The impact of structural inversion on the hydrocarbon system, northwest Mosul area, Case study Sasan (Sarjoon) Oil Field.

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Abstract: Sasan field is in Nineveh governorate, 46 Km northwest Mosul city. The present Sasan structure was discovered from surface mapping and 2D seismic defined the Upper Cretaceous reservoir but due to poor data quality, any estimate of oil in places are highly uncertain. Sasan structure from seismic shows Block-Faulted anticline covering a small area (Sasan East). Several normal faults appear to separate SA-2 from SA-1 affected the hydrocarbon system in these two wells. The more possible realistic interpretation is an inverted graben, thick Shiranish Formation in Sasan wells support this interpretation.

The model suggest that normal faults created the accommodation during Late Cretaceous (Sinjar trough) and subsequent Tertiary compression uplifted the depocenter creating the topographic depression which interpretated as a fault propagation fold. The last compressional structures can only have been filled with remigrated petroleum from breached, older traps, earlier structures could have been filled by migration from an actively generating source rocks. The exploration potential in the old Sasan structure configuration is good but it is still an exploration play not a commercial oil discovery, although oil is present in Shiranish, Hartha/Mushora and Wajnah formations but not clear if it is recoverable.

Gas present in deeper formations, both the oil and gas traps are breaching traps. The best exploration targets should, therefore, be old structures, produced by Late shoulders of Sinjar basin contain many such leads as the prospective leads nominated A, B, C and D.

Second best are old structures which have been partially restructured and whose closure has been modified, but not breached. The prospective reservoirs will be at Late Cretaceous, Early Cretaceous and Late Triassic.

Keywords: Sasan Structure, Inversion, Breaching, Remigration, Prospective Leads

الخلاصة: يقع حقل ساسان ضمن محافضة نينوى ، على بعد 46 كم شمال غرب مدينة الموصل . أن تركيب ساسان الحالي تم اكتشافه من خلال المسح المسح السطحي والمسح الزلزالي الثنائي الابعاد لمكمن الطباشيري الأعلى ولكن بسبب رداءة نوعية المعطيات من المسح الزلزالي ونتائج الحفر جعل من أي تخمين للاحتياطي الهايدروكاربوني للحقل غير موثوق بدرجة كبيرة . أن المقطع الزلزالي لتركيب ساسان بين طية محدبة متفلقة كتليا تغطي مساحة صغيرة (تركيب ساسان الشرقي) . كما أشر المقطع الزلزالي وجود العديد من الفوالق الاعتيادية تفصل البئر ساسان واحد عن البئر ساسان اثنين وهذه الفوالق أثرت بدورها على النظام الهايدروكاربوني لهذين البئرين . أن التفسير الأكثر واقعية لمنطقة تركيب ساسان يدلل على وجود خسفة منقلبة وان سماكات تكوين الشيرانش لابار الحقل تدعم هذا التفسير . يوحي الانموذج المقترح بأن فوالق التمدد وفرت الفراغ اللازم (حوض سنجار) خلال فترة الطباشيري المتأخر وادى التضاغط في فترة الثلاثي الى رفع مركز الحوض الرسوبي منشأ منخفض طوبوغرافي فسر على انه طية زاحفة متفلقة . أن التراكيب المنضغطة الاقدم تم ملئها من خلال إعادة هجرة الهايدروكاربونات من مصائد قديمة متكسرة ، اما التراكيب الناشئة حديثا فقد تم ملئها من هجرة هايدروكاربونات من صخور مصدرية مولدة نشطة .أن القدرة الهايدروكاربونية لمكامن الجزء العلوي من تركيب ساسان القديم على الرغم من ايجابيته ولكنه لا يرتقي الى اكتشاف نفطي تجاري على الرغم من وجود النفط في تكاوين الشيرانش ، الهارثة/ المشورة والوجنة ووجود الغاز في المكامن العميقة ولكن يبقى من غير الواضح اذا كان بالإمكان استخراج هذه الهايدروكاربونات تجاريا .أن المصائد النفطية والغازية هي مصائد متكسرة (متهالكة) ولذلك فالخيار الاستكشافي الأول لهذه المنطقة يجب ان يكون بأتجاه التراكيب القديمة المتولدة على اكتاف حوض سنجار والحاوية على العديد من الفرص الاستكشافية الواعدة والتي تم تحديدها بالمواقع أ،ب،ج ، د . أما الخيار الثاني فهو التراكيب القديمة التي اعيد بناءها جزئيا والتي تغيرت انغلاقاتها التركيبية من غير ان يصيب التكسر مصائدها . أن اعمار هذه المكامن المهمة هي في فترات الطباشيري المتأخر والمبكر بالاضاقة الى الترياسي المتأخر .

1. Introduction

The Field is in Nineveh Governorate, 46 km northwest of Mosul city. Topographically the area is hilly, dissected by m any deep wadies.

In 1938, the area of the field was covered by surface geological survey and showed that the Sasan Structure was an anticline trending East-West, with 11 km long and 6.4 wide. Dips measured on the Northern flank, range 20-35 degrees and the Southern flank from 7-16 degrees. A smaller anticlinal structure was identified to the southwest of the main Sasan Structure, having a structural size of about 8.0 X 2.5 km2, separated from the Sasan structure by synclinal saddle {1}. This dome was called Sasan West to separate it from the main Eastern dome.

In 1955 the first exploratory well was drilled at the crest of the Eastern dome and reached a total depth of 2950 m. in the Mus Formation. encountering oil shows which were discovered in the Shiranish, Hartha, Jawan / Mauddod of the Cretaceous. {2}.

In 1960 the area was covered by seismic surveys. Interpretation results was not conclusive. Another seismic survey was conducted, by Iraqi National Oil Company (INOC), through the period 1972-1974, covered mostly the western part of Sasan Structure. The results obtained were of bad quality. Nevertheless, the seismic maps showed that the Sasan Structure is represented by a domal structural shape complicated by many faults at deeper horizons {3,4}. In 1974, the second exploratory well (SA-2) was drilled to explore the hydrocarbon prospects and to clarify the structural configuration. The well reached a total depth of 2995 m in Baluti Formation (L. Jurassic). Results obtained from this well showed the existence of oil and gas at several horizons, proved from test results {5}.

In 1976, the area was again covered by seismic surveys. Interpretation results were also not conclusive. As a results, the structural picture of the field, in particular the deeper horizons remain unsolved, which might be due to the structural complexities of the area at deeper horizons (Fig-1).

Fig.1. Location of Sasan (Recently nominated Sarjoon) Field.

2. The Main Objectives of the present Study:

2.1. Define the influence of structural inversion on the hydrocarbon system of Sasan oil field.

2.2. Suggest the most suitable promising location for the next well.

3. TECTONIC Setting

Sasan field is part of the Foot-hill Zone (Low Folded Zone). The geological terminology of Buday and Jassim has been used in the present work {6}. It is about 200 km wide, bound by the Mesopotamian Zone in the southwest and the High Folded Zone in the northeast (Fig. 2). South of Sinjar, the Foothill Zone is in contact with the Stable Shelf units {7,8}. Sinistral strike slip movement is postulated by Ameen {9}. The contact with the High Folded zone is delineated by the sudden elevation of the sequence exposing the Paleogene succession in the anticlines of the High Folded Zone in comparison with the deep Neogene filled depressed block of the Foothill Zone to the southwest. The Foothill Zone was the site of deposition of thick Neogene molasse; the eastern half of the zone, known as the Butmah-Chemchemal subzone was elevated during the Paleogene as indicated by the development of Upper Paleocene to Eocene shoal deposits {10}. The Foothill zone is characterized by long anticlinal structures with very broad shallow synclines; upwards continuation of gravity field indicates that some anticlines are often associated with basement elevation. Some buried structures are (Fig. 2) also existed in the broad synclinal areas and are associated with diverging drainage system {11,12,13,14}. In the Mosul area where a thinner sedimentary column occurs above the basement and where carbonates associated with the thinning of the Jurassic and Cretaceous sequences are present. The folding style here is different. The folds are shorter (about 20-30 km), arranged in an en-echelon pattern and possess a simple harmonic character relative to those to the south of the high. Generally, most anticlinal structures of the Foothill Zone are asymmetrical to the southwest except in the area around Mosul where anticlines may have faced asymmetry, one to the north and the other to the south. The dominant fault system in the zone is the NW-SE system and is often found in association with the anticlinal structures {15,16,17}.

As indicated above, the main master fracture directions controlling the basin and swell patterns and distribution were NW-SE and NE-SE (i.e., longitudinal and transverse). Variation of as much as 20° in these main trends occurs frequently along the same lineament. The NW-SE trend is the original extensional trend which developed over a wide area as rifting and separation of the Cimmerian blocks occurred in the Early Mesozoic (Permian-Triassic into Early Jurassic) {18}. Along this trend compartmentalization of basins by up and down movements, separated from each other often by horizontal motion along the conjugate NE-SW trend, not infrequently occurred to form longitudinal subsided ridges, sometimes of a short-lived nature, or more evident and persistent horsts and grabens. Inversion of sectors of these "longitudinal basins" by transposition through wrench motion or vertical block uplift along the NE-SW fractures gave rise to such features as the Sinjar trough {19,20,21}.

This northern basinal area extended eastward into Laurestan province of western Iran. It is bounded to the north by the submerged Mosul High which also separates it form the Southeast Turkey Shelf. To the west is the submerged Rutbah Platform and the submerged Khleisia High. It appears that there was a narrow channel that existed between the Mosul and Khlesisia highs and this allowed a direct link between the northern basinal area and the Syrian Trough that occupied most of the central Syria and extended towards north-western Iraq (Sinjar Trough) {22,23,24}.

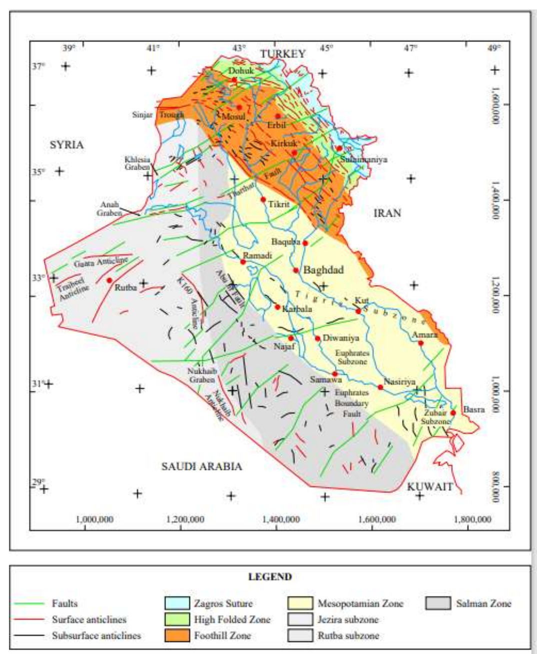

Fig.2. Tectonic map of Iraq (After Buday&Jassim,1984)

4. Geological Setting

Two wells were drilled in Eastern dome. The first (SA-1) was drilled in 1955 to a depth of 2950 m and stopped in the Mus Formation. The second well (SA-2) was drilled to a depth of 2995m and terminated in Baluti formation {2,5}.

Stratigraphically, the Hydrocarbon potentials (oil & gas) are contained mainly with six pay zones of Mesozoic age. Four of these pay zones are housed within the U. and L. Cretaceous and the other two pay zones are within the Middle and Lower Jurassic. These pay zones consist of variable lithologic characteristics ranging from fractured Basinal rocks of Mud / Wackstone as for the pay zones of Shiranish, Mashora & Sargelu, to shoal facies of pack /Grainstone as for the pay zones of Mauddod, Mus & Butmah, to evaporitic facies as for Jawan pay zone.

The chronostratigraphic column of Sasan field, based on SA-1 & SA-2 data is shown in table (1). It must be noted that most of the lower Cretaceous and Upper Jurassic sequences were eroded not only in Sasan field but, in almost, in the whole region of Northwest Iraq {13}.

rifting west striking faults in the Sinjar-Abd el Aziz area causing substantial thicknesses of syn-extensional Late Campanian-Maastrichtian marly limestones to be deposited there. A latest Cretaceous collisional event along the northern Arabian Plate margin terminated the extension in the Sinjar-Abd el Aziz area. Eocene-Miocene suturing of Arabia to Eurasia had little effect on the structures of area, despite being the cause of significant uplift in the adjacent Palmy ride fold and thrust belt. Rather, the stress reorganization and northward Arabian Plate movement experienced since Pliocene time has caused reactivation of the normal faults in a reverse sense in northeast Syria-northwest Mosul {23,24,25}. Fault-propagation folding, and structural inversion have resulted in the topography that persists in the area today. This late-stage structural reactivation is critical to Cenozoic and Mesozoic anticlinal hydrocarbon trapping in the area. Paleozoic horizons remain to be fully explored {26,27}.

Table 1: Shows Chronostratigraphic events in Sasan Field.

M.Y	AGE		TECTONIC	STRA	FORMATION
	PLIESTO		*INVERSION	T1	
	PLIOCENE		*FORELAND BASIN	T2	
10-	MIOCENE	LATE			
		MIDDLE	*SEDIMENT LOADING	T3	LOWER FARS / JERIBE
20-				T4	
		EARLY	*THERMAL SAG	T5	SERI KAGNI
30-	OLIGOCENE	LATE	*THERMAL SAG	T6	
40-		EARLY	*REBOUND	T7	
	EOCENE	LATE	*THERMAL SAG	T8	
50-		MIDDLE	*FORELAND BASIM		
60-		EARLY	*THERMAL SAG	T9	Aaliji
70-	PALAEOCENE	LATE	*REBOUND		
80-		EARLY			
	MAESTRICHTIAN		*INVERSION	K1	Shiranish
90-	CAMPAIAN		*PAST RIFT FORELAND BASIM		Hartha
100-			*SYN RIFT	K2	Mashora/ Wajnah
110-	SANTONIAN				
120-	TURON	L		K3	
		E	*PASSIVE MARGIN	K4	Gir Bir
	CENONANIAN				
	ALBIAN			K5	Mauddod
					Jawan
					Batiwah
	APTIAN			K6	Shuaiba
					Ratawi

M.Y	AGE		TECTONIC	STRA	FORMATION
				K6	
	BARREMIAN				
	HAUT	L	*POST RIFT	K7	
		E			
	VALANCINIAN				
	BERIASIAN	L			
		E		J1	
	TITHON	L			
		E		J2	
	KAM	L			
		E			
	OXFOR			J3	
	CALLOV				
	BATHON		*PLATFORM COLLAPSE	J4	SARGELU
	BAJOCIAN				
	AMEN				
	TOARANIAN	L			
		E	*POST RIFT	J5	ALAN MUS
	PLIENS-BACHIAN				
	SINEMORIAN			TR1	BUTMAH
	HOTING	NORIAN			
	TRIASSIC	CARNIAN	*SYN RIFT	TR2	KURRA-CHINE (not penetrated)
				TR3	
		LADINIAN		TR4	
		EARLY	*PASSIVE MARGIN		

5. Material and Methods

Data available suggest that present day structures in the Ninawa region are fault-propagation folds caused by the inversion of pre-existent normal faults {8}.

Sasan structure from surface mapping, identifies a domal closure aligned. WNW-ESE, known as Sasan East & a-3-way, dip closed (N, S &W) high to the West, “Sasan West” aligned WSW-ESE. Sasan East & West are separated by a saddle area, possibly faulted {1}. Sasan East was drilled by SA-1 & SA-2 located 1.1 Km updip to the East. Probable fault of the northern flank of Sasan East oriented along strike. 1200 Km of 2D seismic data is made, 305 Km of the re-processed lines are interpretable quality. Even after re-processing, the quality of this data varies from fair to very poor, only 77Km of these lines cover Sasan Field, the rest extend to the east towards Alan & Atshan Fields and show possible exploration prospects {3,4}. From seismic sections in Sasan area, four seismic events are mapped, the first occur near top Alan Formation, the second is near top Butmah Formation and two deeper events below well TD. The two wells SA-1 and SA-2 show several faults which appear to separate SA-2 from SA-1. They are of extensional normal type (Fig-3).

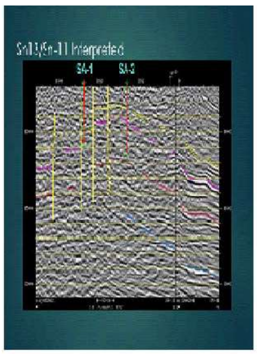

Fig-3: Show several faults appear to separate SA-2 from SA-1.

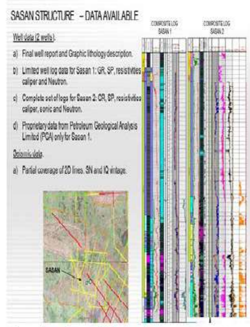

Fig-4: Shows the available data for Sasan structure.

The available data from the two wells SA-1 & SA-2 is shown in the Fig-4 and the Dipmeter log in the well SA-2 confirms the presence of probable fault cut the SA-2 well (Fig-5) besides the presence of subnormal formation pressure in the same interval (Fig-6).

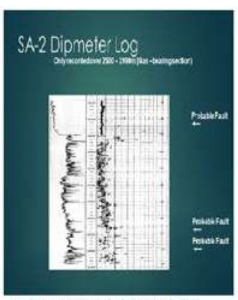

Fig-5: Shows dipmeter log for SA-2 recorded over 2500-2990 m confirm the presence of probable fault cut the well

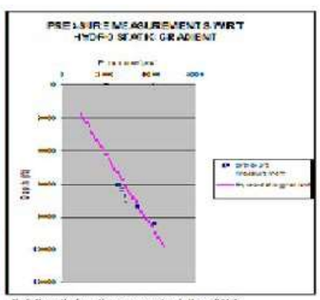

Fig-6: Shows the formation pressure system in the well SA-2.

6. Discussion

The Sinjar area of northeast Syria-northwest Mosul was part of the larger southwest-northeast trending Palmy ride/ Sinjar Basins from Late Paleozoic to Late Cretaceous time {23,24}. Although rifting took place in the Palmy rides/Sinjar in the Late Paleozoic, during the commenced along northwest-southeast trends in the Euphrates Fault System beginning in the Coniacian. In later Cretaceous time, extension began across east-Mesozoic most of the stratigraphic thickening was subsidence related. Following plate tectonic reorganization in Cretaceous time,

Structural inversion is a reversal of deformational processes must a commonly a depressed region is uplifted. Deposition occurs in the presence of normal faults such that a thick section is developed on the downthrown sides e.g., half graben or small rift basin. Low areas are then turned inside out into highs, usually by a combination of compression and wrenching. The final product is an anticlinal or structural high into which sedimentary unit thicken.

Structural inversion can strongly affect the petroleum prospectivness of an area in which it occurs {28, 29, 30, 31, 32}. To reach the above discussion a regional composite seismic sections were constructed to the area around Sasan structure nominated D-D′) (Fig-7) & (Fig-8) {29}. Only one strong reflection can be partially mapped across this composite line. Several interpretations (including different structural models) can be done with this data, and all can be completely valid (Fig-9). One possible interpretation (widely used by literature) is an inverted graben. Thick Shiranish Formation in Sasan wells support this interpretation. The model suggests that normal faults created the accommodation during Late Cretaceous (Sinjar Trough?) and subsequent tertiary compression uplifted the depocenter creating the topographic expression which is interpreted as a fault propagation fold (Fig-10). The regional seismic line also shows several other structural highs lie in the area between Sasan Field and Alan & Ibrahim Fields nominated as A, B, C and D and Sasan West structure may also be prospective (Figs-11 & 12).

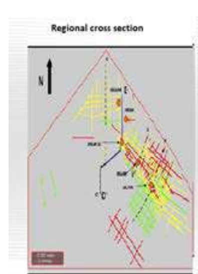

Fig-7: Regional seismic line was constructed extend from N-SW (D-D′) after O.E.C.20

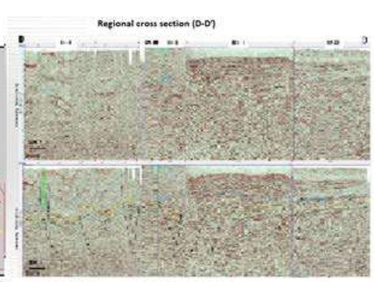

Fig-8: Regional cross section (D-D′) After O.E.C.2010

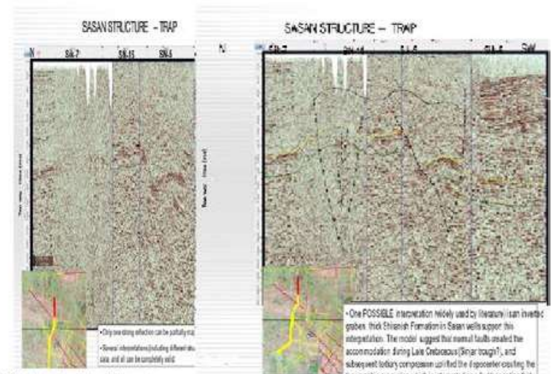

Fig-10: Represent a fault propagation fold.

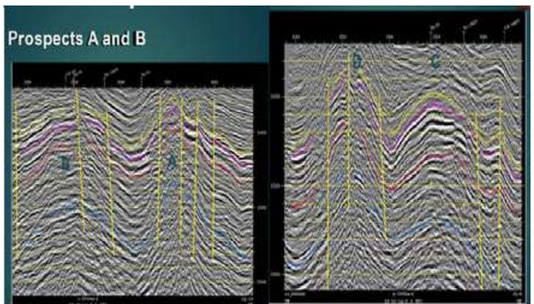

Fig -11: Shows two prospective leads nominated as A & B

Fig-12: Shows the two other prospective leads nominated as C & D.

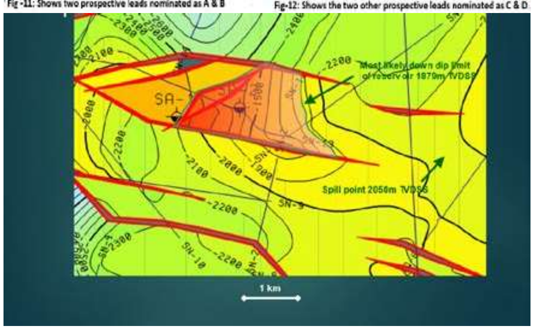

Fig.13. Shows Top Wajnah depth map within Sasan Area.

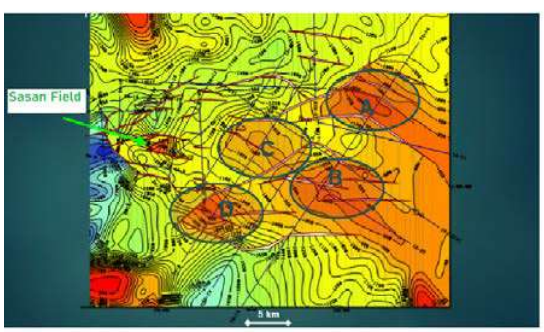

Fig.14. Top Wajnah depth map in the area between Sasan Field & Alan- Ibrahim Fields shows the four prospective leads nominated A, B, C & D.

The timing of formation of structural traps in the studied area shows that the potential structural traps were produced in three stages:
The first, during rifting episodes (mainly early Late Cretaceous). The main trap types are tilted fault blocks. The Earlier rifting in Mid-Late Triassic time may also have produced similar traps.
The second, The Early Tertiary phase of compression may have created more traps. The compression event only affected the NW part of the studied area.
The third, A phase of compression in the Late Pliocene to Recent produced the anticline seen at surface. This structure is above older extensional structure that has been inverted {33,34}.
As concerning, the timing of generation and migration, the potential source rocks has been identified. Generation from this is likely to have occurred during the periods of rapid burial.
Late Cretaceous in the Sinjar basin, several kilometers of Upper Cretaceous post-rift sediments were deposited. This may have been sufficient to cause generation from Triassic source rocks (Kurra Chine Formation) {8, 27}. The Early Tertiary inversion episode would have temporarily “switched off” generation within the basin. Trap breaching and remigration: many structural traps created by Late Cretaceous rifting and, possibly, by Early Tertiary compression, could have been petroleum-filled. In areas strongly affected by the Late Tertiary compression most of these traps were structurally modified,
probably leading to breaching or spillage. Some of this remigrated petroleum may have found its way into new traps. Similarly, the Early Tertiary compression may have liberated petroleum by breaching older extensional traps {33,34}.

7. Conclusion:

7.1. Potential traps were formed by Late Cretaceous extension, and by phases of compression in the Early and Late Tertiary. The last phase of compression ended petroleum generation.

7.2. The last compressional structures can only have been filled with remigrated petroleum from breached, older traps, earlier structures could have been filled by migration from an actively generating source rocks.
7.3. The exploration potential in the old Sasan structure configuration is good but it is still an exploration play not a commercial oil discovery, although oil is present in Shiranish, Hartha/Mushora and Wajnah formations but not clear if it is recoverable.
7.4. Gas present in deeper formations, both the oil and gas traps are breaching traps.
7.5. The best exploration targets should, therefore, be old structures, produced by Late Cretaceous extension or Early Tertiary compression, which have not been restructured by Late Tertiary compression. The faulted areas north and south shoulders of Sinjar basin contain many such leads as the prospective leads nominated A, B, C and D.
7.6. Second best are old structures which have been partially restructured and whose closure has been modified, but not breached.
7.7. The prospective reservoirs will be at Late Cretaceous, Early Cretaceous and Late Triassic.

8. Recommendation:

8.1. Several other structures highs have been shown by 2D seismic data.
8.2. These structures lie between Sasan Field and Alan & Ibrahim Fields.
8.3. Further mapping is recommended preferably 3D seismic.

9. References:

[1] Al-Jumaily,R. and Dr. Domaci,L.,CSc. Geological and Tectonic Position of Jebel Sasan-Jebel Ishkaft Area, NW of Tel Afar, Iraq. Journal of the Geological Society of Iraq, Vol.IX,1976, Pp.101-115.

[2] Final Report on Well Sasan No.1. Mosul Petroleum Company Limited, Sep.1958. pp. 29

[3] Seismic Section for Sasan-Ishkaft Area, O.E.C.2006.

[4] Seismic Section for Sasan Structure (Sasan Area),O.E.C.2006

[5] Final Geological Report on Well Sasan No.2, I.N.O.C.1976. pp.13.

[6] Buday, T., 1980. The Regional Geology of Iraq. Vol. 1. Stratigraphic and Paleogeography. Puplications of GEOSURV. Baghdad. 445p.

[7] Paleo and New- Tectonics of the Mosul fault and its Impact on the Tectonics of the Foreland Area of Iraq. Iraqi National Journal of Earth Science, Vol.13, No. 1, Pp.59-74. 2013

[8] Aqrawi, A. A. M., Goff J. C., Horburu, A. D., and Sadooni, F. N., 2010. The Petroleum Geology of Iraq. Printed in Great Britain by Cambrian Printers

[9] Ameen M. S., 1992. Effect of Basement Tectonic on Generation, Migration, and Accumulation in Northern Iraq, The American Association of Petroleum Geologists Bulletin, Vol. 76, No. 3, pp. 356 - 370.

[10] Jassim, S. Z., Karim, S. A., Basi, M., Al-Mubarak, M. A., and Munir, J., 1984. Final report on the regional geological survey of Iraq. Vol. 3. Stratigraphy. internal report. Geological Survey of Iraq. Jassim, S. Z., and Goff, J. C., 2006. Geology of Iraq. First edition. Printed in the Czech Republic.

[11] Fouad, S. F. A. 2015. Tectonic Map of Iraq Scale 1: 1000 000, third edition. Iraqi Bulletin of Geology and Mining, 11(1): 1-7.

[12] Ibrahim, A. O., 1985. Tectono-stratigraphic Investigation in the Southern Reaches of the Simple Folds Zone of Iraq, Unpub. M Sc thesis, Univ. of Mosul, Iraq. 218 p.

[13] Kadir, M. M., 2008. Geodynamic Study of the Northeastern Margin of the Arabian Plate, Unpub. Ph. D thesis, University of Mosul, Iraq, 206 p.

[14] Nadir, P. Y., 1983. Geological-Structural Study of West Mosul - Telafar with Details on Shaikh Ibrahim Anticline. Unpub. Report, IPC, Iraq, 36 p.

[15] Numan, N. M. S., 1984. Basement Control of Stratigraphy Sequences and Structural Pattern in Iraq, Jour. Geol. Soci. Iraq, Vol. 16-17, pp. 8 - 24.

[16] Sharland, P. R., Archer, R., Casey, D. M., Davies, R. B., Hall, S. H., Heward, A. P., Horbury, A. D. and Simmons, M. D., 2001. Arabian Plate Sequence Stratigraphy, GeoArabia special publication Vol. 2, 317 p.

[17] Ziegler, M., A., 2001. Late Permian to Holocene Paleofacies Evolution of the Arabian Plate and its Hydrocarbon Occurrences, GeoArabia, Vol. 6, No. 3, pp. 445 - 504.

[18] Numan, N. M. S., and Al-Azzawi, N. K., 2002. Progressive versus paroysmal Alpine folding in Sinjar anticline Northwestern Iraq. Iraqi Journal of Earth Science, 2 (2): 59-69.

[19] Sadooni, F. N., 1995. Petroleum prospects of upper Triassic carbonates in Northern Iraq, Journal Petroleum Geology, 18:171-190. Van der Pluijm, B. A., and Marshak, S., 2004.

[20] Al-Azzawi, N. K. B., 2003. The Structural Development of Fold Shape in the Foreland Belt of Iraq and Its Tectonic Implications, Unpublished Ph.D Thesis, College of Science, University of Mosul, Iraq, 208 p.

[21] Boulton, S. J., 2009. Record of Cenozoic Sedimentation from the Amano's Mountains, Southern Turkey: Implications for the Inception and Evolution of the Arabia–Eurasia Continental Collision, Sedimentary Geology, Vol. 216, pp. 29 - 47.

[22] Hardenberg, M. F., 2003. Tectonics and Sedimentation of Early Continental Collision in the Eastern Mediterranean (Northwest Syria), Unpub. Ph. D thesis, Univ. of Edinburgh, UK, 322 p.

[23] Brew, G., Litak, R., Barazangi,M.and Sawaf,T., Tectonic Evolution of Northeast Syria: Regional Implication and Hydrocarbon Prospects.GeoArabia,Vol.4,No.3.1999.Pp.289-318.

[24] Oil Exploration Company (O.E.C), 2009. Interpretation of Seismic Data of Kurra Chine Reflector in Alan Field. Oil Exploration Company (O.E.C), 2010.

[25] Aberystwyt. Awdal, A., Healy, d., and Alsop, G. I., 2016. Fracture patterns and petrophysical properties of carbonates undergoing regional folding: a case study from Kurdistan, N Iraq, Marine Petroleum Geology, 71: 149- 167.

[26] Burberry, C. M., 2015. The effect of basement fault reactivation on the Triassic-recent geology of Kurdistan, North of Iraq. Journal of petroleum geology, 38:37-58. CGG, 1974.

[27] Edilbi, A. N., Kolo K., Muhammed, N. R., Yasin, S. R., Mamaseni, W. J., and Akram, R., 2019. Source rock evaluation of shale interval of Kurra Chine Formation, Kurdistan Region-Iraq: An organic geochemical and basin modeling approach. Egyptian Journal of Petroleum, 8: 315-331.

[28] Fustic, M., Bennett, B., Huang, H., and Larter, S., 2012. Differential entrapment of charge oil-new insights on McMurray Formation oil trapping mechanisms. Marin and Petroleum Geology, 36: 50-69. Gussow, W. S., 1954.

[29] Differential entrapment of oil and gas – fundamental principles. American Association of Petroleum Geologists, 38: 816 – 853.

[30] Update the Structural map of Kurra Chine Reflector using seismic data. Numan, N. M. S., 1997. A plate tectonic scenario for the Phanerozoic succession in Iraq. Iraqi Geological Journal, 30 (2): 85-119.

[31] Dunnington, H. V., 2005. Generation, Migration, Accumulation, and Dissipation of Oil in Northern Iraq, GeoArabia, Vol. 10, No. 2, pp. 39 - 84.

[32] Lowell, J., D. Structural Styles in Petroleum Exploration, OGCI Publication, Tulsa, Fifth Printing -July,2003.459 P.

[33] Gilchrist, J.R., Cater, J.M.L., Ries, A.C., Tucker, J.W.,1988. Structural styles in the foothills and foreland areas of the Taurus Overthrust Belt, SE Turkey (Abstract: petroleum in thrust belts conference, Bordeaux).

[34] Lovelock, P.E.R., A review of tectonics of the northern Middle East Region. Geological Magazine, Vol.121, No.6., pp.589-598.