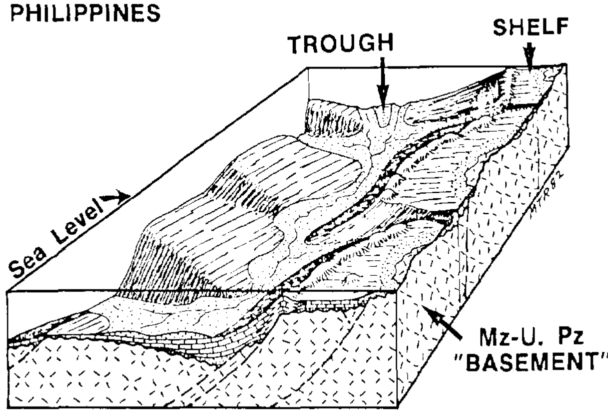
seal over the reef that protects internal reef components from additional submarine diagenesis. Consequently, some primary porosity remains intact, that, with continued submergence, may bypass meteoric diagenesis and still remains to become enhanced by late subsurface events.

Within core samples of Cretaceous and Miocene reefs, porosity created by late-stage dissolution is facies specific and predominantly moldic and enhanced primary (skeletal and interparticle). Submarine cements occlude some primary porosity in each reef facies. However, back-reef facies result in higher observed porosity because primary permeability allowed greater access for dissolving fluids. Stylolites that form and remain open within reef packstone-grainstone facies act as avenues for fluids that dissolve skeletal grains along narrow adjacent zones within the rock matrix. This late-stage dissolution can produce significant porosity where primary permeability is still preserved. Limited early submarine cementation inhibits burial compaction and acts to preserve porosity. Where stylolites extend into back-reef mudstone and wackestone facies, a higher percentage of impermeable muds and a limited amount of skeletal grains available for dissolution prevent development of significant porosity. Late-stage subsurface dissolution within reefal buildups, whether by widespread, pervasive fluid migration or as fronts along stylolite zones, is commonly facies-controlled by primary porosity and permeability characteristics. Thus, the distribution and degree of submarine cementation are important to both the early and late development of porosity in reef reservoir facies, even though sometimes for indirect reasons.

LOWER MIOCENE FACIES
NW PALAWAN
PHILIPPINES



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Alternating Carbonate and Siliciclastic Deep-Water Facies in Tectonic Evolution of Northwest Palawan Margin (Philippines), South China Sea

Shifting Mesozoic and Cenozoic tectonic events controlled the deposition of thick alternating sequences of deep-water carbonate and siliciclastic sediments on the northwest margin of the North Palawan crustal block.

Highly deformed Jurassic to Lower Cretaceous rocks at the base of the section may have originated in a fore-arc region along the South China margin. This convergent margin shifted into a broad extensional region in the Late Cretaceous or early Paleogene. The Late Cretaceous through the early Eocene is generally a time of hiatus in the rock record, but rocks of this age may occur in half grabens under the northwest Palawan slope.

Late Eocene to mid-Oligocene dolomites and limestones were deposited in restricted to open marine environments as the rifted Mesozoic terrain subsided. During sea-floor spreading from the mid-Oligocene to early Miocene in what is now the central South China Sea, extensive carbonate deposition of reefs, platform lagoons, and deep-water sediments draped the trailing (northwest) edge of the southward-drifting North Palawan block. Over 1 km (3,300 ft) of diverse deep-water carbonate facies was deposited in an upper slope to basin setting. Turbidites were derived from reefal sources dominated by benthic forams, coral, and coralline algae. Mudstones formed by off-bank transport and settling of platform lagoon muds differ from normal pelagic deposits rich in planktonic forams. Deep-water carbonate units show a continual up-section decrease in abundance of reef- and lagoon-derived sediment and are abruptly overlain by deep-water siliciclastics.

Seismic profiles indicate late early Miocene tilting and partial emergence of the North Palawan block, during which clastic sediments prograded around and over relict carbonate platforms and deposited thick deep-water sequences on the northwest Palawan slope. These siliciclastics were deposited in submarine fan complexes as sand-rich middle to inner fan channels, outer fan lobes, and pelitic interchannel and interlobe deposits. After crossing the submerged carbonate terrain, turbidites were axially confined to a northeast-trending trough and formed a stratigraphic wedge several hundred meters thick against the slope of the relict platforms. Eroded shallow-water carbonate lithoclasts were commonly incorporated within siliciclastic turbidites. Turbidite sandstones are texturally submature feldspathic litharenites and subarkoses, and indicate a source terrain of quartzo-feldspathic sediments and metasediments, chert, volcanics, and acid-intermediate plutonic rocks. Petrologic studies thus support seismic and dip-meter interpretations that these sediments were derived from emergent pre-Tertiary rocks of the North Palawan crustal block.

Regional uplift in the middle Miocene was followed by mid to upper miocene subsidence, producing additional siliciclastic wedges on the northwest margin. The last regional uplift event, latest (?) Miocene, was characterized by wrench and reverse faulting. Miocene tectonism may have resulted from collisions of the North Palawan block with now adjacent terrains in the South Palawan, Mindoro-Panay, and North Sulu Sea regions. The northwest Palawan margin has been tectonically quiescent since the early Pliocene, marked again by carbonate deposition of reefs and flanking deep-water deposits.

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Pore Geometry: New Techniques for Quantitative Analysis

Accurate measurements and high resolution three-dimensional displays of pore geometry have been achieved using sophisticated optics, three-dimensional image analysis, and techniques of computer tomography. These new methods allow detailed analysis of low permeability pore structures with isolated secondary porosity. Examples under study include Cotton Valley tight gas sands, Smackover carbonates, and Whitestone limestone.

The procedure is to "serially section" rock samples, either by successive 2μm grindings or by microtoming brominated-epoxy/epoxy "double pore-casts." SEM images or photomicrographs of the sections are digitized, and these successive images are reconstructed into three-dimensional data sets. These data sets are then analyzed for such parameters as grain size and shape, pore volume, connectivity, and permeability.

Computer graphic displays are generated using techniques developed for biomedical applications. Colored images of the reconstructed three-dimensional pore structures are photographed from many viewing angles. These multiple views are combined by a special lens-mirror optical imaging system to produce "parallax panoramagrams" which show 20° of "rotation." Panoramagrams provide high resolution, high magnification displays which can be viewed with the naked eye, without special equipment.

State-of-the-art computer graphics, research quality optics, and new image analysis techniques have been used to provide a rigorous approach to understanding pore geometry. This novel synthesis shows particular potential for the study of hitherto intractable, complex structures.

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Biostratigraphy and Phylogeny of Paleocene Radiolaria

In the radiolarian biostratigraphy of the Cenozoic Era, only the majority of Paleocene Epoch has hitherto remained unzoned. Submarine sediments recovered from DSDP Sites 208 and 327 of the southern ocean, contain rich and well-preserved radiolarians, thus providing an opportunity to fill this gap and to complete the radiolarian zonal scheme. The majority of forms, including some new taxa, are presented and discussed.

A rather diversified radiolarian fauna appears in early early Paleocene, but species belonging to the genus *Byryella* made their initial appearances only during the middle Paleocene. Throughout the Paleocene, numerous well-known Cenozoic forms made their first appearance. By using co-occurring microfossils for stratigraphic correlation, these initial appearances can be placed within the pre-existing planktonic zonation and geochronometric framework. The phylogeny of *Byryella* has been investigated throughout the Paleocene section.

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Slope and Deep-Sea Fan Facies of Miocene Castaic Formation and Lower Part of Ridge Route Formation, Ridge Basin, Southern California

The late Miocene marine Castaic Formation in Ridge basin is over 2,000 m (6,600 ft) thick and consists mostly of slope and deep-sea fan facies. The Castaic Formation is vertically transitional into the overlying Marple Canyon Sandstone Member of the Ridge Route Formation and laterally interfingers with the Violin Breccia to the southwest. The slope facies consists of poorly bedded mudstone interbedded with sandstone, conglomerate, and coquina deposits interpreted as turbidite-filled slope channels. The slope facies follows the northwest trend of the basin and occurs on the northeast, north, and southwest sides of the basin. The slope channels have laterally adjacent levee deposits. Paleocurrents in the channels are to the west-northwest and southwest-southeast, whereas paleocurrents in the levee deposits are to the northwest-southeast. Large slide blocks, slump-folded strata, and breccia beds are common in the slope facies.

Deep-sea fan deposits consist of inner and middle fan channel and interchannel facies and outer fan depositional-lobe facies. They are confined to the center of the basin, interfinger into slope facies to the southwest and northeast, and are overlain by nonmarine fan-delta complexes to the north. The channels contain thick sandstone deposits that thin and fine upward and are laterally discontinuous, whereas the adjacent interchannel deposits consist of thin-bedded sandstone and mudstone sequences which form inclined wedges of highly slump-folded strata. Depositional-lobe facies thicken and coarsen upward and consist of interbedded sandstone and mudstone which form laterally continuous deposits with minor channeling and slump folding. Paleocurrents in these deposits are to the south-southeast and suggest sediment transport down the axis of the basin from the north-northeast.

Ridge basin was a relatively shallow-marine trough about 6 km (4 mi) wide and 10 to 20 km (6 to 12 mi) long. The deep end of the basin was to the southwest and connected to the Ventura basin across the San Gabriel fault. Typical deep-sea fans did not develop in Ridge basin during Castaic Formation time; instead extensive slope deposits formed along the margins of the basin and thick but narrowly confined turbidite-filled channels and depositional lobes filled the valley or trough of this basin.

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Reservoir Facies Zonation Using Wireline Logs

Sedimentary rocks can be described an distinguished from others not only by their lithology, geometry, sedimentary structures, and fossil content but also by their overall response on the electric logs—their "electrofacies." FACIOLOG processing zones together those sections of a lithological sequence which have a comparable suite of electric log responses to give an electrofacies zonation.

Geologists have traditionally used electric logs as a basis for zonation when drawing up composite (lithological) columns. FACIOLOG processing now offers the potential of treating all the logs, including the dipmeter, on an objective and quantitative basis. The electrofacies zonation is made by cross-plotting all the log responses on a multi-dimensional set of axes and then using cluster analysis to identify locally dense areas. Each cluster represents a series of depth intervals with a similar suite of log responses (an electrofacies). The degree of similarity of the various clusters is then expressed in the form of a dendrogram, and the complete well section is displayed with each level assigned to its own particular electrofacies.

How closely does the "electrofacies zonation" correspond to the more conventional lithofacies zonation? Generally there is good agreement because electric logs, especially with new services such as the litho-density and natural gamma ray spectrometry tools, respond to the basic mineralogy of the rock matrix as well as the fluid content. FACIOLOG processing also incorporates the high resolution information from the dipmeter, which corresponds to the basic sedimentology.

Because of the usually good match between the electrofacies zonation and the lithological zonations in cored sequences (especially in siliclastic sequences), FACIOLOG processing can be used to extrapolate the results of core analysis into those sections in the well where there is no core.

A new 22 in. (56 cm) wide presentation format allows all the logs, the dipmeter curves (with GEODIP or CLUSTER tadpoles), and the electrofacies zonation itself to be used as a basis for integrating all the information acquired when a well was drilled. Lithological descriptions from cuttings and cores or other stratigraphic information can easily be integrated onto the flexible format. Presenting all the logs together and having the additional advantage of the quantitative electrofacies zonation is clearly an aid to well-to-well correlation. With data banks, specific electrofacies zones may now be automatically traced across