geoconvention
Calgary • Canada • June 20-22 2022

# Paleotopographic highs and incised valleys at the top of the Middle Ordovician Hawaz Formation, Murzuq Basin, SW Libya: New insights from high-resolution seismic attributes

*Aiman Ezzaroug[1], Osman Salad Hersi[2], Mohamed Buker[1], Fathi Hamoud[1] and Ahmad Alzaruk[3]*
*[1]Akakus Oil Operation, [2]University of Regina, [3]Schlumberger*

## Summary

The Middle Ordovician Hawaz Formation is a siliciclastic lithostratigraphic unit that occurs in the Murzuq Basin SW Libya. The formation contains excellent sandstone reservoirs preserved in paleohighs intervened by paleovalleys. The latter are filled by post-Hawaz, fine-grained (mudrock) deposits of the Melaz Shuqran Formation. Many oil fields extract resources from the Hawaz Formation and this study is focused on the nature of the upper surface of the formation in the H Field of Block NC-186. The Hawaz-Melez Shuqran contact is defined by a prominent erosional unconformity with significant topographic disparity represented by incised valleys and paleohighs. Previous studies proposed that faults are the main causes for the irregular topographic disparity of the contact surface. Although rejuvenated Precambrian faults do exist and disturb the lower Paleozoic stratigraphic succession, this study documents that the highs and the lows of the contact surface between Hawaz and Melaz Shuqran formations are due to glacially-induced erosional features. Thus, the observed features are incised valleys and positive erosional remnants. This understanding is facilitated by analyzing seismic attributes of Relative Acoustic Impedance (RAI), Seismic Variance (Edge Detection), Amplitude Contrast, Generalized Spectral Decomposition (GSD) and Root Mean Square (RMS) Current. The analyzed seismic data reveal several valleys that are elongated depressions that are rectilinear to slightly sinuous segments with U- and V-shaped morphologies and flanks sloping between 10 to 25 degrees. They do not show any apparent relationship as they are arranged as single channels. This study envisages that the valleys are filled by tight lithologies that generate discontinuity between the reservoir layers of the Hawaz Formation. Our approach of utilizing different seismic attributes demonstrates the importance of the 3D seismic attribute analysis to understand the relationship between subsurface structural features and hydrocarbon system. This understanding is deemed to be fundamental to the success of future development, localizing injector wells and production of oil from Hawaz Formation and other fields that may subscribe with morphological features and lithologic attributes comparable with the Hawaz-Melaz Shuqran stratigraphic relationship.

## Introduction

The Hawaz Formation is hydrocarbon-producing, Middle Ordovician siliciclastic rock that occurs in the Murzuq Basin, SW Libya (Fig. 1A). This basin preserves a number of reservoir rocks that produce oil from a significant number of fields (e.g., the fields shown in Fig. 1B). The Hawaz Formation is among prolific units in the basin. It has a maximum thickness of about 180 meters (Davidson et al., 2000) but post-Hawaz erosion has locally reduced it to zero (Hallett and Clark-Lowes, 2016). The formation consists of different lithologic units of deltaic to shallow marine sandstone that grade to fine sandstone with mudrock interbeds. The formation is confined by two

prominent unconformities with the underlying Cambrian sandstones of the Hasawnah Formation and overlying shales of the Melaz Shuqran Formation. The latter is unconformably overlain by glacio-fluvial to glacio-marine succession (Fig. 2). Late Ordovician Mamuniyat Formation lies unconformably over the Melaz Shuqran Formation. The Hawaz Formation is well-preserved in the H Field located in NC-186 Block (Fig. 1B). The H Field is located in the typical Hawaz Paleo-high structure with northwest-south east trend direction tilted gently to the south with a Four-way dip closure. The formation is lithostratigraphically divided to seven units (H1 to H7, from top to bottom). The upper H1 to H3 layers are very tight whereas the underlying H4 to H6 constitute porous sandstones that form the main pay zones of the formation. The clean reservoir intervals can be easily recognized and correlated from one well to another (Fig. 3). The lowest unit (H7) is tight and not considered as a reservoir. The reservoir units are laterally discontinuous (from one field to the next) and are commonly intervened by tight mudrocks of the Melaz Shuqran Formation. More thorough analysis on the lateral and vertical distributions of the reservoir and non-reservoir units is paramount for more rigorous exploitation of the oil in place.

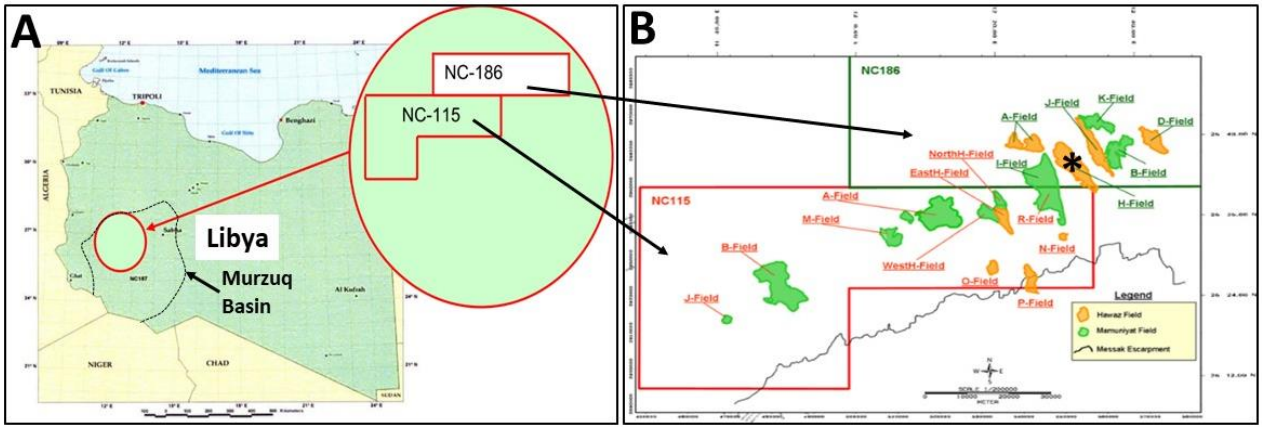
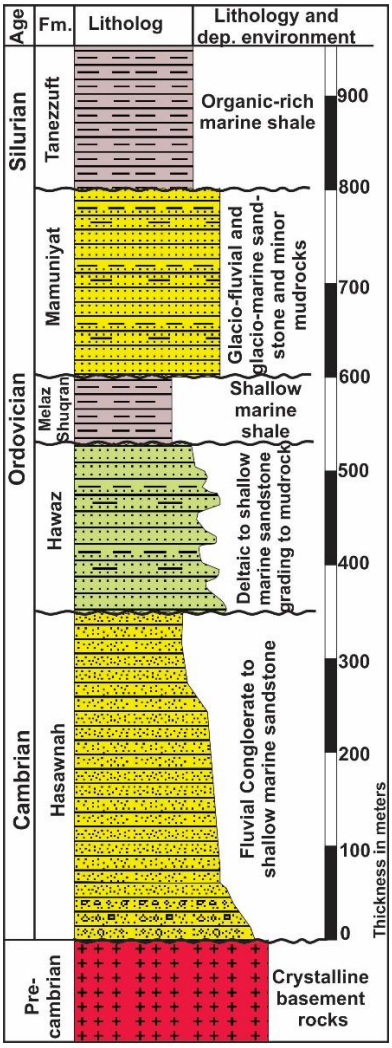



Fig. 1A – Location of the Murzuq Basin and approximate location of the block (NC-186) where H Field is located. 1B- Oil fields in the two blocks of NC-115 and NC-186. The asterisk shows the location of the H Field.

## The Top-Hawaz Formation erosional unconformity

The upper boundary of the Hawaz Formation is irregular with significant topographic variations defined by deep depressions that intervene between positive structures. The depressions are filled by the shale-dominated facies of the Melaz Shuqran Formation. The latter forms lateral permeability barrier which hinders potential lateral migration of the oil across the Hawaz reservoirs. Thus, the reservoirs are compartmentalized by the depression-filling Melaz Shuqran tight rocks. The irregular geomorphologic pattern of the upper unconformable surface of the Hawaz Formation has been interpreted as the result of tectonic disturbance that generated horsts and grabens (Castro et al., 2009), apparently comparable to basin-and-ridge topography. Unlike these previous endeavors, we recognize that the irregular unconformable surface of the Hawaz Formation resulted from deep differential erosional activities incurred by the Late Ordovician

glaciation. High resolution seismic attributes furnish new insights on the top-Hawaz erosional surface. It is the purpose of this study to analyze the seismic data and document the nature and causes of the irregular paleo-topographic surface at the top of the Hawaz Formation. We also provide the potential implication of our findings for the success of hydrocarbon production.



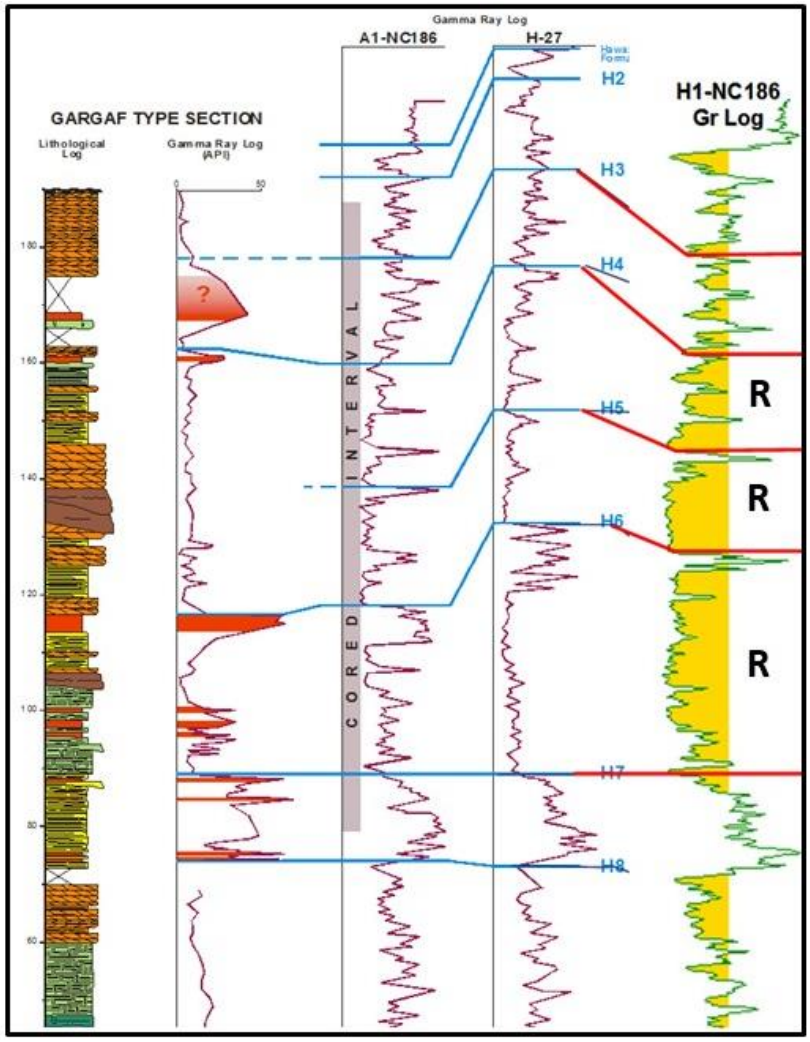




Fig. 2 (left) Generalized Precambrian to Silurian stratigraphy of the Murzuq Basin. The Hawaz Formation is Middle Ordovician stratigraphic unit confined by two erosional unconformities (redrawn from Davidson et al., 2000).

Fig.3 (right) Stratigraphic log of the Hawaz Formation from the type locality (Gargaf type section) and gamma ray logs from three wells. The different lithologic units are correlated and the prominent reservoir units (R) are shown

## Seismic attributes for paleotopographic and stratigraphic characterization

This study utilizes 3D Seismic poststack volume which has good coverage on the reservoir area and is also sensitive to ascertain lithofacies spatial distribution over the area of study (Pigott et al., 2013; Barnes, 2016). Thus, we employ Seismic attributes to characterize the reservoir. It is deemed that usage of the seismic attributes in the H field study can assist extraction of more information from conventional seismic data that can support the paleotopographic and paleo-environmental interpretations. The analyzed seismic data reveal several valleys that are elongated depressions. These valleys rectilinear to slightly sinuous segments (Fig. 4A) with U- and V-shaped morphologies (Fig. 4B) and flanks sloping between 10 and 25 degrees. They do not show any apparent relationship as they are arranged as single channels. The seismic attributes used for the morphological expression of the top-Hawaz unconformity and for the lithological discrimination among different rock unis include Relative Acoustic Impedance (RAI), Variance (Edge Detection), Amplitude Contrast, Spectral Decomposition and Root Mean Square (RMS) Current (Koson et al., 2014; Torrado et al., 2013). These attributes allowed detection of the paleohighs and valleys that define the top of the Hawaz Formation, as well as the different lithologic properties of the valley-filling non-reservoir units from the sandstone reservoirs of the Hawaz Formation. Spectral decomposition attribute was used to determine the thickness (depth) of the valley-filling glacial Sediments by using frequencies from 10 Hz to 70 Hz. The analysis of the seismic attributes clearly display glacial tunnel valleys in the seismic horizon slice very clearly (Fig. 4C and Fig. 4D).

## Discussion

The valleys at the top of the Hawaz Formation are interpreted to have formed through the subglacial loading and incision of an underlying, mud-dominated, ice distal succession deposited during glacial advance. The architectural characterization of the Middle Ordovician valleys has important implications for petroleum exploration because it allows model the distribution of heterogeneities within the sand fairway. The behavior of the wells drilled near the valley indicate that these valleys are stratigraphic barrier and influence oil field production patterns. This is considered to be the reason why it was difficult to model in previous studies of reservoir simulations. This approach is significantly different from previous studies (Castro et al. 2009) that indicated a set of faults limiting the Palo-highs to the east and small slip fault located in the northern area of H field. In our study, the inferred seismic attributes support the interpretation that no faults appear at Hawaz level. This study also envisages that the valleys are filled by tight lithologies that made discontinuities between the reservoir layers of the Hawaz Formation. Our approach of utilizing different seismic attributes demonstrates the importance of the 3D seismic attribute analysis to understand the relationship between subsurface structural features and hydrocarbon system which are fundamental to the success of future development, localizing injector wells and production of oil from Hawaz Formation in Murzuq Basin, Libya.

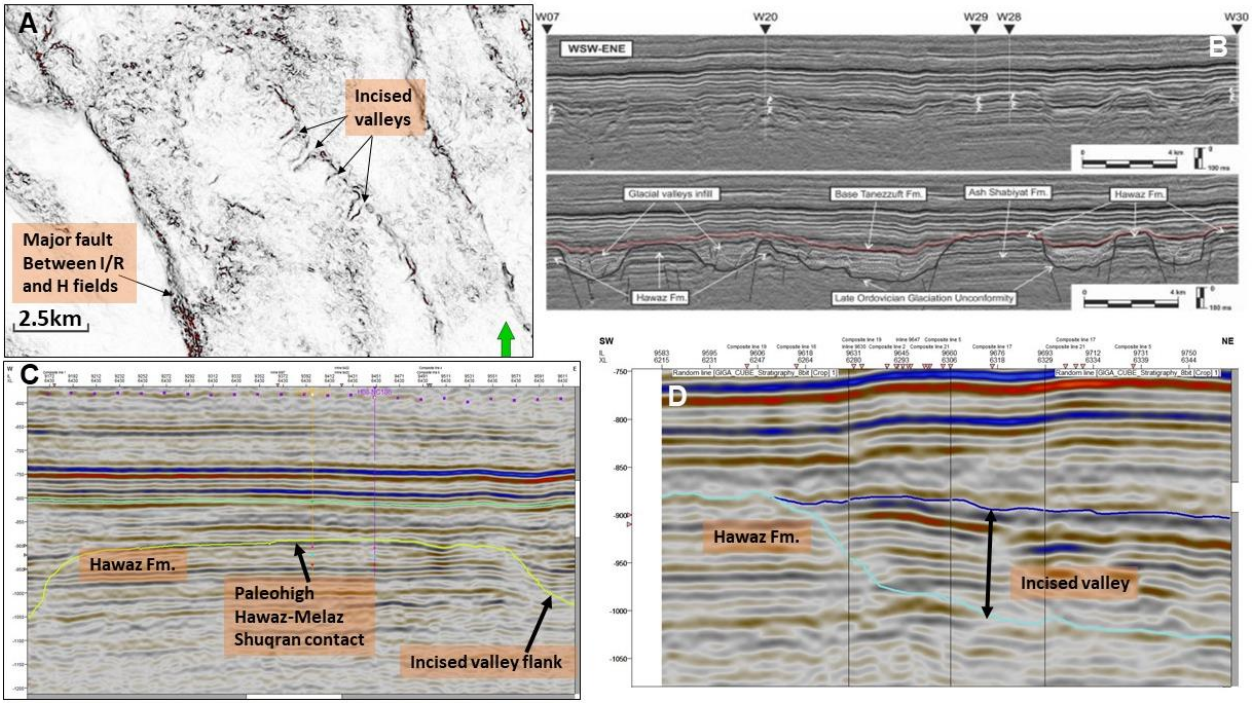



Fig. 4A shows map depicting the variance attribute of the seismic data. It clearly shows the incised valleys at Hawaz Formation Level. 4B- Uninterpreted (upper) and interpreted (lower) seismic profile showing the irregular paleotopographic surface at the top of the Hawaz Formation. 4C and 4D show more detailed seismic profiles demonstrating the paleohigh and incised valley attributes of the upper surface of the Hawaz Formation.

## Acknowledgements

The authors express their gratitude to the Akakus Oil Operations and Schlumberger-Libya for allowing the usage of the seismic data for this study.

### References

Barnes, E. 2016. Handbook of Poststack seismic attributes. Society of Exploration Geophysicists, 268 pp.

Castro, A.A., Fanjul, J.P., and Gaaim, A.2009. Field development strategy applied to a North African field using reservoir simulation through an integrated asset team work. Society of Petroleum Engineering, SPE-120761, 23 pp.

Davidson, L., Beswetherick, S., Craig, J., Eales, M., Fisher, A., Himmali, A., Jho, J., Mejrab, B., and Smart, J. 2000. The structure, stratigraphy and petroleum geology of the Murzuq Basin, southwest Libya. In: Geological Exploration in Murzuq Basin edited by Sola, M.A., and Worsley, D. Elsevier Science B.V., 295-320.

Hellet, D., and Clark-Lowes, D. 2016. Petroleum geology of Libya. Elsevier. 391 pp.

Koson, S., Chenrai, P., and Choowong, M. 2014. Seismic attributes and their applications in seismic geomorphology. Bulletin of Earth Sciences of Thailand, 6: 1-9.

Pigott, J.D., Kang, M., and Han, H. 2013. First order seismic attributes for clastic seismic facies interpretation: Examples from the East China Sea. Journal of Asian Earth Sciences, 66: 34-54.

Torrado, L., Mann, P., and Bhattacharya, J. 2013. Application of seismic attributes and spectral decomposition for reservoir characterization of a complex fluvial system: Case study of the Carbonera Formation, Llanos foreland basin, Colombia. Geophysics 79(5): B221-B230. DOI: 10.1190/GEO2013-0429.1