Introduction to Special Issue on INTEGRATED BASIN STUDIES (IBS) — a European Commission (DGXII) project

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Background of the IBS project

This issue contains papers issued from the Integrated Basin Studies Project (IBS) which is part of a larger program of the European Commission DGXII, entitled Geosciences II. The IBS project (EC contract JOU2 - CT92 - 0110) originated in Geosciences consultation meetings, the first of them being held in Strasbourg in June 1989 under the auspices of Mr Hubert Curien, former French Minister for Research and Technology, and the subsequent meeting being held in Brussels. These consultation meetings have resulted in the conclusion that a main axis of future research in Geosciences should be the study of sedimentary basins, upstream of industrial activities, mainly the oil and gas industry but also water resources management, the mining industry, the storage of undesirable products and coastal engineering. They also resulted in the conclusion that future research on sedimentary basins should fulfill two requirements: integration of disciplines and modelling. Such a conclusion may now seem trivial but was not so generally accepted at that time.

In this spirit, the IBS project was designed to provide the oil and gas industry with a new generation of models for basin formation, basin evolution and basin fill architecture from basin scale to reservoir scale. Its main objectives are the linkage of crust thermo-mechanical behaviour to basin formation and deformation mechanics and the corresponding modelling, the quantification of tectonic control on the sedimentary record and the analysis of compaction and mass and heat transfer. The IBS strategy is to link subsurface data to field data, and an important part of the project is devoted to thematic field studies in European sedimentary basins of different tectonic styles, taken as natural laboratories.

Basin research has gone through a rapid evolution during the last decade, in particular through the development of new acquisition and processing methods for seismic data and advances in drilling technology. Modelling provides an important tool to analyse different aspects of basin formation processes and find their tectonic expression in the basin fill. The need for 3-D modelling techniques and models capable of linking processes operating on basinwide to sub-basin scales is increasingly recognized and a significant effort has been made in the IBS project to develop a new generation of basin formation models coping with these needs (see also Cloetingh et al., 1993a; Van Wees and Cloetingh, 1994). As many data required to test these models reside in industrial companies, IBS has promoted a closer link between academic research and basin studies carried out by industry. The participation of the petroleum industry has been vital in this project and IBS has been able to establish a well functioning system of cooperation that not only facilitated data access, but most important, guaranteed the suitability of the end products of the project. This has led to an intensive exchange of modelling concepts and data sets between industry and academia. The IBS project has also used extensively the International Lithosphere Program Task Force “Origin of Sedimentary Basins” (See Cloetingh, Sassi and Task Force Team, 1994; Cloetingh et al., 1993a,b; 1994) to implement planning and to discuss preliminary results. It also builds partly on joint research through the European Commission TEMPUS and PECO Programs on Pannonian basin studies (Horvath, 1993; Van Balen and Cloetingh, 1995; Van Balen et al., 1995; Horvath and Cloetingh, 1995).

A stimulating aspect of the activity of the IBS group is the creation of a research network in the corresponding field of knowledge which comprises now 30 teams belonging to eight European countries (England, France, Germany, Hungary, Norway, Spain, Switzerland and The Netherlands). This demonstrates the capacity of the procedures used by the DGXII of the European community to formulate a really European research space. PhD students and young researchers form an important component of the research groups...
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cooperating in the IBS. The integrated nature of basin research and the strong international cooperation in IBS appears to be a positive factor in their training, also in view of future employment within the petroleum industry.

Themes of the IBS and highlights of recent developments

Extensional basin formation mechanisms

Rheology forms a key factor in the dynamics of extensional basin formation (Vilotte et al., 1993; Bassi et al., 1993; Quinlan et al., 1993). Important advances have been made over the last few years in our understanding of continental lithosphere rheology (Burov and Diament, 1995), supporting a finite strength of the lithosphere during extension. The formulation of the latter in terms of a level of necking in the extending lithosphere (Braun and Beaumont, 1989; Kooi et al., 1992; Bassi et al., 1993; Spadini et al., 1995) has significantly affected predictions for rift shoulder development and basin fill.

In IBS we have tested models for extensional basin formation through a systematic comparison with data sets from selected basins. North-Western Europe and the North Atlantic margin are, together with the Pannonian basin and parts of the Western Mediterranean, key areas in Europe for the study of extensional basin formation. The paper by Cloetingh et al. (this issue) addresses the question of whether basin extension in convergent regimes is fundamentally different from intracratonic extension. As shown by this contribution, inferred differences in necking level during extension can be largely explained by differences in the pre-rift history of the lithosphere underlying these basins. Of particular importance appears to be the pre-rift configuration of the crust and lithosphere, affecting the level of stresses required to induce extension, and yielding insight into the role of orogenic collapse in extensional basin formation. The paper by Séranne et al. (this issue) on the Gulf of Lion also points to a key control by pre-rift Pyrenean orogeny on the mode of extension in this young rifted margin. In the paper by Robinson et al. (this issue), important differences observed between the tectono-stratigraphic evolution of the Eastern and Western Black Sea are examined by using a model incorporating a finite strength of the lithosphere during extension. These authors demonstrate a key control exerted by differences in pre-rift structure of the Eastern and Western Black Sea on the post-rift evolution of this basin. All these studies show the existence of strong differential uplift at the flanks of these extensional basins, highlighting the need to quantify the amount of erosion at the basin margins. Forward modelling can now be successfully combined with back stacking of eroded sediments from rift shoulders, constrained by fission track data and modelling (Van der Beek et al., 1994; Kooi and Beaumont, 1994), which will lead to a better understanding of this aspect of basin evolution.

Causal relationships predicted by large scale models for flank uplift can also be explored on the sub-basin scale, where the role of faulting has been modelled by the application of, for example, flexural cantilever models (Kuszmir et al., 1991). Ter Voorde and Cloetingh (1995) recently coupled a large scale model for the isostatic response of the lithosphere to basin loading with small scale models incorporating faulting developed by Waltham (1989). These models offer a framework for exploring the role of stresses on the stratigraphy of tilted fault blocks as well as the consequences of faulting on fluid flow (Kniipe, 1993). Stresses form a crucial aspect of the formation (Zoback et al., 1993a) and evolution of sedimentary basins (Cloetingh and Kooi, 1992; Ziegler, 1992; Daudré and Cloetingh, 1994). On a basinwide scale stresses are an important factor in the control of basin stratigraphy.

Map of IBS basins discussed in the papers of this issue.

Numbering refers to the following publications:

Areas (natural laboratories) selected for the Integrated Basin Studies project (IBS)

THEME 1: EXTENSIONAL BASIN FORMATION MECHANISMS AND BASIN FILL
1. Cloetingh et al. (Black Sea, Pannonian Basin, Tyrrhenian Sea, Gulf of Lion, North Sea, Barents Sea, Valencia Trough)
2. Séranne et al. (Gulf of Lion)
3. Robinson et al. (Black Sea)
4. Horváth (Pannonian Basin)
5. Jordt et al. (Central North Sea)
6. Nottvedt et al. (Northern North Sea)

THEME 2: FORELAND BASIN EVOLUTION AND BASIN FILL
7. Vergés et al. (Eastern Pyrenees)
8. Millán et al. (Eastern Pyrenees, Ebro Basin)
9. Jin et al. (South-Eastern German Molasse Basin)

THEME 3: COMPACTION AND HEAT AND MASS TRANSFER
10. Vasseur et al. (Laboratory study)
11. Aplin et al. (Norwegian Margin)
Between tectonics, eustasy and climate in the control of sequence architecture. The contribution by Millán et al. (this issue) builds on these interpretations for the modelling of the flexural evolution of the Southern Pyrenean foreland basin, supporting the existence of important lateral variations in crustal rigidity, connected to the Neogene opening of the Valencia Trough. These authors also examine, through modelling, the role of palaeo-relief in erosion and sedimentation dynamics of the basin. These studies have set the framework for detailed modelling on the sub-basin scale. The importance of coupling large-scale basinwide flexure, thrusting on sub-basin scale, and eustasy for forward stratigraphic modelling of piggy-back basins in foreland fold-and-thrust belts has been demonstrated recently by Zoetemeijer et al. (1993).

The paper by Jin et al. (this issue) focuses on the subsurface record of the Molas basin of Southern Germany. These authors discuss sequence stratigraphic aspects of the basin fill, which will be used in future work to verify the relative roles of tectonics and eustasy by the use of large-scale modelling, developed in the IBS programme (Peper et al., 1994).

Compaction and heat and mass transfer
Incorporation in basin models of the rheology of compaction, i.e. of the physical laws which link, during the course of basin evolution, deformations and failures of compactable sediments to stresses and pore pressure, is essential to perform the work dedicated to the modelling of basin deformation and fill. Indeed, compactable sediments, mostly clays, make up 60 to 70% of the basin fill on average and, therefore, compaction may have considerable effects, which have to be computed and taken into account to properly restore subsidence, thickness of sediment layers (Perrier and Quiblier, 1974), and the geothermal evolution of the basin fill. Lithology and petrofabrics of clays and shales, which rule these effects, are as variable as those of sandstones and carbonates. However they have received much less attention so far, probably because of the difficulty of their study.

Furthermore, compaction creates in compactable media, pore pressure gradients which are responsible for mass transfer in the form of an expulsion of water and hydrocarbon fluids (Magara, 1978; Ungerer et al., 1984; Bethke, 1985; England et al., 1987; Durand, 1988; Ungerer et al., 1990) eventually accompanied by chemical effects in the environment (Franks and Forester, 1984), and are also responsible for associated phenomena such as the development of overpressure and seal failure (Magara, 1981). Compaction is also responsible for variation of thermal conductivity in compacting sediments (Brigaud et al., 1990). For all these reasons, the incorporation of compaction rheology is particularly important in ‘basin simulators’ dedicated to the needs of the petroleum industry, which describe the formation and the accumulation of hydrocarbon fluids in the frame of basin evolution (Doré et al., 1993; Larsen et al., 1992; Horbury and Robinson, 1993; Parnell, 1994). In such simulators, for instance Temispac (Ungerer et al., 1990), compaction rheology is described by a set of simple pragmatic laws: (i) the so called ‘effective stress law’, as initially proposed by Smith (1971), following the formalism of Terzaghi...
decreases faster as a function of porosity than described load (50 MPa). It is shown that the permeability injection and water removal under low water vapour (hydraulic conductivity, thermal conductivity). It is measurements, transmission electron-microscopy microstructure (granulometry, specific surface area from 0.1 to 50 MPa so as to characterize after each step cell. Measurements are made after loading by steps Austell's kaolinite in a specially equipped oedometric describes compaction experiments conducted on St. stones from a North Sea well. The study emphasizes the importance of the mean grain size, i.e. of lithology, as a key factor of compaction rheology. It also suggests that prudence is necessary when interpreting the variations in sonic logs in terms of pore fluid pressure, because these variations might be due to lithological variations in clays as well. A composite β log, derived from electrical logs, is proposed to follow the lithological variations in wells. The paper by Vasseur et al. describes compaction experiments conducted on St. Austell's kaolinite in a specially equipped oedometric cell. Measurements are made after loading by steps from 0.1 to 50 MPa so as to characterize after each step microstructure (granulometry, specific surface area measurements, transmission electron-microscopy imaging), pore space (porosity by mercury injection and water removal under low water vapour pressure) and macroscopic transfer properties (hydraulic conductivity, thermal conductivity). It is verified that the void ratio at compaction equilibrium is linearly dependent on the logarithm of the mean effective stress, as explained above, up to the maximum load (50 MPa). It is shown that the permeability decreases faster as a function of porosity than described by the Kozeny–Carman formula which is used in ‘conventional’ basin simulators. Surprisingly it is also found in these experiments that the radial thermal conductivity increases with compaction while axial conductivity appears to be constant or even to decrease.

Future steps in the IBS

IBS has just reached its mid-assessment term. A number of key questions on the dynamics of basin development remain to be solved, offering a large number of challenges for the project. In this context continued studies of the deep structure of basins and the interaction between basin development, basin structural grain and local and regional stresses are obviously required. In addition, the mechanics of crustal deformation and the architecture and development of break up unconformities promises to be an area of vigorous research in the years to come. Furthermore, the conception of better sedimentation models thanks to a careful study of the balance between erosion and sedimentation in basins which are tectonically active at present times will be a major way of research to complete the work. This will not be possible in the frame of IBS, which ends on 31 December, 1995, but can be done by the researchers who are involved in the network which has been created thanks to IBS and to the task force ‘Origin of Sedimentary Basins’ of the International Lithosphere Programme.

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