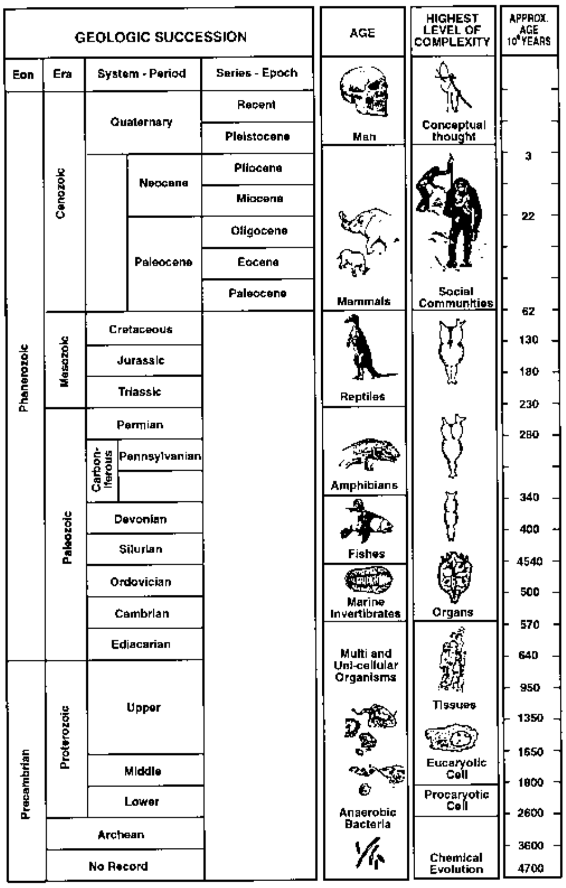
Presentation to Palawan University students Puerto Princesa – Philippines

1996



As a start…
A very summarized history of life

Geological time. Known Universe was formed some 15-20 billion years ago and the earth some 4.5 billion years. Life appeared 3.5 billion years ago and the predecessors of man some 3.5 million years. Oil and gas explorers deal with rocks and hydrocarbons ranging in age from about 200 million to a few million years. Older hydrocarbon accumulations do exist but are less frequent.

Exploration for Oil and Gas

Geological Background (types of rocks, tectonics, etc.)

Principles of Hydrocarbon Accumulations (the required ingredients)

The Exploration Process

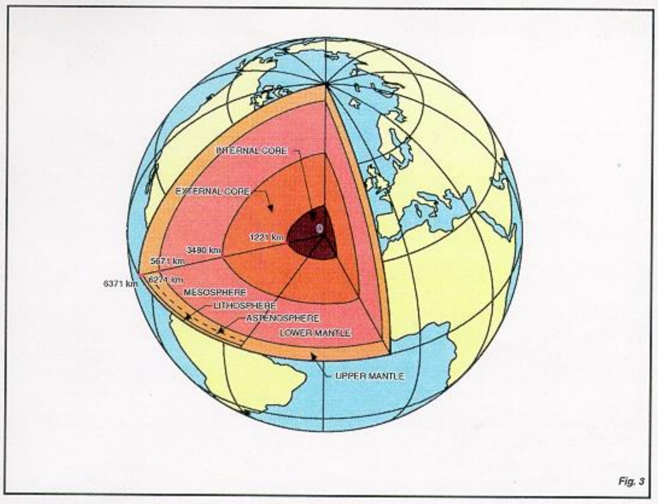


Fig. 3

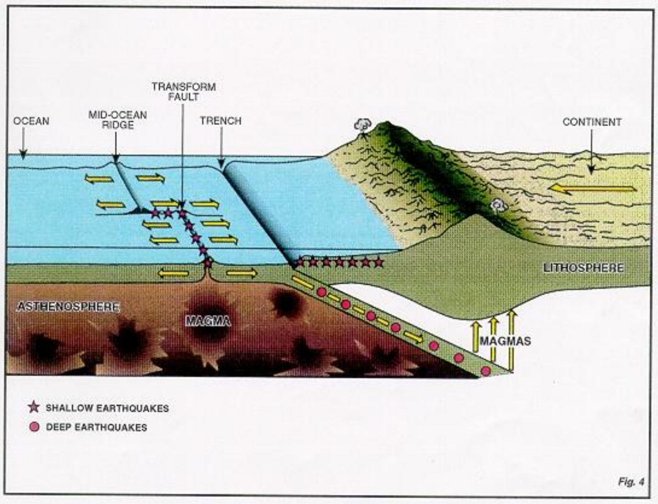


Fig. 4

Top: the earth consists of an external shell of solid rocks (lithosphere), some 100 km thick and floating on a thick, viscous layer of molten rocks (top of the asthenosphere). The latter is underlain by the mantle composed of iron and magnesium-rich rocks and eventually by the earth core made up principally of nickel and iron. The temperature of mantle and core is very high (1500 to 6000^{0}C). The temperature difference between the earth's interior and its surface induces a transfer of the heat between the two in order to reduce this disequilibrium. Heat transfer is partly by conduction across the rocks, partly by radiation and mainly by convection. The latter mechanism relates to the movement of hot rock material (magma) towards the earth's surface and downwards upon cooling; this continuous movement of matter takes place in so-called convection cells. The convection movements drag along the lighter fragments of lithosphere which are thus drifting on the earth's surface and, of course, interact with each other. There are about a dozen of those lithospheric fragments or plates, as shown below.

Very high mountain ranges, such as the Himalayas or the Alps (Europe) are mainly formed when continental plates of equal, low average density collide.

In summary, oceans are created by divergence of the continents; none of the actual oceans is older than 200 million years. Older oceans have been subducted into the asthenosphere; remnants of such oceans are nowadays found as deformed rocks in mountain ranges. Mountain ranges are formed by collision of plates, oceanic versus continental, continental versus continental or oceanic versus oceanic. The net result (altitude, amount of crustal shortening, etc) will depend on the relative composition of the colliding plates

Plate interactions include divergence and convergence. The third mode, whereby plates pass along each otherbut a surface expression of such relative movements is illustrated below (so-called transcurrent faults like the Philippine Fault). The plate movements account for all the deformations of the earth's crust , which include the formation of the mountain ranges and of the oceans, as well as smaller scale features (folds, faults) as observed at a scale ranging from outcrop, through rock sample down to electron microscope.

Magma is rising to the ocean floor, adding thus oceanic crust at the location of the mid-ocean ridges. Both plates separated by the mid-cean ridge drift then apart (diverge). As the area of the earth is basically constant, an equal amount of crust must disappear, which it does in the subduction zones (to which oceanic trenches are associated); there, the heavy, cool oceanic crust sinks into the asthenosphere, normally along the inclined subduction surfaces until it reaches its melting point. The movement of the downgoing slab is the principle cause of earthquakes as experienced in the Philippines and elsewhere. Along with the melting of the descending lithospheric plate, new magma is generated, which is lighter than the surrounding rock and rises to the surface where it forms the well known volcanoes of the Pacific island arcs (by the explosive emission of gas rich molten rock fragments and dust).

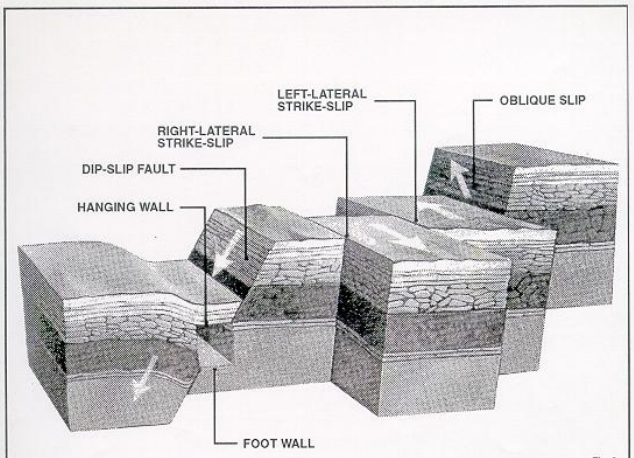


Fig. 8

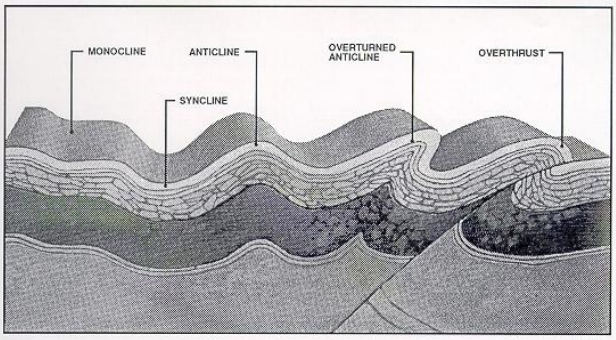


Fig. 10

Fig. 9

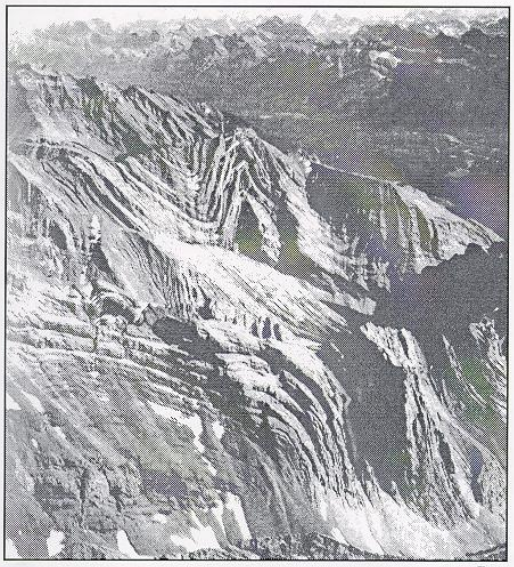
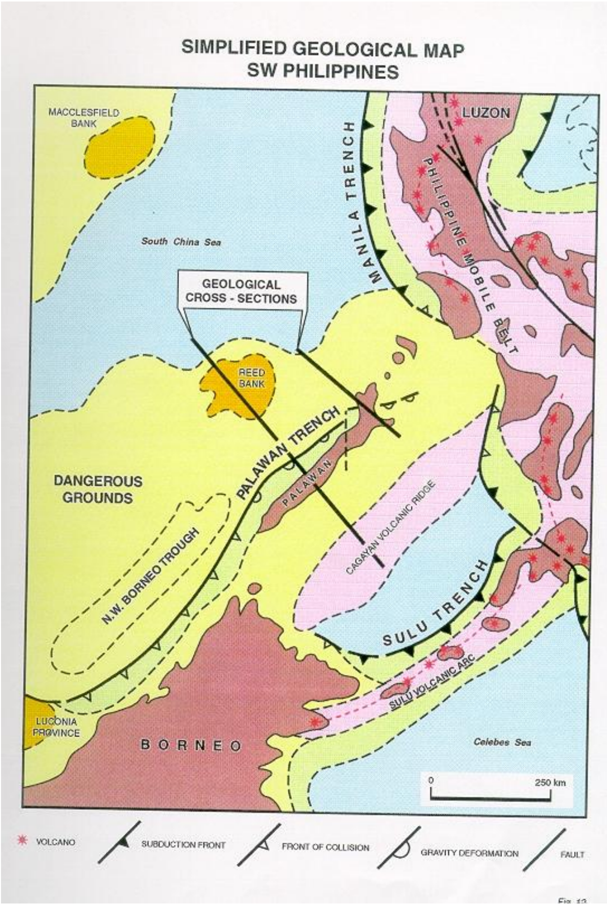


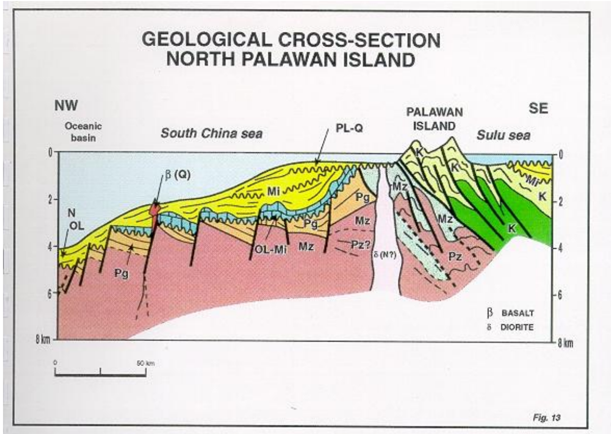
Fig. 11

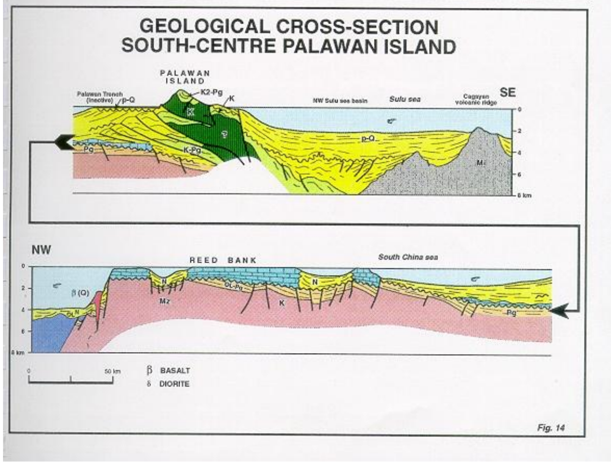
Various types of extensional and strike-slip/transcurrent faults observed in the earth's crust, be it in outcrop or in the subsurface. Faulting normally affects indurated, brittle rocks and is restricted to the crust. Normal faults (top left) increase the distance between the blocks thus separated and are therefore the response to extension/stretching.

Strike-slip faults (bottom left) are caused by lateral, oblique compression if the overburden is thick and heavy. Example of surface fault related to the 1994 North Mindoro earthquake. Rice fields are clearly displaced along the rupture (transcurrent component in addition to a less obvious vertical displacement).

Bottom right: folds of various curvature and a reverse fault resulting from lateral compression; the same result can be obtained by crumpling a napkin!). Example of folds within a mountain range.







Geological sections across North Palawan and the adjacent South China Sea. The section was constructed by surface observation , in the mountains of Palawan, and by interpretation of offshore seismic data. Palawan Island clearly represents a zone of compression with thrusts, reverse faults and folds, which is diminishing in intensity towards the offshore. The offshore represents predominantly a zone of extension with normal faults, related to the opening of the South China Sea, which was later covered by a wedge of sediments derived from Palawan Island. The section at the bottom epicts the geology across part of the Sulu Sea, Palawan and Reed Bank. The latter is underlain by continental crust drifted from China and shows mainly extension/divergence features (normal faults).

The Philippine arc is squeezed between the Pacific Plate moving westward at a rate of 10 cm/year, the Eurasian Plate considered stable (reference) and the Indo-Australian Plate moving north-norteastward at a rate of 8 cm/year.On the Pacific side the current collision is absorbed by the Marianas and the Philippine-East Luzon subduction zones; collision of Luzon with the South China Sea "block" is taken up by the Manila subduction zone.

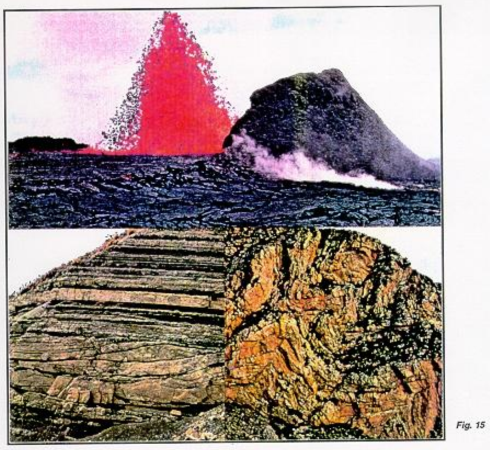
Large scale structural map illustrating the various units forming the Philippines.archipelago:

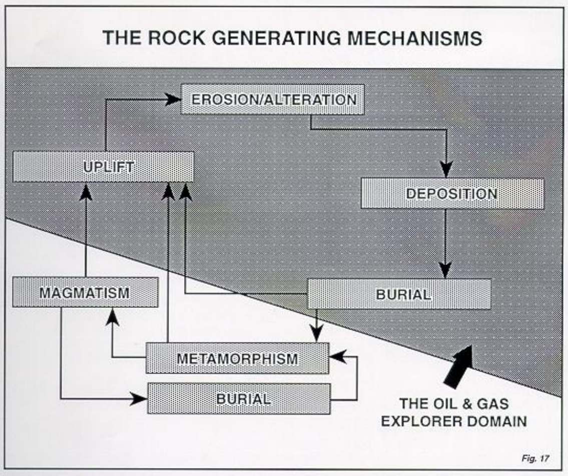
- the S-shaped Luzon, Visayas and Mindanao Arc (or Philippine Arc);\
- the triangle-shaped South China Sea, which opening during the last 50 million years separated the Cuyo Bank, Reed Bank and Palawan from mainland China (to which these units were previously attached);
- the continental fragment including Cuyo Bank, etc;
- the Sulu Sea;

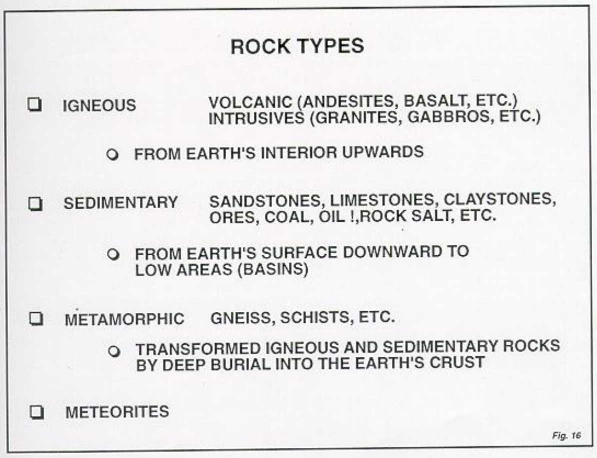
– the Sulu Arc and the Celebes Sea.

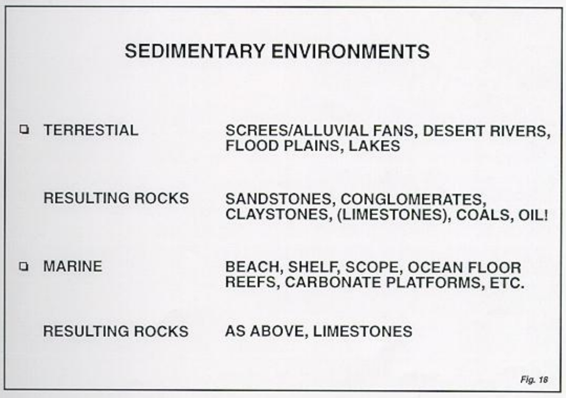
The transcurrent S-shaped Philippine Fault runs along the Philippine Arc, which is currently active and the source of earthquakes.

Accretionary wedge/melange/arc refer to rocks scraped from the ocean floor in the process of subduction and accumulated as wedges along collision zones.









Left top and bottom : the three main types of rocks:

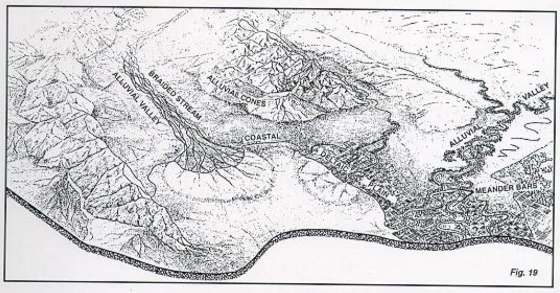
– igneous, in this case volcanic rocks. Red-hot lava is erupting at the surface of the volcano probably on one of the Hawaiian islands). In the Philippines, the ascending magmas have a different composition, are richer in light elements and erupt explosively (e.g.andesites of the Pinatubo and Mayon volcanoes). If the magma does not reach the earth surface and solidifies at great depth, other rocks result, such as granites, gabbros, etc;

– sedimentary rocks, characterised by layering resulting from the depositional processes of rock particles under subaerial or aquatic conditions. These are the rocks of interest to the oil and gas explorer (and also to the coal and metals explorer!);

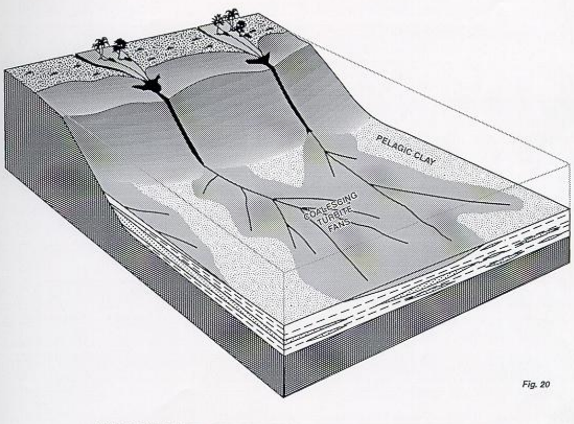
– metamorphic rocks, which are produced by the transformation of any rock type under conditions of high temperature (typically in excess of 300 ^{0}C) and pressure (deep within the earth's crust). Those rocks normally keep the chemical composition of the original rock and are layerd/banded and folded/crumpled. At very high temperatures, melting occurs creating thus a new magma which will ascend in the earth's crust (effectively becoming an igneous rock!).

Top right: relationships between the various rock types, the so called rock loop. Surface erosion and chemical alteration of preexisting rocks, destroys those rocks and produces sands and clays. The latter are then transported to low areas by water and/or wind and subsequently deposited. Deposition can take place on the flanks of the mountains, in alluvial plains in thne river beds, in lakes, in deserts (sand dunes) and eventually in the sea. The particles of sand and clay thus deposited are referred to as sediments; they are covered by successive layers of younger sediments and are therefore continuously buried at greater depths until this process is stopped by compressional events, depletion of the sediment source, etc..During this burial, sediments are compacted and undergo cementation by minerals derived from interstitial waters : they become rocks. Further burial at even greater temperatures will lead to metamorphis and eventually complete melting of the rock, producing thus an igneous rock. Subsequent uplift which may expose the rocks to atmospheric conditions, may result from mountain building processes or lowering of the sea level; and the erosion/alteration cycle starts again, closing thus the rock loop.

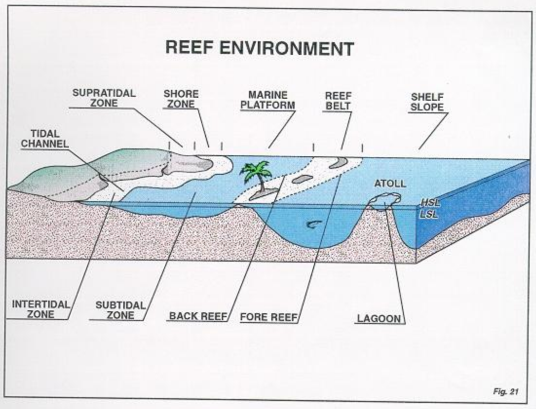
Bottom right :broad subdivision of sedimentary environments of deposition and the resulting rocks. Limestones, as occurring for instance in Nido , have not been mentioned in the preceding paragraph as they do not strictly derive from the erosion of previous rocks. They are normally formed under marine conditions, although their formation in lakes is well documented. The most spectacular limestones are those formed by living organisms such as corals and algae, referred to as build-ups or reefs, which can be important hydrocarbon reservoirs. Other types of limestones are formed through compaction and cementation of beach sands derived from previous limestones, etc.

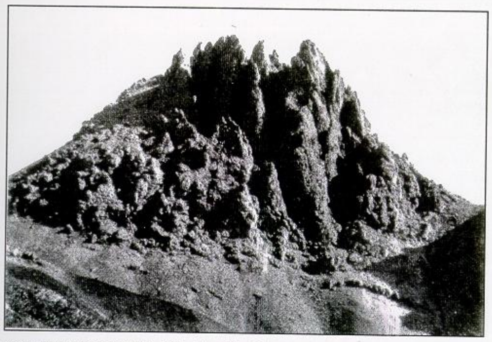


COASTAL - TERRESTIAL DEPOSITIONAL ENVIRONMENTS



DEEP WATER DEPOSITIONAL ENVIRONMENTS





An exhumed reef, approximately 600 m in lenght and 300 m in height, in the Proterozoic Little Dal Group, Mackenzie Mountains, Northwest Territories, Canada. The castellated core of microbial limestone is sorrounded by coarse flanking beds of reef talus.

Fig. 22

Top left : terrestrial to shallow marine depositional environments.

Bottom left : example of deep marine setting where sands, which have bypassed the shelf, are funnelled through canyons to deep sea plains. There, they are deposited as fan-shaped bodies. The current transporting these sands (also with gravels and clays) are called turbidity currents.

Top right: environments favourable to the formation of reefs.abound in the Philippines. The picture is self-explanatory.

Bottom right, picture of an exhumed reef some 600 million years old.

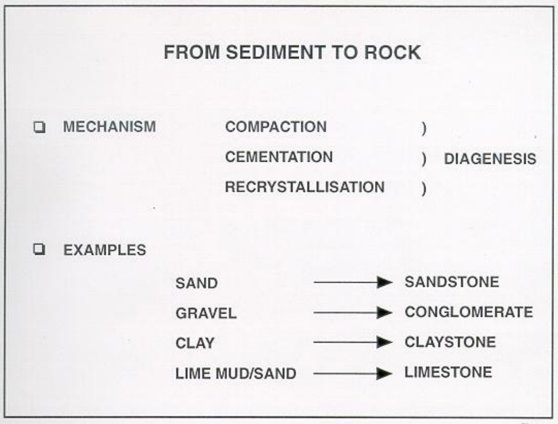


Fig. 23

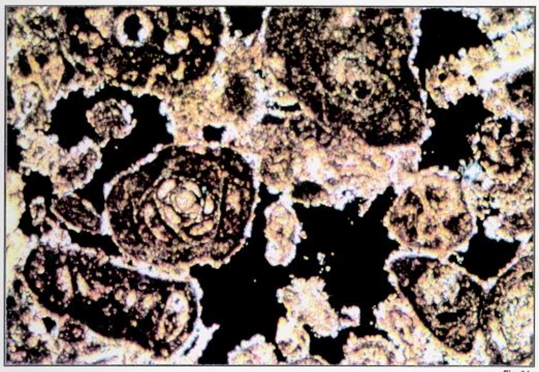


Fig. 24

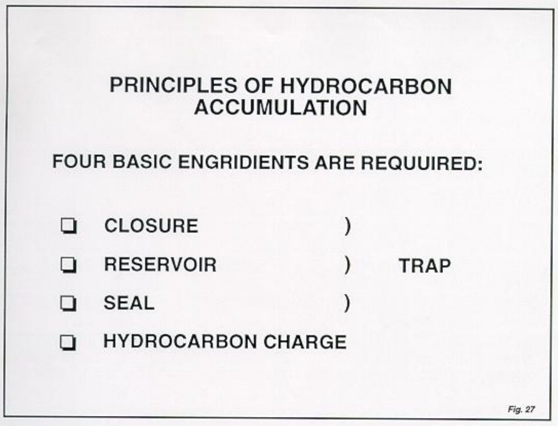


Fig. 27

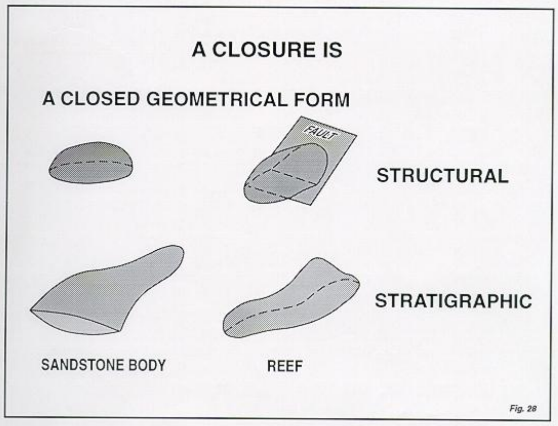


Fig. 28

Mechanism of sedimentary rock formation. The analysis of those sedimentary rocks may provide a clue about:

– the age of the sediment based on the plant and animal remains (fossils) included in the rock. Species of living organisms have appeared, evolved and disappeared, and are therefore used as time indicators. Some minerals precipitated within the rock can also be used as radiometric time markers.

– the environment in which the sediment was deposited based on the plant and animal remains, the geometry of the layer concerned and its overall relationship with the surrounding deposits, and eventually on the cementing minerals since the latter form under well defined physico-chemical conditions.

Bottom left: example of a little compacted and cemented limestone made-up of marine microfossils. Very large magnification of a very thin slice of rock as seen under the microscope, through transparency.

Tectonic events relate to main timing of deformation, either by extensional (Rift) or compressional processes (collision). Main horizontal stresses are an indication of the direction of the extensional or compressional forces, as derived from the geometry and direction of faults and fold axes.

One of the important tasks of the explorer is to reconstruct this succession of layers in time and space. Such a reconstruction should indicate the value of the rocks in terms of hydrocarbon source-rocks, reservoirs and sealing potential (to be discussed below).

PRINCIPLES OF HYDROCARBON ACCUMULATIONS

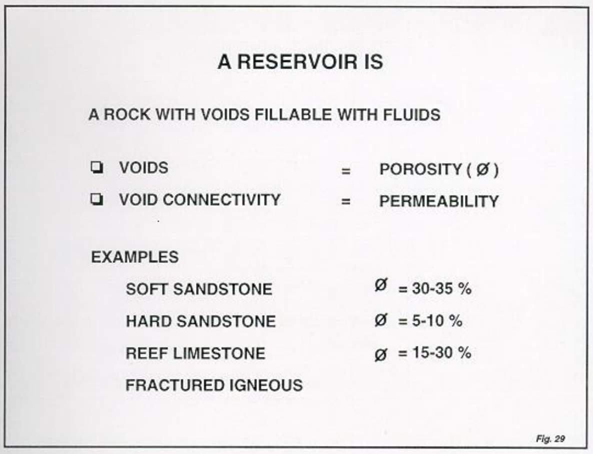


Fig. 29

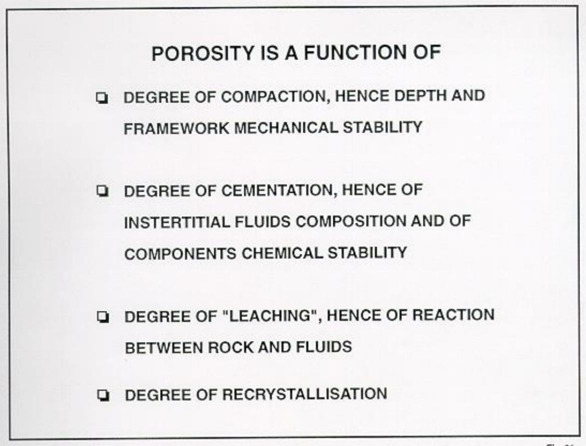


Fig. 31

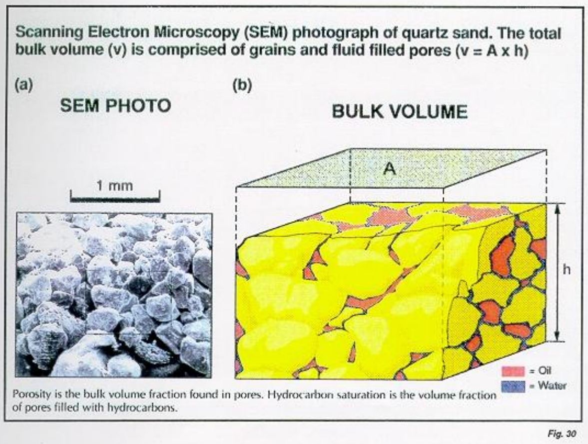


Fig. 30

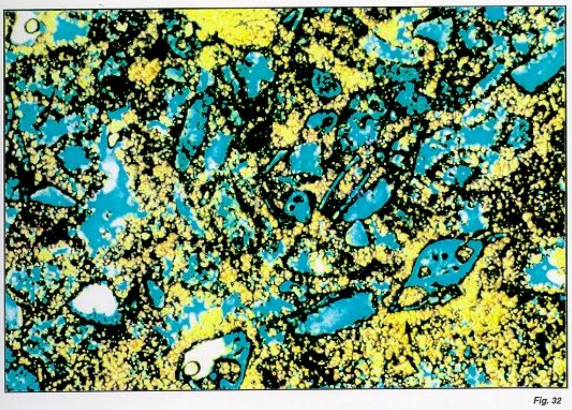


Fig. 32

Top right: for a hydrocarbon accumulation to be present, four conditions must be fulfilled:

- the presence of a closure, i.e. a geometrical configuration of the reservoir rocks that prevents lateral or vertical escape of the hydrocarbons when adequately sealed;
- the presence of a reservoir rock containing interconnected pores where hydrocarbons can accumulate;
- the presence of a seal or cap-rock that is impervious to the passage of hydrocarbons;
- the availability of hydrocarbon charge, i.e. the likelyhood that hydrocarbons are generated and can migrate to the trap.

If one of those conditions fails, there will be no accumulation.

Bottom right: Examples of closures (preceding picture))

Top left: definition of "reservoir". The interconnected pores or voids between the grains/fragments is called porosity and is expressed as a percentage of the total rock volume.
The interconnectivity of pores is referred to as permeability and is measured in Darcy or Millidarcy units. The higher the permeability, or easiness for liquids to flow, the higher the so-called well productivity, and the better the economics of development/production of the reservoir. This factor is critical for development in deep waters as is the case offshore NW Palawan. Generally, the higher the porosity, the higher the permeability; however, there are exceptions, especially in limestones. An important factor determining the permeability in sandstones is the average grain size; the larger the grains, the larger the pore throats and the easier the flow of liquids and gases. Another important factor, also critical for porosity, is the sorting of the grains; the more equal the grain diameters, the lesser the chance for smaller grains to fill the pore space.

Bottom left: visualisation of a sandstone reservoir. Reservoirs always contain a certain quantity of water adhering to the grains which cannot be displaced by the hydrocarbons migrating into the reservoir. This water can be inherited from the environment in which the sediment was deposited or represent brines migrating upwards from underlying sediments.

Top right: porosity critical factors are:

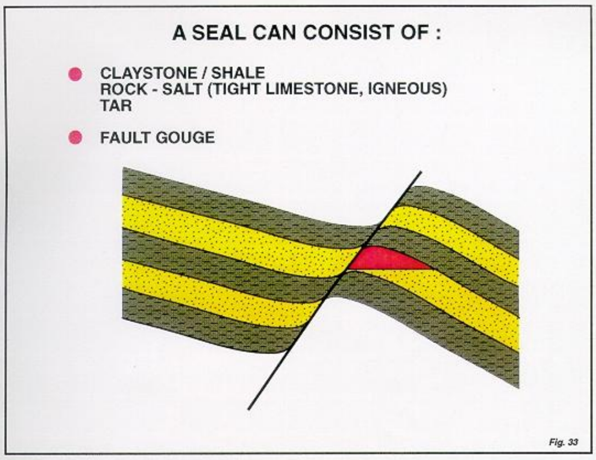
- the degree of compaction which will increase with increasing depth of burial, but will depend also on the mechanical stability of the grain/rock framework. Soft grains will be easily deformed and fill the por space;

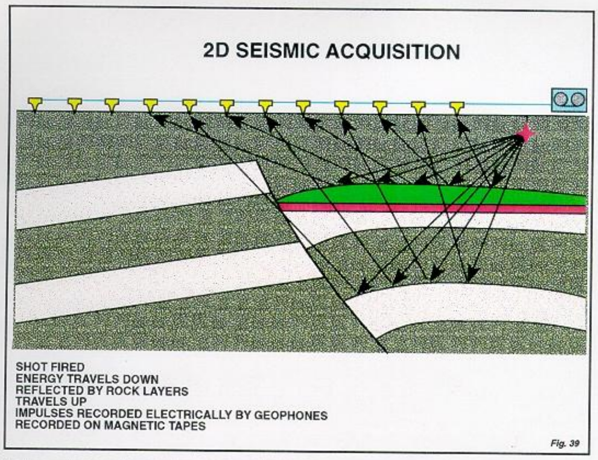
- the degree of cementation by newly formed minerals such as calcite, quartz, clay minerals (the most frequent). Hence strong influence of the interstitial water chemistry and chemical stability of the rock components (whose atoms can be leached/dissolved and later precipitated);

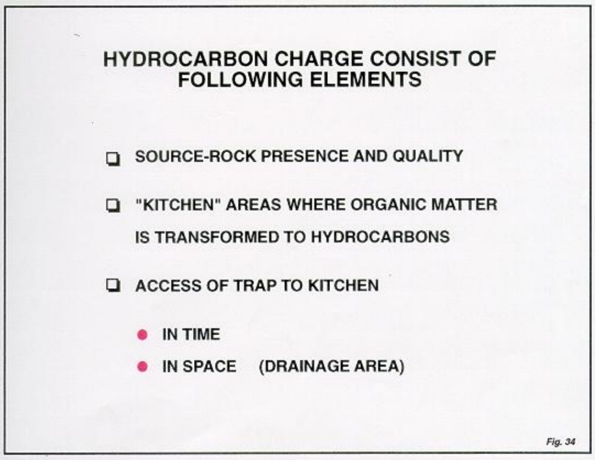
- the degree of leaching of the rock components by chemically aggressive interstitial waters. Leaching can create large amounts of porosity, especially in limestones;

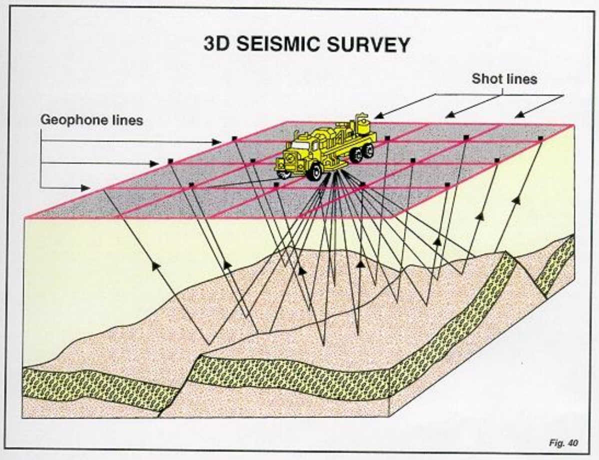
- the degree of recrystallisation of the grains, which is a function again of the grains' chemical stability under the prevailing conditions (temperature, pressure, pH, Eh).

Bottom right: example of severely leached limestone composed of microfossils and calcite cement. Porosity is indicated in blue.







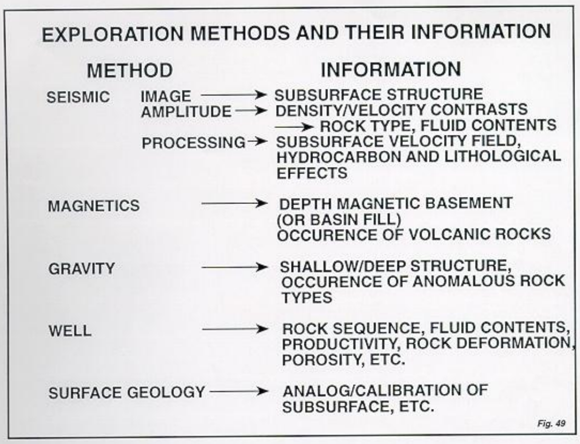


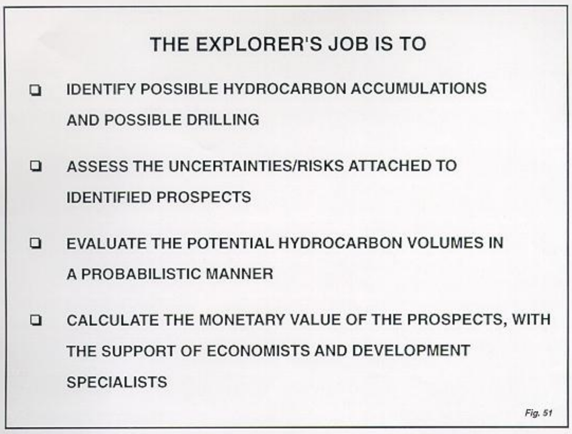
Top left: examples of sealing rocks and sealing fault gouge.

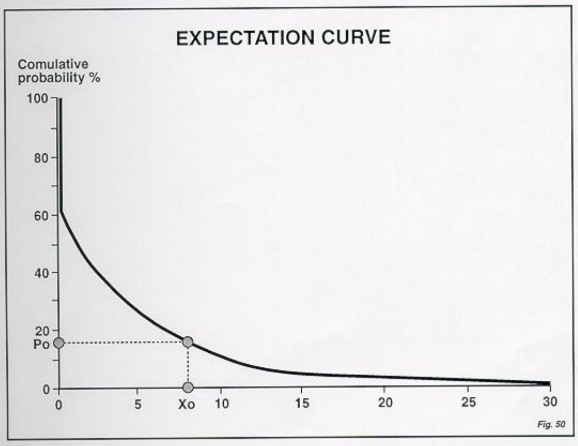
Bottom left: components of charge are:

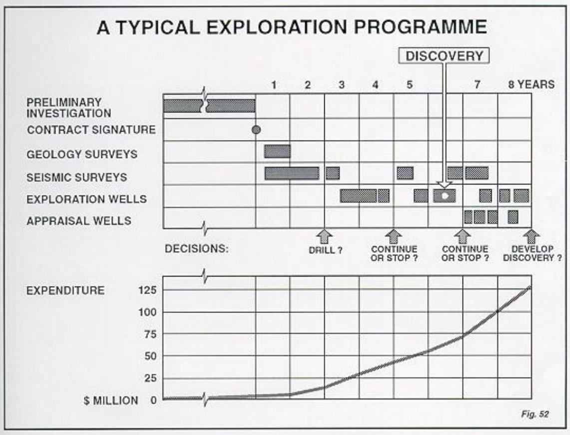
- the presence of a source-rock of adequate quality, i.e. with sufficient organic matter content to generate hydrocarbons in appreciable quantities. A lower limit of 1% organic matter volume is accepted to define a potential source-rock as such;
- the presence of areas, so called "kitchens", where the potential source-rock has been subjected to temperatures leading to the transformation of the organic matter into oil and/or gas;
- an access of the trap to the kitchen area, which would allow expulsed hydrocarbons to migrate from the source-rock to the reservoir. This is referred to as migration path. This access must fit both in space and in time; if the trap has been formed after the hydrocarbons have been generated, then charging is not possible.

EXPLORATION PROCESS









Top right: the explorer's tasks are described. Most important, and not highlighted, is the fact that the explorer is a gambler who tries to reduce the uncertainties of the game as much as possible.

Top left: listing of the type of information provided by the various geological and geophysical methods.

The first essential step is to generate a geological model of the area under consideration, which satisfies all the available data and fits with what is known from the surrounding areas. Based on this model, new data have to be acquired, processed, interpreted and integrated in order to reduce the identified uncertainties; the latter pertain to the presence of the necessary ingredients for an accumulation to occur. After integration of all new and old data, the potential reserves of the identified prospect(s) as well as their economic value (including risks) are evaluated. This last exercise can result in the definition of drilling location(s), in the abandonment of the project or in the decision to acquire more data and/or conduct further studies.

Bottom left: example of so-called expectation curve of hydrocarbon volumes to be potentially discovered. Because of all the uncertainties mentioned above, the explorationist cannot provide a unique figure for the potential volume of hydrocarbons trapped in a given undrilled prospect but has to come up with a range of possible volumes. The various possible volumes and their attached probability of occurrence are usually shown as "Expectation Curves" (Volume on x-axis and cumulative probability on y-axis). In `the present case, the curve describes a volume distribution whereby there is 15% chance that the prospect contains 8 million barrels or more.

Bottom right: typical exploration programme with decision points and related investments. Large sums are involved in an exploration campaign which can or cannot result in a commercial discovery. In this case, some 125 million US$ were spent without having produced one drop of oil! The Shell-Oxy Venture has spent in their offshore SC38 block some 175 million US$ and the decision to develop the gas reserves of Malampaya has not yet been taken!

The risks involved in hydrocarbon exploration are well known : of the 288 exploration wells drilled in the Philippines less than 5% discovered hydrocarbon accumulations! The total oil production since inception is in the order of 48.5 million barrels, an amount far from that required to offset the exploration expenditures.

The Philippine Archipelago contains some 21 sedimentary basins with some chance of hydrocarbon occurrences. Whilst some of the basins offer good possibilities /prospectivity, others are only marginally prospective. It is up to the explorers to find the key to new reserves!

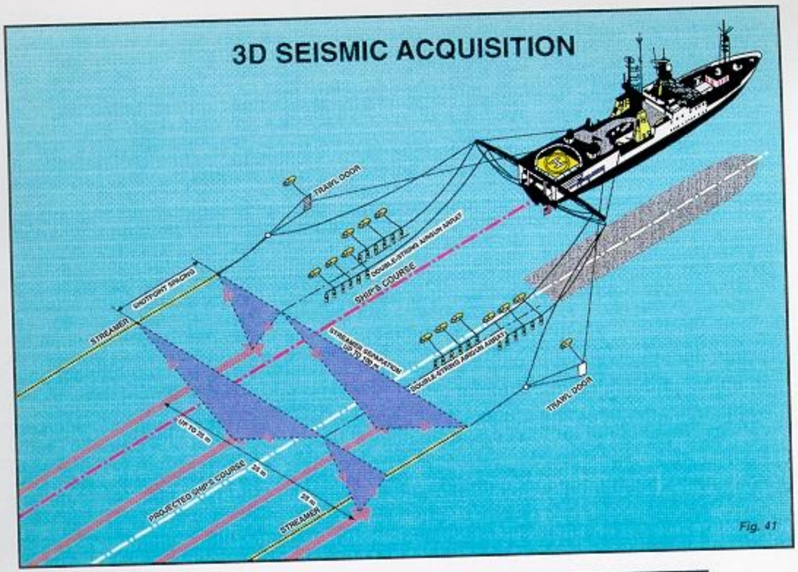


Fig. 41

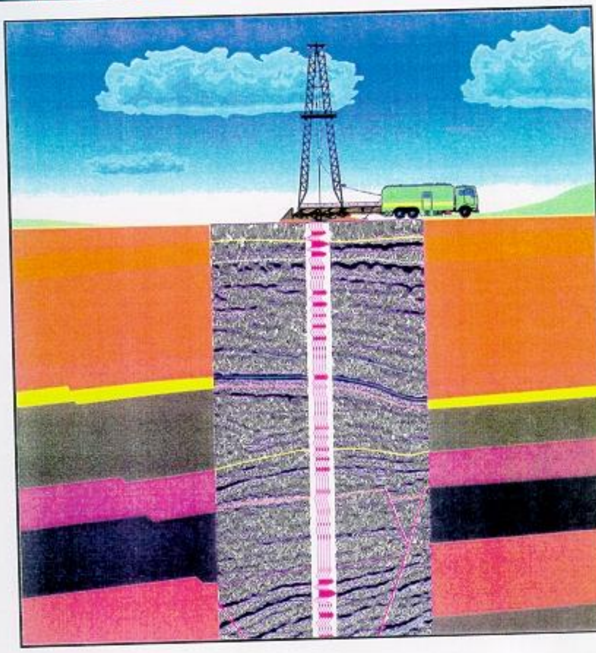


Fig. 42

Seismic data can be acquired as 2D or 3D representation of the subsurface.

2D seismic data provide information on the subsurface structure of the sedimentary layers in a vertical plane extending from the surface to depths at which the seismic signals notably deteriorate. 2D seismic data are generally acquired in such a way as to form a regular grid of intersecting parallel lines. The end result of a 2D survey is thus an incomplete picture of the subsurface, where information is concentrated along planes separated by volumes of no data. The skilled seismic interpreter is expected to add a geological meaning to the data in terms of age, rock type and deformation of the reflectors, as well as to fill the data gaps between the lines with geology (by interpolation and conceptualisation).

On land, shock waves are generated either with the help of dynamite charges made to explode within holes (a few metres to a few tens of metres deep) or with the help of truck mounted vibrators. The reflected sound waves are recorded by sensitive geophones, planted in the ground; the reflected waves cause the ground to vibrate, which movement is transformed by the geophones into electric current. The latter travels along cables, laid on the ground, to the observer's station where the electric signals (intensity) are digitally recorded. The raw data thus recorded consist of positioning, time and seismic amplitude values; processing of those data with powerful computers is required to obtain an image in time of the subsurface, which the explorer can interpret. Offshore, the shock waves are generated by the sudden release of air from so-called air-guns, which does not affect the marine fauna. The reflected waves are causing pressure differences in the water, which are recorded by pressure sensitive hydrophones, floating just below the water surface. The signals are also digitally recorded on the towing seismic boat. The main difference with land acquisition lies in the fact that the cables, with their trains of explosive and recording stations are continuously dragged by the boat, whilst on land the relocation of the cables and attached instruments relies on transport by man (in forest areas) or by truck (in open terrain like deserts).

The main difference with the 2D data lies in the fact that 3D data cover the entire volume of the survey area and thus provides a much improved picture of the subsurface. The acquisition of 3D data is obviously more time consuming and more expensive. However, in many cases the technical advantages (and eventually economical ones) far outweigh the increased acquisition and processing costs. Nowadays, the acquisition of 3D data has become a routine step of professional field development. Such data were acquired in the Philippines for the Malampaya-Camago, Octon and Maniguin discoveries. The benefits of acquiring 3D data in the exploration phase to better define the potential traps and future drilling locations are being also increasingly recognised.

The processing of 3D data, because of their huge quantity (see Fig.44), requires even more powerful computers and is very time consuming : a 250 km^2 survey will need some 6 months of processing. The resulting subsurface picture and the possibility to quantitatively analyse the data more than justify the effort spent in acquiring and processing the data.

Top: the marine 3D-seismic data acquisition method with a 3D seismic boat towing the air-gun arrays and the recording cables. The geometry of the acquisition parameters (length of the cable, cable spacing, etc) is designed to obtain the best possible image of the subsurface objective (traps and reservoirs). Cable lengths of up to 6 km are nowadays currently used to target very deep objectives and to allow the quantitative assessment of reservoir properties and of the possible occurrence of hydrocarbons.

Bottom: very short seismic data can be acquired in the vicinity of a drilled well. The various reflectors can then be identified with certainty and tied to the more regional data.

COST OF SEISMIC AQUISITION

❑ 2D	LAND	5 - 10,000 US $/km
	MARINE	1,000 - 2,000 US $/km
❑ 3D	LAND	20 - 30,000 US $/km
	MARINE	10 - 20,000 US $/km

Fig. 45

SC 38, SEISMIC COVERAGE AS AT 31.12.94

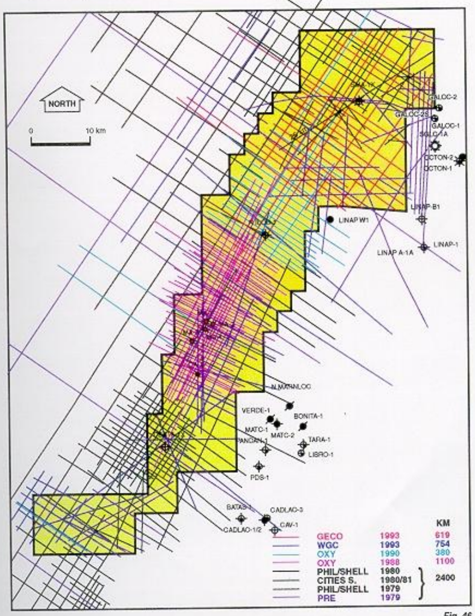


Fig. 46

EXPLORATION UNCERTAINTIES ARE RELATED MAINLY TO

❑ WELLS	ONE POINT, HIGH RESOLUTION
❑ SEISMIC	AREAL (DEPENDS ON DATA COVERAGE), LOW/MED RESOLUTION
❑ GRAVITY AND MAGNETICS	VERY INDIRECT MEASUREMENTS, MODEL DEPENDENT, LOW RESOLUTION
❑ SURFACE GEOLOGY	SUPERFICIAL ONLY
❑ AERIAL PHOTOGR.	SATTELITE PICTURES, ETC HIGH SUPERFICIAL RESOLUTION

Fig. 47

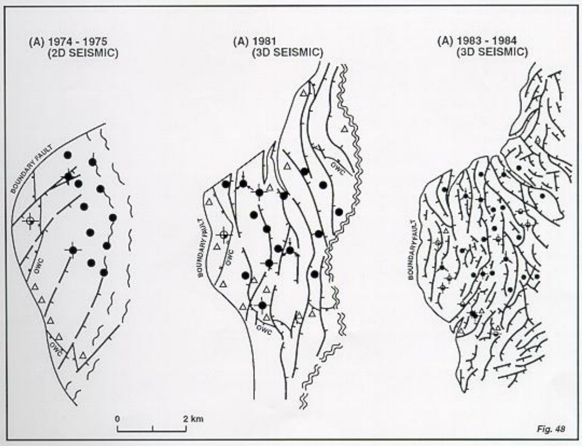


Fig. 48

Top left: indication of costs involved in both 2D and 3D seismic acquisition.

Bottom left: 2D seismic coverage of Shell-Oxy offshore block SC38, NW Palawan. The total line km exceed 5,000 km; costs can be estimated on the basis of the figures provided above!

Top right: list of uncertainties attached to the various observation methods used in exploration suggests that a combination of the various methods will provide the most reliable evaluation results.

Bottom right: evolution of the fault pattern of this North Sea field as a function of the age and type of seismic data used is striking. The pattern based on the latest 3D data bears little resemblance to that based on the 2D data and is much closer to reality. These changes in fault pattern had a high impact on the positioning of development wells as well as on the assessment of the field's recoverable oil.