JKAU: Mar. Sci., **Vol. 17,** pp: 153-165 (2006 A.D. / 1427 A.H.)

Morphological Features and Sedimentological Aspects of Wadi Al-Kura, North of Jeddah, Western Coast of Saudi Arabia

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Abstract. Raised carbonate-siliciclastic terraces, alluvial terraces, sabkhas, coral reef flat and topographic high hills formed of crystalline rocks are the characteristic landforms identified from the satellite images and field investigation of wadi Al-Kura. These geomorphic units reflect both the climatic and structural conditions that prevailed in the Late Quaternary period. The exposed successions differ considerably with respect to recent carbonate sedimentation in the other different areas. It exhibits an intimate association of pure carbonates in the form of reefs, mixed siliciclastic-carbonate and pure siliciclastics, mainly in the form of alluvial fans. The region thus offers an opportunity to determine the factors which control generally rapid transitions from one mineral facies to another. Three cycles of sedimentation have been documented. These cycles reflect tectonic effects and see level changes. Climatic phases from semi-arid to humid are deduced.

Introduction

The western margin of Saudi Arabia, which forms the present coastline, is traversed at some places by tidal creeks that extend several kilometers inland. These creeks are considered to be drowned river valleys formed during lowered sea levels at times when the rainfall was greater in the region. Reef carbonates occupy vast area of the coastal plain and provide valuable information on the Quaternary climatic variations in the west coast of Saudi Arabia (Sestini, 1965; Skipwith, 1973). These reefs vary in width from 0.5 km to 10 km and attained different heights above the mean sea level. Sometimes these reefs are covered by old alluvium and fan deposits derived from the weakly metamorphosed sediments and basic volcanics of the Jeddah Group (Skipwith, 1973).

Jado and Zotl (1984) recognized that marine and terrestrial terraces along the Red Sea coast of Saudi Arabia, unconformably overlie Pliocene sediments and were formed mainly by eustatic sea level changes and subordinately by vertical tectonics. The most recent terrace occurs between 6 and 10 m and represents the last interglacial high sea level dated by uranium/thorium at about 9500 to 120,000 year BP. A small terrace or wave cut notch located 2 m above today sea level is related to the Holocene transgression. The terrace levels are relatively constant along the NW Red Sea coast confirming minor vertical displacement during the Quaternary. Recent sedimentation along the Red Sea coast is characterized by alluvial fans related to the mountainous hinter-land, that slope gently towards the sea. Partly reworked by wadi systems, the fans sometimes grade into coastal sabkhas developed as wide littoral plains or into reef assemblages along the coast (Jado, 1989).

Blatzer *et al.* (1993) studied both climatic and tectonic events recorded by Plio-Quaternary sedimentary terraces and fans along the Egyptian coast of the Red Sea.

Wadi Al-Kura (Fig. 1) lies north of Jeddah in the central eastern coastal plain of the Red Sea, its extension towards the sea is named Sharm Obhur, with its shores formed of thick coral formation. The origin of the alluvial fan of wadi Al-Kura is related to Plio-Pleistocene peripheral uplift of the hinterland (Sellwood and Netherwood, 1984). Sea level fluctuations recorded in the shore zone permit the exposure of large coral reef terraces and permanent lagoonal inlets. Fault displacements have subsequently affected the coral reef terraces. Besides this outcrop at wadi Al-Kura, basalts occur at the base of the Quaternary sequence and are overlain by the conglomerates and coralline limestone (Skipwith, 1973). Fine to medium sand and mud with coral fragments and salt occasionally cover the reef sediments.

The Quaternary reef sediments in the coastal plain north of Jeddah are dominated by low Mg-calcite that is considered to have been formed by diagenesis of high Mg-calcite and aragonite (Basaham, 1998). While the alluvium derived from the low grade metamorphic rocks and volcanic basalts of the Jeddah Group forms the source of the clay material in the coastal sediments (Behairy, 1980). Radiocarbon dating of coral limestone samples from the raised terraces between Jeddah and Yanbu reveals four marine transgressions on the west coast of Saudi Arabia from the Mid-Pleistocene to the Recent (Behairy, 1983). These terraces are believed to be influenced by several inter-related factors; eustatic sea level fluctuation, tectonic movement, climatic and hydrographic conditions (Basaham, 2004).

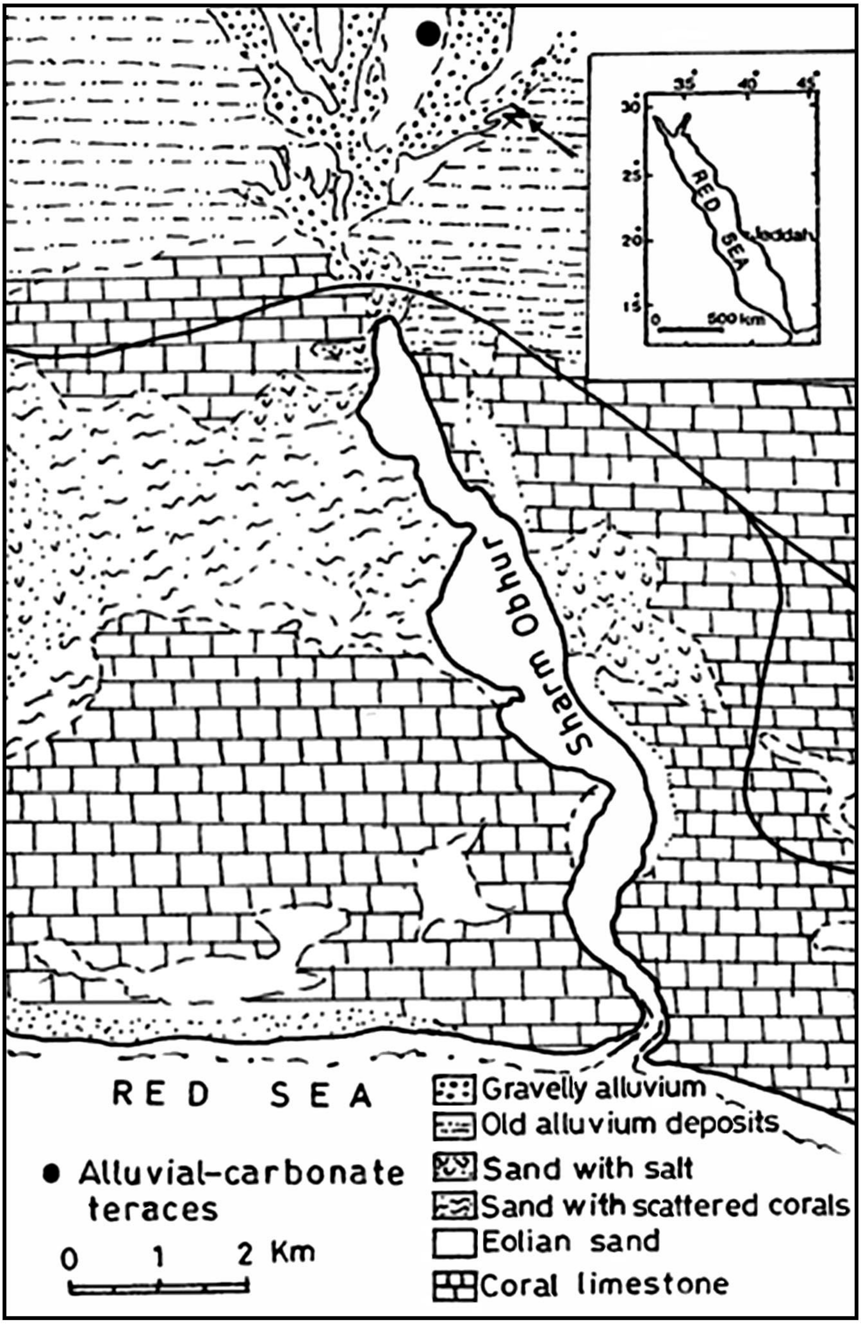

Fig. 1. Location of the studied sequence and geology of the area (modified after Skipwith, 1973).

Field Investigation, Sampling and Methodology

IKONS image of Wadi Al-Kura have been obtained from the King Abdulaziz City for Science and Technology. The image of the Sharm Obhur area obtained by IKONS acquired on March 2003 distinguishes features, environments and kinds of rocks. These can be deduced from different patterns which delineate specific shapes and can be related to familiar geological features. The dry land appears yellow while the wetted land shows brown color in the landsat image (Fig. 2). In addition to this, a series of field investigations were carried out to collect the information and samples required for this study.

Fig. 2. Landsat image showing Wadi Al-Kura and the end of Sharm Obhur.

The outcrops of Wadi Al-Kura (Fig. 3A) are represented by three uplifted rock units with thicknesses reaching to about 3.5m (Fig. 3B). They are formed mainly of siliciclastic and carbonate rocks representing the Quaternary raised alluvial fan and reef terraces. The wadi itself is characterized by the development of sabkhas (Fig. 3G&H). Two types of sabkhas can be distinguished; one is barren and dark brown colored and the other is vegetated sabkha. They are characterized by thin salt crust cover. Alluvium terrace with thicknesses less than one meter is formed of fine sand and silt (Fig. 3E&F). Finally, a light brown coral reef flat occurred on the surface of the ground (Fig. 3A&C). Samples were collected from the different facies present and subjected for textural and mineralogical analyses.

Bulk mineralogy was determined using X-ray diffraction analysis. Identification of minerals is based on the detection of the characteristic diffraction peaks using tables of key lines listed by Chen (1976). The peak height of the biggest intensity for each mineral present has been measured and the relative percentages of each mineral have been calculated. The clay fractions have been separated by sedimentation technique and the clay minerals are determined by X-ray diffraction method (John *et al*., 1954; and Brown, 1972). Heavy minerals were separated from the very fine sand fraction using the bromoform as a heavy liquid and identified under the polarizing microscope (Milner, 1962). Identification of sedimentary features and events are the main objectives of the present research.

Geomorphology and Climatic Conditions

Morphology of the coastal region is dominated by the proximity of high basement relief, everywhere visible from the shore. Regional uplift subsequent to rifting clearly favors important siliciclastics supply to young basins. The 10 km wide coastal plain is cut by frequent wadis. These numerous fluvial channels, although active sporadically, flow nearly every year since the high-relief hinterland tends to induce a regular, if low, rainfall favoring an efficient terrigenous supply to the marine basin in spite of desert conditions (Purser *et al*., 1987).

The arid nature of the Middle East climate also tends to influence the textures of the terrigenous sediments; because of low humidity, chemical alteration of the bed rock is limited and clay mineral formation is probably low. Terrigenous sediments, therefore, tend to be coarse. Sediment transportation tends to be limited to the coastal plain and shoreline environments and thus doesn’t impede offshore reef growth, while coarse textures favour rapid decantation and the quick return to clear-water marine conditions (Purser *et al.*, 1987).

(A) (B)

(C) (D)

(E) (F)

(G) (H)

Fig. 3: (A) Natural view of Wadi Al-Kura.
(B) Raised alluvial-carbonate terraces.
(C) Coral reef flat suface (light colour) beside dark brown sabkha deposits.
(D) Conglomerate fan deposits (lower bed) and mixed carbonate-siliciclastic bed (upper bed).
(E&F) Alluvial terraces.
(G&H) Sabkha deposits developed in Wadi Al-Kura.

A bedded sequence of Late Quaternary age in Wadi Al-Kura is composed of conglomerate with argillaceous cement, sandy limestone, coralline limestone and red siltstone from base to top, situated about 3.5m above the sea level (Fig. 4). Although the carbonate rocks are very common and widespread along most of the Red Sea coast, alluvial fan deposits and siliciclastic-carbonate overlain by pure reef are localized within Wadi Al-Kura and reflect both climatic and tectonic conditions. Field observations indicate a discontinuous tectonic uplift during and after their formation. Tectonic events interacting with climatic and eustatic episodes, are recorded in the Late Pleistocene deposits of this area. The alluvial fan deposits occupy the graben basins (tectonic traps) that were more effective during the climatic phase prior to deposition of the last interglacial reefs when the arid climate was temporarily interrupted by relatively humid phase.

Results and Discussion

Samples analyzed from the alluvial-coral reef terrace outcrops in Wadi Al-Kura exhibit marked lithological and mineralogical variations from bottom to top (Fig. 4). The alluvial fan bed occurs in the bottom of the succession with thickness of 1.7m. This bed is composed of well sorted conglomerates especially at the bottom and top, while argillaceous sands are embedded in between reflecting high density flows that imply high energy hydrodynamics associated with the discharge of very strong flash floods typical of semi-arid climate. The poorly sorted argillaceous sands exhibit graded bedding with red muddy sediments due to the oxidation of iron material. This bed represents fan deposits typical of debris flows. Their depositional environment, paleogeography and source rocks are discussed and deduced below.

X-ray diffraction analysis of the raw argillaceous matrix proved that it consists mainly of quartz, feldspars and clay minerals in decreasing order of abundance. Feldspar is dominated by plagioclase. A remarkable lack of maturity is indicated by the abundance of detrital feldspar and little clay implying lacking of chemical weathering. This reflects the arid climate prevailed at time of fragmentation of rocks. However, the lack of chemical weathering and poor sorting suggests flash-flood conditions in a dry climate and differ from the present climatic conditions which are considered to be hyper-arid according to Plaziat *et al.* (1998). Calcite is uncommon while halite is recorded in all analyzed samples (Table 1). Heavy minerals identified in the argillaceous sands and the overlying siliciclastic beds are dominated by opaques (47.6 to 38.3%) and weathered minerals (41.5% to 28.3%) (Table 2). The non-opaque heavy minerals include; augite, chlorite, hornblende, epidote, ZTR (zircon, rutile, tourmaline), kyanite and garnet arranged in decreasing order of abundance. This

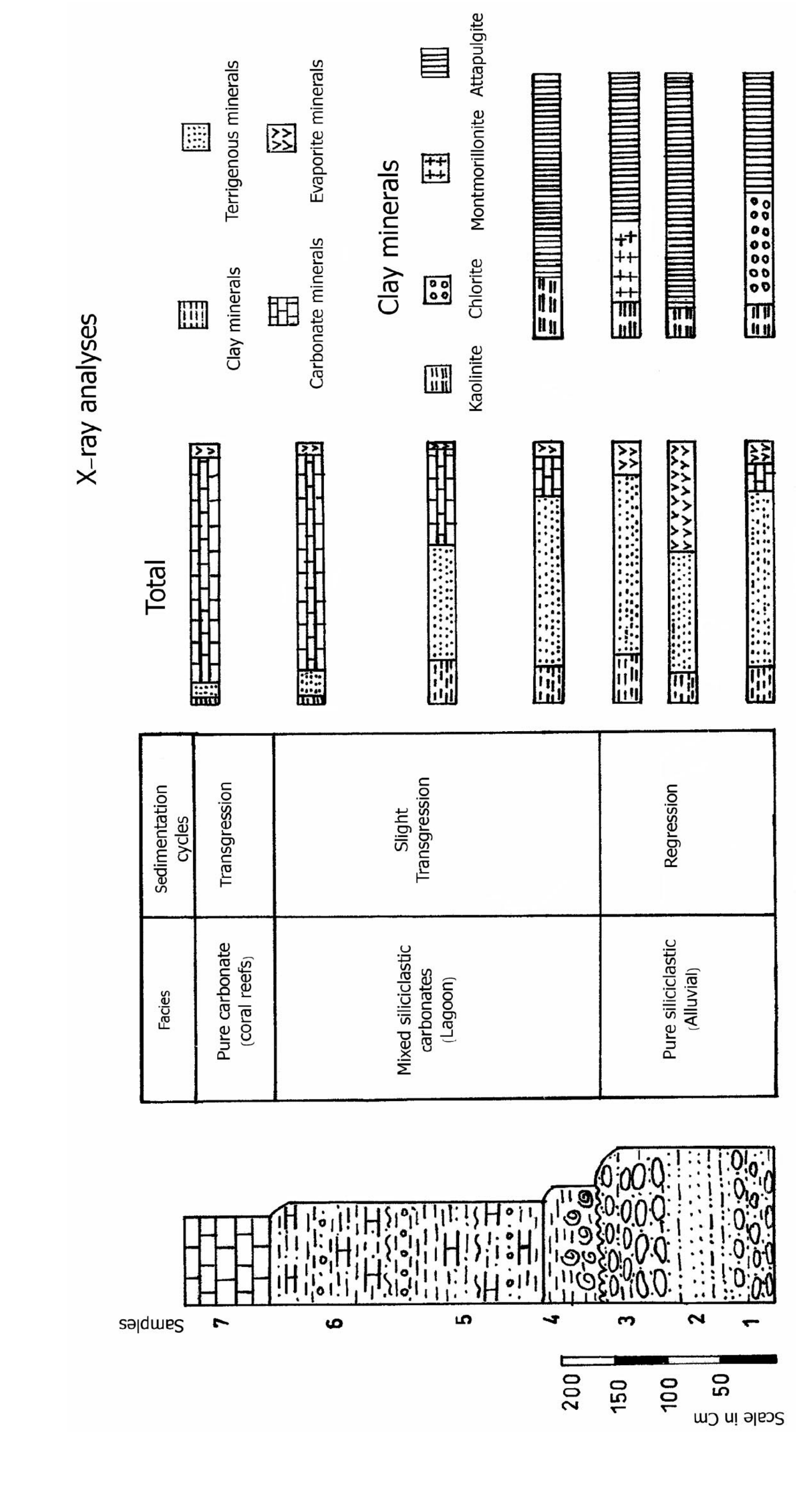

Fig. 4. Raised alluvial-carbonate sequence, cycles of sedimentation and mineralogy, Wadi Al-Kura area.

Table 1. Bulk mineralogy in the raw samples from uplifted terraces of Wadi Al-Kura (determined by XRD).

S. no.	Litho	Ch	Attp	I/M	Amp	Qz	KF	PF	Cal	Dol	Hal
1	Carb.	1	–	–	2	3	1	2	86	–	5
2	Mixed	2	–	1	1	4	–	5	81	–	6
3	Mixed	5	5	2	3	7	31	–	13	34	2
4	Mixed	4	2	3	6	43	6	16	15	–	5
5	Terrig.	7	4	3	5	39	5	25	–	–	12
6	Terrig.	5	4	–	3	35	–	25	–	4	3
7	Terrig.	5	6	–	3	48	5	15	10	–	8

Litho = Lithology; Ch = Chlorite; Attp = Attapulgite; I/M = Illite-Montmorillonite; Amp = Amphibole; Qz = Quartz; KF = Potash Feldspar; PF = Plagioclase Feldspar; Cal = Calcite; Dol = Dolomite; Hal =

Table 2. Relative percentages of heavy minerals determined in the sand fraction of the studied terraces in Wadi Al-Kura.

S. no.	Opaq	Hb	Aug	Epid	ZTR	Biot	Chl	Ky	Gar	W.M.
2	45.1	11.7	28.8	1.4	1.0	–	15.4	–	–	41.5
3	47.6	17.7	29.2	1.6	10.6	–	20.0	–	–	30.7
4	44.7	12.0	23.8	2.5	1.2	–	19.7	1.8	–	38.7
5	38.3	14.5	18.3	10.3	3.5	1.0	20.0	1.3	1.0	30.0
6	43.5	19.5	61.4	6.9	3.4	0.6	22.3	0.3	1.7	28.3
7	40.6	11.0	27.1	6.9	4.3	0.3	14.5	1.5	1.3	32.8

Opaq = Opaque; Hb = Hornblende; Aug = Augite; Epid = Epidote; ZTR = Zircon,Tourmaline, Rutile; Biot = Biotite; Chl = Chlorite; Ky = Kyanite; Gar = Garnet; W.M = Weathered Minerals.

association of minerals reflects derivation from metamorphic and volcanic igneous rocks. The Jeddah Group also occurs farther inland where it is regionally metamorphosed to the greenschist facies (Jackaman, 1972).

The clay minerals detected in the separated clay fraction from the argillaceous sandstone is dominated by attapulgite (identified by its characteristic first reflection peak at 10.5Å) with a small amount of kaolinite (Table 3), while chlorite and montimorillonite are less common. This leaves attapulgite as most common clay mineral, which might have formed from alteration of montmorillonite (Yaalon and Wieder, 1976 and; Weaver and Beck, 1977). These sediments were probably laid down in a braided-stream environment and may represent the alluvial deposits of a proto-Wadi Fatima according to Gheith and Abou Ouf (1997).

Table 3. Relative percentages of clay minerals determined in the separated clay fractions of the studied terraces.

S. no.	Kaolinite	Chlorite	Mont.	Attapulgite
4	–	24.3	–	75.7
5	13.5	–	28.8	57.7
6	12.3	–	–	79.7
7	13.3	42.9	–	43.8

The alluvial fan bed is overlain by a 2.6m thick bed of hard fossiliferous mixed siliciclastic-carbonate. It represents the main transitional facies between reef and the underlying alluvial fan. The bulk mineralogy is either dominated by detrital quartz, feldspar and clay minerals mixed with subordinate amount of calcite or dominated by calcite with few detrital constituents. In general, carbonate concentration shows an upward increase. Attapulgite (palygorskite) and chlorite are the common clay minerals detected in the separated clay fraction. The recorded high amount of attapulgite here may indicate calcretization of the limestone. Attapulgite is considered to be unstable and weathers to montmorillonite when rainfall is high. Its origin is related to authigenesis and can be formed by direct precipitation from solution (Singer and Norish, 1974). The primary requirement for attapulgite precipitation is alkaline Mg-rich conditions. Thus the process increases the Mg/Ca ratio of the vadose water probably enhancing conditions favorable for attapulgite formation (Watts, 1976). The heavy minerals found are dominated by opaques, augite, chlorite, hornblende and ZTR in decreasing order of abundance. Weathered minerals represent nearly half the concentration of the heavy minerals identified.

The top bed is mainly considered to be uplifted coral reef and consists of calcite. This carbonate reef deposit also indicates moderately humid climate conditions.

The facies changes reflect both climatic and structural conditions. The outcrop sequence in Wadi Al-Kura represents 3 cycles of sedimentation (Fig. 4); regression, slight transgression (lagoon) and transgression. The regression cycle is dominated by land derived material, the mixed cycle represents both marine precipitation, especially in a lagoon basin still provided by terrigenous material, and finally the third cycle represents mainly marine pricipitation.

The recorded evaporite minerals point to an arid climate. However, aridity also favors the close association of carbonate and siliciclastic sediments. Deposition of the overlying coral reef indicates clear, carbonate producing waters, where the low input of terrigenous clays is due to reduced chemical weathering. The Quaternary and Recent coastal environments of the Egyptian Red Sea and Gulf of Suez are characterized by rapid lateral facies variations; carbonates, evaporites and siliciclastic sediments exist in close proximity (Purser *et al.*, 1987). Despite the active supply of continental detritus, carbonate facies are developed; the reef carbonates in particular, extend along most of the Red Sea coast. Mansour (2000) dealt with Quaternary reef terraces along the Egyptian Red Sea coast and mentioned that reefs with their siliciclastic associations occur in the form of repeated cycles reflecting tectonic effects and lower sea level changes. However, rapid lateral transitions between continental siliciclastic and marine carbonate facies are favored by a particular morphology closely related to the active distributional tectonic setting within the Red Sea rift. The structural depressions tend to trap much of the episodic siliciclastic input, favoring permanent carbonate production in the nearby littoral environments. The occurrence of alluvial fan deposits represents very short flood periods followed by clear water marine conditions, favouring reef growth and carbonate sedimentation that are quickly re-established.

Conclusions

Investigation of the outcrop formations in Wadi Al-Kura reveals three raised terraces forming the Pleistocene sequence. It comprises continental sediments and shallow water carbonates with mixed siliciclastics composition. It represents alluvial fan deposits, siliciclastic-carbonate and pure carbonate reef rocky beds forming the main sedimentary facies that implying climatic conditions significantly varied from arid to humid. The alluvial bed represents a regressive phase accumulated during a period of low sea level, while the reef beds reveal transgressive phases developed during sea level rise. Tectonic deformation recorded synsedimentary faulting contemporary with the sedimentation of alluvial fan deposits, and deformation of the emergent reefs during the last glacial period and Holocene.

Acknowledgments

The author wishes to express deep gratitude to Prof. Dr. Amin M. Gheith, Dept. of Marine Geology, Faculty of Marine Science, King Abdulaziz Univ. for his support, valuable suggestions and revising the manuscript.

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الظواهر المورفولوجية والسمات الترسيبية المستنبطة من الدراسة الحقلية والصور الفضائية لوادى القراع، شمال جدة ، الساحل الشرقى للبحر الأحمر

رشاد أذدى بانتن

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ص.ب٢٠٢٠٧ ، جـــدة ٢١٥٨٩ - المملكة العربية السعودية

المستخلص. أفادت الدراسة الحقلية وفحص الصور الفضائية لمنطقة وادي القراع وجود الظواهر المورفولوجية التالية: شرفات الحجر الجيري، والفتاتيات السيليسية المرفوعة، والشرفات الطينية، والسبخات، ومسطحات الشعاب المرجانية والتلال ذات الطوبغرافية المرتفعة التي تتكون من الصخور المتبلورة.

تعكس هذه الوحدات االجيومورفولوجية كل من الظروف المناخية والتركيبية السائدة خلال زمن الرباعي المتأخر. تختلف تلك التتابعات المكشوفة عن ترسيب الكربونات الحديثة في المناطق الأخرى. فهي تعكس مصاحبة الكربونات النقية على شكل شعاب ، سيليسيات فتاتية مختلطة بالكربونات والفتاتيات السيليسية النقية التي على شكل المراوح الفتاتية. لذلك فإن المنطقة تعرض دراسة لتعيين العوامل التي تبين الانتقال السريع من سحنة معدنية إلى سحنات أخرى. تم استنباط ثلاثة دورات ترسيبية تعكس تأثير كل من الحركات التكتونية وتغيرات منسوب سطح البحر. تم استنتاج أطوار مناخية شبه جافة إلى رطبة.