ON THE ALKALI-CARBONATE REACTIVITY OF AGGREGATES FROM IRAQI QUARRIES

Sahil A. Alsinawi

Sadoon Murad

The University of Baghdad

Department of Geology

ABSTRACT

The potential reactivity of carbonate rocks for concrete aggregates is investigated in samples collected from twenty eight quarries, distributed over different parts of Iraq, according to the ASTM: D 75-71. The samples were examined petrographically according to the ASTM: C 295-65, and analyzed chemically for major constituents ($CaCO_3$, $MgCO_3$, and insoluble residue). The samples were also subjected to mortar bar test according to the ASTM: C 227-71; the rock-cylinder test according to the ASTM: C 586-69; and the compressive strength according to the ACI Code 318-56. The concrete mixes were prepared from a low alkali cement (Sarchinar factory) and a high alkali cement (Kufa factory) and the results were compared. The results of the four tests carried, were utilized to give a combined evaluation to the carbonate aggregates from the quarry sites studied. This evaluation will be a useful guide in the choice of suitable crushed carbonate aggregates in situations where gravel and sand deposits are not available or of low quality.

The Alkali-Carbonate Reaction

Two types of alkali-aggregate reactions in concrete are now well established, namely: the alkali-silica reaction and alkali-carbonate rock reaction. A survey of alkali-silica reaction in Iraqi quarries was carried by the senior author(1).

The effect of alkali-carbonate rock aggregate reaction in concrete deterioration was first established in (1957) in the vicinity of Kingstone, Ontario, where an argillaceous dolomitic limestone was involved in the reaction (2).

A differentiation should be made between expansive alkali-carbonate rocks reaction and those reactions developing reaction rims around certain carbonate rock aggregates. The expansive aggregates cause deterioration of concrete by cracking and consequent failure. The rim developing carbonate aggregates cause deterioration by its weathering effect and decline in physical quality of the aggregate and consequently of the concrete (3,4).

The most pronounced reaction known to occur in carbonate aggregates is called as "Dedolomitization". It is a reaction in which the dolomites of the carbonate rocks are attacked by the alkalis of the cement, and accompanied by the development of calcite, and appearance of brucite (5).

The rim-developing carbonate rocks are generally of the same mineral composition and texture as the expansive rock but relatively of lower insoluble residue content and higher dolomite content (6).. The rim zones, were found to be less porous and contain more silica than the interior of the carbonate aggregate particles (3).

A general study of alkali-aggregate reaction in the Middle East was carried during the last two years (7,8,9).

The factors influencing the alkali-carbonate reaction include the cement alkali content (2), the expansive reactivity of rocks (6) the temperature and moisture condition (6), the maximum aggregate size (2), and the porosity and permeability of aggregates (10).

Different methods and approaches were suggested to overcome the reactivity by various workers among which were (11,12, 13, 14).

Methods of Test

A. Petrographic test:

Petrographic examination contributes in several ways to the investigation, selection, testing, and control of aggregates. Preliminary examination of concrete aggregates is performed either in the field or in the laboratory as an adjucent to examination, exploration, and sampling. This may help in locating relative quality and potentially reactive rocks in the field (15).

A recommended practice for petrographic examination of aggregate for concrete is given by ASTM Designation C295.

B. Mortar bar test:

A standard method of test for potential alkali reactivity of cement-aggregate combinations is described in ASTM Designation C 227. The method covers the determination of the susceptibility of cement-aggregate combinations to expansive reactions involving the alkalies (Na & K) by measurement of the increase (or decrease) in length of mortar bars containing the combination during storage under prescribed conditions of test.

C. Rock-cylinder test:

In this type of test either a small rock-cylinder or rock-prism is immersed in 1 to 2 m solutions of alkali. The time needed for this test to yield significant results is from two to six weeks, depending on size of the specimen, concentration of alkali, and reactivity of aggregate (16).

D. Compressive strength test:

The rim-developing rocks in concrete has a determinative effect on strength development. A decline in strength may results when a large proportions of such carbonate rocks are present (3, 6).

Geology of Carbonate Rocks in Iraq

The limestones and dolomites are distributed throughout large parts of Iraq ranging in age from the Devonian to the Miocene. They occur in various forms such as: pure limestones;

marly limestones; dolomitic limestones and pure dolomites. Their geologic formations greatly vary in thickness, extent, or shape, depending on the type of depositional basin, its extent and configuration. Other factors includes rate of deposition, time, and source area. The formations of northern Iraq are generally thicker than elsewhere, this is because of the relatively deeper basin of deposition.

The quarries sampled as shown in figure (1) are of different types depending on the position of the stratigraphic section with respect to the ground surface. This is greatly controlled by the tectonic history of the area.

Quarries of northern Iraq are almost of open shelf type because the area is affected by intensive tectonic movements. Some parts of the western desert are also of open shelf type, while the quarries of river plain are generally of open pit type. Table 1 gives a brief description of the quarry sites investigated.

Despite the original type of rock (chemical, biochemical, or detrital), the limestone and dolomite may be often surface altered to a hardpan by a diagenetic process, which may leads to the concentration of salts near the surface; this frequently occurs in the Middle East countries where evaporation exceeds precipitation (8).

Finally, a complexity in the geology of an area may leads to the complexity of alkali-reaction study, because the rock greatly vary in composition and different kinds of reaction occur (17).

Data Interpretation

Results of petrographic test:

From all studied samples, only two samples showed evidences of deleterious alkali reaction. These includes: Haditha (a) and Rutba (c) calcitic dolomites. These two samples were confirmed to be generally of the same petrographic characteristics. Haditha (a) aggregate have relatively higher insoluble residue but lower dolomitic content.

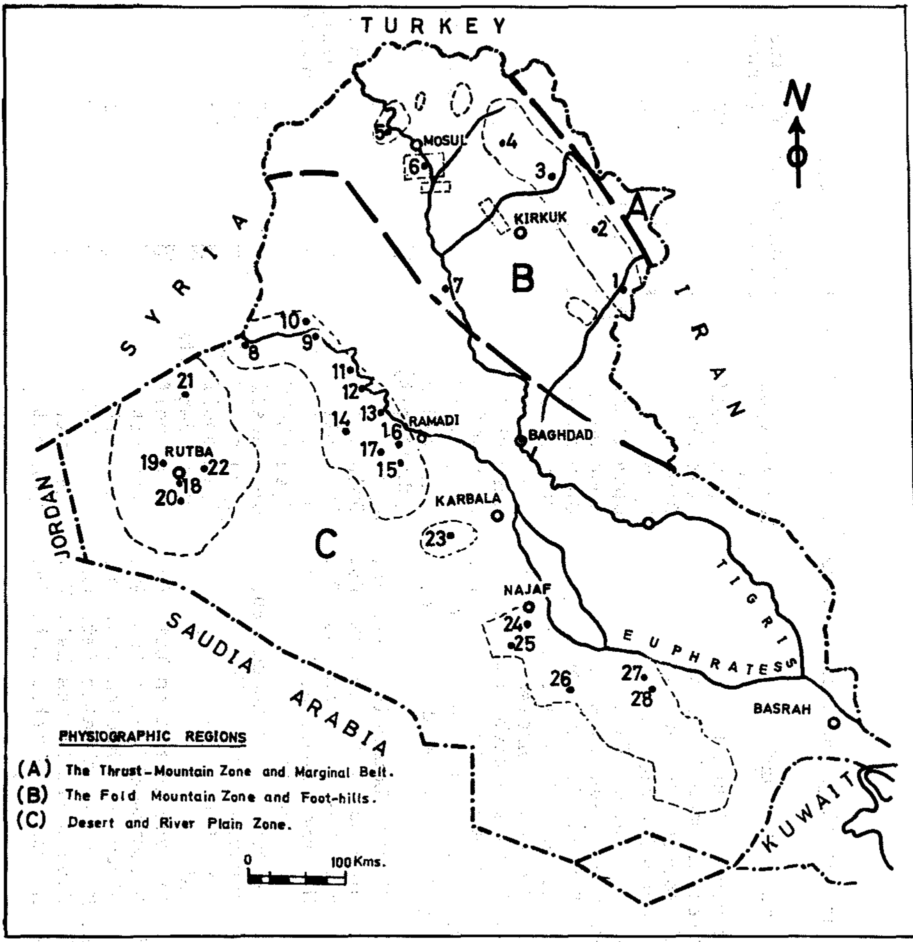

Fig.(1). Physiographic map of Iraq showing areas of major quarriable carbonat rocks and locations of the investigated quarry sites.

Table (1): Brief outline of the investigated quarry sites (see figure 1 for locations).

No.	Quarry name	Geologic Formation	Quarry type	Physiographic region	thickness (meters)
1	Derbendikhan	Eocene-Pilaspi Fn.	Open shelf	Fold Mountain and Foothills zone	70
2	Sarchinar	Cretaceous-Shiranish Fn.	Open shelf		20
3	Dokan	Cretaceous-Shiranish Fn.	Open shelf		70
4	Salah Al-Din	Eocene-Pilaspi Fn.	Open shelf		30
5	Badosh	M. Miocene-L. Fars Fn.	Open shelf		3
6	Hammam Al-Alil	M. Miocene-L. Fars Fn.	Open shelf		4
7	Baiji	M. Miocene-L. Fars Fn.	Open shelf		5
8	Ghussaiba (a,b)	L. Miocene-Euphrates Lst. Fn.	Open shelf		6
9	Rawa (a,b)	L. Miocene-Euphrates Lst. Fn.	Open shelf		5
10	Anah (a,b)	U. Oligocene-Anah Lst. Fn.	Open shelf		10
11	Haditha (a,b,c)	L. Miocene-Euphrates Lst. Fn.	Open pit		3
12	Khan Baghdadi (a,b,c,d)	Euphrates and Anah Lst. Fn.	Open shelf	Desert and River Plain Province	vauable
13	Hit (a,b,c,d,e)	Euphrates and Anah Lst. Fn.	Combined open (shelf+pit)		vauable
14	Kubbaisa (a,b)	L. Miocene-Euphrates Lst. Fn.	Open shelf		8
15	Abu-Sfayya (a,b)	L. Miocene-Euphrates Lst, Fn,	Opin pit		vauable
16	Kilo 45	L. Miocene-Euphrates Lst. Fn.	Open pit		vauable
17	Kilo 60 (a,b)	L. Miocene-Euphrates Lst. Fn.	Open pit		vauable
18	Wadi Msad	Cretaceous-Msad Fn.	Open shelf		1.5
19	Rutba (a,b,c)	Cretaceous-Um Er Rhduma Fn.	Open shelf		20
20	Tayarat	Cretaceous-Tayarat Fn.	Open shelf		20
21	Wadi Swab	Eocene-Dammam Fn.	Open shelf		15
22	Wadi Horan (a,b,c,d,e)	Recent	river deposits		-
23	Shithatha (a,b,c,d)	L. Miocene-Euphrates Lst. Fn.	Open shelf		8
24	Qalat Mazlum (a,b)	L. Miocene-Euphrates Lst. Fn.	Open pit		1
25	Haiydia (Najaf)(a,b)	L. Miocene-Euphrates Lst. Fn.	Open pit		1
26	Shanafia (a,b,c)	L. Miocene-Euphrates Lst. Fn.	Open shelf		2
27	Samawa 1 (a,b)	L. Miocene-Euphrates Lst. Fn.	Open pit		1
28	Samawa 2 (a,b)	L. Miocene-Euphrates Lst. Fn.	Open pit		3

Results of Mortar Bar Test:

The percent linear expansion curves of mortar bars for the different quarry samples with high alkali Kufa factory cement, (1.06% Na_2O total) are shown in figures 2a,3a,4a,5a,6a,7a,8a, and 9a respectively.The percent linear expansion curves of mortar bars for the different quarry samples with low alkali Sarchinar factory cement(0.48% total Na_2O) are shown in figures 2b,3b,4b,5b,6b,7b,8b and 9b respectively. A direct comparasion can be made between the expansion curves for the different samples with high and low alkali cement.

The relatively more expanding mortar bars are those obtained from quarries west of the Euphrates river and the Western desert. Samples obtained from quarries from northern and southern Iraq were generally non or slightly expansive.

The effect of the dilution of the mortar mix of expansive Haditha aggregate with the inert Sarchinar aggregate yeilded some reduction in expansion ,but the deleterious effect remained. Figure 10 shows a comparasion between three haditha mortars prepared from low alkali cement,high alkali cement and a diluted sample with high alkali cement .

Results of Compressive strength test :

There was no observed decline in the rate of compressive strength development with time in all the concrete cubes prepared from all the aggregate types.The rate of compressive strength growth was noticed to be different in different samples. The following quarry site samples gave not accepted strength values in 28 days:Haditha,Haiydia,Ghussaiba,Qalat Mazlum,Samawa 2, Kilo 60,Rawa ,Baiji and Badosh.

Results of petrographic examination of the mortar concrete:

All of the mortars prepared from low and high alkali cement were examined petrographically, and not found to reveal any reaction criteria with the exception of three samples from Haditha,Rutba and Tayarat.Microcracks of appreciable lengh were noticed in Haditha and Tayarat mortar;while the Rutba mortar revealed clear reaction rims .

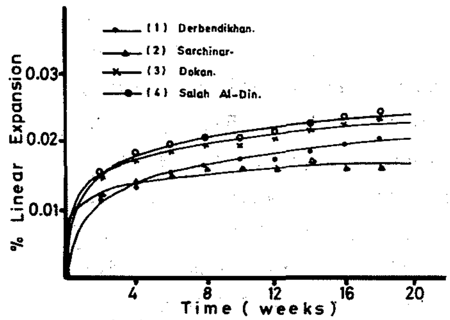

Fig.(2a). Percent linear expansion of mortar bars versus time using Kufa cement (quarry sites 1, 2, 3 & 4).

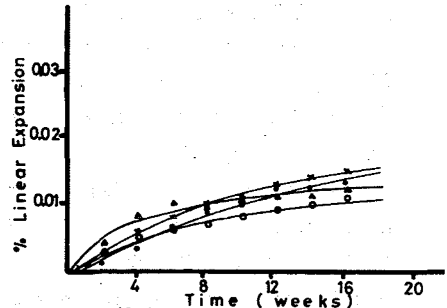

Fig.(2b). Percent linear expansion of mortar bars versus time using Sarchinar cement (quarry sites 1, 2, 3 & 4).

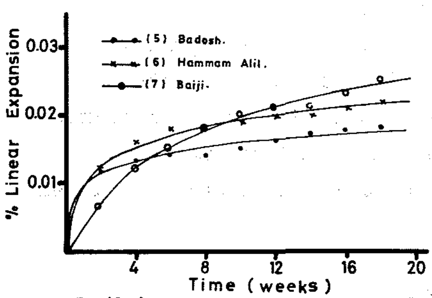

Fig.(3a). Percent linear expansion of mortar bars versus time using Kufa cement (quarry sites 5, 6 & 7).

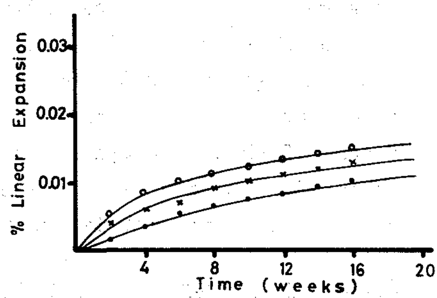

Fig.(3b). Percent linear expansion of mortar bars versus time using Sarchinar cement (quarry sites 5, 6 & 7).

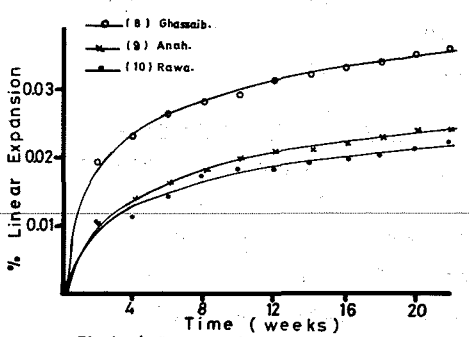

Fig.(4a). Percent linear expansion of mortar bars versus time using Kufa cement (quarry sites 8, 9 & 10).

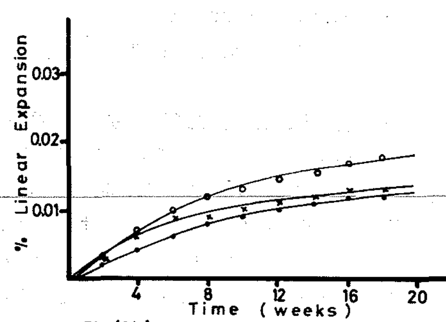

Fig.(4b). Percent linear expansion of mortar bars versus time using Sarchinar cement (quarry sites 8, 9 & 10).

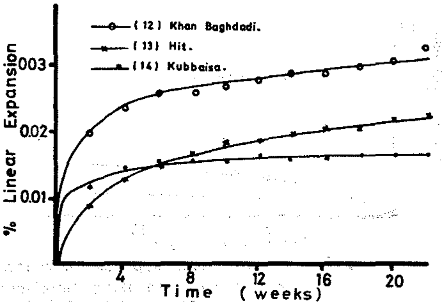

Fig.(5a). Percen linear expansion of mortar bars versus time using Kufa cement(quarry sites 12,13 & 14).

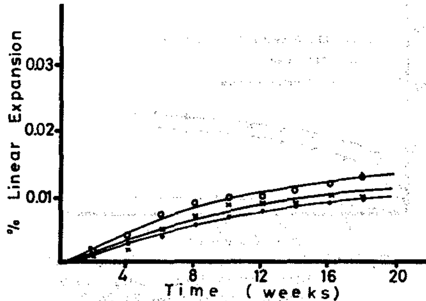

Fig.(5b). Percent linear expansion of mortar bars versus time using Sarchinar cement (quarry sites 12, 13 & 14).

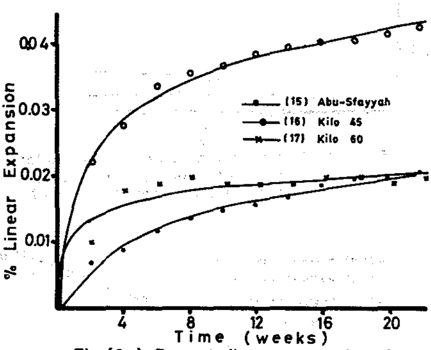

Fig.(6a). Percent linear expansion of mortar bars versus time using Kufa cement (quarry sites 15, 16 & 17).

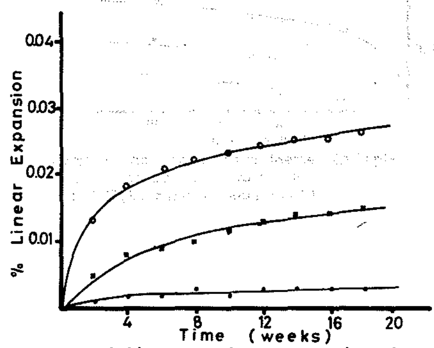

Fig.(6b). Percent linear expansion of mortar bars versus time using Sarchinar cement (quarry sites 15, 16 & 17).

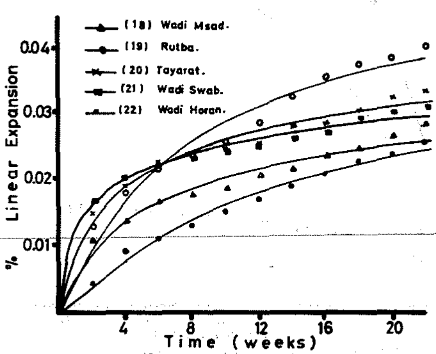

Fig.(7a). Percent linear expansion of mortar bars versus time using Kufa cement (quarry sites 18, 19, 20, 21 & 22)

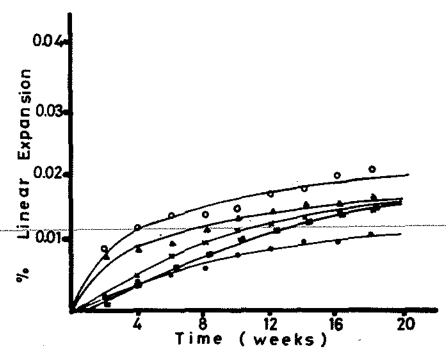

Fig.(7b). Percent linear expansion of mortar bars versus time using Sarchinar cement (quarry sites 18, 19, 20, 21 & 22).

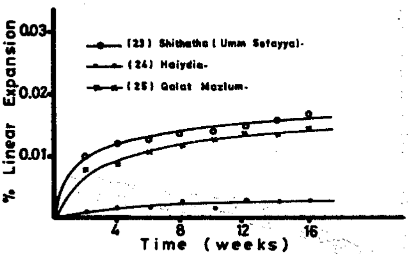

Fig.(8a). Percent linear expansion of mortar bars versus time using Kufa cement (quarry sites 23, 24 & 25)

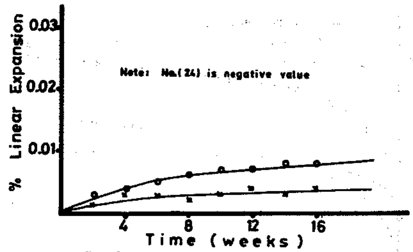

Fig.(8b). Percent linear expansion of mortar bars versus time using Sarchinar cement (quarry sites 23 & 25)

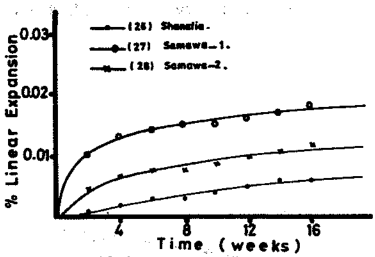

Fig (9a) Percent linear expansion of mortar bars versus time using Kufa cement (quarry sites 26, 27 & 28)

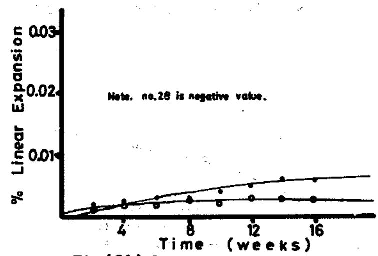

Fig (9b) Percent linear expansion of mortar bars versus time using Sarchinar cement (quarry sites 26 & 27)

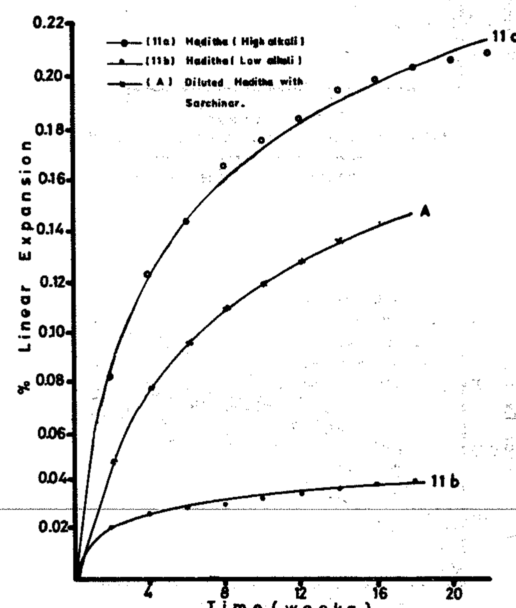

Fig.(10). Expansion curves of Haditha mortar using low and high alkali cement and diluted Haditha aggregate with 50% Sarchinar aggregate using high-alkali cement.

Results of Rock Cylinder Test:

The percent linear expansion data of rock cylinders from twenty five quarries after four weeks correlated well with the fourteen week expansion data of their respective mortar bars. This suggests that the abnormal expansion of the concrete is likely to be due to the abnormal expansion of the aggregates used.

Results of the combined evaluation of the quarries:

Table (2) attempts to compare the results of the petrographic test, mortar bar test, cylinder test and the compressive strength test carried on the samples from all the investigated quarries. An overall grading system is suggested whereby a total of seven grades are distributed among the four test as follows: Three for the mortar bar test, two for the petrographic test, and one for each of the rock cylinder and compressive strength test.

The results of this evaluation can be used as an objective measure for the suitability of the carbonate rocks from Iraqi quarries for concrete aggregate uses.

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Table (1): Combined evaluation of the carbonate quarries.

Quarry Name		Petrographic Test		Rock-Cylinder Test	Mortar Bar Test	Compressive strength test	overall Grading	
		physical quality	chemical quality					
Shanafia	a	satisfactory	innocuous	non-expansive	non-expansive	accepted	6.4	7
	b	fair	innocuous	—				6.5
	c	poor	innocuous	—				6
Derbendikhan		satisfactory	innocuous	non-expensive	slight-expansive	accepted	6.0	
Sarchinar		satisfactory	innocuous	non-expansive	slightly-expansive	accepted	6.0	
Salah Al-Din		satisfactory	innocuous	non-expansive	slightly-expansive	accepted	6.0	
Anah (a,b)		satisfactory	innocuous	non-expansive	slightly-expansive	accepted	6.0	
Abu-Sfayya(a,b)		satisfactory	innocuous	non-expansive	slightly-expansive	accepted	6.0	
Samawa 1	a	fair	innocuous	-	slightly-expan-	accepted	5.7	5.4
	b	satisfactory	innocuous	non-expansive	slightly-expansive	accepted		6.0
Hit	a	satisfactory	innocuous	non-expansive	slightly-expansive	accepted	5.7	6.0
	b	satisfactory	innocuous	-				5.9
	c	fair	innocuous	non-expansive				5.5
	d,e	fair	innocuous	-				5.4
Dokan		fair	innocuous	non-expansive	slightly-expansive	accepted	5.5	
Wadi Msad		fair	innocuous	non-expansive	slightly-expansive	accepted	5.5	
Hammam Al-Alil		fair	innocuous	non-expansive	slightly-expansive	accepted	5.5	

Shithatha	a,d b c	fair poor satisfactory	innocuous innocuous innocuous	- - non-expansive	slightly-expansive	accepted	5.4	5.4 6.0 4.9
Haiydia	a b	poor fair	innocuous innocuous	- non-expansive	non-expansive	not accepted	5.3	5.0 5.5
Kubbaisa	a b	poor fair	innocuous innocuous	non-expansive -	slightly-expansive	accepted	5.2	5.0 5.4
Tayarat		satisfactory	innocuous	slightly-expan-sive	moderately-expansive	accepted	4.9	
Wadi Swab		satisfactory	innocuous	slightly-expan-sive	moderately-expansive	accepted	4.9	
Khan Baghdadi	a b,c d	satisfactory satisfactory fair	innocuous innocuous innocuous	non-expansive - non-expansive	moderately expansive	accepted	4.8	5.0 4.9 4.5
Badosh		fair	innocuous	non-expansive	slightly-expansive	not accepted	4.5	
Rawa	a b	fair fair	innocuous innocuous	non-expansive -	slightly-expansive	not accepted	4.5	4.5 4.5
Wadi Horan	a b c,e d	satisfactory fair poor satisfactory	deleterious innocuous innocuous innocuous	- - -	slightly-expansive	not accepted	4.3	3.9 3.9 4.9 4.4
Samawa 2	a b	poor fair	innocuous innocuous	- non-expansive	slightly-expansive	not accepted	4.2	3.9 4.5

Qalat Mazlum	a b	fair poor	innocuous innocuous	slightly expansive	-	not accepted	4.2	4.4 3.9
Kilo 45		fair	innocuous	moderately-expansive	moderately expansive	accepted	4.0	
Kilo 60	a b	poor poor	innocuous innocuous	non-expansive -	slightly-expansive	not accepted	4.0	4.0 4.0
Rutba	a b c	fair poor satisfactory	innocuous innocuous deleterious	slightly-expansive slightly-expansive	moderately expansive		3.6	4.4 2.5 3.9
Ghussaiba	a b	fair poor	innocuous innocuous	non-expansive -	moderately expansive	not accepted	3.0	3.5 2.5
Baiji		poor	deleterious	slightly-expansive	slightly-expansive	not accepted	2.9	
Haditha	a b c	fair fair poor	deleterious innocuous innocuous	expansive non-expansive -	expansive	not accepted	1.3	0.5 2.5 1.0

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Jersey