The Basal Cretaceous Sandstone of Lebanon Past, Present and Future Climate Change Threats

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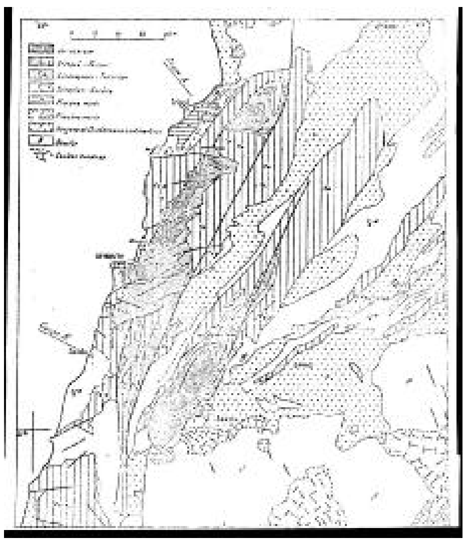
Abstract

The predominantly ochre Basal Cretaceous Sandstone (BCS) of Lebanon, which displays a good similarity with the "Nubian Sandstone" of Jordan and Egypt, consists of non-fossiliferous, relatively pure quartzic sandy beds, alternating with shaly intercalations, that outcrop mainly in Central Lebanon, and also in the Southern part. It is considered to be of fluvio-deltaic origin, though some deposits may have occurred in non-marine conditions. Their main characteristics are: medium-grained, generally well sorted, sub-rounded grains, with hematitic or lemonitic cement associated with clay (especially Kaolinite), high porosity but generally poor permeability, covered with maritime conifers which have partly been destroyed due to urbanization, criss-crossed with faults, and drained by a few torrential streams such as Beirut river (drainage basin 231 sq. km; Melton Ratio 0.124; Relief Ratio 0.05, prone to flooding). The formations are thus most vulnerable to erosion due to gravitational and molecular stresses. The rest of the outcrops consist mainly of limestone and dolomite, plus some basaltic formations. Contrary to eolianite decalcification assumptions made by L. Dubertret, 1945, H. Fleisch, 1956 and other authors, the BCS had "appeared" to be the origin of the coastal ochre sands of Beirut and its southern suburbs (P.G. Zumoffen,1926). Other authors agreed, including G. El Kareh (2008) who reinforced the hypothesis through a quantitative approach and parametric comparisons. He roughly estimated the order of magnitude of the ochre sands to be 112 Million cubic metres, excluding those that found their way into the sea. Assuming that erosion first affected the thin, say 3m thick, occasionally sharply dipping BCS covering the top of the Jurassic, now bared out, the ochre sands would correspond to 37 square kilometers, compared to the present areal distribution, say 370 sq. km (maximum thickness 250 m). The hypothesis of climatological exacerbation during the Pontian (late Miocene) (P. Sanlaville,1977; G. El Kareh, 2008) that was suggested as the main factor which led to the disaggregation, transport and deposition of the underlying clays and the coastal ochre sands may well be applicable in future, though with a different pattern. Current and expected climate change, believed to constitute factors of increased temperatures and heavier concentrated precipitations, would cause cyclic differential dilatation and pronounced interstitial pressures, disaggregation of the porous blocks, liquefaction of the unconsolidated pockets and entrainment toward the coast along the steep slopes of the Western mountain chain. This could result in further drastic and extensive erosion of the colorful parts of the BCS and structural damage or even wash-out of buildings, leaving remnants of the ferruginous grayish-black formations, unless preventive action were taken such as silicate injections and buttressing in the light of a geotechnical study. The question would arise as to whether UNESCO or other organizations might favorably consider financing such an operation. The actual formations are indicated in the attached map. Old hypothetical contours probably generally coincided with the outer limits of the top of the Jurassic (dash lines) Future contours are predicted to recede inwards from the present one (dotted lines). .

1. Introduction

The oldest outcrops of Lebanon, Fig 1[1], consist of Jurassic calcareous rocks occasionally overlain or faulted with non-fossiliferous colorful quartzic sandstone, mainly on the Western part of the Lebanese mountains, which abounds with transversal faults and a few torrential streams. The sandstone is particularly vulnerable to erosion and the purpose of this paper is to present what could have been its configuration in the distant past, bearing in mind the existence of a substantial volume of coastal ochre sands, and how it may be affected in the far future by current and expected climate changes. The need for protective measures is emphasized.



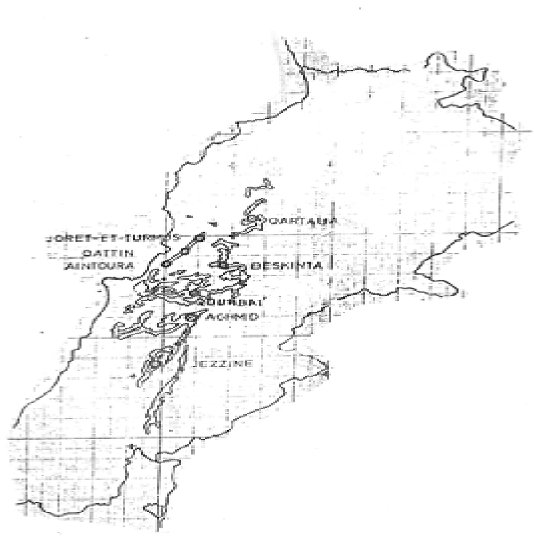


Fig 1. Geological map of Lebanon (L. Dubertret, 1945) Jurassic formations are represented by oblique left to right lines.The BCS is included in the Lower Cretaceous formations represented by dot clusters.

Fig 2 The Basal Cretaceous Sandstone shown separately. A few sampling localities are indicated.

2. Characteristics of the sandstone. The sandstone is non-fossiliferous, apart from lignite, and has variously been referred to as “lignitiferous”[2] , “Neocomian” [3], “Chouf Sandstone”[4] etc In this paper, we shall use the more commonly accepted expression “Basal Cretaceous Sandstone” (or BCS), which is the English adaptation of “Gres de Base”[5] suggested because of its uncertain age. Its present distribution is included in the Lower Cretaceous formations of Fig.1, and shown separately in Fig.2. The most accepted hypothesis is that it is mainly of fluvio-deltaic origin, deposited concurrently with the Upper Jurassic orogenic movements, and intense volcanic activity. Tectonic movements resulted in several transversal faults, both normal and revcrse. Average textural parameters of the BCS based on cumulative frequency curves [6] are given below:

Md 1.78 (0.28mm) QDPhi (Krumbein) 0.56 SKPhi (Folk) 0.06

Binocular examination shows generally medium and sub-rounded but often assorted quartz, peppery or coated with clay/ iron hydroxide, and free opaques in the finer fractions. Quartz content is of the order of 90%, the rest consisting of clay minerals, mainly Kaolinite, iron oxides and other Heavy Minerals, mainly Tourmaline.

There are several shale or clay intercalations in the BCS, as well as several pockets of unconsolidated fine sand. One 300m deep detailed boring [7] revealed numerous alternations between various clays, sandstone, ferruginous sandstone and basalt. The formation's hydrographic constants were reported to be:

Transmisssivity T = 10^{-6} to 10^{-4} sq.m./s (compare to hydraulic conductivity of adjacent faults 10^{-4} to 10^{-3}). Storativity $S=3x10^{-4}$.

The formations are very prone to erosion and occasional landslides under "normal" climatic conditions. To verify what their behavior might be under "abnormal" conditions, two samples of the sandstone, one almost non-ferruginous and the second highly ferruginous were placed in the freezer of a domestic refrigerator for twelve hours[8]. The first one crumbled easily when removed; the second one resisted, apart from surface grains detachment. A second set of experimental tests were recently carried out to check the possible effects of climate change: a sample of non-ferruginous but compact fine-grained sandstone pebble extracted from a fresh excavation at three metres depth was placed in an oven and its temperature raised by 8 degrees C, and then dipped in water. Only surface grains detachment was observed. However, after a third such cycle, it became brittle, easily fractured into two pieces by light pressure.

This behavior can be explained as follows. In the case of dry rocks, a rise in temperature would increase the pressure of air in the pores due to the considerable difference between the cubic expansion coefficients of air and quartz crystals. Heavy precipitation would increase interstitial pressure through clay swelling, particularly that of Illite.

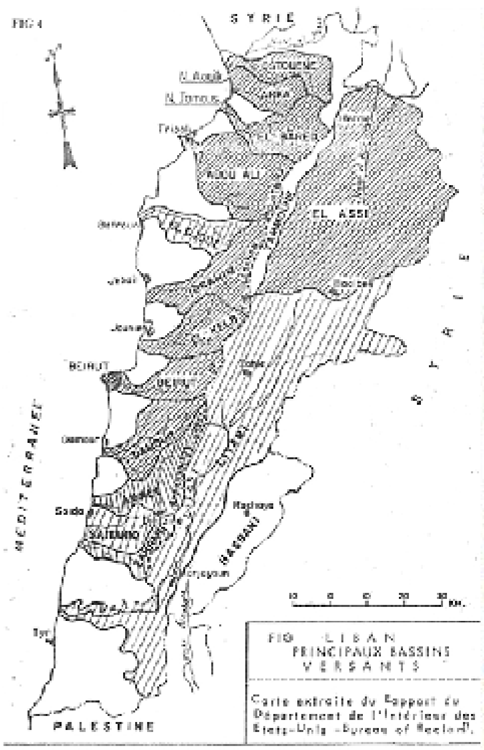
3.The drainage basins that affect the BCS (Fig 3) [9]

The main streams of which the drainage basins include the BCS are, from North to South, Nahr (=river) el Joz, Nahr Ibrahim, N. el Kelb, N.Beirut, N.Damour and N.Awali (Bisri and Barouk) Their hydrographic characteristics are as follows:

Drainage Basin, sq.km.	150-410
Watershed length, km	30-48
Relief Ratio	0.02-0.09
Melton Ratio (M.A. Melton, 1957)	0.06-0.16

They are all prone to flooding [10] but, so far, only exceptionally to debris floods. However, one of them, Nahr Beirut, may have been responsible for debris flows (see below)

Fig Fig Fig



DRAINAGE BASINS OF LEBANON

Fig 4. Extracts from the drainage basin of Nahr Beirut.
In Carte Geologique, Flle de Beyrouth (Dubertret, 1951).
(Dubertret, 1951).

4. The coastal ochre sands

The piemonts (foot-hills) and, especially Beirut southern suburbs and Beirut itself, as well as some other parts of Lebanon, mainly North of Beirut, consist of ochre sands which have also been referred to in varying terminologies, and their genesis has been the subject of a controversy. According to P G. Zumoffen [2], the sands "appeared to originate from the denudation of the lignitiferous sandstones of Lebanon, which occurred toward the end of the Pliocene or the early Quaternary periods". J. Bourcart [11] expressed a similar opinion in rather vague terms. L. Dubertret [12,13] considered the sands to have been the result of decalcification by rain of the BCS and of the eolianites (="Ramleh") . He did add that decalcification alone could not account for the high iron content of the sands and was inclined to attribute this to a distant eolian source.

The decalcification hypothesis was repeated by E. deVaumas [14], M. Rossignol [15] and H. Fleisch [16] though Fleisch finally conceded that decalcification alone was not the answer (verbal communication).

P. Sanlaville [17] clearly doubted the decalcification hypothesis and agreed with Zumoffen, without mentioning him, adding some qualitative circumstantial details, but concluded that more research was required to understand the significance of the "couches rouges" (the coastal ochre sands).

Through a quantitative approach and parametric comparisons, G. El Kareh [8] invalidated the decalcification hypothesis and went on to corroborate Zumoffen's impressions. He roughly estimated the order of magnitude of the coastal ochre sands at 112 Million cubic metres, excluding those that found their way into the sea, and the corresponding area of the eroded BCS at 37 square kilometers, and established kinship of the sands with the BCS through granulometric, morphoscopic, chemical and mineralogical correlations.

5. Probable sites of denudation of the BCS and circumstances that led to this phenomenon.

In Fig 4[18], the BCS is represented in green patches; J7 in light grey and J6 in blue.

The curvilinear, occasionally convex and corrugated contour lines of the BCS overlying the top of the Jurassic (J7) appear to suggest past flows resulting in denudation of the calcareous rocks from their relatively thin strata of BCS at some stage of their history (dash-lines)

The direction of the dips toward the low parts of the drainage basins, particularly that of Nahr Beirut, lend credibility to this assumption.

A very rough estimate of the projected area of the J7 in the latter is 30 sq. km, comparable to that assumed above on the basis of 3m thickness. The old contour line of the BCS probably coincided with the outer limit of the J7 (Fig 4).

On the basis of the above determinations and experiments, the author was able to support Sanlaville's [20] suggestion that the disintegration and transportation of the BCS occurred during the Mindel/Riss climate exacerbation. He added that the clays underlying the coastal ochre sands had been deposited within short geological intervals. It is interesting to note that Dubertret [1] had stated that these clays were of Pliocene (Plaisancian) age, while the lacustrine marls of Zahleh- piedmont of the eastern flank of the Lebanon chain, and of the Damascene, to the East of the Anti-Lebanon chain, were deposited toward the end of the Miocene (Pontian), but presented no arguments in support of his statements.

6. Likely impact of current and future climate changes.

It is thus reasonable to assume that future climate exacerbation may well affect the BCS again since it would appear probable that the BCS will experience more than three cycles of drying, heating and wetting to which a sample was experimentally submitted.

The pockets of unconsolidated sand would undoubtedly be entrained, probably through liquefaction; the non-ferruginous, clay-coated, or clay-rich sandstone blocks would first be disintegrated through swelling and consequent interstitial pressure, and those with a positive dip entrained. The ferruginous formations would resist erosion. The buildings erected on non-ferruginous sandstone after destruction of the conifers are likely to suffer damage, even wash-out. The contour lines of the BCS, particularly in N. Beirut drainage basin, would tend to recede inwards (dotted lines in Fig 4)

7. Protective measures.

A survey is thus necessary, followed by geotechnical stabilization measures. Risky areas must be identified, and protective measures might include silicate injections underpinning of the foundations, buttressing, and certainly, deviation of flash flooding away from foundations. The total cost of such measures is high, and financial assistance should be sought form such organizations as UNESCO or UNDIP.

The BCS might be eroded through landslides or even mass flows mobilized by hydrostatic pressure and induced by sub-soil instability unless such measure were taken in time.

8. Conclusions

The Basal Cretaceous formations of Lebanon would be at risk if climate change does follow predicted patterns. Disintegration of the non-ferruginous formations might take place before the end of the century, unless mitigation and adaptation strategies were implemented at an early stage.

9. List of Figures and captions.

Fig 1 Geological map of Lebanon (L. Dubertret, 1945). Jurassic formations are represented by oblique left to right lines. The BCS is included in the Lower Cretaceous formations represented by dot clusters.

Fig 2 The Basal Cretaceous Sandstone of Lebanon shown separately (a few sampling locations are indicated)

Fig 3 The drainage basins of Western Lebanon.

Fig 4. Part of the drainage basin of Nahr Beirut, extracted from Dubertret's Carte Geologique au 1/50000, Flle de Beyrouth, including the actual configuration of the BCS in this basin.

10. References

[1] Dubertret L., Carte Geologique du Liban (1945)

[2] Zumoffen G.,Geologie du Liban, Barrere, (1926).

[3] Dubertret L., Verbal communication (1943)

[4] Walley C.D., A Revision of the lower Cretaceous stratigraphy of Lebanon. Geologische Rundschau. Springer Berlin/Heidelberg , Vol.72, No 1, . Pages 377-388 (Feb 1983).

[5] Dubertret L, Lexique Stratigraphique International. 3. Asie. Fasc. 10c1: Liban (1959)

[6] Wakim Sh., Petrography of the Basal Cretaceous Sandtones of Central Lebanon. Thesis. AUB (1968)

[7] Majdalani M., Note sur les caracteristiques hyddrogeologiques des Gres de Base de la region de Bqaatuta (Liban). Annales de Geo. Univ. St Joseph, V. 2, 1-27 (1981)

[8] El Kareh G., Probable Genesis and depositional process of the Coastal Ochre Sands of Lebanon. 33rd Internaional Geological Congress. Oslo (2008)

[9]United States Dept. of the Interior. Bureau of Reclamation. Water Resources Investigations (1958)

[10] Wilford D.J.,Sakals M.E,.Innes J.L.,Sidle R.C.,Bergerud W.A.,Recognition of debris flow. debris flood, and flood hazard through watershed morphometrics. Landslides 1: 61-66 (2004)

[11]Bourcart J.,Recherches stratigraphiques sur le Pliocene et le Quaternaire du Levant. Bull.Soc.Geol.Fr. 5e s. T. X. (1940)

[12] Dubertret L. Sur la structure de la plateforme de Beyrouth et sur ses Grees Quaternaires. C.R. Soc.Geol.Fr., 83-85 (1940)

[13] Dubertret L., Geologie du Site de Beyrouth, avec Carte Geologique au 1/20000. Delegation Generale de France au Liban (1945)

[14] De Vaumas E. Le Liban. Etude de Geographie Physique. Firmin-Didot. (1954)

[15] Rossignol M. Sedimentation palynologique dans le domaine marin quaternaire de Palestine. Etude de Paleo-environnement. Notes et Memoires sur le Moyen-Orient. Museum National d'Histoire Naturelle (1969)

[16] Fleisch H. Depots Prehistoriques de la cote libanaise et leur place dans la chronologie basee sur le Quaternaire Marin. Quaternaria III, 101-132. (1956)

[17] Sanlaville P. Etude geomorphologique de la region littorale du Liban. Univ. Libanaise. (1977)

[18] Dubertret L. Carte Geologique au 1/50000. Flle de Beyrouth. (1951)