EGI Energy & Geoscience Institute
AT THE UNIVERSITY OF UTAH

Since 1972

IN DEVELOPMENT

Heterogeneity of Fine-grained Unconventional Reservoirs

Principal Investigator:

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Investment per Sponsor
$68K (USD)

Duration
12 months

Project I 01287

VALUE

- Conceptual models of depositional patterns, architecture, and regional to nano-scale qualitative and quantitative characterization approaches and heterogenous features of extent, thickness, geomorphology, stratigraphic occurrence, lithofacies, facies architecture, geochemistry, mineralogy, structure, natural fractures, porosity, permeability, pores and pore structure, pressure, rock mechanical properties, and other properties of representative fine-grained tight to shale reservoirs;
- Thorough understanding of the relationship between geologic variables and their heterogeneity, reservoir quality, hydrocarbon accumulation and production of unconventional plays;
- Predictable models of heterogeneity to help companies understand the guidelines of exploration and production for marine, transitional, and lacustrine settings in different tectonic settings in the U.S., Canada, Argentina, and China at multiple scales;
- Access to an atlas of typical fine-grained reservoirs and interdisciplinary database.

KEY DELIVERABLES

1. Variation features of facies, electrofacies, geochemistry, mineralogy, petrophysics, pore system, natural fracture, geomechanical property, and other properties of fine-grained unconventional plays within sequence stratigraphic framework in marine, transitional, and lacustrine settings in different tectonic settings in the U.S., Canada, Argentina, and China;
2. Statistical and artificial neutral network methods, 3-D geostatistical modeling, and case studies of qualitative and quantitative characterization of reservoir heterogeneity;
3. Impacts of heterogeneity of reservoir properties on reservoir quality, hydrocarbon accumulation, and production;
4. Database of digital results (photos of outcrops, cores, petrology, facies, porosity, permeability, and other properties) of representative unconventional plays;
5. Meeting presentations and project report (electronic and hard copy).

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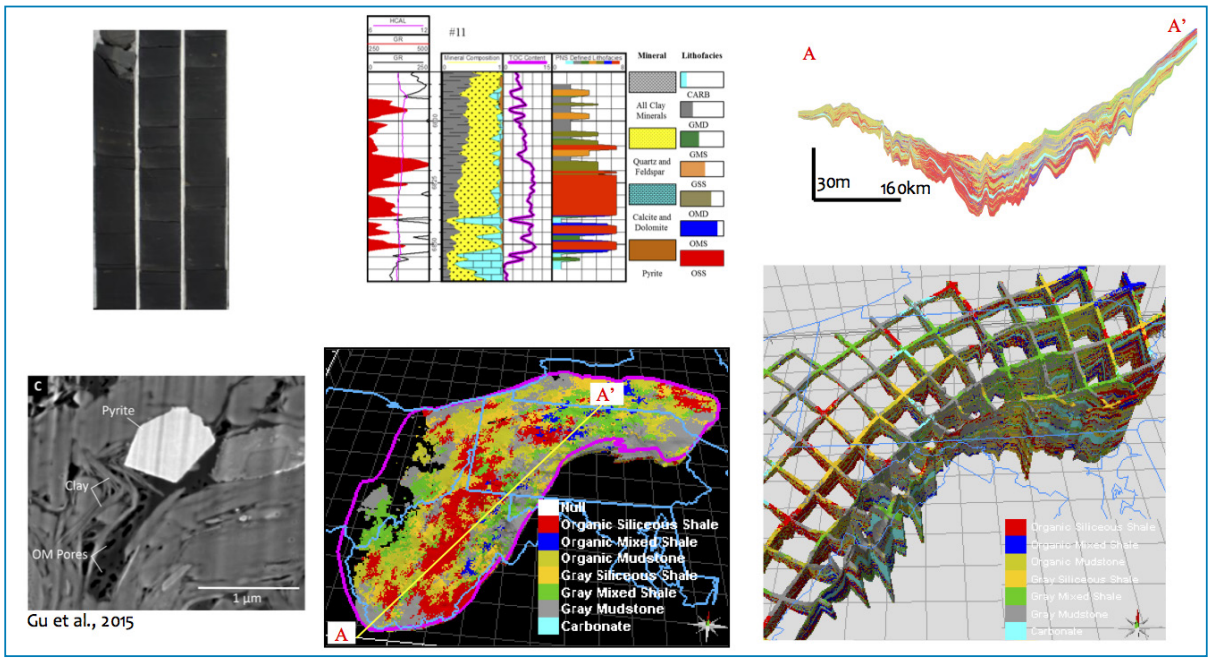

Image courtesy of project team member Dr. Guochang Wang

Phase 1 will focus on 4–5 fine-grained unconventional plays listed in Table 1 based on sponsors' selections. Devonian Marcellus shale in the U.S. and Silurian marine Longmaxi shale in China are suggested for inclusion in Phase 1 based on significant accumulation of geologic and production data through recent research. Phase 2 will extend to additional representative fine-grained unconventional reservoirs worldwide based on sponsors' feedback. More detailed studies will be further conducted and a more robust database will be built in Phase 2.

Rationale & Methods

The fine-grained depositional systems deposited in lacustrine, transitional and marine settings include the organic-lean sandy turbidite systems and fine-grained sedimentary rocks that hosts organic-rich source rock and/or are associated with organic-rich deposits (Figure 1). The fine-grained turbidite systems have been studied well in terms of their distribution, geometry, architecture, heterogeneity, and reservoir quality variation in the last decades due to extensive exploration and development of deepwater turbidite reservoirs throughout the world and numerous analogs to outcrops. For the latter fine-grained systems deposited in lacustrine, transitional, and marine settings, organic-rich shales are important source rocks and seals in petroleum systems and are increasingly important as unconventional shale plays. The fine-grained organic-lean carbonate and siltstone associated with organic-rich shale are currently important unconventional tight oil/gas plays. These fine-grained unconventional plays have revolutionized the energy world and will continue to be the E&P's focus worldwide. Despite their apparent homogeneity and similar gross petrologic similarities due to fine-grain nature, fine-grained reservoirs are actually highly heterogeneous when examined in detail and in fine-scale in terms of variations in reservoir facies, stratigraphic architecture, and reservoir and fluid properties in space. The successful productions in fine-grained unconventional systems are from various lithofacies (e.g., chalk, calcareous shale, siliceous shale) derived from various depositional processes in marine, lacustrine, and transitional settings, and the productions are related, directly or indirectly, to the geology of different fine-grained systems.

Table 1: Key Basins and Fine-grained Unconventional Plays

Country	Basin	Fine-grained Unconventional Plays
United States	Appalachian Basin	Devonian Marcellus shale and Ordovician Utica shale, marine foreland setting
	Williston Basin	Devonian to Mississippian Bakken tight oil play, marine cratonic setting
	Permian Basin	Devonian Woodford shale, Mississippian Barnet shale, Pennsylvanian Atoka shale, Permian Wolfberry tight play, marine setting
	Gulf Coast Basins	Cretaceous Eagle Ford, marine foreland setting
	Denver	Cretaceous Niobrara tight/shale play, marine foreland setting
	Uinta	Tertiary Green River tight/shale oil plays, lacustrine rift setting
Canada	Western Canadian Basin	Lower Triassic Montney shale play, marginal marine ramp setting
	Western Canadian Basin	Upper Devonian Duvernay mixed tight siliciclasstic and carbonate play, marine Cratonic setting
Argentina	Neuquén Basin	Upper Jurassic–Lower Cretaceous Vaca Muerta tight oil and shale gas play, marine foreland setting
China	Yangtze Platform including Sichuan Basin in the Upper Yangtze	Lower Silurian shale gas play, marine foreland setting
	Ordos Basin	Upper Triassic tight oil and shale gas plays, lacustrine foreland
	Bohai Bay Basin, Ordos Basin and other areas in North China	Carboniferous to Permian transitional shale gas play and Lower Tertiary tight and shale plays in lacustrine rift setting

The postdepositional alterations, e.g., diagenesis and tectonic deformation, further compound the heterogeneity inherited from assemblages of various facies. Even the organic-rich shales can contain impermeable facies and very tight reservoirs, porosity and permeability actually vary significantly (several orders of magnitude) between different plays and within one play. The basin-scale to nano-scale variations in lithofacies, fabrics, mineralogy, petrophysics, geochemistry, and mechanical property between different fine-grained systems, and within one system, have been observed and tested (Figure 1), which may indicate that diverse tectonic settings and depositional processes determine the variations in geometry, facies, architecture, porosity, and permeability, which leads to the heterogeneity. The vertical and lateral heterogeneity of facies, rock fabrics, mineralogy, geochemistry, petrophysics, etc., vary from macro-scale to nano-scale and the upscaling from small scale to large scale has been

challenging due to poor understanding of heterogeneity. These geologic heterogeneities also directly and indirectly affect the porosity, permeability, hydrocarbon accumulation, production, and residual hydrocarbon distribution.

Characterizing the reservoir variations and geologic heterogeneities has been found to play a key role in the reservoir assessment, drilling, completion, sweet spot prediction, production performance, sweep efficiency, and recovery factor. But the heterogeneity of fine-grained unconventional reservoirs have not been systematically studied due to a lack of good methods for characterizing fine-grained unconventional reservoirs, limited understanding caused by short exploration and production history, and sparse measurements of the reservoir properties by individual institutes and researchers. So far, academics and industry are still striving to understand the science of the heterogenous unconventional reservoirs and how hydrocarbons are accumulated and how production performs in the tight to ultra-tight reservoirs. The industry activities and advancements in nano-imaging and tight rock testing technologies have resulted in the tremendous understanding of the geologic, geochemical, mineralogical, petrophysical, and geomechanical properties of unconventional reservoirs, hydrocarbon origin, occurrence, migration and accumulation within fine-grained reservoirs, and better exploration and production strategies and methods, but the successful reservoirs associated with reservoir properties and heterogeneity patterns have not been summarized. This has slowed down the replication of the success of unconventional oil and gas productions in North America.

This study is proposed based on the extensive experiences and expertise of EGI and its collaborators' in global unconventional tight/shale oil and gas plays. This project will characterize the heterogeneity of variables of properties of fine-grained unconventional reservoirs in different depositional and tectonic settings using representative type plays, e.g., marine Niobrara tight oil plays in the U.S., marine Bakken tight oil plays in cratonic setting in the U.S., marine siliceous to clay rich Marcellus shale gas plays in foreland tectonic setting in the U.S., marine carbonate rich Eagle Ford shale oil plays in the U.S., marine silty Montney shale in ramp setting in Canada, marine Silurian Longmaxi shale gas plays in foreland setting in China, lacustrine Green River tight oil plays in Uinta Basin in the U.S., lacustrine Triassic Yanchang shale plays in foreland setting in Ordos Basin China, and transitional Carboniferous to Permian plays in cratonic setting in Ordos Basin and Bohai Bay Basin in China. The data for this study include geology of typical unconventional plays, outcrop, well logs, cores, mineralogy, geochemistry, petrophysics, well tests, production, etc. Systematic and qualitative description and re-interpretation of unique characteristics of the geology, facies, architecture, geochemistry, mineralogy, petophysics and production or production potential of the representative unconventional plays will be conducted.

A new robust and practical quantitative method for heterogeneity characterization will be employed to reveal the variations of reservoir properties both laterally and vertically and their effects on the reservoir quality, hydrocarbon accumulation, and production.

The goals of the characterization of fine-grained unconventional reservoirs heterogeneity are to understand the distribution, extent, geometry, continuity, and variations in reservoir properties (e.g., mineralogy, geochemistry, porosity, permeability, bedding, density of natural fractures, pressure) of representative fine-grained unconventional plays covering tight oil/gas and shale plays in marine, transitional and lacustrine settings. The heterogeneity of the fine-grained systems across a wide range of spatial scales will be investigated in detail based on accumulated uninterpreted data from previous studies, new data collection from collaborators, various research organizations and companies, and data mining from public sources. The key properties and factors controlling reservoir quality, hydrocarbon

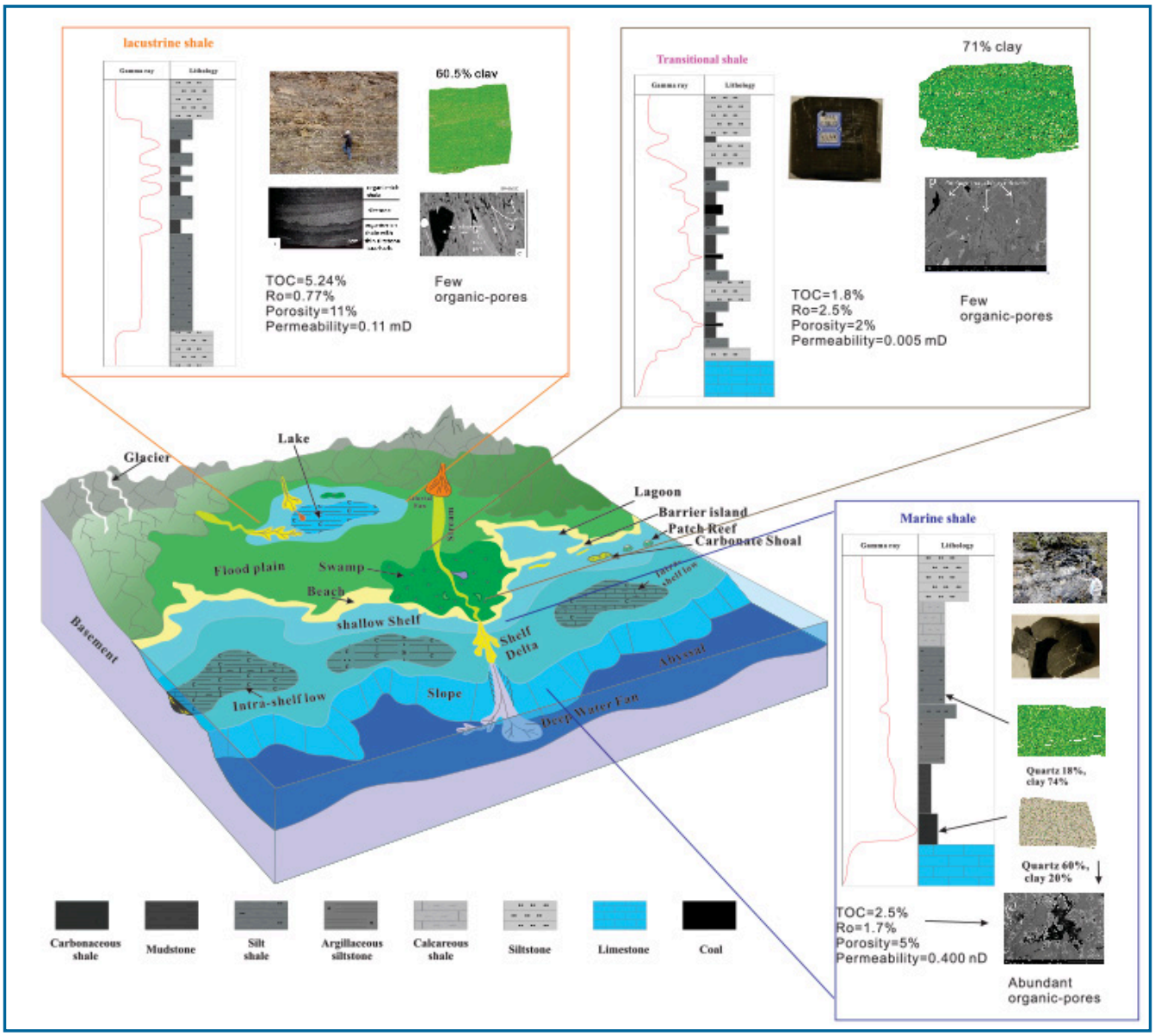

Figure 1. The fine-grained depositional systems in lacustrine, transitional and marine settings and their variations in lithofacies, mineralogy, geochemistry, petrophysics, etc from regional scale to nano-scale.

accumulation, and production will be addressed. The purpose is to generate big pictures of fine-grained reservoirs in terms of variations of properties, and heterogeneity patterns and impacts of the key properties of different settings on hydrocarbon accumulation and production.

The long-range research program will apply the distribution of facies and quantitative geometry, architecture and heterogeneous properties of reservoirs of fine-grained systems to constrain the reservoir modeling and simulation (and even hydraulic fracturing) to better understand the reservoir quality and enhanced recovery based on the parameters of various properties derived from this study. It will allow sponsors to apply the concepts and methods to develop a more refined predictive capability in petroleum exploration and development of similar type of rocks in their own plays or look for new ventures of similar and different geologic settings.

Data Sources

Data will be derived from accumulated uninterpreted data from previous studies, new data collection from collaborators, various research organizations and companies, EGI database, public domain, sponsor contributions, and through new analyses carried out at the EGI laboratory for core and/or outcrop samples.

These data include, but are not limited to, regional geological information, seismic and wireline logs, core and outcrop description, geochemistry data, XRD data, petrophysics data, petrology data from QEMSCAN, SEM and FIB-SEM, Nano-CT, MICP (mercury intrusion capillary pressure), CO_2 and N_2 adsorption, completion report, well tests and production data.

Collected data and laboratory results will be integrated into a comprehensive database for CA sponsor delivery. Data provided by sponsors will be used for interpretation and detailed information, e.g., geographic information can be kept confidential upon request.

Methodology

This study will employ a multi-scale multi-disciplinary integrated approach to examine the detailed sedimentological, structure, mineralogical, geochemical, petrophysical, petrological, and reservoir pressure study in conjunction with the regional geological study, reservoir characterization, petroleum systems analysis, and production characterization. The variations in properties of the various facies of fine-grained systems will be evaluated, correlated, and quantified to a database. Large-scale and micro-scale, e.g., nano-scale characterization of reservoir properties, will be bridged systematically to summarize the unique characteristics of each facies in specific setting.

Scope of Work

This project aims to provide summative, qualitative, and quantitative models of heterogeneity for key fine-grained unconventional reservoirs and their applications to exploration and production. The project will focus on the following areas:

1. Interpret and re-interpret the outcrop and subsurface data of typical fine-grained unconventional reservoirs to investigate the distribution and trend of rock properties, e.g., lithology, grain size, texture, structures, geochemistry, mineralogy, fractures, mechanical stratigraphy, petrology, petrophysics, pore types, pore structure, pore size distribution, fluid compositions, etc., for different facies of a specific geological setting and between different geological settings.
2. Develop a systematic approach to qualitatively describe and quantitatively characterize relationship between different property variables and their heterogeneity patterns in time and space at multi-scales;
3. Compare the similarities and differences of the heterogeneity of fine-grained reservoirs deposited in different depositional and tectonic settings from regional scale to micro-scale;
4. Study the external and internal controls and mechanisms of heterogeneity from source to sink and basin dynamics perspectives;
5. Relate the heterogeneity in different depositional and tectonic settings to well log responses, reservoir quality, hydrocarbon accumulation, and production;
6. Build database covering most reservoir properties for typical fine-grained unconventional plays for analog, modeling and simulation;

7. Establish predictable models of deposition, facies distribution, stratigraphic architecture, and reservoir properties within sequence stratigraphic framework and suggest the potential play fairways of different fine-grained systems.

Key Team Members

Staff	Expertise	Role
Shu Jiang Ph.D., Principal Investigator, Research Associate Professor and Coordinator for China Program at EGI	Petroleum geology of conventional and unconventional reservoirs, petroleum systems, sequence stratigraphy	Depositional facies and reservoir heterogeneity characterization of fine-grained unconventional plays, multiscale and multidisciplinary integrated analysis and summary, Project coordinating,
Raymond Levey, Ph.D. Research Professor and Director of EGI	Unconventional resource assessment, sequence stratigraphy and sedimentology	Project advisor
Matthias Greb.M.Sc. Senior Geologic Advisor	Petroleum systems Analysis and geochemistry	Reservoir characterization of tight/shale oil plays in Permian Basin and Gulf Coast Basins
Bryony Richards, Ph.D., Senior Petrologist	Petrology, geochemistry, reservoir characterization	Reservoir characterization, petrophysics and petrology
Guochang Wang Assistant Professor, Saint Francis University	Shale reservoir characterization and geological modeling and numerical simulation	Reservoir characterization of Marcellus and Utica shales
Manas Pathak Ph.D. EGI Affiliate Scientist	Reservoir characterization and simulations	Geologic control on production
Fengcun Xing Ph.D. Visiting Associate Professor	Reservoir characterization	Characteristics of tight gas reservoirs, reservoir geology
Zhenlin Chen, Ph.D. Visiting Associate Professor	Sedimentology and reservoir geology	Analysis of thin section, SEM, XRD, CT data
Yajun Li, Ph.D. Candidate	Petroleum geology	Fine-grained tight oil and gas plays
Yuying Zhang; Ph.D. Candidate	Unconventional geology	Shale reservoir sedimentology and reservoir architecture and heterogeneity characterization
Xianglu Tang; Ph.D. Candidate	Geology of tight reservoir	Shale property and heterogeneity characterization and interpretation of CT, thin section, SEM, XRD, etc.
Shuang Chen; MS Candidate	Reservoir geology	Literature search, summary of reservoir properties
Additional Staff as Needed		

Project Timeline, Report & Investment

Updates and interim data uploads will be announced during the project cycle and provided to all sponsors. A final report will be prepared and delivered following the final meeting. The intitial phase will be 12 months; investment per sponsor is $68,000 (USD). A second phase is planned.

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Research Interests

- Petroleum geology for conventional and unconventional resources
- Geothermal geology
- Sequence stratigraphy
- Basin analysis
- Lacustrine to deepwater sedimentary geology
- Petroleum systems
- Reservoir characterization
- Lacustrine to deepwater depositional systems
- Seismic interpretation integration of geology, geophysics, geochemistry, and engineering

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Shu Jiang, PhD

Research Associate Professor

Coordinator for China Program Development

Senior Research Scientist and Research Associate Professor Shu Jiang joined EGI in 2010. He earned his Ph.D. in Petroleum Geology from China University of Geosciences at Wuhan and completed postdoctoral research at the University of Colorado at Boulder He worked at CNOOC in Beijing for two years where he was involved in a significant gas discovery in Bohai Bay, China.

Shu has over 20 years experience in petroleum geology, sedimentary geology, basin analysis, sequence stratigraphy, petroleum systems, lacustrine to deepwater depositional systems, and unconventional reservoirs research spanning geology, geochemistry, geophysics and petroleum engineering. He is a Certified Petroleum Geologist (CPG), active member of AAPG, SEG, IAS, and GSA and has more than 90 publications to his credit. He also serves as an Advisory Member of the AAPG Shale Gas & Liquids Committee and has convened and chaired many international meetings.

Sequence Stratigraphy, Basin Analysis & Petroleum Systems for Conventional and Unconventional Reservoir Prediction

Shu conducts innovative and applied research in sequence stratigraphy and basin analysis in various tectonic settings by integrating core, well logs, seismic data, outcrop, etc. He proposes practical depositional models and suggest potential drilling targets for both conventional and unconventional reservoirs by integrating petroleum system analysis.

Lacustrine to Deepwater Depositional Systems

Shu's studies include the ancient and modern lacustrine to deepwater siliciclastic sediments transportation from source to sink and characterization of spatial and temporal evolution of depositional element architecture to predict deepwater reservoirs. Projects integrate structural, sedimentological and geomorphic studies and bridge both fundamental and petroleum geosciences.

Reservoir Description & Characterization

His work achieves successful reservoir model characterization by accurate property and architecture of all the siliciclastic depositional elements and uses state-of-the-art interpretation tools on a wide range of outcrop and subsurface data-sets to predict stratigraphic occurrence, 3-D geometry, and geophysical attributes of sandstone, CMB and shale reservoirs from lacustrine to deepwater setting.

Global Experience

Shu has worldwide industry and academic experiences from continental to deepwater setting basins (from East China lacustrine rifted basins, Northern China Cratonic basin, West China foreland basins, to South China Sea passive margin basin, basins in SE Asia, the Rocky Mountains, onshore Africa, and South America ,through deepwater GOM, Angola, Australia basins).