

7 Training Content - About the Course

7.1 Course Overview

The course discusses common structural styles in sedimentary basins and the geometry and evolution of trap-forming structures associated with extensional, salt, compressive, strike-slip and inversion structures. Examples of trap-forming structures from numerous basins worldwide are used to illustrate the concepts. Problem sets provide hands on experience in interpreting and validating subsurface structures using surface, seismic, and well data.

7.2 Course Content

The course is based on the following content:

1.0 INTRODUCTION

- 1.1. Role of Structural Geology in E&P
- 1.2. Concept of Comparative Structural Styles
- 1.3. Controls of Mechanical Stratigraphy
- 1.4. Structural Models and Methods in Interpretation

2 BASIC PRINCIPLES AND METHODS

- 2.1. Fold Geometry and Mechanisms
- 2.2. Fault Parameters and Interpretation
- 2.3. Structure Maps
- 2.4. Structural Cross Sections
- 2.5. Structural Restoration and Validation
- 2.6. Kinematic Reconstruction and Structural Evolution
- 2.7. 3-D Structural Modeling and Interpretation

3 RIFT STRUCTURES

- 3.1. Evolution of Rift Structures
- 3.2. Symmetric Graben-Horst Structures
- 3.3. Rotated Tilt Blocks
- 3.4. Drape Folds
- 3.5. Transfer Zones
- 3.6. Structural Traps

4 LISTRIC GROWTH FAULTS

- 4.1. Regional Framework of Passive Margins
- 4.2. Mechanism of Rollover Folding
- 4.3. Synthetic and Antithetic Faults
- 4.4. Shale vs. Salt Cored Structures
- 4.5. Transfer Zones
- 4.6. Structural Trap Classification

5 SALT STRUCTURES – AUTOCHTHONOUS

- 5.1. Mechanisms of Salt Tectonics
- 5.2. Salt Rollers, Pillows, Diapirs, Bulbs and Canopies

- 5.3. Progressive Evolution of Salt Structures
- 5.4. Mechanisms – Active Diapirism vs. Downbuilding
- 5.5. Salt-related Faults
- 5.6. Classification of Structural Traps
- 6 SALT STRUCTURES – ALLOCHTHONOUS**
- 6.1. Evolution of Salt Sheets
- 6.2. Regional vs. Counter regional Faults
- 6.3. Growth Fault Systems and Mini basins
- 6.4. Subsalt Structures
- 7 FOLD AND THRUST BELTS**
- 7.1. Fold and Thrust Geometry and Mechanisms
- 7.2. Fault-Bend Folds
- 7.3. Fault-Propagation Folds
- 7.4. Detachment and Faulted Detachment Folds
- 7.5. Fold-Thrust Systems
- 7.6. Structural Traps
- 8 FORELAND BASEMENT STRUCTURES**
- 8.1. Regional Framework
- 8.2. First- and Second- Order Structures
- 8.3. Trishear Models
- 8.4. Mode I –Basement Structures
- 8.5. Mode II- Basement Structures
- 8.6. Trap Styles
- 9 INVERSION AND REACTIVATED STRUCTURES**
- 9.1. Mechanisms of Inversion and Reactivation
- 9.2. Characteristic Features- Separation and Growth Features
- 9.3. Fault-Propagation Folding Inversion
- 9.4. Fault-Bend Folding Inversion
- 10 STRIKE-SLIP STRUCTURES**
- 10.1. Distributed vs Decoupled Shear
- 10.2. Structures Associated with Distributed Shear
- 10.3. Transpressional Structures
- 10.4. Transtensional Structures
- 10.5. Releasing Bends- Pull-Apart Basins

7.3 Objectives

After participating in this course the attendee should understand:

- Correctly interpreting structures in compressional, extensional, strike-slip and diapiric environments.

- How to use characteristic features of structures to interpret structures using geological and seismic data.
- How to locate common structural prospects in hydrocarbon basins
- Use of balancing and reconstruction techniques to improve structural and seismic interpretation

7.4 Who Should Attend

This course is intended for Geologists and geophysicists especially those involved in seismic and structural interpretation or trap-forming structures

7.5 Prerequisites

A general knowledge of basic petroleum geology, structural geology and geophysics

7.6 Course Method

It will be based on power point presentation and practical exercise material.

9 Daily Course Schedule

Daily Course Schedule					
Time	Day 1	Day 2	Day 3	Day 4	Day 5
Session 1 09:00 – 10:45	Introduction Role of Structural Geology in Exploration and Production	Listric Growth Faults	Salt Structures	Fold-thrust belts	Basement – Involved Structures
10:45 – 11:00	Morning Break				
Session 2 11:00 – 13:00	Basic Principles and Methods- Folds and Faults, Maps and Cross Sections	Listric Growth Faults	Salt Structures	Fold-thrust belts	Inversion Structures
13:00 – 14:00	Lunch				
Session 3 13:30 – 15:15	Rift Structures	Listric Growth Faults	Salt Structures	Fold-Thrust Belts	Strike-Slip Structures
15:15 – 15:30	Afternoon Break				
Session 4 15:30 – 17:00	Rift Structures	Salt Structures	Compressional Structures – Fold-Thrust Belts	Fold-thrust b	Summary and Discussion

Session 3 13:30 – 15:15	Andersonian vs non-Andersonian behaviour, Geodynamic scenario and regional setting-set up procedure	Field examples, maps and sections; Seismic examples, lines and time slices; exercises for recognition;	Normal fault systems and fault growth; scale of observation; relays and fault interaction	Inversion structure; types of inversion; recognition of inversion structures; field and seismic examples; implications of inversion;	Picking well locations and well paths in folded fractured reservoirs; Fracture intensity and well trajectory; Exercises
15:15 – 15:30	Afternoon Break				
Session 4 15:30 – 17:00	Type of fractures and deformational structures, from small scale to regional	Folds and Folding; Fold geometry concepts; Folds and folding mechanisms; Why it is important to recognize fold type and folding mechanisms; Seismic and field examples/exercises; Fold kinematics	Dipmeter Analysis; Image logs and dip; Some types of plots; determining trend and plunge of structural features; exercise	Fractures and fractured reservoirs; stress and strain and types of fractures; Small scale structures;	Case studies and course participant discussion

Appendix A: CV of Instructor – Professor Shankar Mitra

Professor Shankar Mitra
Monnett Chair and Professor of Energy Resources
School of Geology and Geophysics

EDUCATION

Ph.D., 1976, Structural Geology. Johns Hopkins University, Baltimore, MD.

PROFESSIONAL EXPERIENCE

40 Years of Professional and Academic Teaching and Research

University of Oklahoma, Norman, OK.

Monnett Chair and Professor of Energy Resources (1999 to Present).

ARCO Exploration and Production Technology

Senior Exploration Advisor.

1997 - 1999

ARCO International Oil and Gas Company

Exploration Director, Europe.

1994 - 1997

ARCO Exploration and Production Technology

Manager, Geological Analysis (1991-1994)
Research Director, Structural Geology (1987-1991)
Research Associate (1986-1987)
Principal Research Geologist (1984-1986)
Senior Research Geologist (1980-1984)

1980 - 1994

Cleveland State University

Assistant Professor.

1976 - 1980

RECENT PUBLICATIONS

Mitra, S., 1986. Duplex structures and imbricate thrust systems: Geometry, structural position and hydrocarbon potential, American Association of Petroleum Geologists Bulletin, v.70, p.1087-1112.
Mitra, S., 1987. Regional variations in deformation mechanisms and structural styles in the central Appalachian orogenic belt, Geological Society of America Bulletin, v. 98, p. 569-590.
Mitra, S., 1988. Three-dimensional geometry and kinematic evolution of the Pine Mountain thrust system, southern Appalachians, Geological Society of America Bulletin, v.100, p. 72-95.
Mitra, S., 1988. Effects of deformation mechanisms on reservoir potential in the central Appalachians, American Association of Petroleum Geologists Bulletin, v.72, p. 536-554.
Mitra, S., and Namson, J.S., 1989. Equal-area balancing, American Journal of Science, v. 289, p. 563-599.
Mitra, S., 1989, Fault-propagation folding: geometry, kinematic evolution and hydrocarbon traps: American Association of Petroleum Geologists Bulletin, v. 74, p. 921-945.

- Mitra, S., 1992, Balanced structural interpretations in fold and thrust belts: p. 53-77, in Mitra, S., and Fisher, G.W., eds., *Structural Geology of Fold and Thrust Belts*, Johns Hopkins University Press, Baltimore, 254 p.
- Mitra, S., 1993, Geometry and kinematic evolution of Inversion structures: *American Association of Petroleum Geologists Bulletin*, v. 77, p. 1159-1191.
- Mitra, S., and Islam, Q. T., Experimental (clay) models of inversion structures, *Tectonophysics*, v.230, p. 211-222.
- Mitra, S., and Mount, V.S., 1998, Foreland Basement-Involved Structures, *A.A.P.G. Bulletin*, v. 82, p. 70-109.
- Mitra, S., 2002, Fold Accommodation Faults: *A.A.P.G. Bulletin*, v. 86, p. 671-693.
- Mitra, S., 2002, Structural models of faulted detachment folds, *A.A.P.G. Bulletin*, v. 86, p. 1673-1694.
- Mitra, S., and Leslie, W., 2003, Three-dimensional structural geometry of the Rhourde el Baguel field, Algeria, *A.A.P.G. Bulletin*, v. 87, p. 231-250.
- Mitra, S., 2003, A unified structural model for disharmonic detachment folds and lift-off folds, *Journal of Structural Geology*, v. 25, p. 1659-1673.
- Banerjee, S., and Mitra, S., 2004, Remote surface mapping using orthophotos and geologic maps draped over digital elevation models: Application to the Sheep Mountain anticline, Wyoming, *A.A.P.G. Bulletin*, v. 88, p. 1227-1237.
- Mitra, S., 2005, The Sequatchie anticline, Cumberland plateau, Tennessee: A low-displacement fault -bend fold. *A. A. P. G Atlas on Seismic Expression of Compressive Structures*, No. 53, John H. Shaw, Christopher Connors, and John Suppe, eds.
- Mitra, S., 2005, Structural inversion along the Sakala fault, East Java Sea, Indonesia, *A.A.P.G. Atlas on Seismic Expression of Compressive Structures*, No. 53, John H. Shaw, Christopher Connors, and John Suppe, eds.
- Banerjee, S., and Mitra, S., 2005, Fold-thrust styles in the Absaroka thrust sheet, Caribou National Forest Area, Idaho-Wyoming Thrust Belt, *Journal of Structural Geology*, v. 27, p. 51-65.
- Mitra, S., Correa, G.F., Garcia, J.H., Alvarado, A.M., 2005, Three-dimensional structural model of the Cantarell and Sihil structures, Campeche Bay, Mexico, *AAPG Bulletin*, v.89, p.1-26.
- Dischinger, J. and Mitra, S., 2006, Three-dimensional structural model of the Painter and East Painter reservoir structures, Wyoming fold and thrust belt, *AAPG Bulletin*, v.90, p. 1171-1185.
- Mitra, S., Gonzalez, J.A.D., Garcia, J.H., Hernandez, S.G., Banerjee, S., 2006, Structural geometry and evolution of the Ku, Zaap, and Maloob structures, Campeche Bay, Mexico, *AAPG Bulletin*, v.90, p. 1565-1584.
- Mitra, S., Gonzalez, J.A.D., Garcia, J.H., Ghosh, K., 2007, Ek Balam field: A structure related to multiple stages of extension and salt tectonics, *AAPG Bulletin*, *A.A.P.G. Bulletin*, v. 91, p. 1619-1636.
- Bose, S., and Mitra, S., 2009, Deformation along oblique and lateral ramps in listric normal faults: Insights from experimental models, *A. A. P.G. Bulletin*, v.93, p.431-451.
- Ghosh, K., and Mitra, S., 2009, Structural Controls of Fracture Orientations, Intensity, and Connectivity, Teton Anticline, Sawtooth Range Montana, *A.A.P.G. Bulletin*, v.93, p.995-1014.
- Ghosh, K., and Mitra, S., 2009, Two-dimensional simulation of controls of fracture parameters on fracture connectivity, *A.A.P.G. Bulletin*, v.93, p.1517-1533.
- Bose, S., and Mitra, S., 2010, Analog modeling of divergent and convergent transfer zones in listric normal fault systems, *A.A.P.G. Bulletin*, v.94, p.1425-1452.
- Mitra, S., and Paul, D., 2011, Structural geometry and evolution of releasing and restraining bends: Insights from laser-scanned experimental models, *A.A.P.G. Bulletin*, v. 95, no. 7, p. 1147-1180.
- Miller, J.F., and Mitra, S., 2011, Deformation and secondary faulting associated with basement-involved compressional and extensional structures, *A.A.P.G. Bulletin*, v. 95, no. 4, p. 675-689.
- Bose, S., and Mitra, S., 2012, Controls of listric normal fault styles in the northern Gulf of Mexico: Insights from experimental models, *Marine and Petroleum Geology*, v. 35(1), p. 41-54.

Paul, D., and Mitra, S., 2012, Controls of basement faults on the geometry and evolution of compressional basement-involved structures, A.A.P.G. Bulletin, v. 96, no. 10, p. 1899-1930.

RECENT ABSTRACTS

- Mitra, S., Figueroa, G.C., Garcia, J.H., Alvarado, A.M., 2004, Three-dimensional structural model of the Cantarell and Sihil Structures, Campeche Bay, Mexico, A.A.P.G. Annual Meeting.
- Mitra, S., Figueroa, G.C., Garcia, J.H., Alvarado, A.M., 2004, Cantarell and Sihil Structures, Campeche Bay, Mexico: Three dimensional visualization and interpretation, A.A.P.G. International Meeting, Cancun, October.
- Mitra, S., Figueroa, G. C., Garcia, J.H., Alvarado, A.M., 2005, Three-dimensional structural model of the Cantarell and Sihil structures, Campeche Bay province, Mexico, A.A.P.G. Annual Meeting, Dallas.
- Mitra, S., 2005, Controls of Mechanical Stratigraphy on Fault-Related Folding in Fold-Thrust Belts: Examples from Campeche Bay, Mexico, International Conference on Folding and Thrusting, Beijing, China.
- Mitra, S., 2006, Contrasting Structural Styles of Major Fields Associated with Fold-Thrust Structures in the Offshore Campeche Bay, Mexico, A.A.P.G. Annual Meeting Abstracts.
- Morales, M., Mitra, S., 2006, Structure and Tectonic Evolution of the Provincia Field, Middle Magdalena Valley, Colombia A.A.P.G. Annual Meeting Abstracts.
- Banerjee, S., Mitra, S., 2006, Structural evolution of basement-involved anticlines on the western margin of Bighorn basin, Wyoming. Geological Society of America, Abstracts with Programs, vol. 38, no. 7, p. 414.
- Ghosh, K., Mitra, S., 2006, Characterizing Fracture network patterns in the Teton Anticline, Sawtooth Range, Montana. Geological Society of America, Abstracts with Programs, vol. 38, no. 7, p. 412.
- Bose, S., Mitra, S., 2006, Fault patterns and connectivity along extensional oblique and lateral ramps: insights from clay experiments. Geological Society of America, Abstracts with Programs, vol. 38, no. 7, p. 411.
- Banerjee, S., Mitra, S., 2007, 3-D Structural Model of Structures along the Western Margin of the Bighorn Basin, Wyoming, A.A.P.G., Annual Meeting Abstracts with Programs, v. 91.
- Ghosh, K., Mitra, S., 2007, Fracture Characteristics of Folded Carbonates, Teton Anticline, Sawtooth Range, Montana, A.A.P.G., Annual Meeting Abstracts with Programs, v. 91.
- Bose, S., Mitra, S., 2007, Fault Patterns and Connectivity along Extensional Oblique and Lateral Ramps: Insights from Experimental Models, A.A.P.G., Annual Meeting Abstracts with Programs, v. 91.
- Bayer, W. S., Mitra, S., Slatt, R., Boljen, S.S., and Pomerene, J.S., 2007, Structural and Stratigraphic Evaluation of the Southern Belgian Anticline Area, North Midway-Sunset Field, San Joaquin Basin, California, A.A.P.G., Annual Meeting Abstracts with Programs, v. 91.
- Banerjee, S., and Mitra, S., 2008, 3-D Structural Model of Basement-Involved Anticlines Along the Western Margin of the Bighorn Basin, Wyoming, A.A.P.G. Annual Meeting 2008, San Antonio.
- Bose, S., and Mitra, S., 2008, Experimental Modeling of Transfer Zones In Listric Normal Fault Systems, G.S.A. Annual Meeting, 2008, Houston.
- Bose, S., and Mitra, S., 2008, A Transfer Zones in Listric Normal Fault Systems: Insights from Clay Experimental Models, A.G.U. Annual Meeting, San Francisco, 2008.
- Ghosh, K., and Mitra, S., 2008, Two-Dimensional Simulation of the Controls of Fracture Parameters on Fracture Connectivity, G.S.A. Annual Meeting, 2008, Houston.
- Ghosh, K., and Mitra, S., 2008, Fracture Connectivity Patterns of Folded Carbonates, Teton Anticline, Sawtooth Range, Montana, A.A.P.G. Annual Meeting 2008, San Antonio.
- Mitra, S., and Paul, D., 2011, Experimental Modeling of the Controls of Basement Faults on Structural Geometry: 1. Single and Opposite Vergent Structures, G.S.A. Annual Meeting, Minneapolis.

Paul, D., and Mitra, S., 2011, Experimental Modeling of the Controls of Basement Faults on Structural Geometry: 2. Offset and Relay Structures, G.S.A. Annual Meeting, Minneapolis.
Mitra, S., 2011, 3-D Structural Models of Complex Trap-Forming Structures: Applications to Petroleum Exploration and Production, Geo_India International Conference, New Delhi.
Mitra, S., and Paul, D., 2012, Experimental Models of transfer zones in rift systems: 2. Synthetic transfer zones, G.S.A. Annual Meeting, Charlotte.
Paul, D., and Mitra, S., 2012, Experimental Models of transfer zones in rift systems: 1. Convergent and Divergent transfer zones, G.S.A. Annual Meeting, Charlotte.

BOOKS

Mitra, S., and Fisher, G.W., eds., 1992. Structural Geology of Fold and Thrust Belts, Johns Hopkins University Press, Baltimore, 254 p.

PROFESSIONAL ACTIVITIES

Associate Editor, A.A.P.G. Bulletin (9 years).

Chair, G.S.A. Structure and Tectonics Career Contribution Award Committee, 2005.

Chair of Sessions for A.A.P.G., G.S.A. National, and various International Meetings.

Reviewer of manuscripts for A.A.P.G. Bulletin, G.S.A. Bulletin, American Journal of Science, Journal of Structural Geology.

HONORS AND AWARDS

A.A.P.G. Wallace Pratt Memorial Award, AAPG Bulletin, 1988.

A.A.P.G. John C. Sproule Award, AAPG Bulletin, 1988.

A.A.P.G. Wallace Pratt Memorial Award, AAPG Bulletin, 2007.

CONSULTING

Continuing Education Course Instructor

A.A.P.G., Canadian Society of Petroleum Geologists, Columbian Association of Petroleum Geophysicists, Mexican Association of Petroleum Geologists, S.C.A., NExT, Fusion, CAREC, Petrogroup, Geological Society of Trinidad and Tobago, Geo-India, and numerous international corporations.

Structural and Petroleum Geology Projects

PEMEX, Fusion, S.C.A., and Other Corporations (2001 to Present).

Expert Witness

Chesapeake vs. Marathon, Oklahoma City, 2002

BP vs. SONATRAC, International Court, Paris, 2009.