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Sedimentary Basins and Crustal and Upper Mantle Reflectors North, West, and South of Britain

Many of the basins crossed in nearly 2,000 km of 15-sec profiling by BIRPS are half grabens formed against Caledonian and Variscan thrust faults that have been reactivated as normal faults during Mesozoic stretching.

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Deep Seismic Sounding in Europe

During the past 3 decades, several seismological techniques have been used to explore the deep structure of Europe. Profound lateral variations in the lithosphere-asthenosphere system became immediately apparent from the observed delay of teleseismic P-waves. On the basis of a uniform dispersion analysis of all the presently available long-period Rayleigh wave observations and applying a new method of regionalization, a map outlining the thickness of the elastic lithosphere in Europe could be constructed.

Regions of markedly thinned lithosphere are the Tyrrhenian and Balearic basins of the western Mediterranean Sea. Another extensional structure of particular interest is the "Central European rift system," which extends from the western Alps to the North Sea. In contrast, an increased lithospheric thickness has been found beneath the Betic Cordillera and the Alps which must be ascribed to underthrusting and subfluence leading to the formation of a pronounced lithospheric "root" reaching to a depth of about 200 km. Long-range seismic refraction profiles have permitted insight into details of upper mantle structure to depths of nearly 400 km in a few tectonic provinces.

Travel-time and amplitude data obtained in crustal seismic refraction experiments, supplemented by wide-angle and near-vertical reflection observations, have made it possible to study the major features within the continental crust of Europe. Regions selected for detailed studies include the southern part of the Iberian Peninsula, the Pannonian basin, the Rhine graben rift system, the northern Alpine foreland, and the Alps.

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Rank of British Coalfields in Relation to Geothermal History and Geologic Structure

Most coals in the United Kingdom were formed during the Carboniferous; the majority are of Westphalian age. The coalfields display a great diversity of size, geologic structure, and rank. Examples include: (a) certain coalfields of the Midland Valley of Scotland, where rank is generally low but capricious because of widespread igneous activity in the form of sills and dikes, (b) the contrasting low-rank Northumberland coalfield and higher rank Durham coalfield to the south, the former lying in a deep sedimentary trough, the latter situated on the eastern margin of a stable block that has a complicated geothermal history, and (c) the South Wales coalfield with its easterly low-rank coals extending to a western area of high-level anthracitization, the cause of which has never been explained satisfactorily. The small Kent coalfield, the Yorkshire coalfield with its northeasterly extension to the new working Selby coalfield, and the new Oxfordshire coalfield, which is at present undeveloped, will also be discussed. Rank variation will be illustrated by vitrinite reflectances measured in borehole sections and by reflectance maps that are not generally available for British coalfields. Some of these maps are based on actual measured reflectances undertaken for marketing purposes by the National Coal Board. Others have been prepared from coalfield seam maps, originally constructed from coal chemical parameters, using what are now acceptable chemical parameter-reflectance correlations.

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Thermal Gradients in Sedimentary Basins

The major features of many sedimentary basins can be understood in terms either of lithospheric stretching or of tectonic loading of the lithosphere. These models allow broad predictions to be made concerning the thermal evolution and the hydrocarbon-maturation histories of the basins in question.

In any particular basin, however, the conductive temperature structure is liable to be modified significantly by the convective transport of heat by circulating pore fluids. Even very slow flows that are too small to be detected during drilling or by conventional hydrologic techniques may have a significant influence if they persist over long periods. Such flows have been demonstrated in the North Sea and the Alberta basin and may operate over a depth of several kilometers and have horizontal dimensions of tens of kilometers.

Much remains to be learned about the causes and behavior of circulations of this kind. By disturbing the conductive distribution of temperature, they delay the maturation of hydrocarbons in some areas and accelerate it in others. They may influence the migration of hydrocarbons, both directly and indirectly, through modification of the permeability structure by solution and precipitation. It is not possible to interpret the fine structure of sedimentary basins and the distribution of hydrocarbons within them without an understanding of these processes.

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Geodynamics of French Oil Basins

The Paris basin, the Aquitaine basin, and the Rhine graben share at least some slices of their geologic histories, even though the diversity of their complete histories largely commands the large variations in their petroliferous characteristics.

The Triassic and Jurassic series belonging to a rifting type basin are favorable to the deposition of both source and reservoir rocks.

The slowing down, then stoppage of subsidence during the Cretaceous and Tertiary Eras in the Paris basin has limited the maturation of source rocks and the formation of structures.

In the Aquitaine basin, the renewal of subsidence during the middle Cretaceous produced large strike-slip faults and the formation of narrow folded troughs. Later, the Tertiary orogenesis renewed the subsidence and formation of structures, resulting in a diversity of traps and the formation of a tar belt on the northern margin of the basin.

The Rhine graben was formed during the Tertiary between 2 large faults nearly north-south in direction. This renewal of subsidence resulted in a new generation of hydrocarbons within a complex faulted structural context.

Subsidence accompanied by fairly high thermal flux appears as one of the main conditions for the generation of hydrocarbons; subsidence may also generate block faulting favorable to their trapping.

On the other hand, too strong a subsidence may produce a poor petroliferous province, because of over-heating, erosion, or loss by seepage.

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Italian Oil and Gas Resources—Present Situation and Future Development

The sedimentary sequences of the Italian region were deposited mostly on the African continental margin and in the contiguous ocean that was generated by Jurassic spreading. The lithology and thickness of the carbonate deposits were controlled from the Triassic to Early Cretaceous by tensional tectonics that preceded and accompanied the oceanic opening. In later times, the prevalently clastic sedimentation was conditioned by the position of the areas subject to erosion and by the morphology of the basins or, in other words, it was the consequence of the compressive tectonics and the Alpine and Apenninic orogeny. Six major structural units can be identified: the Island of Sardinia, a fragment of the European continental margin that escaped the Alpine compressive tectonics; the Tyrrhenian Sea, a Miocene-Pliocene tensional area with an oceanic-type

crust; the Southern Alps fold and thrust belt; the Apennine fold and thrust belt, where nappes of regional extension are present; the Foredeep; and the Foreland. The majority of the gas reserves discovered in Italy are located in Pliocene sandy reservoirs of the external Apennines and the foredeep. They originated during diagenesis through the action of bacteria on the immature organic matter contained in coeval shales. Most of the oil and part of the gas have a thermogenic origin from Mesozoic source rocks, mainly black shales deposited within Middle and Upper Triassic restricted basins. These shales matured during the Neogene, and the oil therefrom migrated into the adjacent Mesozoic carbonate reservoirs or, where tectonization was more intense, into Tertiary clastic reservoirs. Also, it is probable that a minor part of the oil found in Tertiary sandy reservoirs might have been originated by the organic matter contained in the shales of the Miocene Flysches. Presently (1982), gas and oil are the most important energy resources of Italy, covering about 9.8% of the national energy demand. Petroleum exploration, which started about a century ago and which has been intense since 1950, has not yet exhausted the possibility of additional interesting discoveries that appear to be conditioned mainly by the progress of exploration techniques.

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Orogenic Clastic Wedges of the Alps and Apennines

The simple equations—flysch = turbidites, and molasse = marginal marine to continental deposits—are untenable even in Alpine collisional settings where the terms originated (e.g., the turbidite nature of most Apennine molasse). Because sedimentologic definitions of molasse and flysch are inadequate, it is necessary to rely on the tectonic setting of these deposits, although too many different usages have made the terms ambiguous in this respect. The terms are used herein only in regard to compression-related settings (including back-thrust and late-stage normal faulting), and for already completed or well-developed orogenic cycles. Time of emergence of the framework of the main chain from the mobile belt is taken as the reference for separating flysch (pre-emergence) from molasse (post-emergence). In Alpine belts, flysch basins have disappeared, but molasse basins are still present except for some deformed and uplifted parts. The emergence criterion requires that a significant drainage area was exposed to stream erosion, rather than just to gravity sliding and mass wasting. The time of emergence can be tested by facies analysis, as long as that analysis is made in a spreading place because chain building is incremental owing to orogeny migration (i.e., the rate of depocenter shifting is a significant parameter).

Orogenic basins of the Alps and Apennines varied much in size, lifetime, basement type, clast composition, mode and rate of filling, type of closure (tectonic or sedimentary), etc, but generally group around some of the following modes: (1) typical or Alpine flysch, (2) typical foreland molasse, (3) atypical or foreland flysch, (4) atypical foreland molasse, (5) atypical "piggy-back" molasse, and (6) intermontane and "back-arc" molasse.

(1) The typical or Alpine flysch was formerly large, turbiditic-abyssal wedges slowly deposited on a closing ocean floor and its margins, during a long "punctuated" collisional event (Late Cretaceous-Eocene). They eventually formed allochthonous slabs, detached from their basement, and obducted first on the European craton (Alpine orogeny), then on the African craton (Apennine orogeny). The main representatives of this type are the so-called Helminthoid (carbonate) Flysch.

(2) The typical foreland molasse consists of large, conformable or unconformable shallow-marine to continental wedges, that accumulated at a high rate in a major foredeep, laterally fed by the adjacent chain. These are represented by the north Alpine Molasse Group (Oligocene-upper Miocene), and the youngest undeformed "skin" (5%, upper Pliocene-Holocene) of the Po-Adriatic basin fill.

(3) The atypical or foreland flysch developed when large, conformable, deformed turbiditic-bathyal bodies were emplaced in major elongated foredeeps migrating on a shortening continental margin (African), which was activated after the Alpine collisional phase (Oligocene-Miocene). The sedimentation rate was higher than that of the typical or Alpine flysch, but did not prevail through subsidence. The basins where the foreland flysch developed were bounded mostly by subaqueous structural highs. Dispersal was longitudinal, with the main sources in the adjacent suture belt (i.e., supply of molasse type). Typical representatives of

this class are the Macigno, Cervarola, and Marnoso-Arenacea Formations.

(4) Atypical foreland molasse deposits are conformable, partly deformed, large turbiditic to deep-water wedges, where the rates of subsidence and deposition were tremendous (up to 4-5 km/m.y.). The source of these deposits was sliding, giant debris flows (olistostromes), and axially deflected clastics from lateral emerging thrusts. These deposits are atypical with respect to the classic Alpine molasse, but they typify more than 90% of the Apennine foredeeps from the Po plain (upper Miocene-Pleistocene) to the Ionian Sea. They are also found in the early stage of filling of the North Alpine foredeep, where they usually have the qualities of flysch (e.g., Annot Formation).

(5) The atypical "piggy-back" molasse is mostly small to medium wedges of turbiditic-hemipelagic material filling separate basins. These basins formed at various stages on the Apennine thrusts and were carried with them to the foreland. Presently, the "piggy-back" molasse overlies autochthonous clastic wedges. Older deposits of this type (the Oligocene-Miocene Ranzano-Bismantova sequence) were close to and fed by the Alps suture zone (i.e., the source was basically Alpine molasse that was tectonically recycled in the Apennines). Younger deposits (upper Miocene-Pleistocene) reflect the emergence of the Apennines (real molasse).

(6) Intermontane and "back-arc" molasse are small to medium-size bodies unconformably filling fault-bounded basins. The highly variable subsidence and sedimentation rates resulted in a predominance of deep-water to continental deposits (i.e., partly typical and partly atypical). As the back-arc area of the Alps was the African craton (equal to the Apennine foreland), much of the "retro-Alpine" molasse was involved in Apennine thrusting. However, part of it remained in place (the Tertiary Piedmont basin). The "retro-Apennine" molasse is still accumulating in grabenlike basins around and in the Tyrrhenian Sea.

Examples of specific stratigraphic and sedimentologic attributes of the various types of wedges, with particular reference to types 3, 4, and 5 in the Apennines and Po basin, are being studied in the Pyrenees and Hellenides, in relation to their hydrocarbon potential.

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Tectonic Evolution of the Apennines

Italy's backbone is a fold-thrust belt of Cretaceous to Holocene tectonic age. It involves Paleozoic basement, thick Mesozoic carbonates, exotic terranes of western Mediterranean origin, and eastward migrating foredeeps. Foothills structures contain commercial mixtures of immature and mature gas. These structures and the giant Malossa field nearby encourage exploration.

Plate motions, a quantitative tool in Apennine exploration, result from 2 components. Crustal coherence across the eastern Mediterranean invokes the motions between Europe and Africa, and Tertiary tectonics of the western Mediterranean add a local component.

The Apennines are a collision belt with a polarity flip in the north and persistence in the south. Fossil arc material is scarcely recognized, but plate-size clastic sources include European foreland highs and Tethyan terranes in the north, and the Betic-Sardinian belt in the south. Recent volcanism occurs in 3 settings: arc, bent and fragmented foreland, and basin-range type extension.

Refraction-seismic data suggest thrust repetitions of the Moho at odds with surface structure in polarity and location. In detail, these data are contestable, but their regional significance must be honored. It confirms estimates of stretching at Tethyan passive margins, flexing of viscoelastic foreland, 3-dimensional overlap of Europe, Alps, and Apennines, and, perhaps, crustal shear zones mapped at the surface.

Style elements common to fold-thrust belts include ramps with decollements, duplexes, and blind thrusts. Interleaving thrust arcs suggest crustal control of ramps. Polyphase recumbent folds in several settings record the attaining of critical taper. Normal faulting is abundant and similar to the Idaho-Utah thrust belt.