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NEAR-SURFACE DEPOSITIONAL PROCESSES INFERRED FROM 3D SEISMIC DATA, OFFSHORE NILE DELTA, EGYPT

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The West Delta Deep Marine (WDDM) Concession lies 50-100 km offshore of the present day Nile Delta. The water depth ranges between *circa* 200 and 2000 metres. The area contains the entire spectrum of stratigraphic elements of a siliciclastic submarine depositional system, and is renowned for an exceptionally well developed Pliocene slope channel system.

High-resolution 3D seismic data has been used to create images of the seabed and reconstruct surface and near-surface depositional processes by combining time sections and a variety of seismic attribute extractions (coherency, dip, azimuth, amplitudes, etc.). This methodology provides a unique opportunity to collect morphological observations and quantify the dimensions of sedimentary bodies.The most common features of the WDDM Concession seafloor are mass transport complexes (MTC's), channels, small diapirs, gas chimneys and sediment waves. MTC's cover large portions of the study area and mainly consist of debris flows; slides and slumps are also common. They can be generated in different ways and derive from the shelf or from remobilisation of essentially hemipelagic deposits on the slope. As such, their geometry, volumes and areas greatly vary across the study area. They appear to be sensitive to previous topography and tend to smooth the relief created by older sediments (for instance lows created by differential compaction). However, they can also create accommodation space by liberating large volumes of sediments that have been subsequently re-deposited more distally. Coherency extractions and dip maps show the external geometries of debris flows at a scale that is normally not achieved even with high-resolution seismic data. Although debris flows are normally characterised by low amplitude and/or reflection-free patterns, they can be often divided into three areas: a proximal area characterised by scarps, often associated with faults and by an upper stepped profile and erosional base; an intermediate portion characterised by tabular bases and tops (occasionally containing undisturbed intervals that represent remnants of an original well-bedded sequence); and a distal area characterised by pressure ridges indicating a series of thrust faults. These originate small depressions on the seafloor that are filled by onlapping deposits or draped by background slope sediments. Erosional scours at the base of MTC's have been identified and can be traced downdip as linear grooves. MTC's are the dominant deposits on the present day sea floor of the WDDM Concession and are also common in the subsurface, where they represent a significant portion of the succession.

TURBIDITE BED SCALING: IDENTIFICATION OF FAN ENVIRONMENTS FROM BOREHOLE AND OUTCROP ANALYSIS

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The statistical analysis of turbidite bed-thickness and grain-size distributions is potentially a powerful tool in the identification of submarine fan environments. The Mid-Eocene Ainsa depositional system, Spanish Pyrenees, provides an ideal study natural laboratory for the analysis of frequency distributions, where all fan sub-environments are recognised, and 8 continuous cored intervals have been recovered. This unique dataset has facilitated investigations into the characteristic bed-thickness, grain-size distribution curves for specific sub-environments within the turbidite system, demonstrating the influence of erosion, non-deposition and amalgamation processes on bed thickness. The understanding of delivery mechanisms responsible for turbidite emplacement within the depositional system has only be possible where modification of the turbidites has been minimal, e.g., outer-fan environments.

THE VAR FAN DISTAL LOBE (LIGURIAN SEA, MEDITERRANEAN): SIDE-SCAN FACIES, SEISMIC ARCHITECTURE, NATURE OF DEPOSITS

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The Var submarine fan is located in the Ligurian Sea (North-western Mediterranean) off France and extends to 300 km seaward of the Var delta. It covers an area of 16,200 km^2 and has been deposited throughout the Pliocene and Quaternary. A complete data set, collected on the Var distal lobe, provides EM12 multibeam bathymetry and acoustic imagery, sparker seismic and 3.5 kHz profiles, SAR deep towed side-scan sonar image and piston cores.

The Var fan lobe is located at a water depth of 2700 m and at a distance of 230 km from the Var canyon head at the base of the north-west Corsican margin and is fed apparently by only one major channel: the Var fan valley. The lobe (80 km long and 40 km wide) is located at the base of the Corsican slope, which is incised by about ten canyons in the area and lateral inputs by these canyons occur.

Based on bathymetric and imagery data, we have identified four interfingering events, which are directly related to the present entry point of the lobe. The 3.5 kHz profiles permit to distinguish two main types of sediment transit at the surface of the lobe. A major one oriented North-south, which is located in the central part of the lobe, and several minor ones oriented either East-west or North-south.

The high reflectivity in sidescan sonar and the poor penetration in the 3.5 kHz profiles indicate that it is an extremely sand-rich lobe. The cores confirm the high sand content in the lobe and show two main sandy deposits. The first type, corresponding to massive sand packet, is located in the central part of the lobe and is associated to the major transit axis. The second type of deposits is made of a succession of fine sandy turbidites, and is associated to the minor transit axis. C14 dates obtained on shells and pteropods indicate that the lobe is still active and was active during the Holocene. The lobe is constituted by a stack of seismic units. The analyse of their general shape shows a progressive shifting of the entry point to the West until its current position.

APPLICATION OF OUTCROP, PROCESS MODELS AND HIGH RESOLUTION 3D SEISMIC IN THE DEVELOPMENT OF THE HOLSTEIN FIELD, DEEPWATER GULF OF MEXICO: A SUBSURFACE ANALOG FOR PONDED-BASIN TURBIDITE RESERVOIRS

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The Holstein Field development in the deepwater Gulf of Mexico has completed pre-drilling of selected wells for production. Reservoirs comprise stacked, turbidite sheet sands deposited in a ponded basin above salt. With minimal appraisal data prior to development, a greater emphasis was placed on integrating outcrop analogs and process models with spec 3D seismic data to plan development. Proprietary high resolution 3D data and new drilling results have validated models and permitted the refinement of facies and permeability models to evaluate options for future reservoir management. Holstein in turn provides a 3D subsurface analog for exploration and development.

Topographic and structural controls on sedimentation are evident in a variety of bounding surfaces and margins on 3D seismic. These are trap analogs for exploration and also keys to facies and permeability prediction for further development. In a series of punctuated depositional episodes, common vertical sequences and facies associations demonstrate evolving intrabasinal, topographic controls from highly-confined to less-confined, base to top:

? 1) Repeated thin sands with bed caps from captured low density flows form segregated layers.

? 2) Upward-thickening beds with improved sorting and permeability result from confined high-density flows absent of the unconfined, low-density, upper-storey component. These facies demonstrate high continuity.

? 3) And finally amalgamation, erosional modification and sediment bypass arise from minimal confinement with significant spatial variability in reservoir quality depending on the nature of abandonment.

At reservoir scale, depositional topography dominates facies variability but structural and extrabasinal controls introduce rate dependencies and contribute to the spatial variability.

With high well costs in deepwater, the challenges remain focused on well count, placement, timing, and injection sweep efficiency. The models contribute their greatest value to the development phase and beyond into the operations phase to generate reservoir management options.

SUBMARINE VOLCANIC PROCESSES AND FACIES IN DEEP WATER ENVIRONMENTS: IMPACT ON SURFACE ENVIRONMENTS, RESERVOIR ARCHITECTURE AND MATURATION

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Although deep-water environments are dominated by pelagic, hemi-pelagic, deep-bottom current and mass-transport processes, in many deep-water environments, volcanism fundamentally affects the dynamics and the topography of the environment, and the nature of the sea floor sequences accumulating. Submarine volcanism can involve regionally extensive systems such as oceanic spreading ridges, large intraplate basaltic igneous provinces (LIP's; e.g. Ontong Java Plateau), small intraplate basaltic provinces (e.g seamount and lava fields), subduction related volcanic arcs, and rift related volcanic systems. Volcanism can occur on oceanic, arc or continental crust.

The high hydrostatic pressure associated with great water depth tends to inhibit magmatic explosive vesiculation and also phreatomagmatic explosive volcanism. Deep submarine volcanic successions therefore contain a greater proportion of coherent and autoclastic lavas than subaerial counterparts with the same volatile content. Lava flows may be local or extend hundreds of kilometers from vent. Geometries vary from sheet-like to lobate to high relief domes which substantially modify sea-floor topography. Some pyroclastic deposits occur and although some originate from deep-water volcanoes, many originate from shallow marine or subaerial volcanoes. Dispersal occurs by pyroclastic and aqueous suspension fallout, pyroclastic flow and sedimentary mass-transport processes.

In volcanically active submarine basins with significant sedimentary fill. substantial high level intrusions into the unconsolidated sediment succession should be expected. Unless the rising magma has considerable upward momentum, the magma will intrude laterally into the sediment pile because it is denser and because the sediment has little confining strength. Intrusive geometries may be sill or dyke – like, or highly irregular. Intrusions may propagate kilometers from the source conduit. The geometry of sill, dyke and lava complexes may significantly affect the geometry and size of stratigraphic traps.

Lavas, sills, irregular intrusions can be good cap rocks. Fragmental deposits of vitric material may also become good cap rocks, even if originally highly porous. Vitric deposits are highly susceptible to alteration, and, porosity is prone to occlusion by secondary alteration minerals and cements, especially if basic in composition. Igneous events only affect maturation history if they have regionally extensive geothermal effects. Even large intrusions by themselves will have only local thermal effects. Such thermal effects may be largely dissipated if abundant pore water exists in unconsolidated sediment because water has a high heat capacity and acts as a heat sink.

RECENT SEDIMENTARY PROCESSES ON HIGH LATITUDE MARGINS (NW ANTARCTICA PENINSULA)

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The aim of the present work is the characterisation of the recent sedimentary processes of the distal continental margin of the Antarctic Peninsula. Two areas have been studied: the Bransfield and Palmer Archipelago margins. The margin of Bransfield (73 km) is defined by a continental slope that is connected to a small and enclosed basin, whereas the margin of Palmer (190 km) is an open margin characterised by a slope and a well developed continental rise. The sedimentary environments of both distal margins display a wide range of sediments transport systems, involving mostly slides/slumps, debris flows and turbidite currents. The sediment affected by these processes, deposits on the slope and are also funnelled by submarine valleys. There are valleys on both continental slopes and they are represented by gullies (>10-15 km long, 2 km wide) and the Gebra Valley (10 km wide, and 30 km long) in Bransfield. The continental rise of Palmer is incised by several canyons (< 100 km long) formed by instability processes that merge seaward evolving to large rectilinear channels (>100 km long) separated by elongated sedimentary mounds (>100 km long). The upbuilding of these mounds has been conditioned by the interplay between the overspilling of the passing turbidity currents and their sweeping by bottom currents. The walls of these channels also display evidences of instability processes in the form of slumps and debris flows that favour their enlargement.

The sedimentary models displayed by the continental slope of both margins have been conditioned by the advance and retreat of ice sheets, uneven sediment supply and morphology of the margins. The downslope processes involving slumps/slides, debris flows and turbidity currents dominated during the glacial and initial stages of interglacial periods. Their resulting deposits are dominant in those areas of the distal margins off the mouth of cross-shelf throughs and/or off the shelf break progradation reached distalmost positions. These areas are associated in full glacial conditions with fast flowing ice streams and in consequence with important sediment fluxes of sediment. Contrasting, the continental rise of Palmer margin is dominated by cannibalization processes of their deposits and it seems not to be related with glacial-interglacial periods. These processes superimpose to the alongslope ones that are related to bottom currents allowing the reworking of large depositional areas with gravitative deposits. The larger-scale sediment features observed on Palmer margin is because this one is wider, with well-developed physiographic provinces and receive a relative high volume of sediment supply due to the larger exposure of hinterland.

STUDY OF LATEST QUATERNARY PROCESSES OF THE TEXAS-LOUISIANA INTRASLOPE BASIN PROVINCE TO DEVELOP ANALOGS FOR HYDROCARBON RESERVOIRS

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To better understand hydrocarbon-reservoir geometry and composition of deep-water intraslope-basin deposits, we are conducting a series of studies (Gulf Intraslope Basins Project, GIB) of modern depositional analogs of the deep Gulf of Mexico intraslope basins province. GIB Phase 1 employed systematic regional interpretation and mapping of high-resolution seismic facies (3.5 kHz echo character) throughout the intraslope basin province to reveal the geometry, scales, architecture and depositional processes of Late Quaternary intraslope-basin deposits and the adjacent abyssal seafloor. Seismic interpretation reveals that localized mass-transport processes are ubiquitous throughout the intraslope basins and consist of a wide spectrum of slumps, slides, and debris flows. Sediment facies recovered in piston cores were used to "ground truth" these seismic facies interpretations, including differentiation of turbidites from related sandy mass-flow deposits (e.g. debris flows). Some cores taken from slump/debris-flow deposits interpreted on 3.5 kHz profiles contain muddy mass-transport deposits with exotic mud clasts and folds, whereas other cores contain ungraded medium-to-coarse sands with dispersed pebbles and clasts. Ponded sediments on seismic records generally turn out to be sandy or muddy turbidites when sampled by cores. Leveed channels, although uncommon, do feed turbidites to small fans and ponded lobes in some intraslope basins through complex fill and spill histories (e.g. Trinity/Brazos).

Of special interest is a highly channelized area of apparent widespread sandy deposits that occurs on the continental rise seaward of the Rio Grande River. Here numerous low relief channels are present and seismic facies and cores indicate extensive sand deposits. This may represent an area of sandy braided channels and related deposits. A few large turbidite pathways extend completely through the intraslope-basin province (e.g. Bryant Canyon) and feed turbidites and related gravity-controlled mass flows to extremely large channel-levee systems and fans (e.g. Bryant and Alaminos fans), which extend 100's of km seaward from the Sigsbee Escarpment. These large fans appear to have stacked channel-levee systems and lobes that probably contain thick sand deposits of great lateral extent, and may be modern analogs of subsalt Miocene plays such as Thunder Horse and Mad Dog. We also observed and mapped extensive fields of migrating sediment waves south and east of the Sigsbee Escarpment. These waves indicate that strong, regional bottom-currents, probably the Loop Current, have redistributed sediments throughout large areas of these deep-sea fans. Biostratigraphic analyses of ~90 cores reveal that glacio-eustatic sea-level fluctuations control downslope transport of sediments into intraslope basins during the latest Quaternary. Transport of terrigenous sediment was predominant during lowered sea levels associated with glacial phases.

ON THE INITIATION OF RELATIVELY SMALL, SINUOUS CHANNELS IN DEEP WATER SETTINGS

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The identification of relatively small scale (100-200 m wide) deep water channels, commonly with a sinuous planform appearance, has become widespread in recent years, both in oceanographic data from modern fans and in sub-surface data from slope settings. Considerable attention has been paid to the behaviour of these channels, but there has been limited discussion of their initiation.

There is an emerging consensus that sinuous channels evolve from low to high sinuosity via an early phase of bend growth. Coupled with this is the observation in sub-surface data that straight channels are just as common as sinuous channels, though they receive less attention. Channels develop higher sinuosity by the growth of subtle bend defects in the original channel that force the high velocity line to deviate from the centre line, hence initiating bend growth. The premise that sinuous channels are initiated as relatively straight channels transfers the issue of channel initiation to the formation of relatively straight linear scours or channels.

Two alternative processes are envisaged: i) either subtle, pre-existing linear topography is enhanced by the erosional effects of numerous turbidity currents; or ii) catastrophic flows form linear scours either as gouge tracks in debris flows or mega-grooves in a turbidity current and channels subsequently evolve via the effects of higher frequency, lower magnitude flows. Several lines of evidence suggest that initiation by infrequent, catastrophic flows prevails, particularly during periods of lowstand in sea level when shelf-edge deltas collapse infrequently. The means by which these channels are initiated impacts on their up-dip extent, their connectivity and hence their reservoir attributes.

THE ORINOCO TURBIDITE SYSTEM AND ITS CONNECTION WITH THE VIDAL MID-OCEAN CHANNEL: A LARGE AND COMPLEX SUBMARINE DRAINAGE PATTERN

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The Orinoco Turbidite System and its connection with the Vidal mid-ocean channel forms a complex submarine drainage system that is shaping a large area of the northwestern Atlantic Sea. It comprises the following elements: submarine canyons, submarine channels (rectilinear, sinuous and braided), depositional lobes, instability deposits (mass flow deposits and turbidites), and a mid-ocean channel. This drainage system is about 2000 km long extending from shallow waters down to > 5500 m water depth. Once the material from hinterland erosion of Venezuela, Surinam and Guyana arrives onto the continental margins it is moved to deep-sea areas. Confined turbidity currents running along at least three submarine canyons transfer sediment in the western part of the Orinoco Turbidite System (Venezuela margin). The turbidite sediment arrives to distal areas and part of it is distributed toward the north forming a northward distributary system that feeds the basin adjacent to the Barbados deformation front. Here, the sediment is distributed by sinuous and braided channels and deposits forming depositional lobes. Another part of sediment escapes eastward toward the Demerara Abyssal Plain in the form of channelled turbidity currents running along the Orinoco Valley (310 km long). This valley, that forms an eastward distributary system, is recent in age (Pleistocene), and also receives sediment along its southern margin coming from the Venezuela, Guyana and Surinam continental margins in the form of unchannelised mass flows and turbidity currents. This valley connects with the Vidal mid-ocean channel at about 5000 m water depth, and then the drainage system formed by the Orinoco Turbidite System and Vidal mid-ocean channel trough the Orinoco Valley is also recent in age (Pleistocene).

At about 5000 m water depth, the Orinoco Valley evolves into an area having a practically flat-lying seafloor where the valley loses its morphological expression. Nevertheless, the paleo-pathway of this valley can be identified in the subsurface as continuing eastward until reaching the Vidal mid-ocean channel. This means when the Orinoco Valley formed the sediment transfer between the Orinoco Turbidite System and Vidal mid-ocean channel occurred by channelled gravity flows. Today, although there is not evidence of channelled features, there are acoustic evidences of a functional connection in the form of gravity flows that remain unconfined. These confined and unconfined gravity flows arrived to the head of a tributary channel of the Vidal mid-ocean channel. The Vidal mid-ocean channel (930 km) long channel runs northward in the Demerara Abyssal Plain and displays a complex pathway, varying from to rectilinear to very sinuous. The sediment travels along the channel in the form of high-energy gravity flows that erode the valley floor and walls. This erosion favours the incorporation of sediment to the passing gravity flows. The sediment-charged flows arrive to the Barracuda Fracture Zone, cross it and deposit their charge onto the Barracuda Abyssal Plain contributing to its filling.

THE MAGDALENA SUMARINE CHANNELS: QUANTITATIVE ANALYSIS AND IMPLICATIONS FOR FLOW CHARACTERISTICS

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The Magdalena submarine channels are one of the principal architectural elements of the Magdalena turbidite system that locates on the tectonically active margin off Colombia (Caribbean Sea). These channels display morphologic features similar to those described in many large mud-rich fans in passive continental margins. Nevertheless, the Magdalena submarine channels display a length relatively shorter than that displayed by many mud-rich fans. The singularity of the Magdalena submarine channels is that they are fed and directly connected to very short and short-lived submarine canyons. The recentmost channel, named channel IA, has been selected to be studied in detail and quantify its geometry. This channel can be described as a sinuous leveed channel bounded by a depositional talweg and levees that rise tens of metres above the surrounding seafloor, although in some places the talweg is below it. The high volume of sediment supply has conditioned the upbuilding of the channel IA above the surrounding seafloor suggesting its constructional character.

The quantitative analysis of the channel IA gives us a tentative estimation of flow characteristics. The channel IA displays a sudden geometry change in the inflection point of the margin profile, changing from a channel with well developed levees to poor developed levees. This may suggest that it was built by mixed (sandy mud) turbidite flows. The finer fraction mostly spill over the levees up to 171 m above the channel floor in the upper course. Assuming bank-full flow conditions and favoured by the relative high margin gradients, the mixed turbidite currents were relative thick (at least > 171 m), necessary to maintain the levees in constant aggradation at least along the channel upper course. The purge of most of their fine fraction and decrease in margin gradients favoured a flow evolution to sandy rich turbidity currents, a decrease of spill over deposition and then a poor development of levees in the lower channel course. In addition, local changes in flow thickness, concentration and velocity occur due to avulsions, scarps and holes on the channel floor, and profit of sediment due to entrance of mass flow deposits. These sedimentary processes and morphological features produce changes on the talweg gradients. The variations in the channel relief and topographic aggradation profiles suggest that a local gradient decrease produces a decrease in flow thickness and then in flow velocity (assuming that there is also a slight decrease in sediment concentration related to the increase in flow thickness) and vice versa.

GULLIES AND CHANNELS IN THE NE ALBORAN SLOPE

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Ultrahigh resolution seismic profiles (TOPAS) and multi-beam bathymetric information off the NE Alboran Sea (Almeria Margin) reveal the existence of a complex pattern of valleys that cover more than 300 km^2 at the right margin of the Almeria Canyon (water depths between 300 and 1250 m). The studied valleys can be grouped in two types - channels and gullies- according to their size, morphology and seismic features. Sixteen channels have been identified. They are leveed channels with channel infilling and typical U-shaped cross-sections. Channels have lengths of 2.5-22 km, widths of 0.3-1 km and relieves smaller than 15 m. In contrast, the six gullies lack present-day depositional features and are shorter and deeper than channels, with lengths minor than 12 km, and relief up to 40 m. Their widths range between 0.5 and 1 km, and the cross-sections are V-shaped. Channels and gullies have general N-S to NNW-SSE directions, perpendicular to the regional slope gradient. They have low sinuosity, except in the areas affected by La Serrata Fault (NE-SW direction) where axis display sharp changes in direction and gradient. Channels and gullies spatial distribution is complex. Channels display a convergent hierarchical pattern, where shorter channels merge with larger ones that flow into the Almeria Canyon at depths between 1100 and 1250 m. Three gullies flow in the middle of the area occupied by channels and form part of the same hierarchical pattern, as they converge into one of the main channels at 600 m deep. Another three gullies locate at the eastern area, and flow directly into the canyon, at 765, 910 and 960 m deep. Valleys also present downslope variations in their characteristics. Three valleys can be classified as channels along their itinerary, except in an area located at the meridional side of La Serrata Fault, between 650 and 950 m deep, where they display morphologic and seismic characteristics of gullies. Channels and gullies also differentiate by their seismic imprint. Channels present high and low acoustic amplitude chaotic reflections in axis and levees that can be identified in the uppermost 100 ms. In contrast, gullies cut a parallel homogeneous bedding. Only in some profiles overbank deposits can be detected in the subbottom layers (>25 ms deep). A thin semitransparent layer (5-7 ms) drapes almost the entire area.

The higher sediment discharge during sea-level lowstands could have favoured the initiation of gullies and channels development. Channels and gullies characteristics and spatial distribution should be related to changes in the local sediment transport from gravity flows. The properties of the gravity flows vary downslope, alongslope and with time, conditioning the presence or absence of the overbank flows, and so the development of channels or gullies respectively. Tectonic features and variations in the regional slope gradient seem to have conditioned the downslope changes of channels and gullies characteristics. The presence of a thin semitransparent layer over the whole system suggests that channels and gullies have been inactive since recent times. This work was supported by the projects REN2000-2150-E and EASSSS-III-HPRI-CT99-0047 (HITS) and REN2001-3868-C03-03 (MARSIBAL).

MOATS, CHANNELS, VALLEYS AND FURROWS IN THE GULF OF CADIZ CONTOURITE DEPOSITIONAL SYSTEM

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The *Contourite Depositional System* in the Gulf of Cadiz middle slope is a complex morphological area with different sectors. The central sector has important morphological highs as the NE-SW ridges and isolated diapirs related to tectonic processes and the basement outcrop that forms the Guadalquivir Bank. Regarding to the oceanographic setting, the Mediterranean Outflow Water (MOW) acts as a high-density thermohaline current, being divided in cores and branches by the effect of bottom topography. The interaction between the current and the morphological highs causes the development of a complex Erosive Features System. The system includes four types of erosive features: a) The Alvarez Cabral *Contourite Moat* follows the trend of the Algarve margin at the upper slope base (depths from 500 to 900 m). It is 80 km long, with vertical incision depths up to 100 m. This moat is bounded by the upper slope to the north and by the Faro-Albufeira Drift to the south. b) Nine *Contourite Channels*, with lengths ranging from 7 to 110 km, are located at the S-SE side of the main relieves at depths between 450 and 1500 m. Channels trend is NW in smooth areas and NE near the lineal ridges and the Guadalquivir Bank, where the vertical incision depth reaches 300 m. c) Two *Erosive Furrows* have been found at the southern part of the study area (915-1225 m deep). They have lengths of 17.5 and 55 km, a general NE trend and incision depths minor than 100 m. d) Twelve *Marginal Valleys,* 3.3 to 28.4 km long, are situated at the NW side of isolated diapirs and ridges (depths of 490-1120 m). The general valleys trend is NE, parallel to that of the ridges, and the vertical incision depths reach 260 m.

Multibeam echosounding and high-resolution seismic profiles give information about the processes involved in the erosive features origin and evolution. The *Erosive furrows* low relief suggests that they have been caused by weak current veins separated from the Mediterranean Lower Core in the proximal sector close to the Strait of Gibraltar. The *Moat* is originated by the MOW Upper Core, that erodes the upper slope and deposit the contourite drift at the southern flank. *Channels* are formed by the MOW Lower Core branches, and are mainly affected by erosive processes, with channel infillings in small areas. *Marginal Valleys* are formed by the erosion produced by a secondary downslope circulation at the relieves NW side. This work was supported by the projects CICYT MAR-98-02-0209 (TASYO) and REN2001-3868-C03-03 (MARSIBAL).

DEEP SEA CHANNEL EVOLUTION ON THE ANGOLAN MARGIN

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Deep-sea channels form important hydrocarbon reservoirs in the Tertiary sediments off Angola, west Africa. However, the controls on slope evolution and channel morphology are poorly constrained. High resolution 3-D seismic data in the subsurface Tertiary off Angola reveal patterns in channel geometry from highly sinuous to straight forms. Different geometries of sinuous channels are observed, from simple channels which aggrade, to highly connected laterally and vertically aggrading systems. Sinuous channels are often entrenched in contrast aggradational channels which are generally narrow and straight in plan view. The slope morphology is observed to evolve from a more convex to a smoother, less convex form. We illustrate some of the relationships between slope, sinuosity, channel width and channel geometry on a geologically complex margin dominated by salt tectonics and turbidite sedimentation. This work has implications for the reservoir potential of turbidite slope systems on continental margins characterised by salt tectonics and complex topography.

PALEOSEISMIC RECORD OF THE SW IBERIAN MARGIN EARTHQUAKE EVENTS: FIRST RESULTS OF THE "PRIME" CRUISE

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The Southwestern Margin of the Iberian Peninsula hosts the convergent boundary between the European and African Plates, and is characterized by a significant seismic activity, source of the largest events in Western Europe, such as the A.D. 1755 Lisbon earthquake and tsunami (M_w 8.5). Recently acquired swath-bathymetry, TOBI sidescan sonar and high-resolution and multi-channel seismic reflection data reveal the surficial expression of several fault structures (e.g. Marques de Pombal, San Vicente, and Horseshoe Faults) and large submarine landslides located <100 km offshore Portugal. Folding and reverse faulting of the Quaternary units together with the swarm of surface seismicity along these structures suggest present-day tectonic activity, which might pose a significant earthquake and tsunami hazard to the coasts of Portugal, Spain and Morocco. However, assessment of seismic risk in SW Iberia is largely based on the relatively short period (about 40 years) of instrumentally recorded earthquakes. The paleoseismic record potentially preserved in deep-sea cores can be used to determine the past activity of the faults and yield an earthquake recurrence rate. To calculate the style and motion of the active faults, we plan a detailed sampling and study of the most recent mass-wasting deposits and turbiditic units associated with the seismic cycle of the faults. Although a number of mechanisms have been suggested to account for turbiditic triggering, in the case of SW Iberia, earthquakes are the most likely mechanism to explain synchronous, long distance apart turbidites. For this, we planned the PRIME project (Paleoseismic Record of the south Iberian Margin Earthquake events) in the frame of the EU Large Scale Facility (HPR –CT-2001-00120) and ESF-EuroMargins SWIM projects. The main aim of PRIME is to resolve the shallow geometry and kinematics of the fault systems in SW Portugal, and to study the geological effects of individual earthquakes and secondary structures derived from the shaking, such as landslides near the fault. During the PRIME cruise, which will be carried out during July 2003 on board the French RV *Marion Dufresne*, we plan to acquire a total of 4 giant CALYPSO piston cores located on the Tagus and Horseshoe Abyssal Plains, and on the footwall and hangingwall of the Marques de Pombal Fault. Sedimentological, geochemical, and paleomagnetic analysis together with dating (^{14}C, ^{210}Pb, oxygen isotopes and paleointensities) of the turbiditic events will be carried out after the cruise. The paleoseismic record will allow us to know the recurrence interval and slip rate of the active faults, and help to evaluate the seismic activity of the identified faults, with the final goal of assessing the earthquake and tsunami hazard in the SW Iberian Margin.

3D STRATIGRAPHIC MODELLING OF DEEP-WATER SETTINGS: COMPARISON OF ANCIENT AND MODERN CASE STUDIES

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We will present in this poster the principles and some applications of a 3D stratigraphic model, named Dionisos. This numerical model allows user to quantify the interaction between the three main processes: accommodation (tectonic, eustasy and compaction), supply (clastic supply and carbonate production) and transport of sediment. The transport of sediment is simulated using three sets of equation, in order to reproduce the interaction between long-term permanent evolution of sedimentary processes, short-term hyperpicnal flows, and catastrophic slope failures and debris-flows.

Two applications will be presented to illustrate these principles in modern case studies: the Indus and Orenoque deltas and theirs deep-water fans. Two other applications on ancient case studies will also be presented to enhance the interest of such a modelling to better understand the ancient systems: a confined basin (the Annot Sandstone, France), and a passive margin setting (the Pab Sandstone, Pakistan).

SEDIMENT-VELOCITY DYNAMICS OF QUASI-STEADY TURBIDITY CURRENTS ACROSS BREAKS IN SLOPE

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To understand deposits from quasi-steady turbidity currents (QSTCs) at breaks of slope, laboratory experiments were conducted in a 6m-long flume tank. Typical runs lasted for 8 minutes, significantly longer than short duration flows that are often cited in the literature. The flow velocity field was measured using an ultrasonic Doppler velocity profiler (UDVP), and suspended sediment concentration with an acoustic backscatter system (ABS) and siphon sampling. Linking the high temporal resolution of the UDVP and ABS datasets provides new insights into the process of QSTC deposition.

The QSTC flowed down the slope, across a slope break onto a horizontal floor. The slope angle was changed between experiments. Velocity and concentration measurements were made on the slope, at the slope break and downstream of the slope break. Mean velocity profiles demonstrate that the height of the maximum mean velocity and thickness of the flow increase downstream. This is due to water entrainment and sediment fallout resulting in deceleration of the flows. Temporal structure, in the form of eddies, is present in both datasets. This is demonstrated by flow field visualisation of two-component velocity vectors and wavelet analysis of the velocity time series, showing time-dependent peaks in power (variance). Spatial structure is examined by calculating the layer-averaged velocity (U), and the downstream evolution of the gradient Richardson number, which measures the stability of any stratification in the flows. Additionally, grain size estimates in the current are provided from the ABS and siphon sample data.

These experimental flows scale to gravely natural currents, which may be typically sourced from rivers in flood. The quantitative datasets are particularly useful in constraining models of turbidite deposition, as few measurements of natural large-scale flows exist. This approach is currently assisting the identification of ancient QSTC deposits in relation to gradient changes, in the Plio-Pleistocene fan deltas of the Gulf of Corinth, Greece.

ULTRA-HIGH RESOLUTION OUTCROP-SUBSURFACE STUDY OF THE ICHNOFACIES AND SEDIMENTOLOGY OF MID-EOCENE DEEP-MARINE SYSTEMS, SPANISH PYRENEES

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There are very few detailed studies of ichnogenera and ichnofacies in deep-marine sediment cores. This lack of published studies is surprising because the detailed analysis of trace fossils is a powerful tool in palaeoenvironmental interpretation. The clastic sediments in the three Mid-Eocene laterally offset-stacked, deep-marine Ainsa sandy fans show a diverse and well preserved ichnofauna. A quantitative analysis of bioturbation was carried out in core and at outcrop, in channel, levee-overbank, sandy lobe, lobe fringe and interfan or lower slope environments. This analysis shows a diverse and well preserved ichnofauna belonging to the deep water "Nereites ichnofacies".

In the laminated, fine-grained sediments (Hole A6, = fan lateral margin and inter-fan environments), there is evidence of external forcing on the sedimentary environment. This contrasts with the likely tectonic control for the three sand-rich fans (Ainsa I, II and III) penetrated in the other wells (Holes A1, A2, A3, A4, A5, L1 and L2).

THE CONTOURITE DEPOSITIONAL SYSTEMS OF THE GULF OF CADIZ: LOOKING FOR CLUES TO PALEOCEANOGRAPHIC IMPRINTS

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A new morphosedimentary map of the Gulf of Cadiz is presented, showing the Contourite Depositional System (CDS) on the gulf's middle slope. This map is constructed from a broad database provided by the Spanish Research Council and the U.S. Naval Research Laboratory. Our map shows that this CDS comprises 5 morphosedimentary sectors: 1) *proximal scour and sand ribbons*; 2) *overflow sedimentary lobe*; 3) *channels and ridges*; 4) *contourite deposition*; and 5) *submarine canyons*.

The Gulf of Cadiz CDS stems directly from the interaction between Mediterranean Outflow Water (MOW) and the seafloor; its morphosedimentary sectors are clearly related to the systematic deceleration of the MOW´s westward branches, bathymetric stress on the margin, and the Coriolis force. The CDS could be considered as a *detached combined drift-fan*, considering the margin's sedimentary stacking pattern opposite to the pattern on the Hatteras or Hebrides margins where the along-slope processes developed in a more distal part of the mixed system. Conventional wisdom now holds that the largest drift deposits tend to develop in marine basins. However, as indicated by the present work, many kinds of deposits could compose a CDS, and much research remains to be done to determine in detail the genesis and relationships of the sedimentary facies. A CDS can be formed by drift deposits, but also by sedimentary wave fields, channels, moats, furrows, scours, levees, sand ribbons, and sedimentary lobes. All of these sedimentary features could, taken together, be considered clues to the paleoceaonographic imprints related to the same water mass, but they could also be individualized, mainly due to the local behaviour of the current due to sea-bottom stress, producing branches of the current, secondary flow, filaments, internal waves, local turbulence, overflows, helicoidal flow, and other features. This work was supported by the project CICYT MAR-98-02-0209 (TASYO).

FINE-GRAINED SEDIMENT LOFTING FROM MELT-WATER GENERATED TURBIDITY CURRENTS EXTENDING FOR 300 KM FROM AN ICE-STREAM TERMINUS

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Turbidity currents generated from bed-load carrying fresh-water discharges into the sea contain a fluid that is less dense than ambient seawater. From experiments it is known that such currents will eventually lift up from their substrate either in part or as a whole when their density is lowered below that of seawater through settling of suspended sediment from the top or deposition from the bottom of the flows. In the Labrador Sea giant sand and gravel carrying turbidity currents were generated from melt-water discharges from the Hudson Strait ice stream of the Pleistocene Laurentide Ice Sheet during Heinrich events. A distinct depositional facies found on the slope in front of the strait and in proximal parts of the basin suggests that fine-grained sediment lofting from these currents occurred on a large scale. These sediments consist of stacked layers of graded mud that contain floating grains of ice-rafted debris (IRD). This unique combination of graded layers with out-sized particles requires a process depositing graded layers that is slow enough to allow the incorporation of IRD. This is not possible with normal mud-carrying turbidity currents which deposit too fast to incorporate IRD. Where mud turbidites occur on the levees of canyons and tributaries to the Northwest Atlantic Mid-Ocean Channel (NAMOC) or the levees of the NAMOC itself, the IRD form distinct laminae between the turbidites, but are excluded from them. The graded-mud layers with their IRD were previously interpreted as nepheloid-layer deposits (Hesse and Khodabakhsh, 1998). Re-interpretation as lofted-mud facies is a much more elegant explanation as it overcomes the problem of the low density of present-day deep-sea nepheloid layers which typically ranges from 0.01-0.3 mg/l. Lofting of suspended sediment from turbidity currents would start when the density drops below 40 mg/l, the upper limit below which the buoyancy reverses. The IRD-spiked graded mud facies is found exclusively in Heinrich layers within 300 km radius from the Hudson Strait ice stream terminus. Since the lofted-mud facies is restricted to Heinrich layers, the sand-carrying turbidity currents from which fine-grained sediment was removed by lofting are also restricted to Heinrich events supporting the notion that these ice-rafting events were times of maximum melt-water generation.

- *Hesse, R., and Khodabakhsh, S., 1998. Depositional facies of late Pleistocene Heinrich events in the Labrador Sea: Geology 26, 103-106.*

TURBIDITIC SEDIMENTATION IN THE SINOP BASIN, NORTH-CENTRAL TURKEY: RESPONSES TO RIFTING AND COMPRESSIONAL TECTONICS

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The ESE-trending deep-marine basin (>300 km long and ~150 km wide) formed as a part of the Cretaceous Eastern Black Sea rift system and evolved under the Pontide orogenic compression. Initial volcaniclastic sedimentation was followed by the Late Campanian-Palaeocene deposition of tabular, mud-capped sandy turbidites derived from the west, with a slight increase in turbidite thicknesses and an increasing supply of sediment from contemporaneous basin-margin carbonate platform. The succession of sheet-like turbidites is 1800 m thick, lacks recognizable fan lobes and indicates deposition from non-channelized currents of mainly low density, flowing eastwards along the basin axis. The basin at that stage was still wide, but probably consisted of two parallel troughs separated by an incipient compressional ridge, which caused linear, non-radial flow pattern. The succession's uppermost part shows rapid transition into tempestitic offshore facies and wave-worked shoreface calcarenites, a change attributed to the basin-floor uplift by compression. The overlying latest Palaeocene-earliest Eocene variegated mudstones, 200 m thick, indicate a relative sea-level rise that drowned the basin-margin platform and caused cessation of sediment supply and seafloor oxidation. The basin was then split axially into two troughs by a thrust-related popup ridge, while tectonic inversion of the basin's easternmost part activated a siliciclastic source and reversed the transport direction. The overlying Eocene succession, 1400 m thick, includes a couple of palaeovalleys (up to 2 km wide and 150 m deep) with multi-storey palaeochannels, filled with sandy deposits of high-density turbidity currents and subordinate gravelly debrisflows, and numerous sand-filled isolated palaeochannels (>300 m wide and <20 m deep) with common evidence of lateral accretion, all surrounded by sheet-like, mud-capped turbidites. Westward palaeocurrent directions and scarcity of levees suggest axial transport with basin-wide overbank flow. Northward backthrusting narrowed further the Sinop trough and terminated its sedimentation with tempestites and shallow-water bioclastic limestones, whereas the sedimentation in the adjacent Boyabat trough ended with westward axial progradation of a shallow-marine gravelly delta and basin-wide braided fluvial system.

MICROPALAEONTOLOGICAL CHARACTERISATION OF SUBMARINE FAN/CHANNEL SUB-ENVIRONMENTS, AINSA SYSTEM, SOUTH-CENTRAL PYRENEES, SPAIN

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The submarine fan/channel complex of the Ainsa System in the south-central Pyrenees, Spain is in the process of being analysed for its microfossil content.

The aims of this analysis are to establish the age of the system, and to investigate whether the different types of (channel axis, off-axis and levee/overbank) sub-environments that it contains can be discriminated micropalaeontologically, thus contributing to a hydrocarbon reservoir analogue model.

Preliminary results indicate that:

? The Ainsa I fan/channel complex is of early Middle Eocene age on planktonic foraminiferal evidence.
? 2) It was deposited in (lower) bathyal water depths on benthic foraminiferal evidence.
? 3) Channel axis samples differ from levee/overbank samples in their lower unit diversity of benthic foraminifera. The highest unit diversity is at the channel off-axis site, probably indicating the presence here of both in situ and (contemporaneously) reworked species. There is more variability in values at the channel sites than at the levee/overbank site, probably also on account of the effects of reworking.
? 4) Channel samples also appear to differ from levee/overbank samples in their generally higher proportion of infaunal morphotypes, although the extent to which this might be due to reworking or hydrodynamic sorting remains unclear. There is more variability at the channel sites than at the levee/overbank site, possibly on account of the progressive removal through winnowing of hydrodynamically unstable morphotypes of epifaunal "morphogroup" B amd concentration of stable morphotypes of epifaunal "morphogroup" A and infaunal "morphogroup" C.

THE EOCENE – OLIGOCENE GRÈS D'ANNOT OF SE FRANCE : STRATIGRAPHIC RECONSTRUCTION AND MODELLING OF A TURBIDITE RAMP SYSTEM FILLING CONFINED SUB-BASINS IN A FORELAND SETTING

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The Grès d'Annot formation is a well-known turbidite system that has been intensively studied since the 1950's . During Eocene-Oligocene times this formation filled several sub-basins induced by large-scale folding related to the beginning of Alpine thrusting.

Recent research at basin and reservoir scale leads to a better characterization of the relative timing of deformation and sedimentation:

? A new model of small-scale genetic units characteristic of a turbidite ramp has been established : their development is linked to fluvial processes originated from the feeder system (fan deltas) of the southern Corsica-Sardinia massif.

? A general correlation of the large-scale sequences of the main sub-basins (Annot, Sanguinière, Trois Evéchés) is now available : it is based on the stacking pattern of the small-scale genetic units, controlled by systematic datings.

? The 3D architecture of these successive turbidite sequences has been reconstructed : it clearly demonstrates the diachrony of the filling of the different sub-basins, the modification of the sediment sources (geodynamically controlled), and the change of sedimentary processes linked to the transition from ponding to spilling.

? This chronostratigraphic framework has been validated through a 3D forward stratigraphic modelling of the tectonic evolution and sedimentary filling of the whole turbidite system.

A comparison with some modern systems will be proposed.

LARGE-SCALE COLLAPSE PROCESSES ON SUBMARINE LEVEES

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Collapse processes on submarine levees may result in zones of ductile deformation and faulting ten or more km wide, many tens of km long, and up to a few hundred m thick. These processes can completely alter the internal architecture and external geometry of levees, both on the inside (next to the channel), and on the outside of the levee slope facing away from the channel. After collapse, the upper surface of the levee becomes undulatory, with mini-basins where subsequent sediment ponds, and upward-facing projections onto which sediment laps. The deformed zones overlie a common decollement that seems to persist the length and width of the zone. Detailed mapping of seismic data from the northern Gulf of Mexico demonstrates that discrete collapse events occur within the same time interval over the entire collapsed zone. Mapping also shows that collapse occurs repeatedly within the same levee system. The large-scale collapses tend to occur on the right-hand levee (looking downslope). Outcrop investigations of the Upper Cretaceous Rosario Formation indicate that levees can consist almost exclusively of these mass failure deposits, preserving almost no indication of the classic wedge or gull-wing shaped levee. The levee deposits consist primarily of thinly (2-100 cm) interbedded siltstone and sandstone beds. Mass failure occurs at all scales within the levee, and includes: dewatering structures and convolute laminations within beds; beds slumped externally on a small (few cm) to very large (several meters thick) scale; pebbly mudstones up to ten meters thick; and coherent blocks rotated and/or slid on a large (few m thick) to very large (over 100 m thick) scale. In outcrop the right-hand levee also tends to be the collapsed levee, suggesting that levee relief is a factor in triggering collapse.

PATTERNS OF CHANNEL AVULSIONS IN DEEP WATER FANS—ALLO- VERSUS AUTO-CYCLIC CONTROLS

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We attempt here to compile and synthesize information (including also some new 3D seismic data) on the channel avulsion patterns in some deep-sea fans in the world ocean. An avulsion channel pattern that is commonly present in the Amazon and Zaire (Congo) Fans resembles, to varying degrees, the vein pattern in a leaf. We call this a 'dendritic ' pattern. This pattern is characterized by fore-stepping (seaward), or back-stepping (landward) channel avulsions or a combination of both, developed to varying degrees at different hierarchical levels. The dendritic patterns seem to develop along directions perpendicular to the broad trends of continental margins where major sediment inputs for the fans occur. Another pattern, called here, 'radial' pattern occurs in the Indus and to some extent in the Zaire (Congo) Fans. In this pattern channel avulsions occur broadly at one point or in a restricted zone and radiate seaward. This pattern seems to develop either in areas of flat gradients and/or in directions parallel or sub-parallel to the broad trends of continental margins with major sediment input or in areas of flat gradients. In the Bengal Fan, channel avulsions seem to occur in a restricted zone with channels initially radiating, then parallel to one another rectangularly and finally joining at different points further down-dip. In the Mississippi Fan, the channel pattern seems to be intermediate between the dendritic and radiating styles. 3D seismic images in some areas of the Gulf of Mexico provide many details on the anatomy of radial and dendritic styles of channel avulsions.

Gross physiography and depositional topography, increasing channel sinuosity and aggradation, varying discharge volumes, velocities and types of sediment-gravity flows in relation to the accommodation space within the channels (channel relief), sediment grain size and composition, seafloor gradients, channel bank cohesion, and slumping of the levees and blocking the channel are the factors that control the channel avulsion points and the resulting patterns. It is thus clear that both allo- and auto- cyclic factors control the channel avulsions. We believe that the different styles of channel avulsions described above resulted from especially the differences in the discharge volumes and types of gravity flows, sediment grain size and seafloor gradients. In the case of Bengal Fan, the distinctive physiography of the region may also have influenced the channel avulsion pattern.

A FOSSIL MOUNDED ELONGATE AND SEPARATED DRIFTS ON THE MIDDLE SLOPE OF THE GULF OF CADIZ: PALEOCEANOGRAPHY SIGNIFICANCE

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Active drift deposits are related to the regional oceanographic conditions and the physiographic domains where they are developed. So, it is possible to deduce from its morphologic, stratigraphic and sedimentary characteristics the present pathway (or its evolution in the pass) of a water mass. This is particularly relevant when buried contourite drifts are found in the sedimentary record of a basin, because it is possible to reconstruct the paleoceanographic conditions from their study.

Two major fossil elongate-separated mounded drifts (*Huelva* & *Guadalquivir*) have been determined within the central sector of the Contourite Depositional System (CDS) on the middle slope of the Gulf of Cadiz. They have been recognised by a very detail seismic stratigraphy analysis using an abroad database collected since 1989, and obtained during several cruises and projects supported by the Spanish Research Council. In the sedimentary record of both deposits, two main depositional sequences (DS) can be identified, Q-I and Q-II, separated by a marked continuous reflector of strong amplitude and high reflective and erosive surface named *Mid Pleistocene Revolution* (MPR). Both major DS are internally composed of minor seismic units (from A to H). We suggest that Q-I & Q-II constitute high-order depositional sequences related to a 3rd-order cycle of around 800 kyr, and separated by the MPR in the Quaternary, correlated with an important change in the climatic trend known as the "*Mid Pleistocene Revolution*". But, the stacking pattern of the seismic units is different in both fossil drifts, showing a non contemporary time interval for the their activity, influenced by climatic and tectonic changes.

The *Guadalquivir fossil mounded drift* has the most important change in the depositional style between QI and QII in relation with the MPR discontinuity. This stratigraphic discontinuity could be correlated not only with the Mid Pleistocene climatic change, but also with the Guadalquivir Bank uplift, which has produced changes in: the *Guadalquivir channel* pathway, the depositional style and in the partial erosion in the upper part of the QII DS. In the *Huelva fossil mounded drift* the change in the depositional style of the mounded drift is related to the base of the most recent Seismic Unit H (Beginning of the Upper Pleistocene). At this time interval a regional paleoceanographic change in the CDS have been determined as a consequence of the diapiric ridge structures and faults activity, which conditioned a new distribution of the Mediterranean Outflow Water´s branches on the middle slope of the Gulf of Cadiz. This work was supported by the project CICYT MAR-98-02-0209 (TASYO).

INTENSIFIED NORTHERN WEDDELL GYRE FLOW AND SPLITTING OF FLOW PATHWAYS SINCE THE MIDDLE MIOCENE (ANTARCTICA)

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The oceanic crust of the Weddell Sea is bounded to the north by the oceanic Powell and Jane Basins, and the South Scotia Ridge. The Jane arc and backarc system was developed during Early Miocene time, approximately after the end of subduction of the northern branch of the Weddell Sea spreading center. The Weddell Sea Bottom Water (WSBW) flows clockwise in the Weddell Sea, following the Weddell Gyre southward of the Antarctic Circumpolar Current. The WSBW escapes northward to the Scotia Sea through deep gaps of the South Scotia Ridge. The WSBW also flows northward along the South Sandwich Trench towards the South Atlantic.

Data sets were analyzed from multichannel seismic profiles (MCS), swath bathymetry and magnetometric data. The seismic stratigraphy shows a variety of depositional bodies that can be interpreted to outline bottom current patterns from the region during the Neogene and Quaternary. Four main seismic units, separated by regional unconformities are recognized above the oceanic basement. The reflector configurations within these units indicate a distinct change in the depositional style, which reflects a major reorganization of the bottom current processes and probably of the oceanographic regime through time. The two upper units, which show a change to significantly stronger currents, began depositing in the late Middle Miocene and extend to the present, based on the correlation with ODP sites in the region and the age of the oceanic basement.

Different types of sediment drift are deposited in the two upper units and their development is apparently controlled by the seafloor topography. In locations where there is little topographic disruption to the eastward flows of the WSBW, sheeted drift forms. In locations with high-relief ridges that are oblique to the flow, mounded sediment drift deposits are observed on the downstream eastern side of the ridges. Contourite channels form parallel to the eastern side of the ridges. In locations with low-relief ridges, apparent contourite channels develop parallel to the western margin of the ridge, and usually channels exhibit erosion of the right channel margin. The sediment drift and contourite channel deposits suggest that current splays split off from the main eastward WSWB contourite flow and travel northward parallel to the high relief ridges. The grid of regional profiles indicates that the main contourite flow is funneled northward into the central Scotia Sea through Jane Basin and gaps of the South Scotia Ridge. Some flows, however, are diverted northeastward along an area of ridges, blocks and depressions of the eastern South Scotia Ridge in this sector of the northern Weddell Sea.

TECTONIC CONTROL ON THE SEDIMENTARY ARCHITECTURE OF THE ALMERIA MARGIN (ALBORAN SEA): HIGH-RESOLUTION IMAGING

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The continental margin south of Almeria, located at the NE end of the Alboran Sea, is a complex and active area characterized by recent swarms of superficial earthquakes with magnitudes ranging from M_w 5.1 and 4.7 (Stich et al., in press). With the main objective of identifying active structures potentially generators of earthquakes, we recently surveyed this area in the frame of the HITS project ("*High resolution Imaging of Tsunamigenic Structures of the Southern Iberian Margins*", Gràcia et al., 2001). During the HITS cruise carried out onboard the *BIO Hesperides* in September 2001, a multidisciplinary dataset comprising high-resolution (6 m) TOBI sidescan sonar from the Southampton Oceanography Centre (U.K.), Simrad EM12S swath bathymetry and backscatter, TOPAS sub-bottom profiler, and gravity data were acquired. This high-resolution dataset, exhibiting a range of acoustic facies, fully covers an area of approximately 33.3 x 100 km in water depths ranging from 80 m to 1700 m, and provides new insights into the control of neotectonic structure on the Plio-Quaternary sedimentary architecture of the Almeria turbidite system. The Almeria Canyon is a meandering channel system (Cronin et al., 1995) showing steep slopes over most of its course (up to 17%), and confined between the Cabo de Gata Spur, Chella and Sabinal Banks carbonate platforms. North of 36º26'N, the upper to middle part of the canyon parallels the submarine continuation of the Carboneras Fault Zone, following a N47 trend, whereas south of it, the canyon meanders down slope with a net N/S trend. It is about this latitude (36º26'N) that the 60 km long left-lateral Carboneras Fault, showing a slightly positive topography on the seafloor, offsets about 2.5 km into two segments: a north N47 segment and a south N60 segment. The fault also locally modifies the trend of tens of sub-rectilinear highly incised gullies, some of them depicting nicely developed levees, which converge feeding into the Almeria Canyon. Slope instability features (headscarps, detached blocks and debris flows), commonly observed on the flanks of the banks and especially south of the El Sabinal Bank, may also be associated with the seismic activity taking place along this margin.

DIFFERENT-SCALE MASS WASTING ON THE FLANKS OF TYRRHENIAN SEA VOLCANIC ISLANDS (ITALY)

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The flanks of several volcanic islands of the Central and Southern Tyrrhenian Sea have been investigated by long-range side scan sonar, high-resolution seismics and in sectors by multibeam bathymetry. A wide range of instability processes affect most of the seafloor, developing many erosional/depositional features, including a number of different gravity flows (debris avalanches among them), simple-complex slides (sensu Mulder and Alexander, 2001; Mulder and Cochonat, 1996), gullies, canyons with turbidites at their mouth. The scale of the processes is highly variable , the main feature recognized is a debris avalanche located offshore the southern flank of Ischia Island, which extends some 40 km down-slope, to a water depth of about 1100 m, and occurs on gradients of about 1°. It consists of very large blocks (about 5000 blocks with max. dimension of 100x150m) and covers an area of at least 300 km^2, for a volume of about 1.3 km^3. In comparison with other debris avalanches recognized around volcanic islands in oceanic setting (e.g. La Reunion, Canaries, Hawaii) it represents a rather small event. The flanks of Stromboli Island are affected by a complex pattern of instability phenomena, mainly located offshore "Sciara di Fuoco" (NW flank), where instability is still active (slide event of 12/30/02; Chiocci et al., 2003), and offshore the SE flank. Major features are represented by areas characterized by coarse sediments probably related to non-cohesive density flow. The wider area is located offshore the SE flank extending from the shoreline down to the Stromboli Canyon (about 2000 m w.d.) which runs around Stromboli Island, collects volcanoclastic debris and finally develops turbidity flows at its mouth on the Marsili Abyssal Plain. Apart from other controlling factors, mass movements complexity and diffusion result deeply related to seafloor gradient. This relationship is well represented offshore Western Pontine Archipelago (central Tyrrhenian Sea) where a suite of instability/erosional features produce the complete cannibalization of a whole span of the continental slope. This area represents one of the steepest slope of the Tyrrhenian Sea (gradient of 6°-10°, locally up to 30°), extending from the shelf break down to the Vavilov abyssal plain (about 3600 m w.d.). Here on high gradient areas (e.g. upper continental slope), major features are: linear scar-channel systems, dendritic gullies networks, small canyons, simple and complex slides; on low gradient areas (< 3°-4°) instability phenomena develop mainly by non-cohesive density flow (e.g. grain flow) and debris flow deposits.

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HIGH-RESOLUTION GRAIN-SIZE ANALYSIS OF DEEP-WATER SANDSTONES, CAMPOS BASIN, BRAZIL

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Deep-water reservoirs of Campos Basin, Brazil, are part of large depositional systems which delivered huge amounts of sand into the deep-water environments of the basin from Upper Cretaceous to Recent. Commonly, the term "massive" is loosely applied to describe the predominant facies of the reservoir sequences. Although it has been recognized that many of these sandstones are not massive, but non-stratified, presenting normal grading, there has been no systematic way to directly assess the relative amount of truly massive versus non-stratified but graded sandstones. The fine-grained, relatively homogeneous nature of many of these rocks further contribute to the problem, as grading is difficult to document using standard core-description techniques.

Recently, a series of continuous high-resolution (30 cm spacing, or less) sieve and laser grain-size analysis were performed in several Campos Basin reservoirs, encompassing hundreds of meters of cores, thereby allowing a better assessment of grain-size trends. Since most sandstone beds in the basin are of metric thickness, such procedure permitted a good evaluation of grain-size trends. The results showed that in all cases normal grading prevails. Truly massive sandstones, or sandstones with inverse grading also occur, but are extremely rare. In addition, petrographic studies show the occurrence of low amounts (or complete absence) of detrital clay matrix, and dominance of coarse-tail grading, even in fine-grained sandstones. Such data suggest that most of the sandstones of Campos Basin were deposited by turbulent waning turbiditic flows. Normal grading is found even when features sometimes related to sandy debris flows and/or quasi-steady flows, like floating mud clasts or sharp bases are present. Pseudo-matrix, resultant of mud-clast squeezing, locally results in lithologies resembling debris flows, but with normal grading. True debris flow deposits also occur, and are characterized by high amount of mud, floating siliciclastic grains, within a non-graded bed. No evidence of transition between debris flows and turbiditic deposits has been found. On the other hand, grain size gaps are fairly common within the graded beds, indicating that most turbidity currents were density stratified, and suffered one to several episodes of partial collapse and flow rejuvenation.

Dominance of normal grading is observed in a wide range of sub-environments, from channel-fills, to crevasse and spill lobes, and frontal (terminal) lobes. It is also persistent along the depositional profile, from slope to basin-floor systems. The grain size trends documented in Campos Basin sandstones shed some light on the relative importance of different deep-water processes, and on the internal dynamics of the turbiditic currents which formed significant reservoir volumes.

CLIMATIC FLUCTUATIONS RECORDED IN TURBIDITES ALONG THE TOYAMA DEEP-SEA CHANNEL, JAPAN SEA

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Both inversely graded and normally graded turbidites are intercalated in sediment cores obtained from the levee and the terminal fan of the Toyama deep-sea channel system in the Japan Sea. The inversely graded turbidites are interpreted as flood-generated turbidity current deposits (hyperpycnites) while the normally graded turbidites are failure-generated turbidity current deposits (surge-type turbidites). Thus these turbidites are expected to record land climatic changes through frequency and magnitudes of both floods and slope failures of fan delta fronts due to excess accumulation of land-derived sediments.

A sediment core from the mid-fan records the turbidites deposited during the last 2000 years. Grain sizes of turbidites in the core show distinct decrease after AD1200 when the climate shifted from warmer climate (Little Climatic Optimum) to colder one. Detailed correlation between turbidite thickness variation and temperature records in a Japanese cedar during the last two millennia suggests the following evidence. Turbidite thicknesses decreased during cold ages (AD100-200, 400-600, 800-1000, 1300-1400 and 1700-) while they increased when the climate shifted from cold to warm (AD200-400, 700-800, 1000-1200, 1400-1600).

Sediment cores from the levee and the distal fan records fluctuation of turbidite deposition since the Last Glacial (ca. 60ka). Both grain size and turbidite accumulation rate was low during the Last Glacial Maximum (27-17ka) when the Japan Sea was capped by cold and low-salinity water. They had suddenly increased during 17-7ka when the climate had shifted to warm while they have decreased again after 7ka.

The decrease in turbidite deposition and grain size during cold ages may have resulted from the decrease in floods and resultant low sediment supply due to dry climate and consequent low precipitation. The increased floods and consequent higher sediment supply due to higher precipitation may have caused the increase in turbidite deposition and grain size during the transition from colder to warmer climate. The decrease of turbidites and grain size after 7ka may have been attributed to the stabilization of hill slopes due to the increased vegetation and to run out of stored sediments after a long warm climatic interval. Implications of this study would help to understand the land climatic changes of centennial to Milankovitch cycle orders by analyzing deep-water turbidites.

MYTHS OF TURBIDITE SYSTEM CONTROL: INSIGHTS PROVIDED BY MODERN TURBIDITE STUDIES

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*Myth: One fan model fits all fans***.** Both active and passive margins exhibit a variety of turbidite systems (e.g., aprons, fans and channel-levee systems) that result from varying tectonic, sediment supply and oceanographic controls. For example, Cascadia Basin contains aprons (Rogue), fans (Astoria), tectonically confined bypass channels up to 2000 km long (Cascadia Channel), and unusual turbidite systems with plunge pools, sediment waves, channels and lobes (Eel). The Gulf of Mexico intraslope-basin province contains ponded mini-basins (Brazos) and tectonically confined bypass channels that sometimes traverse the intraslope basins and feed abyssal deep-sea fans that vary from small sandy braid-plain fans (Rio Grande) to large mud-rich fans (Bryant, Mississippi). *Myth: Fans form only during sea-level lowstands.* Turbidites occur in Holocene (highstand) sediments of some fans, particularly in active margin settings, where events are triggered by great earthquakes. For example, in Cascadia Basin, earthquake-triggered Holocene turbidite events occur every 34 (southern basin) to 560 years (northern basin). Up to 30 Holocene turbidite events associated with the San Andreas Fault are found along northern California. In the Mediterranean Sea, the outer lobe of Var Fan contains thick (1.5m) sand beds in the late Holocene sediments. Several fans on passive margins also contain Holocene (highstand) turbidites (e.g., Bengal, Mississippi, Zaire). In Lake Baikal, the change from thick Pleistocene-age sand turbidites to thin Holocene-mud turbidites is controlled solely by climate change because there were no of water-level fluctuations. *Myth: Basin-Floor Fans form sequentially before Slope Fans*. The Vail-Exxon Sequence Stratigraphy Model proposed that in submarine fan environments, sandy distal-fan lobes and base-of-channel HARP units are deposited during maximum sea-level fall to form a Basin-Floor Fan, then the more muddy channel-levee systems form the Slope Fan on top of the BFF during subsequent sea-level rise. In reality, coring and drilling of modern fans, especially in Amazon Fan and Gulf of Mexico mini-basins, coupled with swath bathymetry, high resolution and 3D seismic profiling, clearly demonstrate that the HARP and distal fan-lobe deposits interpreted as basin-floor fans form contemporaneously with the channel-levee systems interpreted as slope fans. *Myth: Fan-channel formation, avulsion and switching are controlled by sea-level cycles*. In fact, drilling of multiple channel-levee systems on Amazon Fan demonstrated that formation, growth and avulsion of individual channel-levee systems are autocyclic events, and numerous events can occur during a single sea-level cycle. *Myth: Sandy turbidity currents are commonly triggered by hyperpycnal flow.* Although hyperpycnal flows occur in lakes, hyposaline seas, and locations with glacial sediment supply, beware of this latest turbidite myth. In Cascadia Basin, where some turbidite systems are interpreted to have resulted from hyperpycnal flows, the episodic sand beds of these turbidites can actually be correlated with earthquake triggering. In contrast, the major el niño storm/flooding events of 1964 and 1998 did not produce turbidite sand beds in Cascadia Basin. Even in lakes with hyperpycnal flows, there is generally no correlation observed between the turbidite sand beds and major river floods, which might have triggered hyperpycnal flows.

EXPERIMENTAL AND NUMERICAL MODELING OF SEDIMENTATION OF DIAPIRIC MINIBASINS BY TURBIDITY CURRENTS

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The northern continental slope of the Gulf of Mexico is riddled with numerous subsiding diapiric minibasins bounded by ridges, many of which are connected by channels created by turbidity currents. The region is economically relevant in that these diapiric minibasins constitute focal points for the deposition of sand. These deposits in turn serve as excellent reservoirs for hydrocarbons. A better understanding of the "fill and spill" process by which minibasins fill with sediment as the intervening ridges are dissected by canyons may serve to aid in the location of such reservoirs. A theory is developed to describe sediment deposition in minibasins.

Two key and heretofore unrecognized aspects of the "fill and spill" process are revealed; a) the formation of an internal hydraulic jump as a turbidity current spills into a confined basin, and b) the detrainment of water across a settling interface forming at the top of the ponded turbidity current downstream of the hydraulic jump. It is shown that sufficiently strong detrainment can consume the flow, so that there is no outflow of either water or sediment even with continuous inflow. As the basin fills with sediment, however, overspill is eventually realized. The theory is developed into a numerical model, tested against experiments and applied at field scale.

A POINT-SOURCED CALCICLASTIC FAN COMPLEX (EOCENE ANOTZ FORMATION, WESTERN PYRENEES): FACIES AND CONTROLS

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Calciclastic submarine fans are much less abundant, and thus less well understood, than their siliciclastic counterparts. This contribution describes a fossil case study found in the Eocene Anotz Formation in the western Pyrenees and discusses its architecture and genetic implications. The unit is composed of hemipelagic marls and contains four calciclastic members, some up to 300 m thick, that are well exposed in three-dimensional outcrops and allow inspection of their constituent facies and depositional architecture. These deposits were earlier considered as shallow marine owing to their fossil content (mostly red algae and larger foraminifera), but this interpretation has been reassessed.

Eight different calciclastic facies have been distinguished, all formed by sediment gravity flows (facies A, muddy debrite; B, clast-supported debrite; C, conglomeratic calciturbidite; D, stratified calciturbidite; E, graded calciturbidite; F, cross-bedded calcarenite; G, laminated calciturbidite H, thin-bedded calciturbidite). Paleocurrents show derivation from a shallow-water carbonate ramp to the west.

The eight facies are distributed down slope along four gradational facies belts (FB). FB1 is characterised by slumped hemipelagic marls, cut by erosive-based calcarenitic gullies (facies D and E), and therefore it is interpreted as the upper part of a carbonate slope. FB2 contains thick piles of erosive-based, cross-cutting calciclastic bodies (facies B to F) restricted to a narrow zone along strike. Laterally hemipelagic marls, often slumped, and thin calciturbidites (facies E, G and H) accumulated in apparently higher areas. Thus, it probably represents a major braided channel with marginal levees, which acted mainly as a sediment-transfer conduit. FB3 is dominated by packages of laterally extensive calciturbidites (facies E and G) displaying poorly developed coarsening and thickening-upwards sequences. It is interpreted as a zone of unconfined lobes, created by the expansion of calciclastic gravity flows at the channel mouth. FB4 contains alternating calciclastic deposits (facies G and H) and basinal hemipelagic marls, showing that some diluted flows reached zones far into the basin and formed a peripheral lobe fringe.

Based on the new evidence, each calciclastic member of the Anotz Formation is interpreted as a point-sourced calciclastic submarine fan. Their creation seems to have been controlled by the Pamplona transfer fault, which created conditions for a localised and sustained supply of reworked calciclastic sediments. Moreover, its pulsating activity produced relative sea-level changes, which switched on and off the generation of gravity flows. Contribution to Research Projects BTE2002-03806 (Department of Science and Technology, Spanish Government) and 9/UPV00121.310-14455/2002 (Basque Country University).

PROCESS-BASED UNDERSTANDING OF SEDIMENT GRAVITY FLOWS: ADVANCES AND IMPLICATIONS

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The process-based understanding of subaqueous gravity currents has until recently been predominantly based on physical experimentation, supplemented by some limited measurements from natural flows. This has been due to the destructiveness and infrequent nature of natural flows which has limited the number of field studies and their spatial and temporal resolution, and necessitated the usage of physical experiments. Furthermore, physical experiments have themselves been restricted to largely qualitative studies of high concentration flows (e.g., debris flows) and quantitative studies of low-concentration flows (either purely solute flows (e.g., saline) or particulate flows of up to a few percent by volume concentration). Consequently, our process knowledge of gravity currents is heavily biased towards low-concentration, frequently sediment-free gravity flows, at laboratory scales. Numerical models of gravity currents offer the opportunity to model the full range of gravity currents across all concentrations and over a full range of scales. Progress has been made in developing models that incorporate turbulence using bespoke or commercial computational fluid dynamics (CFD) software. However, these models are restricted to single flow types (e.g., turbidity currents or debris flows) and consequently cannot model the transformation from one type of flow to another (e.g., turbidity currents generated by slope failures), and cannot be validated for a lack of datasets with sufficient spatial and temporal resolution at low-concentrations, and an almost complete lack of quantitative data for higher concentrations.

New developments in physical modelling are presented that will revolutionise our capacity to quantitatively model the full concentration range of subaqueous gravity currents, at sufficient spatial and temporal resolution to validate the latest numerical models. Ultrasonic Doppler Velocimetry Profiling (UDVP) and Ultrasonic High Concentration Meters (UHCM) can provide velocity flow fields and concentration data in flows of up to 40% by volumetric concentration; results from work on flow through submarine channel bends, in opaque two-dimensional turbidity currents, and debris flows will be shown. Initial results of Particle Imaging Velocimetry (PIV) will also be presented, demonstrating the capacity of this technique to provide unprecedented velocity data. Recent fieldwork on natural gravity flows in Lake Lillooet, Canada, has utilised Acoustic Doppler Profiling (ADP) to measure velocity flow fields of currents up to 25 m thick and with velocities up to 0.5 m s^{-1}. The data has revealed a remarkable pulsating signal from continuous input. Such work has the capacity to address the scaling issues inherent but largely untested in small-scale laboratory work, as well as to tie process *directly to deposits* through coring of the resultant gravity current deposits, for the first time definitively closing the process – deposit loop. Finally, work will be presented on a CFD model of gravity currents that can model a range of grain-sizes consisting of both cohesive and non-cohesive particles, across a range of concentrations from debris flows to turbidity currents. This rheological model forms the basis for ongoing work to model flow transformation between high and low concentration flows. Taken together these advances allow us to test and expand on our existing process knowledge, to rapidly move towards predictive numerical models of sedimentation in unconfined settings

SEDIMENT SEQUENCES PRODUCED BY TECTONIC CYCLES IN DEEP-MARINE SEDIMENTS (SEISMOSEQUENCES, MID EOCENE AINSA BASIN, SPANISH PYRENEES

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An integrated subsurface-outcrop study in ancient deep-marine foreland basin sediments, Spanish Pyrenees, shows for the first time the ~10^5-10^6-m-scale, ~10^6 yr, lateral migration of stacked sandy basin-floor submarine fans away from an active fold-and-thrust belt. Fan development and migration were driven by the tectonically-controlled uplift-erosion in the source area and seismically-driven internal deformation and progradation of the progressively collapsing submarine basin slope and shelf. Slope collapse generated debris flows and sediment slides that not only formed much of the topographic template for each fan, but also contributed to their confinement. Following slope collapse, unconsolidated sands and gravels on the narrow shelf were redeposited in deep water, and headward erosion to the feeder coarse grained fluvial systems caused river-derived sands to be fed directly into deep water. Decreased seismic activity caused the submarine fans to be gradually abandoned as an overall fining-upwards, and a new equilibrium profile established. Here we propose that this depositional style of tectonically-controlled coarse sediment pulses to a deep-marine basin (seismosequences), their spatial development and internal organisation, provides a generic model for submarine fan evolution-deposition within other active foreland basins and submarine trenches.

FLOW RECONSTRUCTION AND EVOLUTION OF SINUOUS CHANNELS

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Sinuous submarine channels are one of the main conduits of coarse terrigenous sediments to the deep ocean basins. Our understanding of the dynamics of turbidity current flow and evolution of sinuous channels has evolved dramatically in the last several years with advances in acoustic imaging of both near surface and subsurface channel systems, as well as advances in flow and sediment transport by turbidity currents. In this paper we examine the dynamics of turbidity current flow along sinuous channels and the implications for the formation, maintenance and evolution of sinuous submarine channels. Analysis of the channel morphology, sediments and stratigraphic architecture allow for quantitative reconstruction of paleo-flow in sinuous submarine channels, including flow and sediment discharge, and flow duration. Based on the paleo-flow estimates, it appears that long duration, subcritical turbidity currents are necessary conditions to form and maintain sinuous submarine channels, in particular where these channels extend for hundreds of kilometers across continental margins. Initial channel formation requires erosional turbidity currents, whereas long-term channel maintenance must be associated with net by-pass averaged over several turbidity current events. Lateral channel migration appears to occur as a result of currents that are either dominantly erosional or quasi conservative, whereas dominantly depositional currents lead to channel aggradation and infill. These basic concepts, coupled with an understanding of the dynamics of the flow and paleo-flow characteristics, provide the framework for the development of stratigraphic models of channel formation and evolution.

SILURIAN-DEVONIAN ACTIVE-MARGIN DEEP-MARINE SLOPE SYSTEMS AND PALAEOGEOGRAPHY, ALAI RANGE, SOUTHERN TIEN SHAN, CENTRAL ASIA

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Analysis of mid Palaeozoic successions in the northern part of the Alai Range (Kyrghyzstan and bordering Uzbekistan), Southern Tien Shan, Central Asia, has identified a Silurian-Devonian deep-marine depositional system of basin-slope facies-associations. The turbidite-dominated Pul'gon Formation (Silurian) accumulated in sea-floor depressions and within the inferred basin axis. The large-scale, coarse clastic lenses of the Dzhidala Formation (mostly Devonian) represent the fills of submarine channels/canyons/gullies of the palaeoslope; other slope apron processes include sediment slides, debris flows and olistoliths. We interpret partly time-equivalent condensed sequences of graptolitic black shales, cherts and thin dolomitic limestones as having formed on long-lived topographic highs along the oceanward continental margin of Kazakhstania. The graptolitic shale-rich Chakush Formation (early Silurian) is geographically and petrographically different from the Pul'gon, Dzhidala formations and suggests a different provenance (opposing continental margin or seamount talus). The condensed sequences of the mid to late Silurian Kursala and early Devonian Tamasha formations represent graptolitic mudstone and chert accumulation, respectively, over ca. 10-15 million years, probably on seamounts in the Turkestan (Fergana) Ocean.

The east-west orientated Tien Shan contain strata from opposing plate margins that range through most of the Lower and mid Palaeozoic: the Kazakhstania (Kazakh-Kyrgyz) continent to the north and the Tarim (Afghan-Kyrgyz plate) continent to the south (present co-ordinates). Cambro-Ordovician (Kyrgyz) ophiolites, which occur in the Alai Range, represent obducted fragments of the intervening Turkestan Ocean floor. The Silurian-Devonian formations of the Alai Range represent remnants of a forearc accretionary prism in which deep-marine slope and basin sediments accumulated. These and other stratigraphic units in the Southern Tien Shan were severely deformed by Late Palaeozoic collision events involving essentially N-to-S-directed (present co-ordinates) folding, thrusting and late-stage high-angle reverse faulting and Late Carboniferous-Permian granite intrusions. With uplift and erosion of the orogen, upper Mesozoic sediments rest unconformably on Palaeozoic deposits, and are cut by extensional normal faults.

THE RONCAL MEGABED RE-VISITED

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The presence of re-sedimented carbonate mega-beds has been since long recognised within the Echo Group and profusely discussed in the literature The Roncal mega-bed, is here re-visited at the localities of Urdués, Fago and Vidángoz. Three distinct intervals can be recognised in all of these sections: 1) a lower carbonate *megabreccia* including large limestone slabs, 2) an intermediate mud-dominated *chaotic interval*, and 3) an upper carbonate *megaturbidite*.

The lower *megabreccia* typically shows the effects of strong depositional shear: basal traction carpet and inverse grading, imbrication of the outsize clasts, and upwards extrusion of matrix, first the mud component, and then the coarser grades. Considering the huge proportions of the outsize clasts, turbulence should be ruled out as a liable mechanism to prevent the huge carbonate slabs of immediate sinking. Only matrix strength and overpressure may account. We suggest that the initial large debris flow, because of the depositional shear and the excess pore pressure inherent to the proportions of the flow, got rid off the finer matrix grades by upwards extrusion of the mud component and injection of the coarser grades. The basal megabreccia acquired thus its characteristic textural clast-supported appearance.

? The *intermediate chaotic interval* was formed at the de-coupling horizon between the depositing cohesive portion of the flow and the still moving turbulent portion above. The upward extruded mud from below concentrated here, together with significant amounts of injected coarser matrix grades, fragments from the underlying background turbidites (incorporated here through major shear planes or, more likely, by bulldozing and de-lamination ahead of the decelerating debris flow), and large lumps from the adjacent slope mudstone.

? As to the upper calcarenite-mudstone member, there is general agreement with the initial *megaturbidite* interpretation. The commonly observed Tb-Tc repetitive intervals may be explained as in-flow surges during quasi-steady phases in large turbulent flows.

This model of transport and deposition essentially differs from the preceding interpretations in the combined role of depositional shear, decoupling horizon and upward injection of matrix, and supports the concept of deposition from one single gravity flows of huge proportions.

HALOKINETIC 'CAPTURE' OF SAND-RICH CHANNEL/OVERBANK SYSTEMS WITHIN THE PALAEOCENE FORTIES SANDSTONE MEMBER, PIERCE FIELD, CENTRAL NORTH SEA

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In spite of its apparently distal location within the Palaeocene Forties depositional system, detailed analysis of core data suggest that the Pierce Field area is characterised by an abundance of channel/overbank assemblages. Evidence of low-amplitude sheet-splay or lobe deposits are comparatively rare and typically occur in association with relatively thin abandonment mudstones.

Channel-fills occur either as amalgamated, multi-storey complexes or as the deposits of smaller-scale (and probably more transient) 'scour channels' which are typically isolated within the more heterogeneous channel margin and overbank successions. Significant spatial and vertical variations in the abundance of multi-storey channel complexes are definable across the field area. New biostratigraphic data suggest that an apparently abrupt and widespread increase in the development of channel complexes towards the top of the reservoir can be related to external forcing of the system (marine flooding and subsequent increase in coarse sediment supply). The spatial distribution of large-scale active channel systems, however, is more likely to have been a function of local variations in palaeotopography and accommodation space production around salt diapirs.

Further development of these preliminary interpretations into a fully integrated tectono-sedimentary model for Pierce Field is critical to establishing the updated concepts of reservoir architecture and connectivity that are the key input to field development strategy in this case.

THE DIFFERENT MORPHO-SEDIMENTARY TYPES OF MODERN DEEP-SEA FANS: AN OVERVIEW OF THE LAST RECENT PROGRESS

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Public and private investments in oceanographic research are still fairly modest compared to research funding in other fields. Fortunately, this has not prevented oceanographers from making a number of major discoveries over the last few decades, including the very significant discovery of undersea avalanches and giant submarine valleys.

The study of deep sea fans has generated an abundant literature in the last twenty years. If their structure and mode of development appear to be generally well understood, some turbidite fields recently developed appear fairly substantially different from the models described on outcrops in tectonic contexts of intracratonic basins. Studies conducted onshore on outcropping fossil systems are also limited as outcrop conditions govern the quality of geometric and facies reconstructions. In addition, environmental, climatic and palaeo-geographic conditions are often poorly understood and only part of the turbiditic structure is accessible. Simultaneously, the improvement of subsea exploration techniques (including modern multibeam echosounder, 3D seismic, deep-tow equipments, new core scanning techniques, in situ measurements of sediment physical properties and moorings) have been used by academic research teams, to completely renewed our mind about deep-sea fans and their understanding.

Submarine avalanches, which rank as one of the most spectacular phenomena in marine geology, are caused by the destabilization of sediments which have accumulated at the top of the continental slope. They could cause serious damage to any cables, wellheads or pipelines installed on the ocean floor. But hyperpycnal flows are known to contribute also to mass sediment transfer to the deep-sea.

The purpose of this paper is to point out some of the major discoveries (active processes observation, overflow and sediment waves, distal lobes, confined levees, meanders, avulsion,…) made during the last decade in modern dep-sea fans exploration. Understanding deep-sea fans remain an important target for marine geologists, as such sedimentary systems could become hydrocarbon traps and interest oil companies.

DISCUSSION ON THE MEANING OF THE TERM "TURBIDITY CURRENT" AND "TURBIDITE", AND HISTORICAL PERSPECTIVE

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Recently, various discussions on the hydraulic mechanism of sediment gravity flow are prevailing, and resulted in some confusion on the definition and the usage of terms, "turbidity current" and "turbidite". More serious and influential discussion and confusion have occurred in the industrial sector of the petroleum exploration compared to the academic sector. Some petroleum geologists denies not only the importance of turbidite sandstones as the reservoir rocks, but also the importance of submarine-fan models as the sedimentary environments in the deep water realms (Shanmugam, 2000).

As generally well known, the term "turbidity current" was coined for an unknown flow which was proposed as an agent to form submarine canyons on the slopes (Daly, 1936; Johnson, 1938). Deep-sea sands, graded bedding, and experimental flows supported the existence of such flows in nature, and led to a great evolution in a classical geologic paradigm (Kuenen and Migliorini, 1950). The term "turbidite" was proposed "for all deposits of turbidity currents" (Kuenen, 1957).

Through the accumulation of research on the actual turbidites and related deposits on land and under the sea, the domain of turbidites, or turbidite facies was extremely expanded and organized each other based especially on the submarine fan models in 1970' (Mutti and Ricci Lucchi, 1972; Walker and Mutti, 1973; Walker, 1978). On the other hands, in the experimental and theoretical fields, on the contrary, the definition of turbidity current was confined into the specific flow with specific supporting mechanism of grains, nearly equal to sediment-loaded turbulent flow, in 1970's (Middleton and Hampton, 1973, 1976).

In 1980's, Lowe (1982) proposed the high-density turbidity current reflecting the results of submarine models in 1970's. He widened the realm of turbidity current and turbidite, but, basically, followed the definition by Middleton and Hampton (1973, 1976). As a result, his proposal became halfway.

Shanmugam (1996, 2000) struck the discrepancy in Lowe's proposal. He also accused the definition of turbidity current by Middleton and Hampton (1973, 1976). He proposed to adopt their definition more strictly and narrow, and defined the turbidity current strictly equal to sediment-loaded turbulent current, and demanded to call high- density turbidity current by Lowe (1982) as sandy debris flow. One way to avoid these endless confusion around the term "turbidity current" is to consider them returning to the original definition of turbidity current. Turbidity current must be defined as a total name of an actual flow occurring in nature.

QUANTITATIVE ANALYSIS OF MORPHOLOGICAL PARAMETERS ON THE MODERN ZAIRE DEEP-SEA CHANNEL

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Underwater sedimentological processes that govern construction and organisation of siliciclastic deposits on abyssal plains remain currently misunderstood. Yet the always growing up resolution of subsurface imagery brought to light the existence of large river-fed submarine fans that can reach 10 km thick and more than 1000 km long (Amazone, Mississippi, Indus, Zaïre…). These huge sedimentary units result from the development of highly meandering channel-levee systems spreading out on the sea floor. Relationships between different morphological parameters extracted from bathymetric data led to improve channel-levee growth models.

Multibeam bathymetry and high resolution seismic acquired during the ZAIANGO project (Total Fina Eelf – Ifremer cooperation) covered almost the entire fan surface and permitted to constrain better fan architecture and morphology. The aim of this study is to improve our understanding of channel-levee growth through detailed quantitative analysis of morphological parameters. We show that morphological parameters (levees and channel width and depth, longitudinal channel profile …) clearly record successive phases of channel development and bifurcation. Hydrodynamic-related parameters (wavelength, sinuosity, gradient, width and depth of channel) reveal a periodic evolution linked to the dynamic of turbidity currents themselves. Recurrent changes in the channel slope (T=200 km) are interpreted as the result of periodic variations of the stream power along channel.

HOW TECTONIC PROCESSES AFFECT, AND RESPOND TO, LITHOSTRATIGRAPHY AND SEDIMENT COMPOSITION WITHIN ACTIVE SUBDUCTION MARGINS

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Subduction margins evolve in time and space in response to interplays between tectonics and sedimentation. How tectonism affects sedimentation is well chronicled. Rates of subduction, for example, influence residence times of sediment in the trench wedge. Folds, faults, and mud diapers mold sediment-delivery pathways from shoreline to trench floor; they also help create the architecture of forearc depocenters. Subduction erosion causes margin subsidence. Subduction of seamounts triggers large-scale mass wasting events and warping of forearc structural fabrics. Rapid uplift due to arc-trench collision creates new sources of sediment and new dispersal paths.

Lithostratigraphy and sediment composition can also modulate tectonic processes. Three fundamental parameters need to be considered in this context: (a) texture and mineralogy (especially clay minerals) as controls on sediment's coefficient of internal friction; (b) mineral dehydration (especially smectite and biogenic opal) as contributors to fluid pressure and effective stress; and (c) stratigraphic architecture as a geometric template for permeability, fluid flow, compaction disequilibrium, and compartmentalized overpressure. In the case of Barbados Ridge, the propagating tip of the plate boundary fault follows a weak stratigraphic interval that is enriched in smectite. Other important effects near the prism toe (e.g., deformation-driven increases in bulk density) are superimposed on an intrinsic material weakness inherited from the stratigraphy. In the case of Cascadia, the stratigraphic position of the plate boundary fault, and the sense of vergence of thrust faults within the overlying accretionary prism, shift along the margin's strike. Zonation of clay composition may be the root cause of this structural segmentation. Seaward-vergent faults coincide with illite-chlorite mineral assemblages, whereas landward-vergent structures match mudstones that are enriched in smectite. Presumably, this response is set off by smectite dehydration, which leads to excess pore pressure and reduced shear strength. In the case of Nankai Trough, the frontal decollement occupies a stratigraphic position within a facies unit that changes considerably along strike, due to relief on the underlying igneous basement. Sandy turbidites are widespread above basement plains, whereas coeval strata are hemipelagic above basement highs. Primary facies architecture creates heterogeneities in permeability and fluid flow, such that overpressured compartments develop preferentially where turbidite aquifers are overlain by, or pinch out against, mudstone aquitards. Variations in 3-D thermal structure also direct smectite-to-illite reaction progress in 3-D. Ultimately, clay diagenesis down dip influences the up-dip limit of the plate boundary's seismogenic zone.

NEW PERSPECTIVES AND CHALLENGES IN DEEP WATER EXPLORATION

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Exploration and Production in deep water (>500 m) has increased significantly in the past decade given the excellent success ratio and proven reserves discovered, amounting 57 BBOE as of 2001 (Pettinghill & Weimer, 2001). It is expected that deep water exploration will continue to attract the interest of oil companies since these areas are still underexplored, giant fields are still being discovered and technology will make feasible the production of hydrocarbon accumulations at even greater depths. Deep water exploration is synonymous of turbidite reservoirs. This assessment is justified by the high deliverability per well and large pore volumes needed for a deep water project to be economically feasible, which are found in thick, arealy extensive, porous and highly permeable turbidite reservoirs. Few other depositional systems are capable to deliver high flow rates, and large accumulated production per well drilled. Therefore, turbidites have become a magic word in the oil industry.

Since successful deep water exploration has concentrated in just three areas: Gulf of Mexico, Brazil and West Africa, it could be envisaged that large portions of underexplored world's deep water margins embrace huge amounts of hydrocarbons yet to be found. Obviously this is not true. It we test a reality check and review where the prolific deep water petroleum systems are located and we analyse the ingredients we come up to the following equation: Prolific source rocks + Mobile substrate (either salt tectonics or mud diapirism) + mature-quartz provenance areas + single point sourcing depositional systems (preferred) = hydrocarbon prone deep-water provinces. Examples of this equation are the Gulf of Mexico with Upper Jurassic-Lower Cretaceous sources rocks, overburdened by thick and mobile sedimentary pile at the mouth of Single point paleo-Mississippi, draining quartz-rich source areas. This applies to deep water Nigeria, Lower Congo basin, Campos Basin, etc. but excludes all the active margins (low heat flow, poor sand quality, immature drainage systems..) and most of deep water areas devoided of mobile substrates. Are we running out of promising deep water oil-prone provinces?

With these input parameters it seems that we would have depleted the deep water promising areas and deep water oil fewer is over. This would be true if the above equation is fixed. Now, it is time for the geoscientist to search for alternative deep water plays in different basin architectures with different but alternative ingredients promoting new deep water plays others than pre-existing. One example, Rio Muni Basin (Equatorial Guinea), has proven to provide alternative, subtle prolific stratigraphic traps which have little in common with most common deep water plays: No single point sourcing, no traditional mobile substrate. Therefore there is still too many to learn in the deep water realm. The 21th Century deep water exploration will have to deal with a much better understanding of the heterogeneous turbidite depositional systems and turbidite processes since these systems are extremely rich in stratigraphic trap configurations. This is the challenge and it will need new a multidisciplinary approach. This presentation will cover what in the authors view, are the major challenges and need for a successful exploration.

THE AGADIR PROJECT: UNDERSTANDING CONTROLS ON DEEP-WATER TURBIDITE SAND BODY GEOMETRY IN CHANNEL, CHANNEL MOUTH AND BASIN FLOOR SETTINGS

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Studying variations in bed geometry and internal architecture of individual turbidite beds is not generally possible over distances >10's of km, in both modern and ancient systems. Limited exposure and/or outcrop dimensions hinder long-distance correlation in ancient sequences, while accurate tracing of individual beds over large distances is often difficult in modern systems, mostly due to poor core control and lack of distinctive correlatable horizons. This is especially true across the transition from channel to basin floor.

In the modern Agadir Basin, offshore Morocco, individual turbidite beds can be traced for several hundred kilometres with confidence, due to a unique variety of correlative criteria. Preliminary core studies show that turbidite sheet sands on the basin floor show a wide range of geometries and internal characters, and that these are strongly controlled by variations in flow volume and source area. In addition, geophysical surveys at the mouth of the main feeder channel provide valuable insights into the interplay between erosion and deposition occurring in this area, with abundant erosional scours occurring in a complex bypass zone separating channel and basinal facies. At the distal basin margin the largest flows spill over into a braided channel network, whereas smaller flows are totally confined and pinch out on the basin floor.

The UK-TAPS group have set up an exciting new consortium project based around an intensive coring cruise to the Agadir Channel and Basin, scheduled for early 2004. This will build upon preliminary studies by producing detailed 3-D bed geometries for individual turbidite beds of varying volumes across the transition from channel to basin floor, and also across the transition from distal basin to spill-over channel.

3-D MODELLING OF SUBMARINE CHANNELS SYSTEMS OF THE SCHIEHALLION FIELD, WEST OF SHETLAND, UK

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The Palaeocence Schiehallion oil field comprises various deposits of submarine canyon, and channel systems. Several of these reservoir layers have produced hydrocarbons since 1998 to the Schiehallion FSPO. In order to maximize production and extend field life, the accurate characterisation of the individual reservoir units is critical in providing more accurate production forecasting and in-fill drilling opportunities. Creating detailed geocellular models of the subsurface attempts to capture both depositional and textural variations in the reservoir. The key to producing models that honour both geology, and reservoir properties is to accurately describe the geometry of the geobodies used to fill the model, capture the sedimentological variations seen at wells, and match seismic data (3-D and 4-D data).

In many cases, 3-D seismic data is directly used to condition the in-fill of such reservoir models. Where high-quality, reliable data is unavailable maps are used to control the spatial distribution of reservoir deposits. Maps, however, have limited applicability, due to the difficulties in controlling the vertical relationships between various reservoir facies. By using inherent grid design, and observed net-to-gross variations seen at wells reservoir parameters can be designed to aid in the vertical distribution of facies across a layer.

This simple procedure intends to allow modelers with only map data available to control the architecture of sedimentological in-fill to provide more accurate reservoir models.