Fold-Thrust Belt Exploration

14-16 May 2008

The Petroleum Group would like to thank BG Group, BP, Executive Insight, Global Exploration Services, StatoilHydro and Sterling Energy for their support of this event:

Wednesday 14 May	
09:00	Registration + coffee
09:45	Welcome and opening
	Opening Session (chair Graham Goffey)
10:00	Cooper, Marc (Sherwood Geoconsulting) KEYNOTE: Structural style and hydrocarbon prospectivity in Fold and Thrust Belts: a Global Review
10:40	Scott R (CASP Cambridge), Howard JP, Schekoldin R, Li Guo, Omma JE Curvature of the Novaya Zemlia Fold-and-Thrust Belt and its relationship to the subsidence history of the Eastern Barents Shelf
11:05	Golonka, Jan (Krakow Univ.) & Pietsch, Kaja Normal, blind, thrust and strike-slip faults - record of the geodynamic history of the West Outer Carpathians, Poland
11:30	Tea / Coffee
12:00	Sepehr M (NIOC Iran), Sherkati S, Abdollahhifar I The future exploration targets of the Zagros Fold-Thrust Belt
12:25	Flottman, Thomas (Santos Ltd) & McClay, Ken Multiphase shortening and synorogenic sedimentation in the Zagros Fold-Thrust Belt, Iran- Impacts on hydrocarbon trap formation
12:40	Lunch
	Session 1: Overview (chair Andy Whitham)
14:00	Graham, Rod (Hess) KEYNOTE: Exploration in Fold and Thrust Belt: a Losing Battle?
14:40	Letouzey J (IFP), Jahani S, Callot JP, de Lamotte DF The Hormuz Salt and the structures of the South-Eastern Zagros Fold and Thrust Belt and offshore area
15:05	Blanc E (StatoilHydro), Verges J, Gillespie P, Casciello E, Emami H, Homke S, Ghoodarzi MHG, Egebjerg T,Valinejad M, Hunt D, Sharp I, Livbjerg, Efstathion J, Skott P, Taati F, Rasmussen E Field evidence for a major Early Paleogene folding phase in the Zagros Simple Folded Zone
15:30	Gibbs A (Midland Valley), Seed GGG, Shackleton R Taking Geometry to the Limits and Beyond in Thrust Belt Analysis

15:55	Tea / Coffee
16:25	Turner SA (Imperial College), Weeks DH, Cosgrove JW, Liu JG Fundamental controls on the structural variability of Fold-Thrust Belts in the NW Tarim Basin, China
16:50	Wilson N (Oil Search Ltd), Hill K, Iwanec J, Lund D, Xu K, Mann P, Bradey K Moran Oilfield, Papua New Guinea; A case study
17:15	Taborda, Adriana (Husky Energy) & Spratt, Deborah Tectonic wedging in the Northern Mackenzie Mountains and Southern Richardson Mountains, NW Territories and Yukon, Canada
17:40	Wine Reception

Thursday 15 May	
09:00	Registration + coffee
Session 1: Overview (Enzo Zappaterra)	
09:30	Roeder, Dietrich (Murnau Geodynamics) KEYNOTE: Fold-Thrust Belts at Peak Oil
10:10	de Vera, Jose (RHUL) & McClay, Ken Structure of the Western Brooks Range Fold and Thrust Belt, Arctic Alaska
10:35	Krzywiec P (Polish Geol. Inst.), Aleksandrowski P, Oszczypko N, Sieniawska I, Oszczypko-Clowes M, Kijewska S, Wrobel G, Bukowski K, Siupik J, Florek L Structure, Miocene evolution and hydrocarbon potential of the frontal Polish Carpathians (Pilzno-Andrychow): New model based on integrated analysis of geological and geophysical data
11:00	Tea / Coffee
11:30	Scrocca D (CNR Rome), Doglioni C, Arecco P, Nikolla L, Cannata D, Petracchini L, Recanati R The Outer Albanides: Geodynamic setting, structural architecture, and petroleum potential
11:55	Cook, B.S (Kentucky Univ.), & Thomas, W.A. Potential natural gas plays in ductile duplexes: an example from a Recess in the Appalachian Thrust Belt in Georgia, USA
12:20	Lunch

Session 2: Exploration in Thrust Belts: Case Studies (chair Rob Butler)	
14:00	Newson, Andrew C. (Moose Oil Calgary, Keynote) KEYNOTE: Adding reserves in Fold-Thrust Belts
14:40	Hill KC (Oil Search Ltd.), Iwanec J, Bradey K, Wilson N, Heidorn R Crustal architecture, fold belt development and oilfield compartments in Papua New Guinea
15:05	Bradey K (Oil Search Ltd.), Wilson N, Iwanec J, Kivior T, Kendrick D, Hill K Exploration in the Kutubu oil field, Papua New Guinea
15:30	Charlton, Tim (Manson-Demon) The petroleum potential of the Banda Fold and Thrust belt
15:55	Tea / Coffee
16 :20	Bello D (Geomodels Barcelona), Munoz JA, Roca E, Lopez-Blanco M, Navarro J, Malagon J Stratigraphic control on the Vallfogona thrust geometry: Eastern Pyrenees, Spain
16 :55	Becker, Stephan (RWTH Aachen Univ.) The Aachen fold and thrust belt: an integration of surface geology, reflection seismic and new subsurface data from the deep geothermal well RWTH-1
17 :25	Funedda, Antonio (Cagliari Univ.) Complicated thrust triangle zone in the Variscan foreland of Sardinia
17:50	Wine Reception
19 :00	Conference Dinner

Friday 16 May	
09:00	Registration + coffee
Session 3: Structural Models and Modelling (chair Nigel Duxbury)	
09:30	Duque Carlos (BP), Checa J, Pastore D, Matthews S Seismic Processing in overthrust areas
09:55	Roseway, Jon (C&C Reservoirs) Typical play types and prominent exceptions in Foreland Fold and Thrust Belts

10:20	Wiltschko David V (Texas A&M) & Rodriguez-Roa Fernando Multi-modal approach to balance cross-section drawing: example from the Southern Taiwan Orogen
10:45	Tea / Coffee
11:15	Sulzer C (IFP), Thibaut M, Jardin A, Beche M Applied methodology on a 3D compressive case study: the Gaspe' Belt
11:40	Bump A (BP America), Martinez J, Hossack J A pseudo-3D model of the Llanos foothills, Eastern Cordillera, Colombia
Session 4: Thermal Regimes (chair Graham Goffey)	
12:05	Roure F (IFP), Andriessen P, Callot JP, Gonzales E, Guilhaumou N, Handebol N, Lacombe o, Malamdain J, Mougin P, Ortuno S, Sassi W, Swennen R, Vilasi N The use of paleo-thermo-barometers and coupled thermal, fluid flow and pore fluid pressure modeling for hydrocarbon and reservoir prediction in Fold and Thrust Belts
12:30	Picotti Vincenzo (Bologna Univ.) & Capozzi Rossella The Northern Apennines Petroleum system: an integrated structural-geochemical approach
12:55	Lunch
Session 5: New Models (chair Enzo Zappaterra)	
14:10	Scalera, Giancarlo (INGV Rome) Fold belts built from below
14:35	Sassi W (IFP), Schledert Z, Saeed AM Transpressive force folding and basin inversion: structural evolution of faulting studied by numerical digitization of a sandbox experiment
15:00	Waller TD (Hess), Spang JH, Kilsdonk B New geometric model for detachment folds with applications to deepwater, Western Gulf of Mexico, USA
15:25	Paton, Douglas (Leeds Univ.) Application of tri-shear to syn-compressional growth strata geometry
15 :50	End of Conference

Poster Sessions		
Wednesday 14 May		
11:00 – 16:20	Do thrust faults limit trap potential in the Niger Delta deep water Thrustbelt play?	Kostenko O (Shell Intl'), Naruk S, Hack W, Poupon M, Meyer HJ, Nourse R
	Coupling kinematic evolution of Fold-Thrust structures and basin modeling: Implications for hydrocarbon migration and accumulation in deep-water Niger Delta	Rivero C (Chevron), Muscio G, Muhuri S, Eisenberg R
	Contractional domains of the Niger Delta: Structural styles, influence of mobile shale, and structural-stratigraphic evolution	Wiener RW (ExxonMobil), Mann MG, Cotton WB, Boorman SL, Lopez CJ, Angelich MT, Molyneux J, Barboza SA
	The deepwater Fold-Thrust belt offshore NW Borneo: gravity-driven versus crustal shortening	Hesse S (RWTH Aachen Univ.), Back S, Franke D
	The Barbados accretionary prism-Orinoco delta connection: deformation processes at the south-eastern boundary of the Caribbean Plate	Deville E (IFP), Padron de Carillo C, Huyghe P, Callec Y, lallemant S, Lebrun JF, Mascle A, Mascle G, Noble M
Thursday 15 May		
11:00 – 16:20	Regional geological cross-sections and tectonic style in the Eastern Zagros fold-thrust belt and offshore area, Iran	Jahani Salman (NIOC Iran), Letouzey J, de Lamotte DF, Callot JP
	Upper Pennsylvanian (Kasimovian) potential source rocks and shallow-water carbonates with oil and bitumen inclusions in late Variscan wedge-top basin successions: Picos de Europa imbricate system, Cantabrian Zone, NW Spain	Merino-Tome' OA (Geol. Inst. Spain), Bahamonde JR, Fernandez LP, Colmenero JR, Villla E, Heredia N
	Modeling bed dips in horizontal wells in Fold-Thrust Belts	Newson, AC (Moose Oil Ltd) & Berg, CR
	Advanced remote imaging techniques to map the Zagros Fold-Thrust Belt of Northern Iraq	Banks GJ (FugroRobertson) & Watkins CA
	3D progressive migration of a turbidite-filled syncline in the alpine foreland basin: the Annot Syncline (SE France)	Salles, L (CRPG-CNRS), Ford, M, Joseph, P, Titeux, M-O, Durand-Riard, P, Caumon, G

Wednesday 14 May

Opening Session

Chair: Graham Goffey

Structural Style and Hydrocarbon Prospectivity in Fold and Thrust Belts: a Global Review

Mark Cooper, Calgary, Alberta, Canada (mark-cooper@shaw.ca)

Statistical analysis of reserves in fold and thrust belts, grouped by their geological attributes, indicates which of the world's fold and thrust belts are the most prolific hydrocarbon provinces. The Zagros Fold Belt contains 49% of reserves in fold and thrust belts. Excluding the Zagros, most of the reserves are in thin-skinned fold and thrust belts that have no salt detachment or salt seal, are partially buried by syn- or post-orogenic sediments, are sourced by Cretaceous source rocks and underwent their last phase of deformation during the Tertiary. A significant observation is that the six most richly endowed fold and thrust belts have no common set of geological attributes, implying that these fold belts all have different structural characteristics. The implication is that deformation style is a not critical factor in the hydrocarbon endowment of fold and thrust belts. Other fold and thrust belts may share the structural attributes but not the resource-richness and the factor that differentiates the have from the have not fold and thrust belts is the presence of an effective source rock . There is nothing intrinsic in fold and thrust belts that differentiates them from other oil- and gas-rich provinces other than the prolific development of potential hydrocarbon traps. However within the prolific belts the careful analysis of structural attributes can identify the characteristics of successful exploration targets. Many of the prolific, proven fold and thrust belts still have significant remaining exploration potential as a result of politically challenging access and remote locations.

NOTES

Curvature of the Novaya Zemlya Fold-and-Thrust Belt and Its Relationship to the Subsidence History of the Eastern Barents Shelf

Robert A Scott[1], James P Howard[1], Roman Schekoldin[2], Li Guo[1] & Jenny E Omma[1]

[1]CASP, Department of Earth Sciences, University of Cambridge, Cambridge, UK
[2]Department of Historical and Dynamic Geology, St Petersburg State Mining Institute, St Petersburg, Russia

Two characteristics of Novaya Zemlya immediately stand out on any topographic map: the plan-view curvature (convex towards the Barents Shelf) and the ~600 km westward offset compared with the remainder of the Uralian Orogen. Any regional tectonic model developed for the Novaya Zemlya fold-and-thrust belt must be able to explain these first-order features. However, although several previous studies have sought to explain the offset of Novaya Zemlya from the remainder of the Uralian Orogen, as far as we are aware there has been no previous attempt to link the geometry of structures on the archipelago with a potential mechanism that explains their curvature in plan view.

Many fold-and thrust belts have an element of curvature, and contain a distinctive pattern of structural trend lines within them, but the causes of orogen curvature are often controversial, even in examples where there is a comprehensive understanding of structural geometries and a substantial database of strain measurements with which to predict the precise trajectory of material during deformation. Using field observations, information on geological maps and interpretation of satellite imagery, we seek to demonstrate the link between structural geometries in Novaya Zemlya and the subsidence history of the adjacent eastern Barents Shelf. We find no evidence to support previous interpretations of the fold-and-thrust belt as an orocline (bending of an originally straight deformation belt) and conclude that the offset from the remainder of the Uralian Orogen is a primary feature that results from an original embayment on the margin of Baltica.

NOTES

Normal, Blind, Thrust and Strike-Slip Faults: Records of the Geodynamic History of the West Outer Carpathians, Poland

Jan Golonka & Kaja Pietsch, AGH University of Science and Technology; Faculty of Geology, Geophysics and Environmental Protection, Krakow, Poland (jan_golonka@yahoo.com, pietsch@agh.edu.pl)

The Carpathians form a great arc of mountains, which stretches more than 1 300 km from the Vienna Forest to the Iron Gate on the Danube. The West Carpathians consists of an older range known as the Inner or Central Carpathians and the younger one, known as the Outer or Flysch Carpathians. The Outer Carpathians are built up of a stack of nappes and thrustsheets changing along the Carpathians, built mainly of continual flysch sequences up to six kilometers thick representing the time span from the uppermost Jurassic up to the Lower Miocene. All the Outer Carpathian nappes are thrust over the southern part of the North European platform covered by the autochthonous Miocene deposits of the Carpathian Foredeep on the distance of 70 km. The deep structure of the Polish Outer Carpathians and its basement, that is southern prolongation of the North European Platform, has been recognised by deep boreholes well as seismic and other geophysical survey (Golonka et al., 2006, Pietsch et al., 2007, Ślączka et al, 2006) Tens of deep (up to 4500 meters) boreholes, which reached the Carpathian substratum, allowed recognising depth of the Carpathian thrust plane, its minimal range as well as character of substratum. Generally the thrust plane of the Carpathians plunge slowly to the south in their western part.

The North European Platform is a great continental plate, which was amalgamated in the Precambrian and Paleozoic. Sedimentation cover of the platform consists of Paleozoic, Mesozoic and Neogene sequences. Strongly folded Precambrian metamorphic rocks belonging to the Bruno-Vistulicum terrane (Golonka et al., 2006) are the main component of the consolidated basement. The characteristic features of this boundary are horsts and troughs of general direction NW-SE turning W-E. The formations of the basement are covered discordantly by Devonian and Upper Paleozoic formations.
Faults cutting only the consolidated basement and the Paleozoic cover were formed during the Hercynian Orogeny in the Carboniferous and the Early Permian. The survey area that is actual southern part of the North European Platform constituted the Carpathian orogenic belt foreland, where extensive faults had developed, related to formation of the foredeep. The deformations in the analyzed area – these are normal faults generally of NE-SW orientation.

An oblique collision between the North European Plate and the West Carpathians terranes invading it, lead to development of outer accretion prism, formation of a range of flysch nappes and formation of a foredeep (Ślączka et al., 2006). Through the Miocene tectonic movements caused final folding of the basins fill and created several imbricate thrust sheets (nappes) which generally reflect the basin margin configurations after the Cretaceous reorganization and Paleogene development of the Carpathian accretionary prism. The thrust faults dip southward. Most of the older normal faults were covered by allochtonous flysch nappes forming the blind faults. During the last stage of the geodynamic development the Carpathians thrustsheets moved towards their present position. Displacement of the Carpathians northwards is related to development of dextral strike-slip faults of N—S direction. Typical strike-slip fault is limited on the west and on the east by normal faults, configuration of which is similar to an asymmetrical flower structure. The orientation of this strike-slip fault zones zone more or less coincides with the surface position of the major faults (e.g. Skawa river faullt zone) perpendicular to the strike of the Outer Carpathian thrust sheets. Some normal faults of E-W orientations were renewed during the finel stress period and they controlled formation of morphostructures – horsts and depressions of E-W orientation. A fault of this type is perfectly visible in the seismic profiles 14-1-87 and 17-1-86 (Pietsch et al., 2007). It has the NEE – SWW orientation. This huge fault cuts formations from the Paleozoic basement through the flysch allochthon between the boreholes Zawoja 1, from the south, and Sucha Beskidzka1 and Lachowice 7, from the north. The displacement of nappes of the Carpathian overthrust and diapiric extrusion of plastic formations of the lower flysch units occurred along this fault.

This research has been financially supported by AGH University of Science and Technology in Krakow grant no.11.11.140.159.

References:

Golonka, J. Gahagan, L., Krobicki, M., Marko, F., Oszczypko, N.& Slaczka, A., 2006. Plate Tectonic Evolution and Paleogeography of the Circum-Carpathian Region. In: Golonka, J. & Picha, F. (eds.) The Carpathians and their foreland: Geology and hydrocarbon resources: American Association of Petroleum Geologists, Memoir 84: 11-46

Pietsch K., Golonka J. & Marzec, P., 2007. Relationship of the basement to the flysch of the Outer Carpathians between Wadowice and Babia Góra in the light of reflection seismic survey. (In Polish withEnglish summary). Kwartalnik AGH.Geologia, 33(4/1): 143-166.

Ślączka, A., Kruglow, S., Golonka, J. Oszczypko, N. & Popadyuk, I, 2006. The General Geology of the Outer Carpathians, Poland, Slovakia, and Ukraine. In: Golonka, J. & Picha, F. (eds.) The Carpathians and their foreland: Geology and hydrocarbon resources: American Association of Petroleum Geologists, Memoir 84: 221-258.

NOTES

The Future Exploration Targets of the Zagros Fold-Thrust Belt

Mohammad Sepehr, Shahram Sherkati & Iraj Abdollahifar, NIOC Exploration, Tehran, Iran*

The Zagros Fold Thrust Belt which extends over 1800 km from north east of Iraq to south west of Iran is the most prolific Hydrocarbon rich trust belt of the globe. This fold thrust belt has been a prime target for hydrocarbon exploration for a century and still remains as one of the world most promising regions for the future hydrocarbon discovery. In this paper we used all the latest available data including 3D seismic from the Iranian sector of the belt, to introduce the variety of new and possible future hydrocarbon traps in addition to the traditionally known anticlinal traps. This includes the shallow and relatively small scale anticlines which formed at neighboring of giant anticlines to very deep traps (including stratigrapy traps) formed as a result of movement of Cambrian Hormuz salt or movement along the deep seated fault zones. Some of these targets have been successfully drilled during last few years while the others, remain as potential prospects. This work also highlights the effect of multiple detachments which has resulted in the structural complexity of some undiscovered part of the belt. In order to locate and identify the geometry of remaining traps of the belt, it is essential to acquire all the latest available advance techniques.

NOTES

Multiphase Shortening and Synorogenic Sedimentation in the Zagros Fold-Thrust Belt, Iran - Impacts on Hydrocarbon Trap Formation

Thomas Flottmann[1] *& Ken McClay*[2]

[1]*Santos Ltd, Adelaide, SA, Australia*
[2]*Royal Holloway, University of London, Surrey, UK*

The Dezful Embayment of SW Iran forms the foreland basin of the Zagros Mountains which are a product of multiphase shortening related to the closure of the Tethys Ocean and subsequent collision of the Arabian and Eurasian plates during the Late Cretaceous to Recent.

We describe a re-interpretation of major thrust-structures in carbonate dominated reservoir rocks using original field observations, reprocessed, seismic data, remote sensing, as well as new (seismic supported) regional cross sections.

Early shortening led to minor folding (shortening ~8%) during Late Cretaceous and early Tertiary. This shortening episode is expressed by large scale facies variations in the foreland basin, the proximal facies is formed by a clastic wedge, grading into distal marine shales and a carbonate platform..

The main shortening occurred in two pulses in the Late Miocene to Recent expressed at surface by distinct elevation breaks. Seismic data show that abrupt changes in topographic elevation are associated with out of sequence thrusting related to basement faults at depth. The successive shortening events are also expressed by thick syndeformational clastic successions of the Agha Jari and Bakhtiary formations. The interplay between successive shortening events and associated sedimentation is evaluated in sequentially restored cross sections.

We suggest that fault-related folding in the Zagros fold-thrust-belt is the product of a complex interplay between coeval detachment style faulting and folding and coeval hard-linked basement controlled thrust systems. Basement controlled structuring (<20%) had a profound influence on first order petroleum traps. Successive shortening events coupled with numerous detachment horizons lead to rather complex internal structuring of folds at reservoir level, which look deceptively simple at surface.

The talk highlights how an integration of outcropping reservoir analogues with seismic data complemented by structural modelling techniques can be employed to characterise and improve the understanding and the prospectivity of structurally complex petroleum provinces.

NOTES

Wednesday 14 May

Overview

Chair: Andy Whitham

Exploration in fold and thrust belts - a losing battle?

Graham, Rod, Hess

There is an expression much used on the other side of the Atlantic that 'what comes around goes around'. This seems to apply with a vengeance to the hydrocarbon potential of fold and thrust belts – conferences like this one keep on coming around. One can see why -most of us find fold and thrust belts fascinating and exiting. We like working on them. We would dearly like to see them as significant hydrocarbon provinces and our hopes rise with every jump in the price of oil, and every new LNG facility.

However, we all know that with the obvious exception of the gravitational systems of the passive margins, fold and thrust belts have a major disadvantage as hydrocarbon provinces - they elevate rocks which were once more deeply buried, with consequent damage to the elements of their hydrocarbon systems. It takes a special combination of circumstances to keep a thrust-related structure at maximum burial depth and ensure that structures are developed in time to receive matured and migrated hydrocarbons. Thrust belts have obvious attractions - the potential traps are large and the previous exploration is usually limited. Unhappily, these things exist along with, or because of, a host of problems, not least that the nice big structures are normally very complex geometrically, yet have to be worked with poor and very expensive seismic. It is a hard road.

Another phenomenon which 'comes around and goes around' in the oil industry is the definition of new exploration opportunity – the search for new basins, new ideas, new possibilities. Twenty years ago I was part of a group charged with just this task. We saw fold and thrust belts as part of a 'new geography', sitting alongside the then unexplored deep water continental margins and the liberalising Soviet Union.

In addition to the obvious prerequisites of source reservoir and seal, we defined a number of criteria which seemed to be important for success (burial, age, simplicity and the detachment level in relation to the frontal structures) and homed in on a number of new areas. Mark Cooper has recently done a similar but more sophisticated analysis, identifying as screening criteria burial, the presence or absence of salt seal or detachment, whether the deformation is 'thick or thin skinned' and, most important, the relative timing of maturation, migration and trap formation.
Cooper is optimistic about future exploration and sees a yet to find of 120 billion boe, of which 55.5 billion is in the Zagros. The USGS have a similar view arguing that there is as much hydrocarbon to find as has already been found - somewhere around 135 billion boe.

I am much more pessimistic and attempt to justify this pessimism is made by citing four case histories. The first is has exactly the right characteristics – location, timing and a working hydrocarbon system. In the second the 'success criteria' were less clear and detailed modelling was done try and test the potential. The third is submarine and seemed to have everything going for it, but hasn't worked yet.

The forth should never have worked at all, yet is now an important gas field.

NOTES

The Hormuz Salt and the Structures of the South-Eastern Zagros Fold and Thrust Belt and Offshore Area

Jean Letouzey[1], Salman Jahani[2], Jean-Paul Callot[1], Dominique F de Lamotte[3]

[1]Institut Français de Petrole, Rueil-Malmaison, France (jean.letouzey@ifp.fr)
[2]N.I.O.C., Teheran, Iran
[3]Université de Cergy Pontoise, France

The South-Eastern Zagros fold-and-thrust belt, and the offshore Iranian structures are still under explored for hydrocarbon fluids. New geological field and seismic studies, allow us to present new structural sections, as well as new geological interpretations for the evolution of this region. The activity of salt domes in the Persian gulf, in a foreland position, is a reference for the pre-folding structures of the southern Zagros. This, combined with analogue models, allow us to investigate the parameters controlling salt diapirism and also the role of existing diapirs or salt ridges on Zagros folding.

In the studied area, nearly all the diapirs developed before the Zagros folding probably as early as lower Paleozoic time. These structures developed as emergent diapirs forming islands in the Neogene Sea, or were maintained at depth as buried salt domes. Salt-cored detachment folds and thrusts developed in the Zagros Fold-Thrust Belt during the Neogene time, triggering the uprising of pre-existing diapirs.

NOTES

Field evidences for a major Early Paleogene folding phase in the Zagros Simple folded Zone

Eric Blanc[1], Jaume Verges[2], Paul Gillespie[1], Emilio Casciello[2], Hadi Emami[1], Stephane Homke[1], Mohammad Hassan Ghasem Ghoodarzi[3], Tommy Egebjerg[1], Mehdi Valinejad[3], Dave Hunt[1], Ian Sharp[1], Finn Livbjerg[1], James Efstathiou[1], Pål Skott[1], Farid Taati[3], Eigil Rasmussen[1]

[1]StatoilHydro, [2]CSIC Barcelona, [3]NIOC

The Zagros fold and thrust belt is a seismically active orogen resulting from the collision between the Arabian and Eurasian plates during the Cenozoic.

It contains some of the most prolific hydrocarbon fields in the world most of which are producing from the folded upper Eocene-lower Miocene Shahbazan-Asmari reservoirs units.
These units (Shahbazan and Asmari) were flat lying and underformed during sedimentation and were deformed later on.

Paleomagnetic remanence works in giant fold growth strata close to the Zagros mountain front in western Lurestan indicate that the onset of folding took place after the deposition of the regional sealing unit, the Gachsaran formation (early-middle Miocene) and during the last 8 Ma old (Homke et al., 2006) with the deposition of Agha Jari-Bakhtyari and Quaternary sediments. Our recent fieldwork observations in southeastern Lurestan (this work) indicate though that many of the giant folds in the Lurestan province have recorded a phase of growth pre-dating the deposition of the Shahbazan-Asmari formations. Kinematic restoration even indicates that Paleogene early folding accounts there for up to half of the total shortening measured in cross section and corresponds to a shortening of around 10%.

The origin and driving mechanism of this Paleogene deformation is currently being investigated. Is it not known whether this widespread folding stems from:

- the local onset of continental collision;
- the docking against the Arabian Plate of an isolated continental block;
- the collateral damage zone of an obducted ophiolite thrust sheet onto the Arabian passive continental margin;
- widespread eastward gravity induced salt tectonics collapse over Paleogene flexural basin.

Regardless of the origin of these Zagros folds, their identification has several hydrocarbon implications. One of them being that areas in the Zagros fold and thrust belt which have been previously classified as non prospective, because they lie in zones where HC maturation pre-date the Zagros orogeny, may be, after all, locally prospective.

NOTES

Taking Geometry to the Limits and Beyond in Thrust Belt Analysis

Alan Gibbs, Gianluca Grando Graham Seed, and Ryan Shackleton, Midland Valley

Restoration and balancing have long been vital tools in building models of thrust belts and in enable geologists to identify and fill in “missing” interpretations at depth. Coupled with 2.5d data from conventional maps and/or DEM and satellite interpretations, the 2d section validation techniques can be extended to provide sophisticated 3d modelling tools for construction of full 3d static and 4d kinematic models of thrust belts.

The algorithms which have been traditionally applied, such as flexural slip, fault parallel flow, simple shear, trishear and hybrid “mixed mode” combinations all have specific characteristics that introduce an algorithmic bias into interpretational style and kinematic prediction. These geometric algorithms are dominantly 2d based with plane strain assumptions to allow their extension to 3d by varying displacement gradients but not transport directions.
The interpreter then has to choose and justify the appropriate algorithm, often on the basis of limited observational control.

Despite these limitations the power of the technique should not be underestimated. However, as we require increasing predictive capability from our analysis we need new modelling algorithms which allow kinematic prediction which is not confined by plane strain assumptions or constrained by user choice of transport direction for a particular slip event. In order to provide this additional capability we have developed a “mass spring” approach which allows analytical speed and flexibility comparable with conventional approaches but which delivers full 3d strain and deformation information.

NOTES

Fundamental Controls on the Structural Variability of Fold-Thrust Belts in the NW Tarim Basin, China

S A Turner, D H Weeks, J W Cosgrove & J G Liu, Basins Research Group, Department of Earth Science & Engineering, Imperial College London, London, UK*

*(*Presenting author's e-mail: seb.turner@imperial.ac.uk)*

Variations in the rheology of the sediment pile, the dip of the basal detachment surface and the presence of major, pre-existing structures play important roles in the development of subsequent fold-thrust belts. These controls have important implications regarding the style and organisation of structures (folds and thrusts) and hence the distribution of hydrocarbons in compressional settings. The Kepingtagh fold-thrust belt and neighbouring Kashgar fold belt, NW Tarim Basin, China, provide exceptional examples of active deformation in a foreland setting and show dramatic along-strike variations in deformation style and geometry. Field investigations combined with satellite image interpretation have been used to examine the relationships between pre-existing structures, resultant sedimentary facies and thickness variations, and the architecture of the superimposed fold and thrust belts. The Kepingtagh fold-thrust belt comprises a series of ENE-WSW trending thrusts that define an arcuate salient, exposing a Cambrian through Neogene succession. To the west, the transition from the Kepingtagh fold-thrust belt into the Kashgar fold belt is characterised by an increasing dominance of detachment folds, which expose only a Neogene succession. There is no evidence of thrusting near to the surface, and the geometry of the folds suggests an important element of transpression. The transition from the Kepingtagh to the Kashgar belt appears to be related to a significant thickening of the sediment pile (and possibly an increase in the dip of the basal detachment surface) from east to west. In turn, this may be controlled by the presence of major, pre-existing fault zones such as the prominent N-S trending Piqiang Fault. During the Late Cenozoic, this fault has acted as a transfer fault and lateral ramp within the Kepingtagh belt. Stratigraphic discontinuities across the fault indicate that it was active prior to the Cenozoic, and may have influenced the NW Tarim Basin during the Late Paleozoic and Mesozoic. Understanding the fundamental controls on the evolution of the Kepingtagh and Kashgar fold and thrust belts provides not only an insight into the active deformation of the hydrocarbon-rich Tarim Basin, but can be applied as an analogue for similar fold-thrust belts worldwide.

NOTES

Moran Oilfield, Papua New Guinea: A case study

Nigel Wilson, Kevin Hill, Jeremy Iwanec, Dave Lund, Ken Xu, Phil Mann and Keith Bradey*
Oil Search Limited, Level 27, 123 Pitt Street, Sydney NSW Australia 2000
Email nigel.wilson@oilsearch.com

The Moran Oilfield and is a tight fold with a break-thrust through the overturned forelimb that formed during Pliocene arc-continent collision. The field has proven and probable reserves of ~100 MMBSTO which are mainly contained in an 800m oil column within its 30-50 degree dipping back-limb. The Upper Jurassic Digimu and Toro sandstone reservoirs have typical porosities of 13.5% and effective permeabilities of 200-50 mD, respectively. They are overlain by >1 km thick Early Cretaceous shales and >1 km Miocene limestones. The shales are internally deformed and act as a partial detachment making it difficult to predict the reservoir geometry directly from the limestone carapace. Furthermore, the shales are weakened in the northwestern part of the field due to a volcanic matrix component which heightens internal deformation and borehole instability. Cross-cutting faults define both ends of the field, with an abrupt replacement of reservoir by a limestone repeat to the northwest and an 800m oil column sealed against a water column at the same elevation to the southeast. Internally, the field is also strongly compartmentalized by cross-cutting faults thought to be influenced by underlying basement structures. The steep and variable dips, strongly karstified limestone and extreme topography result in poor quality seismic data. Exploration and development thus require integration of multiple techniques and datasets when conducting structural interpretation. Detailed dating of the surface limestone using 87Sr/86Sr isotopes combined with reservoir mass-balance modeling during production has helped define cross-cutting faults at reservoir level. As deformation is ongoing, recent acquisition and modeling of earthquake seismic data has helped delineate the structure and enabled development of a velocity cube suggesting uplifted basement at depths of ~6 km. Combined with seismic data and balanced cross-sections, this suggests a sub-thrust inversion play yet to be tested.

NOTES

Tectonic Wedging in the Northern Mackenzie Mountains and Southern Richardson Mountains, Northwest Territories and Yukon, Canada

Adriana Taborda[1] and Deborah Spratt[2]

[1]Husky Energy, Calgary, Canada (Adriana.Taborda@Huskyenergy.ca)
[2]University of Calgary, Calgary, Canada (daspratt@ucalgary.ca)

The frontal ranges of the northern Mackenzie Mountains, Northwest Territories, exhibit an abrupt change in structural trend from predominantly N-S in the Mackenzie Plain to E-W in the Peel Plateau area, and N-S again in the Richardson Mountains, Yukon Territory, resulting in a very pronounced arcuate shape. Across the Mackenzie Plain Basin, the Franklin Mountains mirror the changes in the structural trend and parallel the Mackenzie Mountains for a distance of 600 km. Understanding the geological history and structural style of this underexplored region of northern Canada is essential to better define its hydrocarbon potential.
Integrated interpretation of approximately 9,000 km of 2D reflection seismic data, constrained by more than 100 wells and regional and detailed surface geology shows a remarkable consistency in the structural style of the mountain front, despite the marked contrast in structural trend.
The interpreted style of deformation in the region is thin-skinned, regardless of whether the Proterozoic strata involved are metamorphosed or not. The subsurface structure at the mountain front of the northern Mackenzie Mountains and Richardson Mountains is dominated by classic triangle zone geometries and tectonic wedging developed at different stratigraphic levels in Neoproterozoic to Cretaceous strata. In contrast, the prevailing deformation style beneath the northern Mackenzie Plain and Franklin Mountains is a hybrid of detachment folding and fault propagation folding related to the presence of the Evaporite Member of the Upper Cambrian Saline River Formation.

NOTES

Thursday 15 May

Session 1: Overview

Chair: Enzo Zappaterra

Fold-Thrust Belts at Peak Oil

Dietrich Roeder, Murnau Geodynamics

Onshore fold-thrust belts of Mesozoic to Recent age are associated with global compressional margins and with a textbook-size list of geological properties. FTB are also the habitat of 25 % of the known oil and gas (2.8 TBOE), or of 6 % excluding the Middle-East-FTB reserves. Given high crude prices, the last undiscovered 1 to 3 % of TBOE may see exploration despite globally increasing political control. In size, geology, and risk, the offshore FTB potential may be of the same magnitude as the onshore, but it requires significantly higher development costs, higher deliverability rates, and therefore a higher economic threshold. High energy prices and the knowledge of onshore FTB geology will be needed to sustain future investment in deep-water FTB as energy sources.

NOTES

Structure of the western Brooks Range fold and thrust belt, Arctic Alaska

Jose de Vera & Ken McClay

The western Brooks Range fold and thrust belt of Alaska exposes a telescoped Late Devonian through Jurassic continental rifted margin, now preserved as a stack of NE-SW-trending, NW-verging, internally imbricated and regionally folded allochthon thrust sheets. These were emplaced as a result of arc-continent collision during the Middle/Late Jurassic-Late Cretaceous Brookian orogeny and subsequently uplifted by late tectonic activity in the Tertiary. The fold and thrust belt consists of seven tectonostratigraphically distinct thrust sheets or allochthons. The lowermost of these is the Endicott Mountains allochthon, which is overlain by the structurally higher Picnic Creek, Kelly River, Ipnavik River, Nuka Ridge, Copter Peak and Misheguk Mountain allochthons, each representing a distinct part of the ancient continental margin. The thrust sheet stack is separated from relatively undeformed strata of the North Slope foreland basin by a well-developed thrust front, whose position, orientation, vergence and structural styles vary significantly along-strike. These changes are best represented by the Wulik Peaks transverse zone, a regional-scale feature along which the thrust front trends at a high angle to the dominant NE-SW-trending structural grain of the fold and thrust belt. Structural, stratigraphic, and geophysical data suggest that the along-strike changes in the geometry and position of the thrust front and the development of the Wulik Peaks transverse zone resulted from the inheritance in the Early Cretaceous of Late Devonian to Jurassic WNW-ESE- to NW-SE-trending extensional faults of the ancient continental margin. WNW-ESE-trending Tertiary (Eocene) to present-day extensional faults record extensional reactivation of the Wulik Peaks transverse zone and close a remarkable cycle of Late Devonian to Present Day inheritance of WNW-ESE- to NW-SE-trending fault systems.

NOTES

Structure, Miocene Evolution and Hydrocarbon Potential of the Frontal Polish Carpathians (Pilzno – Andrychow): New Model Based on Integrated Analysis of Geological and Geophysical Data

Krzywiec P[1], Aleksandrowski P[2], Oszczypko N[3], Sieniawska I[2], Oszczypko-Clowes M[3], Kijewska S[1], Wróbel G[1], Bukowski K4, Siupik J[4], Florek R[5]

[1]Polish Geological Institute, Warsaw, [2]University of Wroclaw, Wroclaw, [3]Jagiellonian University, Kraków, [4]University of Mining & Metallurgy, Kraków, [5]Polish Oil & Gas Company, Kraków;

The Polish Outer Carpathians comprise several thrust sheets (units) composed mostly of Cretaceous through Paleogene deepwater siliciclastic flysch. The most externally located units in the nappe pile represent Miocene siliciclastic deltaic sediments of the Carpathian foredeep basin. The sub-Carpathian basement is highly inhomogeneous, both regarding its stratigraphy (ranging from Precambrian to Cretaceous) and top surface morphology. Using 11 regional seismic transects located above the Carpathian front (between Pilzno - Andrychow) calibrated by deep wells and additional 2D/3D infill seismic data a new structural model of the orogenic front and its basement has been recently constructed. In the western segement Carpathian wedge is characterised by flat sole thrust located above mostly undeformed Miocene foredeep infill and faulted Palaeozoic basement. Within the tectonic "Gdow embayment" thick-skinned structures detached in the Meso-Paleozoic basement influenced Miocene evolution of the Carpathian front. The central-eastern part of the Carpathian front in the study area is dominated by wedge tectonics induced by combined effect of diverse erosional morphology of the pre-Miocene basement and the extent of the foredeep evaporites. It produced a well-developed triangle zone of the Miocene Zglobice unit, frequently cored by highly deformed salt succession. Results of structural interpretation of seismic data were verified using forward structural seismic modelling. Proven and potential HC accumulations are related to anticlinal bends of horses comprising a passive-roof duplex, and to detachment folds above the roof backthrust. Beneath the floor thrust of the Zgłobice unit, within the erosional paleovalleys cut into the Meso-Paleozoic basement, lower Badenian and/or Paleogene siliciclastic infill could be possibly related to the potential stratigraphic traps sealed by the Badenian evaporites.

NOTES

The Outer Albanides: Geodynamic Setting, Structural Architecture, and Petroleum Potential

Davide Scrocca[1], Carlo Doglioni[2], Paola Arecco[3], Luan Nikolla[4], Domenico Cannata[2], Lorenzo Petracchini[2] & Riccardo Recanati[1]

[1]Istituto di Geologia Ambientale e Geoingegneria (CNR), Sezione La Sapienza – Rome, Italy
[2]Dipartimento di Scienze della Terra, Università La Sapienza – Rome, Italy
[3]Gas Plus Italiana SpA – Fornovo Taro, Italy
[4]Agjensia Kombëtare e Burimeve Natyrore (AKBN), Tirana, Albania

The Albanides, a segment of the Dinarides-Hellenides orogen, share the overall tectonic signature of orogens related to NE-directed subduction zones (e.g., Doglioni et al., 2007). Nonetheless, the external portion of this orogen (i.e., the Outer Albanides) show some remarkable peculiarities, as for instance the presence in its central and northern sectors of a deep basin, the so-called PeriAdriatic Depression. This basin, filled with Neogene-Quaternary siliciclastic and terrigenous deposits more than 6 km thick, developed in Miocene times when the Albanian off-shore and the frontal zone of the outer Albanides accretionary prism (deformed in Late Oligocene-Middle Miocene) were affected by an unexpected strong subsidence.

Although the Peri-Adriatic Depression is generally interpreted as the Albanides foredeep basin (e.g., Roure et al., 2004), its offshore depocenter is characterised by a thinned continental crust (<24 km; Dèzes & Ziegler, 2001), an anomalously high heath flow (>80 mW/m2; Cermak et al., 1996), and a still persisting physiographic depression.

These regional evidences, corroborated by field and seismic reflection data, clearly indicate the occurrence of an Oligocene(?)-Miocene extensional/transtensional phase. This was unrelated to the subduction process, being located obliquely in the foreland, and affecting and collapsing also the active Albanian orogen during Miocene times. Contemporaneous and later to the extension, forward thrust propagation affected and exhumed part of this basin in the Outer Albanides. Therefore the subaerial erosional unconformities, related to the early stages of growth of the belt, have been first collapsed by the rifting episode and sealed by the coeval Miocene sediments, and then uplifted along the thrust belt front during Late Miocene up today.

The Oligocene(?)-Miocene tensional tectonic event and the related thermal input have been generally undervaluated. However they could have played a crucial role for the generation of the Albanian hydrocarbons. The study area shows that in a single region more than one geodynamic setting can coexist, providing evidence for the passive role of plate boundaries in the tectonic processes.

Cermak, V., Kresl, M., Kucerová, L., Frasheri, A., Kapedani, N., Lico, R., and D. Cano, 1996, Heat flow in Albania: Geothermics, v. 25, no. 1, p. 91-102.
Dèzes, P. and Ziegler, P. A., 2001: European Map of the Mohorovicic discontinuity. 2nd EUCOR-URGENT Workshop, <http://comp1.geol.unibas.ch/downloads/Moho_net/euromoho1_3.pdf> Accessed October 10, 2007.
Doglioni C., Carminati E., Cuffaro M. and Scrocca D. (2007): Subduction kinematics and dynamic constraints. Earth Science Reviews, 83, 125-175, doi:10.1016/j.earscirev.2007.04.001.
Roure, F., S. Nazaj, K. Mushka, I. Fili, J.-P. Cadet, and M. Bonneau, 2004, Kinematic evolution and petroleum systems—An appraisal of the Outer Albanides, in K. R. McClay, ed., Thrust tectonics and hydrocarbon systems: AAPG Memoir 82, p. 474 – 493.

NOTES

Potential Natural Gas Plays in Ductile Duplexes: an Example from a Recess in the Appalachian Thrust Belt in Georgia, USA

Cook, Brian S, and Thomas, William A, University of Kentucky, Department of Earth and Environmental Sciences, Lexington, Kentucky, USA (b.cook@uky.edu, geowat@uky.edu)

Sinuous map traces around salients and recesses characterize orogenic thrust belts. In a well-defined Appalachian recess in Georgia (USA), two distinct regional strike directions intersect at approximately 45°; fault intersections and interference folds enable tracing of both structural strikes. The intersection and fold interference exemplify a long-standing problem in volume balancing of palinspastic reconstructions of sinuous thrust belts. Cross sections generally are constructed perpendicular to structural strike, parallel to the assumed slip direction. An array of cross sections around a structural bend may be restored and balanced individually; however, restorations perpendicular to strike across intersecting thrust faults yield an imbalance in the along-strike lengths of frontal ramps. The restoration leads to a similar imbalance in the surface area of a stratigraphic horizon, reflecting volume imbalance in three dimensions.

Around the recess in Georgia, tectonically thickened weak stratigraphic layers--mainly shales of the Cambrian Conasauga Formation and Mississippian Floyd Shale--accommodated ductile deformation associated with the folding and faulting of the intervening Cambrian-Mississippian regional stiff layer. The exposed stiff-layer structures in Georgia may be analogous to those over shale-dominated ductile duplexes (mushwads), which are being developed for natural gas elsewhere in the Appalachian thrust belt.

NOTES

Thursday 15 May

Session 2: Exploration in Thrust Belts: Case Studies

Chair: Rob Butler

Adding Reserves in Fold-Thrust Belts

Andrew C. Newson, Moose Oils Ltd, Calgary, Alberta

The Moose Mountain oil and gas field is 100 kilometers west of Calgary, in the southern part of the western Canadian fold-thrust belt. The field is an antiformal stack of Paleozoic carbonates formed during the Laramide Orogeny. The uppermost sheet of the duplex outcrops at the surface at Moose Mountain.

There are two proven Paleozoic reservoirs, the Mississippian Turner Valley formation and the Devonian Palliser formation. The reservoir rocks are fractured, secondarily dolomitized carbonates with poor matrix porosity and permeability. Both occur in multiple thrust sheets from surface (+2000 m) to regional (-6000m). Production is from at least three sheets with separate gas water contacts and reservoir pressures.

In the past this field has been interpreted using a fault bend fold deformation model. A recent reinterpretation using some of the classic structural tools such as dip domain analysis, down plunge projection and balanced cross sections has resulted in a more robust deformation model for the field. It would now appear that several of the sheets have a strong detachment folding overprint. This revised model has resulted in the discovery of new gas pools that have doubled the original size of the field.

Given the success in discovering new reserves at Moose Mountain with classical structural tools it would appear that these techniques could be successfully applied in other fold-thrust belts around the world.

NOTES

Crustal Architecture, Fold Belt Development and Oilfield Compartments in Papua New Guinea

Kevin C Hill, Jeremy Iwanec, Keith Bradey, Nigel Wilson & Rodi Heidorn, Oil Search Limited, Sydney, NSW, Australia (kevin.hill@oilsearch.com)

The Papuan Fold Belt formed in the Pliocene following Miocene oblique collision of an island arc with the northern margin of the Australian Plate. Oil and gas fields were discovered in the mid 1980s and have been on production since 1990. The reservoirs are Late Jurassic - Early Cretaceous regional sands, sourced from Middle Jurassic black shales and regionally sealed by Early Cretaceous mudstones. The NW-striking Fold Belt overlies N-S-trending basement terranes that have compartmentalized the fold belt and oilfields within it. These terranes probably resulted from the E-W directed Late Permian to Early Triassic New England Orogeny, prominent throughout eastern Australia, abutting Proterozoic basement in western New Guinea. Their existence is inferred from surface geology combined with regional reflection seismic data, high resolution aeromagnetic data, substantial changes in oilfield pressures across 'lineaments' and oil vs gas provinces. Furthermore, analyses of rotation of the stress-field within wells and recently acquired passive earthquake-seismic data indicate reactivation of N-S basement faults that segment fields and occasionally result in pinched casing. In the sedimentary cover, seismic data and over 250 wells show that the productive fields are in closed to tight, often overturned, SW-verging folds formed above a mid-Jurassic detachment. Minor antithetic backthrusts are common and are important elements in trap development for the major oil and gas fields. New regional seismic lines and structural modeling indicate that the Jurassic detachment faults link back into basement thrusts that were probably Jurassic extension faults, some of which have been reactivated as out-of-sequence thrusts. The latter appear to be significant in separating a high pressure zone to the north from normal pressures in the producing fields. A prime example is the 100+million barrel Moran oilfield which straddles a major basement terrane boundary and is segmented by it into producing normal-pressure and non-producing high-pressure compartments.

For further details see http://www.geolsoc.org.uk/gsl/groups/specialist/petroleum/page747.html

NOTES

Exploration of the Kutubu Oil Field, Papua New Guinea

Keith Bradey, Nigel Wilson, Jeremy Iwanec, Tom Kivior, Dan Kendrick & Kevin Hill, Oil Search Limited, Sydney, NSW, Australia (keith.bradey@oilsearch.com)

The 350mmbl Kutubu Oil Field in the PNG Fold Belt is a double-humped structure, comprising the Iagifu and Hedinia anticlines. Exploration in PNG commenced in the 1920's, but Iagifu was the first commercial discovery in 1987 - drilled solely on the basis of surface geology and structural models, and going on production in 1990. Production is from Late Jurassic - Early Cretaceous shoreface and estuarine sand reservoirs with a Middle Jurassic source, sealed by Early Cretaceous shales, all deformed in the Early Pliocene by collision of an island arc with Australia. Early structural models inferred simple thin-skinned fault-bend folds, but further drilling revealed a tight, overturned forelimb and minor backthrusts. By the early 90's it was clear that thrust faults and tear faults divided the reservoirs into several production blocks, some with water above adjacent oil. Also, the structure was interpreted as a fault-propagation fold that developed into a break-thrust and small-scale duplexes were inferred at both reservoir and seal level. Alternatively, others suggested that the structure resulted from half-graben inversion with relatively little shortening. From the late 1990's, acquisition of 5 seismic dip lines and 3 strike lines of varying quality, at a cost of US$80,000/km, combined with data from 50+wells allowed a more complete picture to be developed. The Kutubu field appears to correspond to an area of regional basement uplift, probably inversion, bound by lateral ramps and overlain by thin-skinned folds. Recognition of the basement uplift is important as it reveals the potential for large sub-thrust gas and oil-bearing structures currently under investigation. Within the field, faults smaller than seismic resolution continue to confound the production engineers. Even with our improved understanding, each appraisal well is almost an exploration well as we are frequently surprised by the results. Not for nothing is PNG known as the "Land of the Unexpected".

NOTES

The Petroleum Potential of the Banda Fold and Thrust Belt

Tim Charlton, Saint Omer Ridge, Guildford, Surrey, UK (charlton@manson.demon.co.uk)

The Banda arc-continent collision zone in eastern Indonesia and Timor-Leste is structurally a fold and thrust belt. Numerous oil and gas seeps are found in the Banda forearc islands, and one moderate sized oilfield (Oseil, reserves 39mmbo) is in production in Seram island, with additional nearby small-scale production from Plio-Pleistocene traps (Bula fields). The geology of the Banda foldbelt is widely characterised as complex, but this complexity has been overstated. Large, coherent anticlines are exposed at outcrop (e.g. the Aituto Anticline in Timor-Leste), and comparable structures can be inferred in the subsurface. These anticlines are inversion structures, developed in the late stages of orogenesis below a more complex thin-skinned fold and thrust belt. Syn-rift restricted marine shales and carbonates of Late Triassic age have been characterised as excellent source rocks, whilst broadly contemporaneous coarse clastic sediments shed into the extensional grabens/half-grabens provide potential reservoir sequence. The Late Triassic source and reservoir beds are sealed by thick Early-Middle Jurassic shales that also act as the décollement level for the thin-skinned foldbelt. Inversion of these Triassic grabens should provide a closed petroleum system, with clastic reservoir rocks at the crest of the large, structurally simple anticlines, and high-quality source rocks laterally downdip, sealed above by thick shales. Seismic resolution may be a problem below the shallow-level structural complexity, but these are far-from-subtle structures, and a number of geological and geophysical parameters (the distribution of oil and gas seeps and mud volcanoes; doming of Quaternary reef terraces; gravity data) provide strong supportive evidence for the locations of these potentially giant exploration targets. The Oseil field exemplifies this play, which in addition to Seram is present around the entire southern and eastern curve of the Banda Arc (Savu, Timor, Babar, Tanimbar, Kai).

NOTES

Stratigraphic control on the Vallfogona Thrust geometry: Eastern Pyrenees (Spain)

Daniel Bello[1], Josep Anton Muñoz[1], Eduard Roca[1], Miguel Lopez-Blanco[1], Jorge Navarro[2], Jesus Malagon[2]

[1]GEOMODELS Research Center, Universitat de Barcelona
[2]CEPSA Exploration & Production

The Eastern Pyrenees fold and thrust belt involves an up to 5 km thick succession of Paleogene foreland basin sequences deposited in front of the upper thrust sheets of the southern Pyrenees stack. These sequences are unconformably overlaying either a very thin Upper Cretaceous succession on Paleozoic basement rocks which are involved into an antiformal stack. Paleogene sequences show a 10 km wide and 64 km long syncline (Ripoll Syncline), the hangingwall of the main frontal thrust (Vallfogona Thrust) and constitute a hydrocarbon system which has been explored since the 60's. In the foreland the Paleogene succession is thinner and shows a different facies arrangement. The interpretation of recently reprocessed seismic data (Final Stack and Final Migration) and their integration with surface and well data has been the basis for a new structural model of the area. The presence of an anomalous thick series of evaporitic rocks in the horses underlying of the Ripoll Syncline (unexpectedly drilled for 2000 m in the El Serrat Well) has been interpreted as a facies lateral change of the marls and turbiditic sequence. Such a dramatic facies lateral change acted as a mechanical barrier controlling both the location and geometry of the thrust system.

NOTES

The Aachen fold and thrust belt: an integration of surface geology, reflection seismics and new subsurface data from the deep geothermal well RWTH-1

Becker, Stephan, RWTH Aachen Univ.

The Variscan age Aachen fold and thrust belt forms the northwestern part of the Rhenish Massiv in Germany. In 2004, the geothermal well RWTH – 1 was drilled to a depth of 2544 m into the imbricated thrust-front of the fold belt providing a number of unexpected insights into the subsurface, partially contradicting existing geological models. This study presents an integration of the new borehole data (cores, wireline logs) with the re – interpretated 2D regional reflection seismics. The combined interpretation of dipmeter, formation image logs (FMI) and seismic data yielded encouraging results regarding the subsurface mapping of thrust faults and the highly deformed stratigraphy. One key result is the detection of a major subsurface roof – duplex structure at the front of the thrust belt that possibly formed during the latest pulse of the Variscan orogeny. The new interpretation results bear consequences for the structural restoration and balancing of the fold and thrust belt in that the displacement of individual thrusted blocks is probably much less than previously estimated.

NOTES

Complicated Thrust Triangle Zone in the Variscan Foreland of Sardinia.

Funedda Antonio, Dipartimento di Scienze della Terra, Cagliari, Italy (afunedda@unica.it)

In the Variscan foreland of SW-Sardinia (Western Mediterranean sea), in the Lower Carboniferous period, very close to the front of the nappe zone, repeated stratigraphic successions, km-scale offset of stratigraphic boundaries and an extensive brittle-ductile shear zone occurred. Several generations of folds, thrusts, and foliations developed, resulting in a complex finite structural architecture. The strong penetrative deformation that affected rocks beneath the basal thrust of the nappe stack produced structures with both foreland-directed and hinterland-directed (backthrusting) shear sense. Taking in account the cross-cutting and overprinting relationships, a change of the shortening direction, progressively from N-S to E-W, has been recognized. This progressive change produced the following structures: i) E-W trending open folds. ii) NW-SE recumbent, quasi-isoclinals folds with axial plane foliation and widespread, "top-towards-the-SW" penetrative shearing. iii) N-S trending folds with axial plane foliation. iv) During the final stage of shortening, in response to the buttressing of the foreland succession because the E-W and N-S folding, backthrusts developed. Backthrusting produced a new set of N-S trending folds, with hinterland facing direction (backfolding), that overprinted the foreland facing folds. As a consequence some "thrust quasi-triangle zones" shaped by forethrusts and backthrusts had built-up.

The investigated area provides an example in which conventional fault-bend and fault propagation -folding models are not suitable, and this structural framework might be of interest to understand deformative style in fold-thrust belts.

NOTES

Friday 16 May

Session 3: Structural Models and Modelling

Chair: Nigel Duxbury

Seismic processing in overthrust areas

Duque, Carlos[1], Checa, Jaime[1], Pastore, Daniel[2], Matthews, Steve[1]

[1]BP, [2]Veritas

Seismic data is a key exploration element in overthrust areas. However the acquisition and processing of seismic data in these areas has traditionally been a challenge. The execution of seismic projects is complex and expensive due to the difficulties in access and rough topography.

Latest developments in acquisition and processing techniques have provided significant improvements in the data quality of the acquired seismic data.

In data acquisition there have been significant improvements in recording equipment reliability and the amount of data that can be acquired by increasing the amount of channels that can be handled in the field. There have also been substantial changes in seismic acquisition design technologies that have allowed the acquisition of larger 3D seismic surveys cheaper and faster. In general an improvement in the quality of the acquired data has also been observed.

In the area of seismic data processing the problems remain the same: statics, velocities, noise attenuation, migration and seismic imaging.
All these problems are tightly inter-related. As the processing procedures are executed it requires a proper solution of any previous steps in the sequence. Some of them, such as statics and velocities, depend on each other, making it necessary to take an iterative approach for their solution. The failure to resolve any of the key steps will prevent achieving a good final result in the processing.

A lot of effort has been put by the industry in trying to address these problems.
New refraction statics algorithms have been developed. Refraction tomography is gradually becoming the standard in many areas for the solution of statics problems. These problems are associated with anomalies in the near surface layers.

The derivation of a velocity field in overthrust has always been a challenge due to the geological complexity of the subsurface. No magic tools exist in this area. Having previous experience with the area of analysis makes it easier to determine correct velocity trends. Velocity picking in overthrust differs significantly from conventional environments. It's also important to have a good understanding of the geology of the area.

Important improvements have been achieved in the field of noise attenuation. More powerful algorithms have been implemented for 3D data. These have made it possible to move into the area of pre-stack imaging. It's clear that pre-stack imaging is a critical tool in complex geology areas. The development of faster computers has made pre-stack time migration a standard procedure in seismic processing. New algorithms have been implemented for pre-stack depth migration. More accurate velocity models are built to properly handle the subsurface complexities.

The combinations of all these new tools have provided a new level in data quality for overthrust seismic.

NOTES

Typical Play Types and Prominent Exceptions in Foreland Fold and Thrust Belts

Jon Roseway, C&C Reservoirs Ltd, London

A comparative study of the structure, stratigraphy and petroleum systems of 33 foreland FTBs has revealed the great variety of structural settings that occur among FTBs well-endowed with hydrocarbons. Petroleum system elements show a strong bias towards passive-margin and foredeep megasequences. Around 40% of reservoirs in the studied FTBs are shelf carbonates and 90% of these belong to passive-margin settings. Sandstones of mostly foredeep marine-shelf and continental settings comprise another 40% of FTB reservoirs. 60% of the studied FTB reservoirs are fractured, involving twice as many carbonates as sandstones, and are primarily located in thrust-related folds. Unfractured sandstones make up 33% of reservoirs, typically occurring in thrust-top basins and gently folded foredeeps, while unfractured carbonate reservoirs are uncommon. The overwhelming majority of FTB source rocks are Cretaceous-Tertiary oil-prone marine shales deposited primarily on continental margins, but with a significant minority from basinal foredeep settings. The dominant top-seal lithology is shale, even among giant oil and gas fields. Examples of the commonly successful play types and notable exceptions will be presented.

NOTES

Multi-modal Approach to Balance Cross Section Drawing: Example from the Southern Taiwan Orogen

Wiltschko, David V and Rodriguez-Roa, Fernando, Department of Geology and Geophysics, Center for Tectonophysics, Texas A&M University, USA (d.wiltschko@tamu.edu)

Southern Taiwan marks the transition from accretion above the Manila Trench to the south and Eurasia - Philippine Sea Plate collision to the north. Fifteen serial balance sections through the southern Western Foothills Fold and Thrust Belt (WFFTB) show that the structures making up the transition are influenced by the presence of large pre-existing normal faults. The estimated aggregate shortening for the easternmost fault of the WFFTB is about 40 km. The restored position of the preexisting normal faults places the current trace of the Western Foothills-Slate Belt boundary beneath the Coastal Range. The restoration of WFFTB's rocks to their depositional locations also supports the tectonic model of a crustal-scale thin-skin collisional orogen and rejects a previous hypothesis favoring a deep rooted Central Range. GPS, thermal maturity and thermochronological data have made possible the constraints on these large normal faults. The thermal data indicate that the depth of involvement of the deformation in the orogen deepens to the east but changes character and perhaps deformation mechanism across the Slate Belt -Western Foothills boundary. Thermochronology has constrained both the maximum depth of burial and the timing of uplift of the easternmost thrusts of the WFFTB. GPS velocities largely mimic the location and orientations of ramps, confirm that most folds are actively growing and support the location and activity of blind thrusts at the toe of the WFFTB. A multi-mode approach to restoring cross sections in active or recently active areas measurably increases the constraints where seismic data are poor.

NOTES

Applied Methodology on a 3D Compressive Case Study: the Gaspé Belt

Sulzer, Caroline[1], Thibaut, Muriel[1], Jardin, Anne[1], Beche Martin[1], [2]

[1] *IFP, 1-4 avenue de bois Préau 92852 Rueil-Malmaison Cedex France*
[2] *Université de LAval, Québec*

Modelling precisely the kinematics of structural deformation of a sedimentary basin for petroleum system modelling purpose is still a challenge in 3D. We propose a new modelling workflow for the 4D structural modelling of tectonically complex environments . It is applied to a real case study, located in the central part of the Gaspé Peninsula, Québec part of the northern Appalachians. We focus our attention on the "Lac des Huit-Miles" syncline. It is 35 km wide and reaches 6. km in depth. It comprises Lower Silurian to Devonians rocks of the Chaleurs, Upper Gaspé limestone and Gaspé Sandstone groups. The syncline is limited to the north by the Shickshock Sud fault and to the south by the Causapscal anticline and the Causapscal fault. To realize the complete workflow, the methodology combines geomodelling, 3D restoration, and forward simulation of fluid pressure evolution. Kine3D-1, an IFP plug-in for 3D geological modelling is used to integrate data and build a coherent model at present day, Kine3D-2 is used to restore cross sections and build a coherent kinematic scenario. Next step is the gridding of the model through time for further pressure simulation.

NOTES

A Pseudo-3D Model of the Llanos Foothills, Eastern Cordillera, Colombia

Alex Bump, Jaime Martinez, and Jake Hossack, BP America, Houston, Texas

The Llanos Foothills comprise the eastern side of the Eastern Cordillera of Colombia, an early Miocene to present thrust belt that detaches in Cretaceous rocks. As in most thrust belts, interpretation is difficult due in part to poor seismic imaging and sparse data (a product of rugged, heavily vegetated topography). Nevertheless, work done by BP for the past 20 years and has yielded a pseudo-3D model of the Llanos foothills thrust belt.

An extensive series of cross sections were created in the mid-1990s based on outcrop, well and seismic data. These have been steadily refined with the addition of new well data. Most recently, these sections have been rectified to topographic and geologic maps to create a pseudo-3D model of the frontal thrusts and the easternmost duplex.

Beyond illuminating the basic structure of the thrust belt and its variation along strike, the model illustrates two key points. First, there is a marked contrast in the complexity of sections drawn without the benefit of well data and those drawn with it. The former tend to show relatively simple structures with long, continuous horses, while the latter show far tighter folds, more faulting, and internal ramps and flats within horses. Second, the model highlights some of the inherent difficulties in exploring on the basis of 2D seismic. Many of the frontal structures, which appear prospective for drilling, are either seismic artifacts or real but too shallow to form traps at the reservoir level.

NOTES

Friday 16 May

Session 4: Thermal Regimes

Chair: Graham Goffey

The Use of Paleo-Thermo-Barometers and Coupled Thermal, Fluid Flow and Pore Fluid Pressure Modeling for Hydrocarbon and Reservoir Prediction in Fold and Thrust Belts

Roure F[1&2], Andriessen P[2], Callot J P[1], Ferket H[1&3&4], Gonzales E[5], Guilhaumou N[6], Hardebol N[1&2], Lacombe O[7], Malandain J[1&7], Mougin P[1], Muska K[8], Ortuño S[3], Sassi W[1], Swennen R[4] and Vilasi N[1&4]

[1]Institut Français du Pétrole, 1-4 Ave. de Bois-Préau, F92852 Rueil-Malmaison (Francois.Roure@ifp.fr), [2]VU-Amsterdam, [3]IMP, Mexico, [4]KU-Leuven, Belgium, [5]Pemex, Mexico, [6]Museum Histoire Naturelle, Paris, [7]University Pierre & Marie Curie, Paris VI, [8]University of Tirana, Albania

Basin modeling tools are now more efficient to reconstruct palinspastic structural cross sections and compute the history of temperature, pore fluid pressure and fluid flow circulations in complex structural settings.

In many cases and especially in areas where limited erosion occurred, the use of well logs, BHT and paleo-thermometers such as Ro and Tmax is usually sufficient to calibrate the heat flow and geothermal gradients across a section. However, in the foothills domains erosion is becoming a dominant process, making challenging the reconstruction of reservoir rocks paleoburial and the corresponding calibration of their past thermal evolution. Many times it is usually not possible to derive a single solution for paleo-burial and paleo-thermal gradients estimates in the foothills, if based solely on maturity ranks of the organic matter.

Alternate methods are then required to narrow down the error bars in paleo-burial estimates, and to secure more realistic predictions of HC generation: AFT can provide access to absolute ages for the crossing of the 120°C isotherm and timing of the unroofing, whereas hydrocarbon-bearing fluid inclusions, when developing contemporaneously with aqueous inclusions, can provide a direct access to the pore fluid pressure and temperature of cemented fractures or reservoir at the time of cementation and HC trapping. Further attempts are also currently made to use calcite twins for constraining reservoir burial and paleo-stress conditions during the main deformational episodes.
The methodology integrating these complementary constraints will be illustrated using reference case studies from Albania, Mexico and the Canadian Rockies.

NOTES

The Northern Apennines Petroleum system: an integrated structural-geochemical approach

Vincenzo Picotti and Rossella Capozzi, Dipartimento di Scienze della Terra e Geologico-Ambientali, Bologna, Italy

The Northern Apennines F&T belt formed in the Neogene and evolved through the Quaternary as a uplifting chain and a subsiding foreland (the Po Plain and the Adriatic sea). Notwithstanding the simple style of the telescoped foredeep units, most of the culminations are sealed both by post-compressional deposits in the subsiding foreland and in the chain by the Ligurian nappe, a gravity-driven superficial thrust sheet, consisting of highly deformed oceanic crustal remains.

The structured foredeep deposits are locally charged and, where the cap rock is permeable enough or disrupted by faults, natural leakage of brines and hydrocarbons occurs (oil, gas and condensate), locally associated with mud volcanoes. The study of these fluids allows unravelling the petroleum system of the Apennines and helps localizing the residual potential of this F&T belt.

The geochemistry of the brines allows defining the main processes occurred during expulsion and migration of connate waters, and the relative contribution of meteoric waters to the system. Locally useful for the characterization of the depth of the reservoir is the integration of microbiological information on the present bacterial activity and their thermal affinity. The hydrocarbon geochemistry contributes to the definition of the source and constrains the maturation-migration history.

Integrating these data with the seismic-aided reconstruction of the subsurface structures, it provides a new picture for the Northern Apennines hydrocarbon evolution, with multi-source plays and complex migration pathways, locally controlled by Quaternary tectonic changes.

NOTES

Friday 16 May

Session 5: New Models

Chair: Enzo Zappaterra

Fold Belts Built from Below

Giancarlo Scalera, INGV (Istituto Nazionale di Geofisica e Vulcanologia), Roma

Abandoning the traditional 2-D sections – perpendicular to the trench-arc-backarc zones –, with the help of 3-D plotting on larger scale, which can visualize the entire extent of a Wadati-Benioff zone, a characteristic inhomogeneous pattern of hypocentres along the alleged subduction zones is revealed in the Italian region as well under Mediterranean and circum-Pacific active margins. Filaments and clusters of hypocenters are recognizable instead of planar or spoon-like patterns. Because very hardly a subductive process can produce similar deep hypocentral distributions, a new interpretation of the Wadati-Benioff zones and of their overimposed orogenic zones is proposed. The resulting global tectonics framework involves non-collisional orogenic processes – deriving from global expansion, rifting, isostasy, surfaceward flow of deep material, gravitational spreading, and mantle phase changes. The associated model of evolution of an orogen can be linked to the volume increase of an isostatically uprising mantle column which segments slowly overcome a solidus-solidus boundary of the temperature-pressure phase diagram. A concomitant upward directed force come from the Clapeyron slope of the phase changes (Figure 9) that displace the phase boundaries toward the surface.

The outpouring of the exceeding material drives the gravitational nappes to overthrust the sediments of the pre-existing trough, forcing them on a burial path, which emulate the subduction process, but without reaching depths greater then 50-70 km. At the boundary between uplifting material and down-pushed crust and lithosphere, phenomenon like metamorphism, mixing, migmization, upward transport of fragments of the buried lithosphere etc. are possible. The possibility that lenses-like HP-UHP exhumed fragment could be mechanical product of great earthquakes occurrence at depth not exceeding few tens of kilometres should be considered.

This model of evolution of a fold belt is in agreement with the tomographically revealed P-wave and S-wave high-velocity anomalies underlying – with different slopes – most orogens and arcs, and the obtainable topographic heights are consistent with the values of volume increase that are associated to the main mineralogical phase transitions. In this view, a discontinuous upward movement of mantle materials can be linked to the observed discontinuous evolution of the orogens and to the widespread observation of uplifted coastal terraces.

It is scrutinised if the proposed model is different from the collisional models as that concerns consequences on economic and oil geology.

NOTES

Transpressive Force Folding and Basin Inversion: Structural Evolution of Faulting Studied by Numerical Digitization of a Sandbox Experiment

William Sassi[1], Zsolt Schleder[2], Ahmed M Saeed[2]

[1]IFP, Rueil-Malmaison, France
[2]Midland Valley Exploration Ltd, Glasgow, UK

The evolution of deformation and fault development within a transpressive system with force folding was investigated by detailed structural analysis of an analogue model previously described by Mattioni et al. (2007). The X-ray computer tomographic representation of the 4D-analogue experiment was digitized to provide a total of 15 discrete block-diagrams of two layers of granular materials of a sand-silicone layer cake.

This provides a full 3D framework model of both the key stratigraphic layer interfaces and the arrays of faults in the sand. A pre-existing network of normal faults is submitted to transpression. The digital model is then used to restore or reconstruct the evolution of the sandbox model providing a suite of models describing both the 3d geometry and its evolution through time. The resultant 4D model was then analysed to provide an in depth quantification of the overall faulting processes from the generation of new faults under compressional and later strike-slip stress regimes. This technique which is being used for the first time is giving key constraints to characterise the amount of bulk material volumetric strain and the fault surface generation in relation with the progressive growth of a larger-scale force fold. Comparisons of the derived digital 4D analysis with the published forward model of Mattioni et al (2007) provides new insight to fault and force fold evolution and kinematics which can be applied to the interpretation and analysis of seismic and other data.

NOTES

New Geometric Model for Detachment Folds with Applications to Deepwater, Western Gulf of Mexico, USA

Troy D Waller II, Hess Corporation, Houston, Texas, USA (twaller@hess.com)
John H Spang, Center for Tectonophysics and Department of Geology and Geophysics, Texas A&M University, College Station, Texas, USA (Spang@geo.tamu.edu)
Bill Kilsdonk, Hess Corporation, Houston, Texas, USA (bkilsdonk@hess.com)

We propose new geometric models for detachment folds, which have a deformable lower layer (salt) based on seismic examples from the Perdido fold belt (deep-water western Gulf of Mexico, USA). The weak lower layer can both accommodate massive thickness changes and flow laterally. During folding anticlines move absolutely up and synclines move absolutely down displacing the weak layer until it thins to zero. Anticlines grow rapidly in response to compression coupled with addition of material from beneath subsiding synclines. Previous models consider anticlines to move up but constrain synclines to form in-situ. Our work expands on these by including the effect of compressionally formed downward moving synclines with upward moving anticlines above a mobile (salt) substrate. Analyses of several natural (Perdido) folds indicate flow of material from beneath compressionally formed synclines. Plots of excess-area versus an arbitrary depth to detachment for independently interpreted anticlines and synclines provide both the true depth to detachment and the area either lost or added during deformation.

NOTES

Application of tri-shear to syn-compressional growth strata geometry

Douglas Paton, School of Earth and Environment, University of Leeds.(d.a.paton@leeds.ac.uk)

The deep water Muttekopf Gosau Group, western Austria, provides an exceptional setting to study the interaction of structural deformation, stratigraphy and stratal architectures within a fold-thrust belt system. The basin's principle controlling structure, on the southern margin, comprises two structural domains: a western fold domain and an eastern thrust domain. This change in structural style has a pronounced influence on the basin fill. Strata in the fold domain are not dissected by faults, are laterally continuous, and the axis of accumulation migrates towards the north through time. This migration is interpreted to reflect progressive growth on the confining structure and can be modelled successfully using a tri-shear model. In contrast, strata within the thrust domain are dissected by a number of faults that compartmentalize the basin and result in significant local sand body thickness variations. We propose that the fold domain is underlain by a blind thrust, and that similar folding existed prior to thrusting in the east. The study provides insights into the temporal evolution of a fold to thrust progression and the associated variations in basin fill stratigraphy and stratal architecture. Only through this combined 3D approach of basin analysis can the importance of structural controls on 4D basin development be established.

NOTES

Poster Presentations Wednesday 14 May

Do Thrust Faults Limit Trap Potential in the Niger Delta Deep Water Thrustbelt Play?

Olga Kostenko[1], Steve Naruk[1], Willem Hack[1], Manuel Poupon[1], Hans-Jurg Meyer[1], Rod Nourse[1], Miguel Mora-Glukstad[1], Margaret Mordi[2]

[1]Shell International E&P
[2]Dajo Oil Limited

Recent discoveries in the Nigeria deep water thrustbelt have limited column heights and lack any proven thrust-fault-dependent columns. Whether the play's potential is confined to the 4-way closures above the highest thrust cutoffs, or can include additional thrust-fault-dependent columns is controversial, in large part due to seismic-no-data-zones that obscure the possible thrust cutoffs.

We present a structural evaluation and trap analysis of a Niger Delta deep-water thrust belt discovery. To constrain the structure within the unimaged forelimb, dip panels and fold axial surfaces were constructed from dip meter data from both a vertical hole and a sidetrack well through the no-seismic-data zone. Stratigraphic tops from both wells were projected through the no-data-zone using the dip panels and axial surfaces, maintaining the observed stratigraphic thicknesses. These data and analyses tightly constrain potential fault locations and offsets within the no-data zone.

The resulting balanced and restoreable cross section shows that the forelimb no-data-zone, which was originally interpreted as a thrust fault zone, is simply an overturned limb. Full 3D analysis shows that the overall structure is a faulted detachment fold. The trapped hydrocarbon columns are confined completely within the four-way structural closure, strongly suggesting that the trap's potential is not limited by the thrust faults' seal capacities.

Top seal analyses show that top seal integrity is not a limiting factor for hydrocarbon column heights at this location. By process of elimination, the limited column heights appear to be due to limited access to charge, consistent with both charge modeling and an observed the lack of thermogenic hydrocarbons in nearby structures.

Coupling Kinematic Evolution of Fold-Thrust Structures and Basin Modeling: Implications for Hydrocarbon Migration and Accumulation in Deep–Water Niger Delta

Carlos Rivero[1], Gary Muscio[1], Sankar Muhuru[1], and Richard Eisenberg[2]

[1] Chevron Energy Technology Company, Houston, Texas
[2] Chevron International Exploration & Production, Houston, Texas

The Inner and Outer fold–and–thrust belts of deep–water Niger Delta offer a unique opportunity to study relevant factors that predispose the location and evolution of hydrocarbons accumulations in fold–thrust belts. The fold-and-thrust belts are generated as a contractional response to gravity–driven extension in the shelf. They exhibit prominent and often active thrusting and folding, and structural styles consistent with a basal weak (overpressured) detachment level. Individual and imbricated thrust sheets soling into this base level represent some of the most important structural traps and exploratory targets in the basin. Many of these traps exhibit distinctive wedges of growth stratigraphy compatible with specific kinematic mechanisms and multiple phases of deformation.

Here we present an integrated study that focuses on the understanding of structural trap configurations, their kinematic history, temporal evolution in top and fault seal properties, and the collective influence of these parameters on hydrocarbon charge. We use subsurface data to objectively define the precise location of detachment zones, and balanced structural interpretations to illustrate the role of the detachments on influencing geometry and size of individual oil traps and regional fairways. Through the numerical integration of sequential structural restorations and classical charge modeling, we highlight the impact of ramp geometries and slip history on hydrocarbon migration. Our results also illustrate this relationship by contrasting charge scenarios of shallow versus deep-seated thrust ramps solutions, coupled with alternative scenarios of ages and stratigraphic locations for potential source rocks.

Contractional Domains of the Niger Delta: Structural Styles, Influence of Mobile Shale, and Structural-Stratigraphic Evolution

R W Wiener, M G Mann, W B Cotton, S L Boorman, C J Lopez, M T Angelich, J Molyneux, S A Barboza: ExxonMobil Exploration Co, ExxonMobil Upstream Research Co

The Niger Delta is a passive margin, detached, paired extensional-contractional system driven by gravity and sediment loading. Updip extension is linked to downdip contraction by a regional detachment in mobile shale. Structural styles in the downdip contractional domain include ductile detachment folds, shear fault bend and fault propagation folds, and tear faults.

The fold and thrust belt of the contractional domain is laterally segmented into regions characterized by tear faults and thrusts, backthrusts, forethrusts, and imbricated forethrusts. Tear faults are localized at major displacement gradient zones along delta lobe margins. The distribution of forethrusts and backthrusts is related to critical taper wedge geometry.

Early Tertiary mobile shale in the Niger Delta is characterized by seismic transparency, low velocity, low density, and ductile deformation style, indicating that it is overpressured and mechanically weak. Mobile shale thins basinward in the contractional domain and is associated with changes in physical properties and structural styles.

Structural features controlled distribution of paleogeographic elements and reservoir facies in the evolution of the Niger Delta. The downdip limit of contraction marks the paleo-toe-of-slope where distributive deposits accumulated, whereas ponded minibasin and channelized deposits formed on the slope where contractional deformation prevailed. These paleobathymetric features translated basinwards with time forming an overall progradational stacking pattern.

The Deepwater Fold-Thrust Belt Offshore NW Borneo: Gravity-Driven Versus Crustal Shortening

S Hesse[1], S Back[1] and D Franke[2]

[1]Geological Institute, RWTH Aachen University, Aachen, Germany
[2]Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany

The deepwater region offshore NW Borneo is an active fold-thrust belt that hosts a significant number of proven hydrocarbon accumulations. In the past, two mechanisms have been discussed as primary control for Neogene to recent folding and thrusting in this deepwater province, 1) crustal shortening and 2) gravity-related delta tectonics. In this study, new, balanced interpretations of regional, crustal-scale, depth-migrated 2D multi-channel seismic reflection profiles are presented that provide for the first time quantitative data on tectonic shortening throughout entire deepwater NW Borneo. We use this data for a comparison between deepwater compression on the NW Borneo slope and extensional tectonics on the NW Borneo shelf that enables us to quantify the contribution of shallow, gravity-driven shortening within the amount of total shortening of the deepwater fold-thrust belt. A key result of this balancing study is the observation that gravity-driven shortening in the fold-thrust belt generally decreases from south to north, as opposed to the trend of total shortening. Consequently, the spread of purely basement-driven compression along NW Borneo strongly increases towards the north.

The Barbados Accretionary Prism-Orinoco Delta Connection: Deformation Processes at the south-eastern Boundary of the Caribbean Plate

Deville E[1], Padron de Carillo C[1#], Huyghe P[2], Callec Y[1], Lallemant S[3], Lebrun J F[4], Mascle A[1], Mascle G[2], Noble M[5]*

[1]IFP, 1-4, av de Bois-Préau, 92 852 Rueil-Malmaison, France
[2]Université de Grenoble, 38041 Grenoble, France
[3]Université de Cergy-Pontoise, av du parc, 95031 Cergy-Pontoise, France
[4]Université des Antilles et de Guyane, 97159 Pointe à Pitre, France
[5]Ecole des Mines de Paris, 35 rue Saint Honoré, 77305 Fontainebleau, France
[#]present address: Universidad Simon Bolivar, Cable Unibolivar, Caracas, Venezuela
*present address: BRGM, Service CDG/CG, 3 av. Claude Guillemin, 45060 Orléans, France

Geophysical data acquired in the south-eastern Caribbean deep-marine area show the complexity of the deformation processes occurring in the transition between a frontal subduction zone and a compressional transform system (connection between the active transform fault system of the south of the Caribbean plate and the active frontal accretion zone of the front of the Barbados prism). This area which is also controlled by the high deposition rate of the Orinoco turbidite system is partitioned between a wide variety of recently active tectonic features developed over a large scale diffuse plate boundary. Multibeam and seismic data show sub-linear ramp anticlines developing at the leading edge of the prism, while a complex arrangement of folds is apparent at the southern lateral border of the prism, with notably, interference between different trending fold axes. Near the deformation front of the southernmost part of the prism, the fold-thrust system vanished out toward the south with an en-échelon geometry. In the core of the deformation zone, numerous active mud volcanoes are well developed notably along ramp anticlines. Also massive sub-circular uplift structures can be interpreted as resulting from the tectonic inversion of ancient collapse structures associated with the development of former mud volcano systems. At the southern border of the deformation zone, a sub-linear fault zone crosscuts the Orinoco Delta obliquely with respect to the continental slope, from the Atlantic abyssal plain to south of the Columbus basin where spectacular extension structures develop within this compressive and transpressional area. The Orinoco delta fault zone is characterized by active ENE-WSW normal dextral en-échelon strike-slip faults deforming the sea bottom whereas, according to the focal mechanisms, the underlying structures are opposed to those observed on the surface. We interpret this structural line as a recent reactivation of the Guyana transform margin around the Continent-Ocean Transition. This could be a relatively shallow consequence of a deep shearing of the lithosphere at the southern edge of the Atlantic subducting slab below the Caribbean plate. Structural balancing shows how all these very different recent to active structures can co-exist together and shows notably that an important clockwise rotation occurred within the deformed sediments of the south-eastern edge of the Caribbean plate.

Poster Presentations
Thursday 15 May

Regional geological cross-sections and tectonic style in Eastern Zagros fold-thrust belt and offshore area, Iran

Salman Jahani (NIOC, Iran), Jean Letouzey (IFP, France), Dominique F. de Lamotte (Cergy-Pontoise University, France) and Jean-Paul Callot (IFP, France)

The Zagros fold-thrust belt is the result of a complex geodynamic history which culminated in the Miocene-Pliocene folding. Toward south it is bonded by the Persian Gulf foreland basin. Hormuz series are distributed in the eastern part of the Neogene Zagros fold-thrust belt and Persian Gulf as salt diapirs or circular dome structures. It deposited in an evaporite basin during late Precambrian-early Cambrian age.

Several geological cross-sections were constructed in this region based on seismic images, well data, field observation which covered region from the offshore foreland to the middle part of the fold-thrust belt. Majority of folding in the south part of area formed as box fold which detached above the Hormuz series. Few local detachment layers have been determined in Triassic evaporite and Neogene sediments. Vergency of thrust faults are to the northward which located in the inner par. Calculated shortening in the south part of the fold-thrust belt is around 10 percent. Sediments thickness before Zagros folding have been controlled by thermal subsidence, NW-SE trend flexures in the Persian gulf and tilting in front of Oman mountains. A lot of rapid local sedimentary changing is happened around salt domes. They show salt activity from lower Palaeozoic until recent as salt dome or salt diapir.

Upper Pennsylvanian (Kasimovian) Potential Source Rocks and Shallow-Water Carbonates with Oil and Bitumen Inclusions in Late Variscan Wedge-Top Basin Successions: Picos De Europa Imbricate System (Cantabrian Zone, NW Spain)

Oscar A Merino-Tomé[1], Juan R Bahamonde[2], Luis P Fernández[2], Juan Ramón Colmenero[3], Elisa Villa[2] and Nemesio Heredia[4]

[1]Instituto Geológico y Minero de España, Parque Científico de León, León, Spain (o.merino@igme.es)
[2]Department de Geología, Universidad de Oviedo, Oviedo, Spain
[3]Deptartment de Geología, Universidad de Salamanca, Salamanca, Spain
[4]Instituto Geológico y Minero de España, Oviedo, Spain

Keywords: Source rocks, wedge-top basins, Variscan Orogen, Cantabrian Mountains, Picos de Europa, Carboniferous.

Potential source rocks and shallow-water carbonates with oil and bitumen inclusions are present in Kasimovian (Late Pennsylvanian) wedge-top basin successions in the Variscan foreland and thrust belt in the Cantabrian Zone (Picos de Europa imbricate system, core of the Ibero-Armorican Arc, NW Spain). Those basins formed during the last stages of the Variscan Orogeny when tectonic deformation affected a giant microbial carbonate platform that grew on the distal realms of the foreland basin developed on the Gondawana continental margin. The advancement of the orogenic front caused the break up of the previous carbonate successions into E-W oriented thrust sheets (considering present day coordinates) that were emplaced southwards forming a complex imbricate system that remained mostly submerged during the initial stages of deformation. This portion of the orogenic wedge was characterized by a gently dipping mean topographic surface (α values probably <1º) that approached to sea-level. E-W elongated submarine troughs separated by tectonic uplifts consisting in growth anticlines constituted the main depocentres. Dark grey organic-rich shales forming thick prodeltaic slope mudstone wedges with intercalated calcareous debris filled the troughs in the areas close to the the shoreline of the marine basin. Eastwards, in areas located far away from the alluvial-derived siliciclastic input, thinly laminated dark-grey to black lime-mudstones accumulated in the troughs. Coeval narrow carbonate ramps frequently nucleated on the thrust-top tectonic uplifts.

Elevated burial rates of organic carbon in the wedge-top successions took place due to: 1) enhanced primary productivities (constrained by microfacies analyses, composition of benthic communities and sedimentological data) by the input in the marine basin of land-derived nutrients via riverine runoff; in combination with 2) the wedge-top configuration characterized by narrow and poorly connected troughs separated by shallow ridges that conceivably limited the deep water circulation and favoured the existence of poorly oxygenated bottom waters. Those successions were not deeply buried after deposition. Nevertheless, the presence of oil and bitumen inclusions filling primary and secondary porosities that characterize the carbonate ramp limestones, indicate that maturation of organic matter occurred. Probably a late Variscan tectonothermal event that may be linked to the closure of the Iberoarmorican Arc (see Gutiérrez-Alonso et al., 2004) triggered the thermal maturation of organic matter at shallow burial depths. High CAIs indicating transitional conditions to metamorphism are recorded (Bastida et al., 2004) in the imbricate system.

REFERENCES

Bastida, F., et al., (2004): Transition from diagenesis to metamorphism in a calcareous tectonic unit of the Iberian Variscan belt (central massif of the Picos de Europa, NW Spain, Geological Magazine, 141:617-628.
Gutiérrez-Alonso, G. et al., (2004): Orocline triggered lithospheric delamination, in Sussman, A.J., et al., eds., Orogenic curvature: Integrating Paleomagnetic and Structural Analyses: GSA Spec. Paper, 383: 121-130.
Merino-Tomé, O., et al (in press): The record of an advancing orogenic wedge and evolution from distal foreland basin towards wedge-top sedimentation during Variscan Orogeny. Upper Pennsylvanian (Moscovian-Gzhelian) successions of Picos de Europa (Cantabrian Mountains). Submited to the GSA Bull.

Modeling Bed Dips in Horizontal Wells in Fold-Thrust Belts

Andrew C Newson, Moose Oils Ltd, Calgary, Alberta and Charles R Berg, Resdip Systems, Houston, Texas

Highly deviated and horizontal gas wells in fold-thrust belts are costly and technically challenging to drill. During the drilling of a well it is important to be able to geo-steer the well to optimize the reservoir performance. For this purpose the dip and dip direction of the reservoir formation is necessary. To do this we need the TST thickness of the formation.

Residual Dip Analysis (RDA) software uses three dimensional trigonometry and interactive windows to correct the measured while drilling (mwd) gamma from measured depth to TST. This is done using the following equation:

$$TST = MT \cdot \left(\cos\psi - \sin\psi \cdot \cos\alpha \cdot \tan\phi\right) \cdot \cos\phi$$

MT = measured thickness, TST = true stratigraphic thickness, □ = dip, □ = the dip azimuth minus the borehole azimuth, and □ = borehole inclination from vertical. (Tearpock and Bischke, 1991)

By using eigenvector analysis, vector mean, or vector median to average (smooth) the data, an accurate TST calculation can then be made in zones of highly variable dip density and direction. This TST calculation is carried out on a decimeter scale to accurately predict the distortion of the mwd gamma log.

Using this technique in conjunction with an offset template well it is possible to predict the dip and dip direction of the beds in the borehole while the well is being drilled. This would allow the operator to geo-steer the borehole in real-time to intersect the reservoir formation for optimal reservoir performance.

References:
Tearpock, D.J., and R.E. Bischke, 1991, Applied Subsurface Geological Mapping, Prentice-Hall, Inc. Englwood Cliffs, New York.
Residual Dip Analysis (RDA) software is produced by Resdip Systems, Houston, Texas.

Advanced Remote Imaging Techniques to Map the Zagros/Taurus Fold-Thrust Belt of Northern Iraq

GJ Banks and CA Watkins, Fugro Robertson Ltd

Exploring hydrocarbon potential in complex fold-thrust belt regions requires time-consuming and expensive fieldwork. Terrain, climate or political situation may be unfavourable for extensive fieldwork programmes. Remote imaging offers an alternative, enabling regional to sub-kilometre scale mapping of lithologies and structural fabrics, and identification of areas for focused study.

The Zagros/Taurus Simply Folded Belt and fold-thrust belt in northern Iraq is of current interest to the petroleum industry, yet few advances in mapping or understanding fold-thrust-fracture relationships in cover rocks have been published.

ENVI software has been used for advanced processing of Landsat and SPOT data, and in conjunction with SRTM data. Fine geological detail and structural elements across northern Iraq have been extracted and results include:

Distinguishing between lithological units that are difficult to tell apart on Landsat and SPOT images;
Discerning lineament trends and their ages relative to deformation episodes (of much influence on hydrocarbon recovery) on regional to sub-kilometre scales;
Identifying relationships between lineament trends, shearing, fold geometry and reactivation of deep faults.

Key words: ENVI, advanced remote imaging, mapping, northern Iraq

3D progressive migration of a turbidite-filled syncline in the alpine foreland basin: the Annot Syncline (SE France)

Lise Salles[1], Mary Ford[2], Philippe Joseph[3], Marc-Olivier Titeux[4], Pauline Durand-Riard[4], Guillaume Caumon[5]

[1]CRPG-CNRS, Nancy University, Vandœuvre-lès-Nancy Cedex, Nancy, France
[2]School of Geology, CRPG-CNRS, Nancy University, Vandœuvre-lès-Nancy Cedex, Nancy, France
[3]School of Geology-Geochemistry, Institut Français du Pétrole, Rueil Malmaison Cedex, France
[4]CRPG-CNRS, Nancy University, Vandœuvre-lès-Nancy Cedex, Nancy, France
[5]CRPG-CNRS, Nancy University, Vandœuvre-lès-Nancy Cedex, Nancy, France

The Annot Syncline is a remnant of the alpine Tertiary foreland basin in SE France. The foreland basin was infilled by the transgressive Nummulitic Limestone, the deep water Globigerina Marls and lastly, the Annot Sandstone sourced from the south. These turbidites were deposited in a deltaic setting over period of 10 My (Bartonian - Rupelian) in actively deforming depocentres. Today the Annot Sandstone is superbly exposed in the Annot syncline. During a late deformation phase, the fold axis shifted to the west so that the early western limb now lies on the eastern limb of the late syncline.

The sandstones have been divided into 7 westward onlapping members. New structural data (dip, onlap) are used to constrain the progressive evolution of the synclinal depocentre via stereographic projection analyses, serial cross-sections and construction of a high resolution 3D geometrical model using gOcad software.

3D unfolding and backstripping show the migration of the fold axis during deposition of turbidite facies in the Annot syncline. In addition, the evolution of depocentre dimensions are constrained. Using published biostratigraphic dates, we can propose fold axis migration rates during sandstone deposition.

Burlington House
Fire Safety Information

If you hear the Alarm

Alarm Bells are situated throughout the building and will ring continuously for an evacuation. Do not stop to collect your personal belongings.
Leave the building via the nearest and safest exit or the exit that you are advised to by the Fire Marshall on that floor.

Fire Exits from the Geological Society Conference Rooms

Lower Library:
Exit via Piccadilly entrance or main reception entrance.

Lecture Theatre
Exit at front of theatre (by screen) onto Courtyard or via side door out to Piccadilly entrance or via the doors that link to the Lower Library and to the main reception entrance.

Piccadilly Entrance
Straight out door and walk around to the Courtyard or via the main reception entrance.

Close the doors when leaving a room. **DO NOT SWITCH OFF THE LIGHTS**.

Assemble in the Courtyard in front of the Royal Academy, outside the Royal Astronomical Society.

Please do not re-enter the building except when you are advised that it is safe to do so by the Fire Brigade.

First Aid

All accidents should be reported to Reception and First Aid assistance will be provided if necessary.

Facilities

The ladies toilets are situated in the basement at the bottom of the staircase outside the Lecture Theatre.

The Gents toilets are situated on the ground floor in the corridor leading to the Arthur Holmes Room.

The cloakroom is located along the corridor to the Arthur Holmes Room.

Ground Floor Plan of the Geological Society, Burlington House, Piccadilly