directed nearly towards North – South and East – West. In our opinion, the authors work was very local, while the present study is associated with extensive field work in larger area.

Table 1: Compass azimuth readings of 324 elongated chert nodules in Kometan Formation, Dokan area. The readings are arranged in seven columns as originally measured in the field and feed into P.C.

1	2	3	4	5	6	7
323	300	80	30	33	65	320
344	290	320	340	50	4	333
90	280	25	10	340	21	22
307	320	300	70	357	40	3
306	30	80	42	360	300	320
360	15	310	19	332	330	21
360	15	350	41	360	320	285
323	15	340	330	272	311	3
304	325	23	30	300	290	345
10	355	322	70	330	30	290
325	320	87	11	82	82	32
280	45	315	72	360	312	240
360	45	40	322	50	335	40
80	90	360	20	72	32	21
320	360	20	350	20	70	290
312	330	310	360	300	360	75
360	330	310	18	300	350	70
355	330	30	60	30	340	10
360	290	300	312	340	32	12
35	20	40	340	300	79	40
65	340	333	20	342	81	300
82	300	47	40	88	320	22
60	320	304	40	91	350	304
30	360	11	35	295	315	65
300	280	22	342	340	358	300
310	65	321	294	40	90	280
60	20	32	39	20	93	60
330	70	79	5	290	280	59
345	320	2	323	50	300	50
290	10	24	321	10	360	2
40	330	25	295	11	359	320
360	20	310	293	340	40	275
40	340	63	296	310	310	340
20	330	357	70	80	70	230
320	40	321	60	61	300	280
80	360	91	95	335	30	300
70	330	300	19	3	11	55
360	360	351	366	19	60	20
300	295	12	20	321	284	342
60	90	40	360	360	302	341
320	300	62	358	20	20	88
10	20	290	300	320	92	358
70	290	92	42	360	280	330
15	330	350	41	285	3	333
290	80	307	38	88	71	10
320	80	2	39	60	340	315
295	320	29	280	59	355	
310	20	60	40	60	90	
310	300	340	43	3	319	
40	80	360	92	60	350	

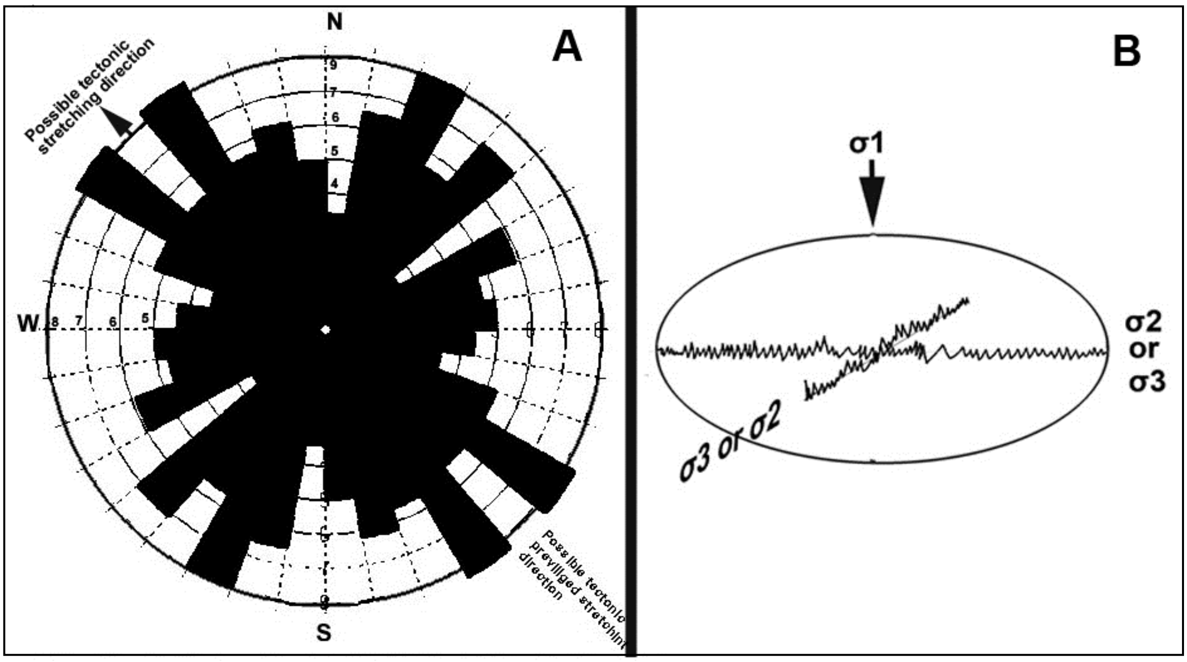


Fig.4: A) rose diagram of the elongated chert nodules in Kometan Formation in Dokan Area, B) Strain ellipsoid of the rock of formation as affected by overburden pressure forming high amplitude stylolites and chert nodules

CONCLUSIONS

This study has the following conclusions:

- The association of common chert nodules and well-developed relatively large-scale stylolites are recorded in Dokan area.
- The stylolite surfaces and long axes of nodules are parallel to bedding surface, while stylolite peaks are normal to beddings.
- The above two conclusions suggest, that the effect of load pressure (lithostatic pressure) was responsible for development of styloites and chert nodules, before folding of the area.
- The concentration of this pressure on Dokan area during Tertiary is attributed to creation of a paleo-swell during Late Cretaceous.
- Thin section and field studies, proved that the nodules are formed by both replacement and displacement.
- The source of silica is attributed to radiolaria and possible upwelling currents.
- Both field observations and rose diagram showed that chert nodules and stylolites have random distribution and have no preferred direction. They are developed under high load pressure by diagenetic processes.

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