[PS]Characterization and Modeling Study of Karst Networks in the Ordovician Carbonate Reservoirs, Tarim Basin*

Duoming Zheng[1], Lijuan Zhang[1], and Feng Shen[2]

Search and Discovery Article #40795 (2011)
Posted August 29, 2011

* Adapted from a poster presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

[1]PetroChina, Wulumuqi, China (zhengdm-tlm@petrochina.com.cn)
[2]GeoReservoirResearch, Stafford, TX (fshen@georeservoir.com)

Abstract

Ordovician-age karst and collapse disturbances were observed from drilling data and seismic interpretation in a Tarim oil field. The seismic evidence of karst features is characterized, with 3D seismic data processing of structure-oriented and fault-enhancement filter, from which volumetric seismic geometric attributes are computed. The reservoir architecture and karst features, such as channels, caves, circular features and fractures/conduits, are detected with dip, curvature and amplitude gradient volumes. The quantified geometric attributes with seismic facies analysis allow precise location of the main karst features (paleocaves and fractures) in 3D. The geological model was built keeping the same resolution as in the seismic cube; thus, this allows karst features in the geological model to be precisely modeled. The connectivity between the karst features is identified; this is the basis for understanding the karst network geometries in the collapsed paleocave systems. The karst network geometries are associated with channeling system and are located at different reservoir depths.

Log electrofacies analysis and calibration with core data and borehole imaging logs lead to the definition of reservoir rock types at wells. The sequential indicator simulation is used to generate 3D reservoir rock type model constrained with rock type logs and seismic impedances. The reservoir effective properties in the geological model are then modeled by integrating well data, seismic impedances and the reservoir rock type model. Karst network geometries are subsequently incorporated into rock type and effective property models. The 3D organization of karst networks is assessed from the integration of model properties and reservoir dynamic data. With the case study, we demonstrate the application of our new integrated approach to the characterization and modeling of karst networks in the Ordovician carbonate reservoirs. Our results show that quantitative integrated characterization of karst networks and effective properties can provide a new understanding of carbonate reservoir modeling and underlying geological controls.

Selected References

Hamid, A., and Sadeghzadeh, F., 2009, Mapping karst diagenetic networks in carbonate reservoir using seismicindicators and well data: SPE 120930, EUROPEC/EAGE Conference and Exhibition, 8-11 June 2009, Amsterdam, The Netherlands.

Janson, X., H. Zeng, R.G. Loucks, Q. Wang, C. Wang, Shunxin Li, Tao Yang, Yiping Xia, and Ligui Xu, 2010, An ultra-deep paleokarst system in the Ordovician, North-Central Tarim Basin, China: High-resolution 3D seismic interpretation: 80th Annual International Meeting, Society Exploration Geophysicists, Expanded Abstracts.

Kosters, M., P.F. Hague, R.A. Hofmann, and B.L. Hughes, 2008, Integrated modeling of karstification of a Central Luconia Field, Sarawak: IPTC12327, International Petroleum Technology Conference, 3-5 December 2008, Kuala Lumpur, Malaysia.

Loucks, R.G., 1999, Paleocave carbonate reservoirs: origins, burial depth modifications, spatial complexity, and reservoir implications: AAPG Bulletin, v. 83, p.1795–1834.

Loucks, R.G., P.K. Mescher, and G.A. McMechan, 2004, Three-dimensional architecture of a coalesced, collapsed paleocave system in the Lower Ordovician Ellenburger Group, central Texas: AAPG Bulletin, v. 88, p. 545–564.

Marfurt, K., 2006, Robust estimates of 3D reflector dip and azimuth: Geophysics, v. 71/4, P29–P40.

Palmer, A.N., 1991, Origin and morphology of limestone caves: Geological Society of America Bulletin, v. 103, p. 1–21.

Characterization and Modeling Study of Karst Networks in the Ordovician Carbonate Reservoirs, Tarim Basin

Duoming Zheng[1], Lijuan Zhang[1] and Feng Shen[2]

1

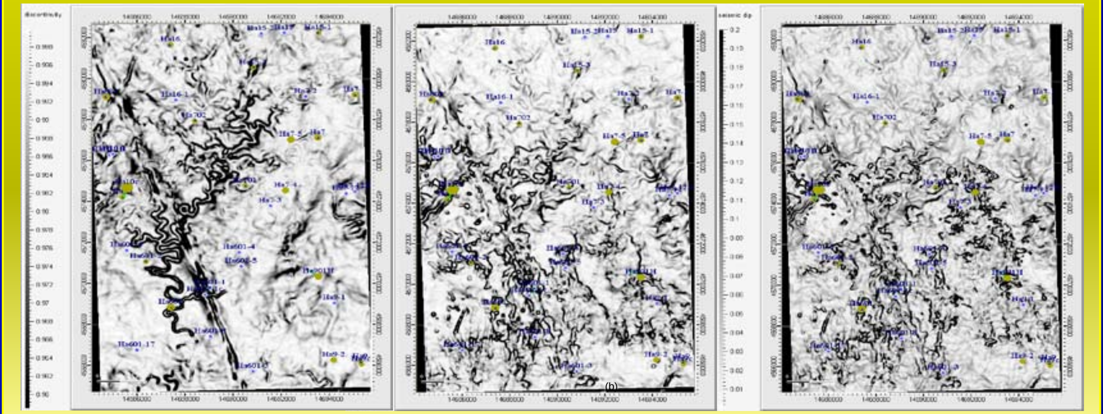
Abstract

Ordovician-age karst and collapse disturbances were observed from drilling data and seismic interpretation in a Tarim oil field. The seismic evidence of karst features is characterized, with 3D seismic data processing of structure-oriented and fault-enhancement filter, from which volumetric seismic geometric attributes are computed. The reservoir architecture and karst features, such as channels, caves, circular features and fractures/conduits, are detected with dip, curvature and amplitude gradient volumes. The quantified geometric attributes with seismic facies analysis allow precise location of the main karst features (paleocaves and fractures) in 3D. The geological model was built keeping the same resolution as in the seismic cube; thus this allows karst features in the geological model to be precisely modeled. The connectivity between the karst features is identified; this is the basis fpr understanding the karst network geometries in the collapsed paleocave systems. The karst network geometries are associated with channeling system and are located at different reservoir depths.

Log electrofacies analysis and calibration with core data and borehole imaging logs lead to the definition of reservoir rock types at wells. The sequential indicator simulation is used to generate 3D reservoir rock type model constrained with rock type logs and seismic impedances. The reservoir effective properties in the geological model are then modeled by integrating well data, seismic impedances and the reservoir rock type model. Karst network geometries are subsequently incorporated into rock type and effective property models. The 3D organization of karst networks is assessed from the integration of model properties and reservoir dynamic data. With the case study, we demonstrate the application of our new integrated approach to the characterization and modeling of karst networks in the Ordovician carbonate reservoirs. Our results show that quantitative integrated characterization of karst networks and effective properties can provide a new understanding of carbonate reservoir modeling and underlying geological controls.

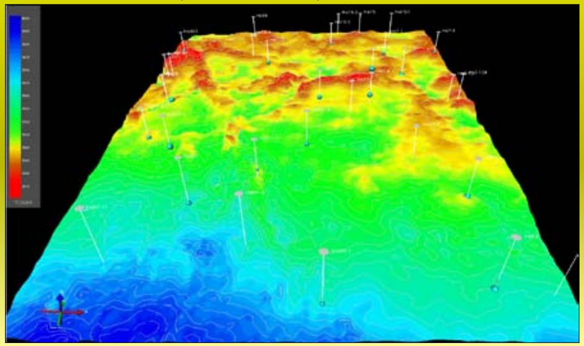
4

Paleokarst Channels: a major component of the paleocave system. The imaged paleokarst channels can be observed with seismic discontinuity and dip attributes and are well developed in the southern part of the project area.



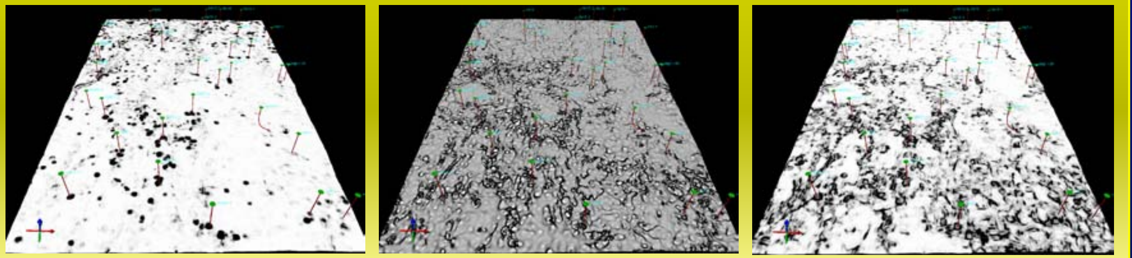
2

Time depth structure map and well locations



5

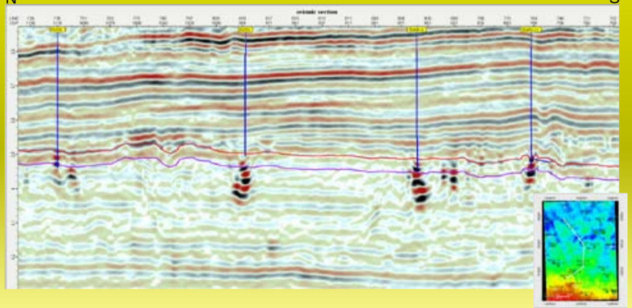
Collapsed Paleocaves: observed with seismic bright strings which can be described with amplitude gradient attribute. Circular black spots highlight individual collapsed caves, occurring as dark circular faults as well as elliptically-shaped faults.



3

Seismic data

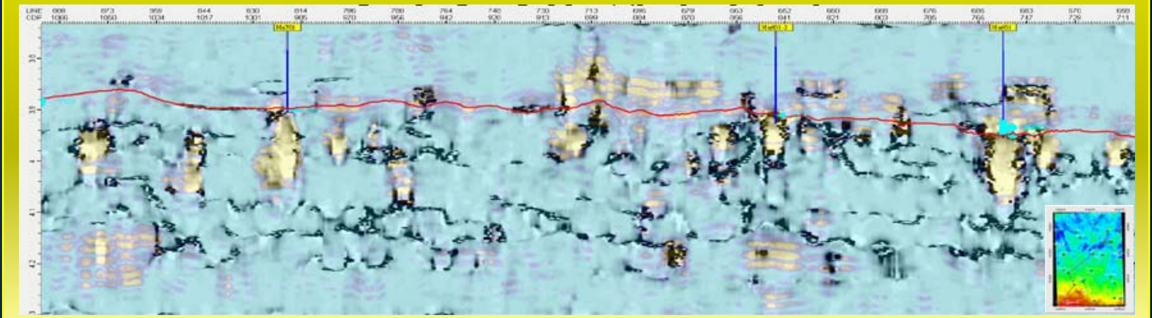
N S



6

Collapsed Paleocaves versus Vertical Faults

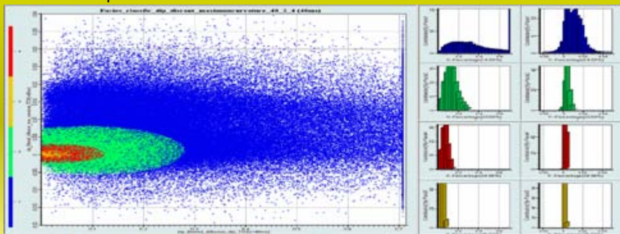
N S



Seismic Characterization Of Paleocave Systems

7

Fracture Seismic Facies Analysis: Cross plot between seismic dip and maximum curvature attributes to rank fracture scales.

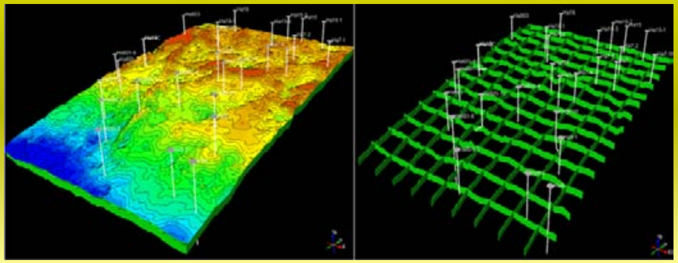


Ranked Fracture	I	II	III	matrix
Maximum curvature	≥0.008	0.004-0.008	0.004-0.002	≤0.002

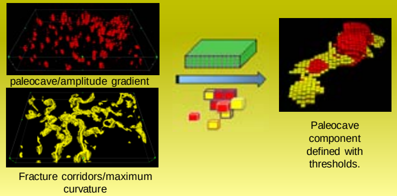
11

Conceptual Model of a Paleocave System

Application to the Geocellular Model

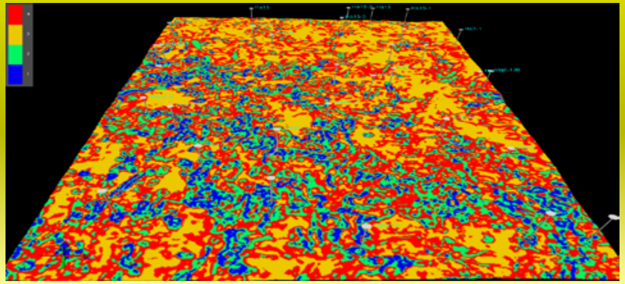


- Connectivity analysis of the paleocave systems.
- Quantifying the spatial geometry of paleocave components.
- Highlight the main karst features and their impacts on the reservoir properties.



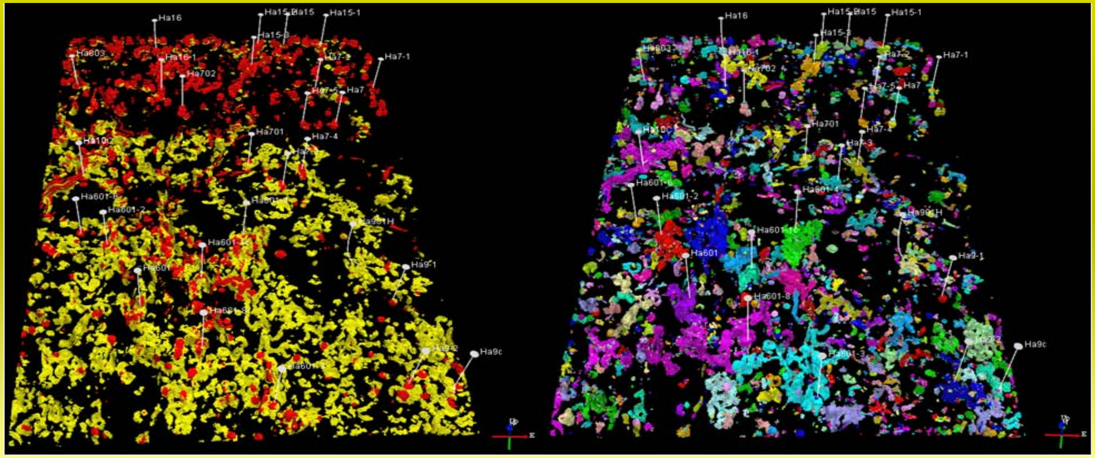
8

Fracture seismic facies



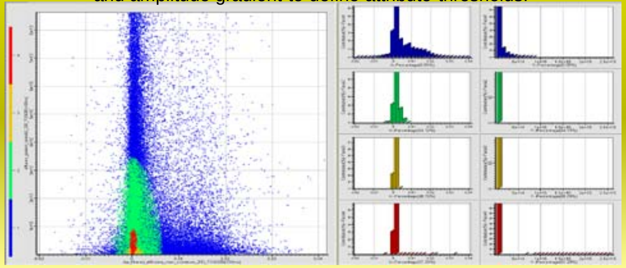
12

Application to Geocellular Model: Karst features and paleocave components



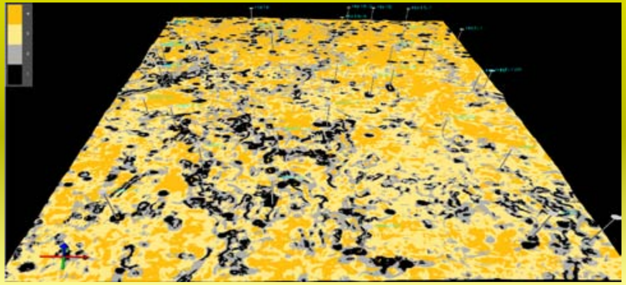
9

Paleocave Seismic Facies Analysis: Cross plot between maximum curvature and amplitude gradient to define attribute thresholds.

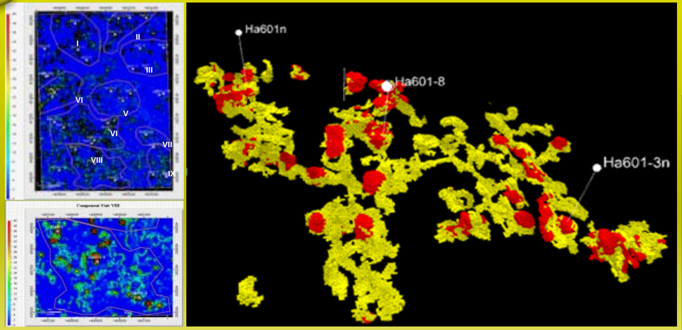


10

Paleocave seismic facies

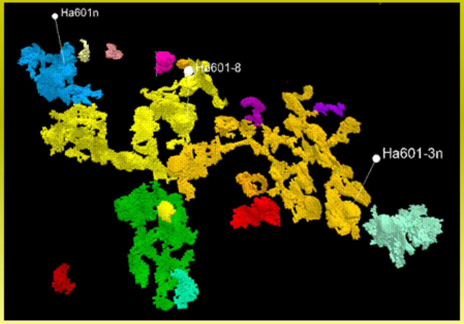


13



Application to Geocellular Model: map of accumulated paleocave thickness (left), karst features (fracture corridors (yellow) and caves (red)) in the selected local unit (right).

Application to Geocellular Model: paleocave components in the selected local unit



Characterization and Modeling Study of Karst Networks in the Ordovician Carbonate Reservoirs, Tarim Basin

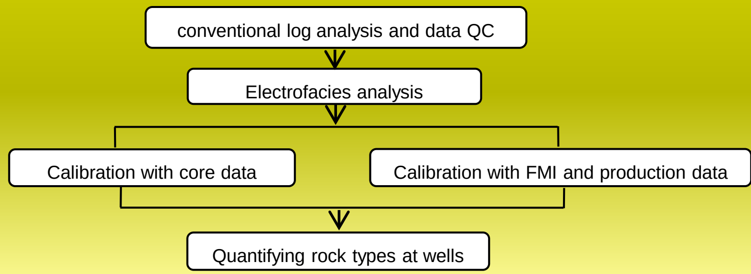
Duoming Zheng[1], Lijuan Zhang[1] and Feng Shen[2]

14

Determination of Rock Types at wells

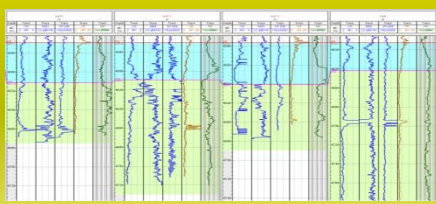
The analysis relies on the integration of the logs, the cores and the production data.

- Determining electrofacies
- Calibrating with both borehole imaging logs and dynamic data

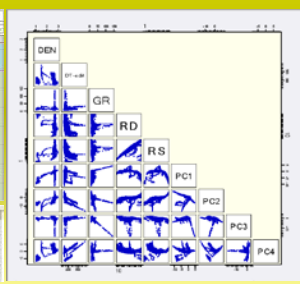


15

Select key wells in the project area by using conventional logs: principal components analysis (PCA) is used to summarize the data effectively and to reduce the dimensionality of the data. Results can be displayed with scatterplot of selected logs and principal components.

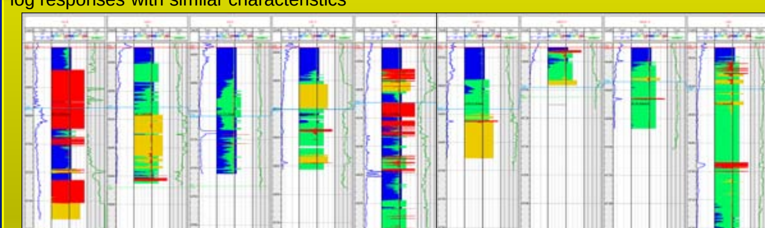


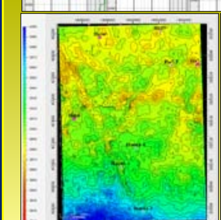
	PC1	PC2	PC3	PC4	PC5
DEN	0.4227	0.5500	-0.0694	0.5201	-0.4835
DT-edit	-0.1909	-0.6282	0.1930	0.7127	-0.1540
GR	0.1999	-0.2985	-0.9321	0.0496	0.0127
RD	-0.6852	0.0943	-0.1956	-0.1917	-0.6682
RS	-0.5248	0.4417	-0.2256	0.4274	0.5439
Eigenvalue	24035.2852	19740.4473	11503.6104	7090.0833	1264.7739
Contribution(%)	37.7705	31.0214	18.0775	11.1431	1.9875
Cumulative Contribution(%)	37.7705	68.7919	86.8694	98.0125	100.0000

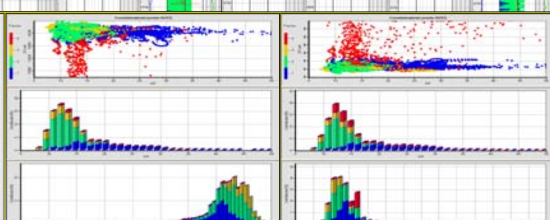


16

Defining electrofacies based on the classification analysis: identifying clusters of well log responses with similar characteristics

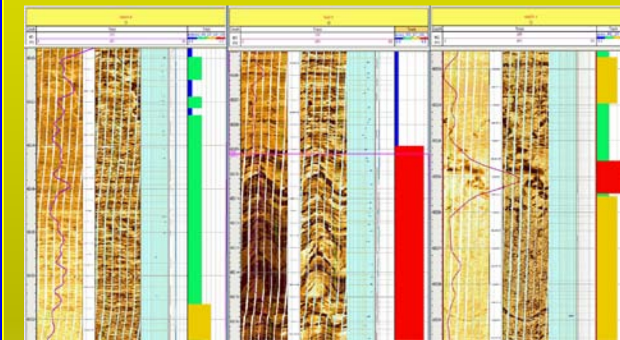


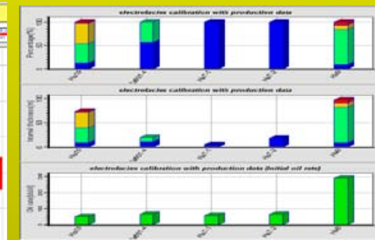




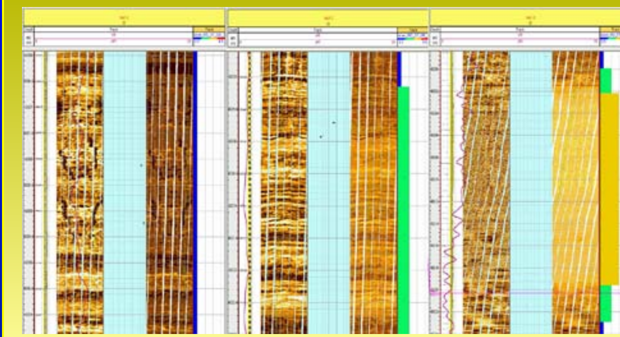
17

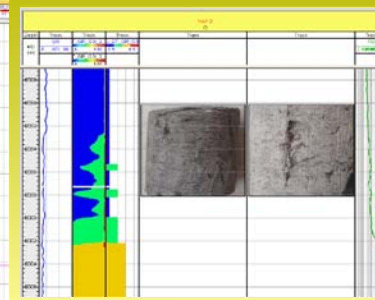
Determination of Rock Types at wells: calibrating electrofacies with both borehole imaging logs and dynamic data (initial production rate).





Determination of Rock Types at wells: Fractures impacts need to be considered when dynamic data is used to calibrate electrofacies.



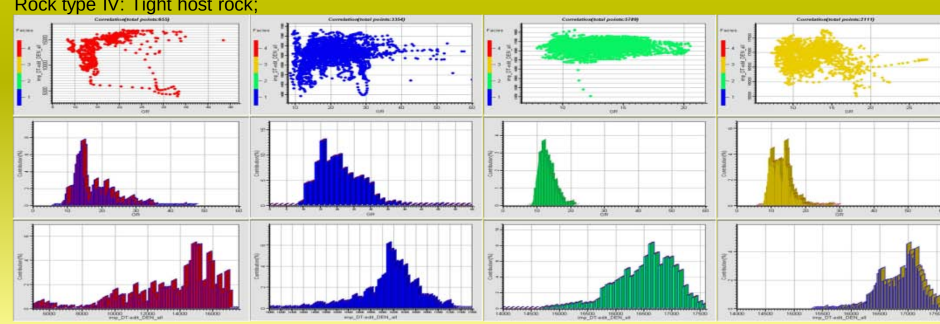


18

Determination of Rock Types at wells

12 wells have conventional logs, which include generally CAL, GR, DENS, DT and resistivity logs (RD, RS). RD, GR and DT are used in the electrofacies analysis. The electrofacies have been grouped into 4 rock-types on the basis of the log response and corresponding facies observed on imaging logs.

Rock type I: Potentially fractured corridors with open caves;
Rock type II: Potentially fractured zones with open caves;
Rock type III: Partially open fractures and vugs;
Rock type IV: Tight host rock;

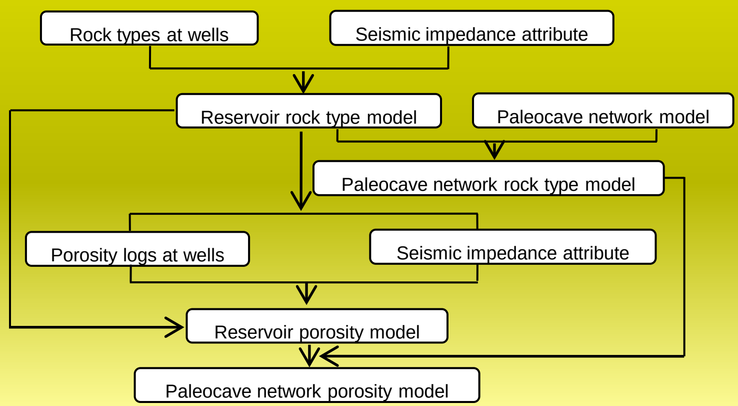


Rock type I | Rock type II | Rock type III | Rock type IV

Quantifying Reservoir Properties in the Paleocave Systems

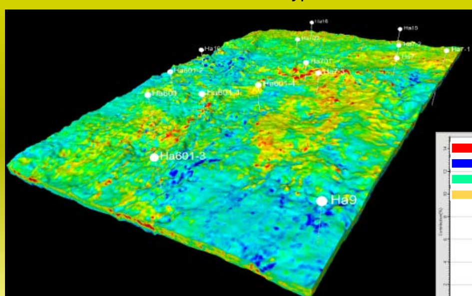
19

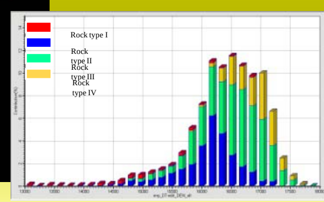
Quantifying Reservoir Properties in the Paleocave Systems



20

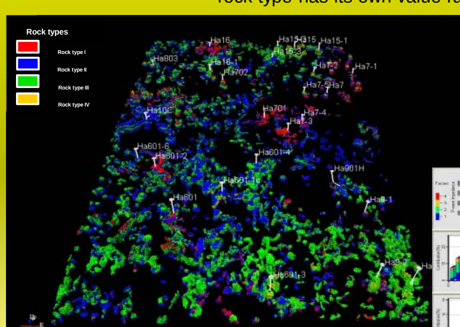
Impedance volume is a constraint for the rock type modeling. Each rock type has its own value range.

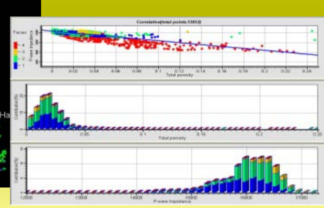




21

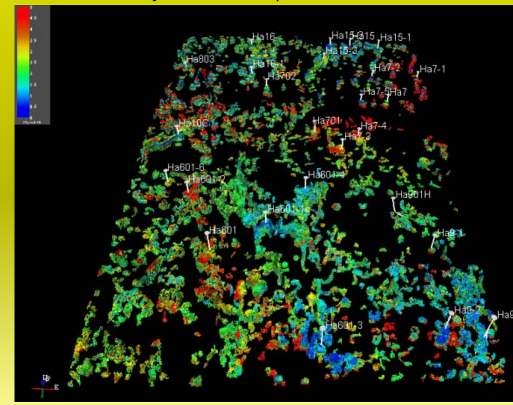
Rock type model is used to constrain the porosity modeling for the paleocave networks. Each rock type has its own value range.



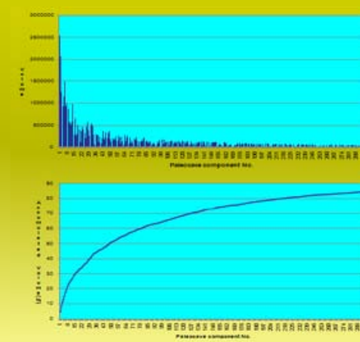


22

Porosity model of the paleocave networks.

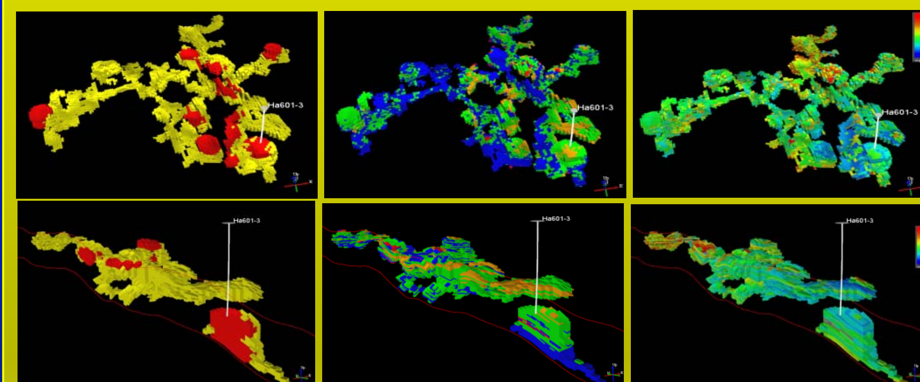


Statistics of the biggest 300 components in the paleocave networks.

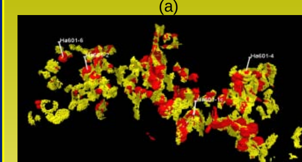


23

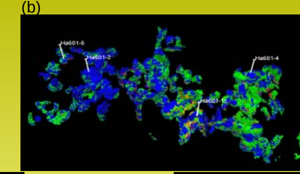
A paleocave component at well 601-3: (a) Karst feature model (cave and fracture corridors) ; (b) rock type model and (c) porosity model.



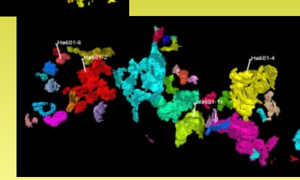
(a) (b) (c)



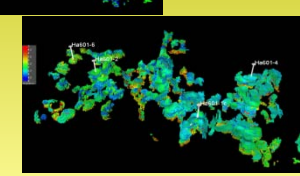
Rock type model in the unit 6



Karst feature model (cave and fracture corridors) in the unit 6.



Paleocave components in the unit 6.



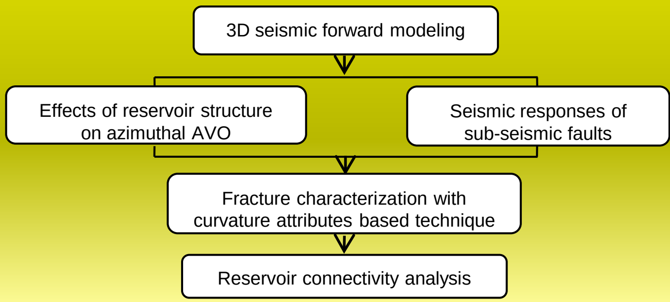
porosity model in the unit 6

Characterization and Modeling Study of Karst Networks in the Ordovician Carbonate Reservoirs, Tarim Basin

Duoming Zheng[1], Lijuan Zhang[1] and Feng Shen[2]

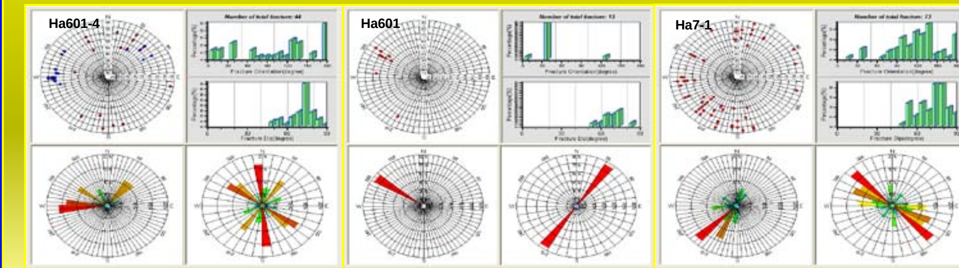
24

Fracture Characterization and Reservoir Connectivity Analysis



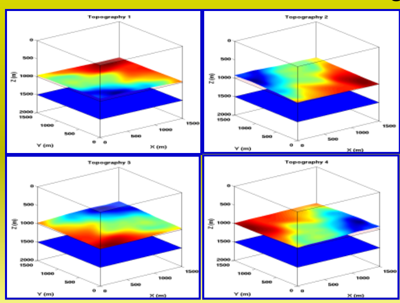
28

Fracture statistics at available wells

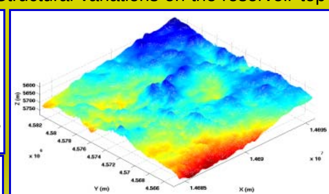


25

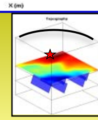
Structure models



Structural variations on the reservoir top

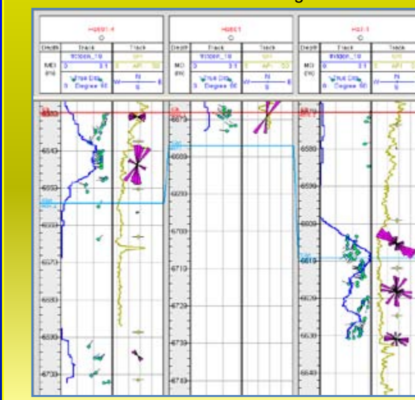


- Vertical fractures
- 25 Hz Ricker wavelet
- Offset = 1500m
- Azimuth: 0º – 90º



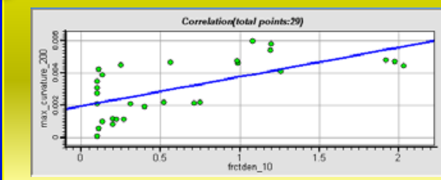
29

Fracture distributions along wellbore



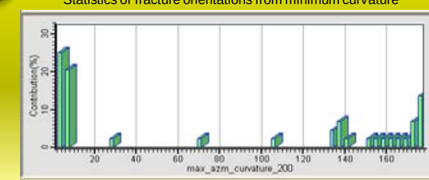
30

Correlation between fracture density and maximum curvature

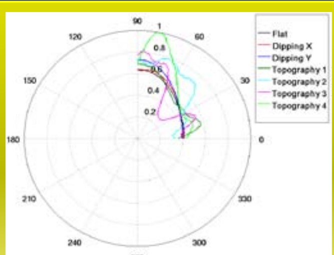


31

Statistics of fracture orientations from minimum curvature

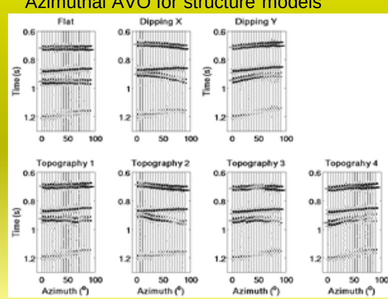


26



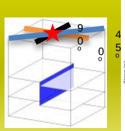
Local structural variations on the reservoir top will cause azimuthal amplitude scattering and distortion.

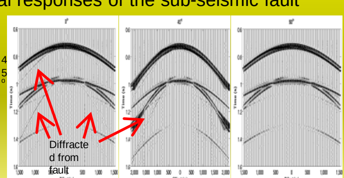
Azimuthal AVO for structure models



27

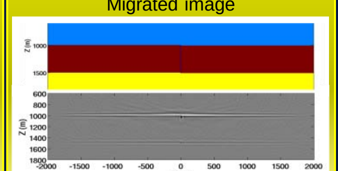
Azimuthal responses of the sub-seismic fault





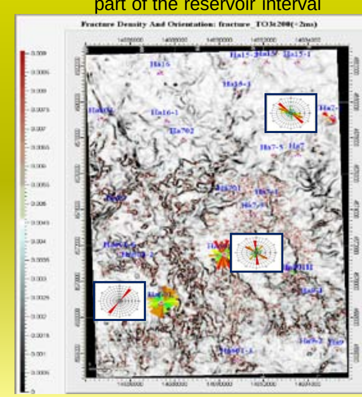
Z-component

Migrated image



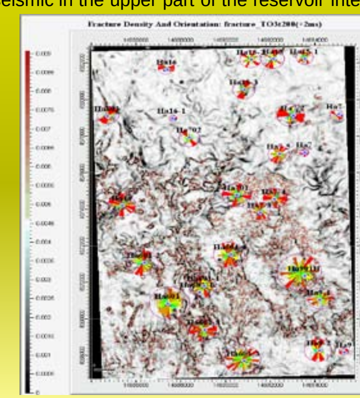
32

Comparison of fracture distributions between seismic prediction and imaging log interpretation in the upper part of the reservoir interval



33

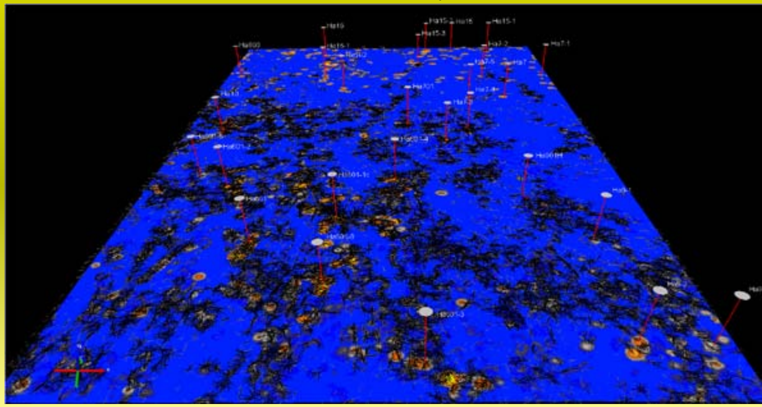
Fracture distributions at well locations predicted from seismic in the upper part of the reservoir interval



Fracture Characterization and Reservoir Connectivity Analysis

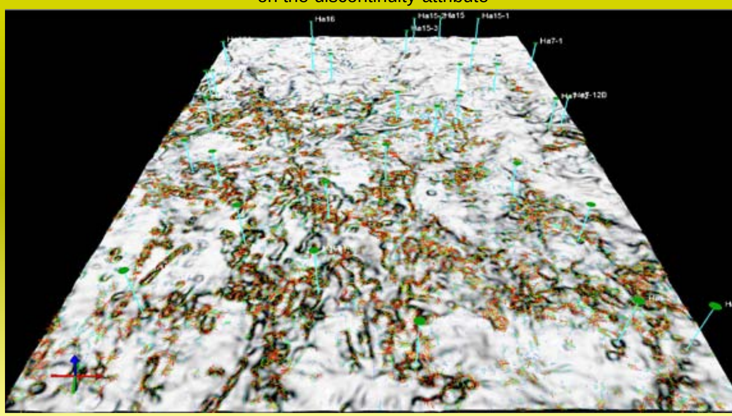
34

Fracture distributions at the depth of 10 ms overlayi
on the accumulated thickness of paleocave networks



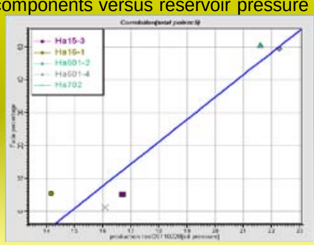
35

Fracture distributions at the depth of 10 ms overlay
on the discontinuity attribute

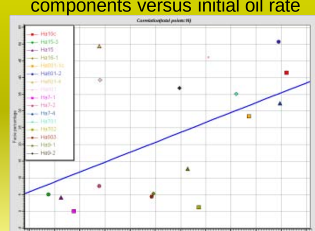


36

Fracture percentage in the paleocave components versus reservoir pressure

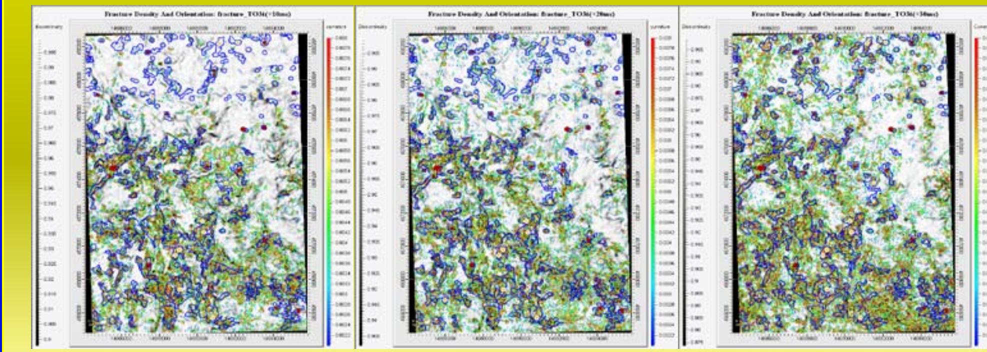


Fracture percentage in the paleocave components versus initial oil rate



37

Boundaries of paleocave networks overlay on the fracture distributions
at the depth of 10 ms (a), 20 ms (b) and 30 ms (c)



(a) (b) (c)

38

Discussion and Conclusions

- Integrating geophysical, geological and reservoir dynamic data helps to provide a reliable characterization of paleocave systems both on scales of the karst features and their distributions in 3D.
- Multi-attribute seismic facies analysis allows quantifying karst features (caves and fracture corridors) in 3D which were validated with drilling data.
- The understanding of connectivity between the karst features was essential to understanding the geology of the paleocave systems. The paleocave systems located in the south and north of the project area are different not only in composition but also in spatial connectivity.
- The comparison of single and complex paleocave components allowed explanation of the differences in production performance. Fractures show important impacts on reservoir dynamic properties.
- The 3D geological model was focused on identified paleocave systems. There are still large uncertainties on reservoir properties due to poor constraints in such reservoirs. The capability to model all types of karst features will constitute an important challenge for the next step.

39

Acknowledgements

This study was a team effort. We sincerely thank the PetroChina and GeoReservoir Research "Tarim project team" for their hard work and many discussions of all aspects of the paleocave reservoir geology.

We thank PetroChina for support of our studies and permission to publish this poster.

[1]PetroChina, Wulumuqi, China
[2]GeoReservoir Research, Stafford, TX