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Recent Trends in Sedimentological Theory and Technique, and Their Application to Petroleum Exploration

by

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ABSTRACT

This report summarises the information that I gathered during Overseas Study in the United Kingdom and the Continent, from July to December, 1967. The practice of listing data "visit by visit" has been rejected, in favour of a more natural grouping of topics; this should be more helpful to the reader.

The most interesting sedimentological trend that I observed, was the critical re-assessment of criteria used to distinguish depositional environments. In particular the whole concept of "turbidites" is being re-examined. Much of this work is being guided by the exciting results of present day sedimentation studies, carried out on highly sophisticated ocean-going research vessels.

Another line receiving much attention is the geochemical study of clays - from both lutites and arenites. This is being used to indicate very specific depositional environments, and also as a prospecting tool to help delineate oil pools.

INTRODUCTION

In July 1967 the Bureau of Mineral Resources sent me overseas for six months training; the bulk of my time was spent in the United Kingdom, but brief visits, to key geological establishments in the major Western European countries, were also undertaken.

There were four broad objectives in this overseas training:-

1. To study the recent developments in sedimentology.
2. To familiarise myself with the latest techniques that could be applied to the petrological study of sediments.
3. To see how petrology is applied to sedimentary basin evaluation, in selected research centres.
4. To study the manner in which petroleum exploration is controlled in France.

The first three topics are dealt with in this report; the fourth is considered in a separate report - "Uniform Petroleum Regulations in France - A Model for Australia?" (Bryan, in preparation).

The information in the present report has been compiled from notes taken during my various visits, supplemented by reference to brochures, work sheets, and reprints, given to me. Some of this information was included in a File Note, prepared in the course of the tour - "Interim Report, 1.7.67 to 16.10.67" (File 66/2010 Part 2, Folios 1-15).

The list of reprints given to me during the visits are indexed under authors in Appendix No. 1; all of these have been lodged with the B.M.R. Library Reprint Collection.

I supplemented the information obtained during visits to various institutes, by attending symposia and lectures, and by participating in field excursions. The more important of these activities are listed below:-

Visits to Geological Establishments

: Geological Institute, State University, Groningen, Netherlands (3rd September 1967)

: Geographical Institute, University of Amsterdam, Amsterdam, Netherlands (7th September 1967)

: Geological Institute, State University, Leiden, Netherlands (6th September, 1967)

: Netherlands Geological Survey, Haarlem, Netherlands (5th September, 1967)

: Marine Geology Institute, Kiel University, Kiel, West Germany (11-13th October, 1967)

: Institute of Geological Sciences, Leeds, United Kingdom (17th September, 1967)

: Institut Francais du Petrole, Paris, France (10-11th October, 1967)

: Fran-Corelab, Paris, France (10th October, 1967)

: Societe Nationale des Petroles D'Aquitaine, Pau, France (10-14th July, 1967)

: A.G.I.P. Direzione Mineraria, Milan, Italy (7-8th July, 1967)

: Conoco Middle East Research Group, Reading, United Kingdom (28th December, 1967)

Attendance at Symposia and Lectures

: 7th International Sedimentological Congress, Reading -Edinburgh, United Kingdom (11-15th August, 1967)

: 6th International Congress of Carboniferous Stratigraphy and Geology, Sheffield, United Kingdom (11-16th September, 1967)

: 6th Meeting, British Sedimentological Research Group, Leicester, United Kingdom (16-18th December, 1967)

: 4th Meeting of Carbonate Sedimentologists, Liverpool, United Kingdom (18-20th December, 1967)

Participation in field studies

: The Lower Palaeozoic Rocks of south-west Scotland, 7th Inter. Sed. Cong. Excursion (16-21st August, 1967)

: The Old Red Sandstone of south-east Wales and the Welsh borderland, 7th Inter. Sed. Cong. Excursion (7-10th August, 1967)

: Old Red Sandstone and Transition Beds of Lower Carboniferous of south-east Ireland - arranged by the University of Reading (3-7th October, 1967)

: Carboniferous of the Pennines of northern England - 6th Inter. Carb. Cong. Excursion (17-22nd September, 1967)

: Carbonate Sediments of Connemarra, western Ireland - arranged by University of Reading (25-27th August, 1967)

: Recent tidal flat and marsh deposits of Ameland, Netherlands - arranged by Professor L.M.J.U. van Straaten (25-27th August, 1967)

Participation in Detailed Laboratory Studies

: Old Red Sandstone of south-east Ireland, Reading University (October-December, 1967)

It is proposed to deal with the subject matter of this report under [redacted] broad headings:-

1. Current views on a wide range of sedimentological topics. This would include discussions of the various depositional environments and special subjects, ranging from the origin of red beds to carbonate diagenesis.

2. The application of current sedimentological theory to the search for hydrocarbons, and to sedimentary basin evaluation generally.

3. The recently developed equipment and techniques used in the study of sediments; these will range from the electron scanning microscope to the use of acetate peels.

Much of my time at the Sedimentology Research Laboratory of the University of Reading was spent on petrological and x-ray diffraction studies of the Old Red Sandstone of Hook Head in south-east Eire.

RECENT TRENDS IN SEDIMENTOLOGY

MAJOR CONTROLS TO PAST SEDIMENTATION

There seems to be an increasing body of opinion that rejects the dominating role of tectonism in producing the variations observed in sediments through the geologic column - as proposed by Krynine (1942) and Krumbein and Sloss (1951). Attention was drawn to two additional sources of variation:-

Geochemical Variations. J.D. Nicholls of the University of Manchester, in a short paper to the British Sedimentological Research Group Meeting postulated that the Precambrian conditions were considerably different from those existing today. He based this on geochemical studies; he is convinced that the following changes have taken place:-

Precambrian sea - higher Mg and Ca.
- less Na and K.

R. Seiver of Harvard University in a paper presented to the Seventh International Sedimentological Congress at Reading - Edinburgh, outlined some of the consequences of the concept that a general geochemical balance existed between the "primitive crystalline material" and the sedimentary accumulations throughout the geological record.

Seiver considers that the oceans represent a pH - buffered system, controlled by silicates rather than by carbonates. He bases this on the greater buffer capacity of the large amounts of silicate present, compared with the inadequate buffer capacity of the carbonates; also the oceans are in a steady state of equilibrium with respect to most of the elements in them.

Such a steady buffered state for the oceans requires that the alkali metals and silica supplied from weathered crystalline rocks must be used up; for if the alkalis and silica were allowed to build up, the ocean would soon become buffered at pH values very much higher than we see today, or that we can infer from past biological evidence. This leads to the simplified conclusion that the dominant process is one of "reconstitution" of weathered materials.

The first implication of this model in terms of the sedimentary column, is that at any time, there should be only a limited amount of badly weathered material present - because the reconstitution of such material is essential to keep the atmosphere and oceans balanced. The second implication is that a reciprocal balance should exist between the amount of limestone precipitated and the amount of silicate reconstituted; for if there is an enormous excess of limestone precipitated, most of the hydrogen ions and the carbon dioxide will be returned to the atmosphere in this way, and there will be only a limited amount available for silicate reconstitution. Extensive limestone deposition will result in the depletion of H_2CO_3 in the ocean - and this will limit the amount of "reconstruction" possible - i.e. late stage diagenesis.

It can be reasoned that periods in the earth's history when extensive vulcanism occurred and great areas of igneous rocks were exposed to weathering, would be times of wholesale depletion of carbon dioxide from the atmosphere by weathering processes; this could lead to colder climates, and to glaciation. At the same time, the carbonate alkalinity of the oceans would be increased.

Similarly, it can be reasoned that the periods during which an excess of chert or silica of some other kind developed in the sedimentary record would have been immediately preceded by a period of very extensive deep weathering; for it is only under these conditions that kaolinite will be altered to gibbsite or diaspore, thus releasing silica, while not affecting the carbon dioxide - alkali balance.

The really important question to answer is whether such oscillations of the system have occurred in the past, or whether there has been any systematic change through geological time. At this stage it is very difficult to answer this question because one would need to know the relative proportions of weathered, unweathered, and reconstituted silicates in the geological record.

Climatic Variation - K.A.W. Crook presented a paper at the Seventh International Sedimentological Congress in which he queried the whole concept of Krynine (1942), that tectonics of both source and depositional areas were the fundamental controls to sedimentation. Crook considered that the theoretical foundation of the tectonic control theory was weak, relying too heavily on "hypothetical analyses of ancient examples which readily promote cyclic arguments". He felt that many of the features attributed to tectonism could equally well be due to climatic changes.

Crook maintained that climate itself is not nearly as dependent on tectonism as suggested by Krynine and others. As an example, he compared the tectonically similar mountain regions of western Antartica, the Peruvian Andes, and the Owen Stanleys of New Guinea; an equally marked contrast could be seen between the deltas of the Mackenzie and Mississippi Rivers.

Crook then discussed other assumptions made in the tectonic theory:-

1. Tectonism determines the lithology of the source area - through control of depth of burial. Crook states that this has not been substantiated by study of seismically active and inactive areas.

2. Tectonism establishes a uniform geomorphic pattern for zones of erosion, transportation, and deposition. Crook stresses that the tectonicity of the source and depositional areas may be quite unrelated, and that the geomorphic pattern itself is established by rainfall and other factors, largely independent of tectonism.

3. Tectonism controls the distribution of sedimentary environments, through its control of the strand line. Crook points to the margin of the Gulf of Carpentaria as an example of a strand line whose position is controlled more by eustatic changes in sea level than by tectonism; nevertheless in this example, the position of the strand line is of fundamental importance in determining the type of sedimentation - as illustrated by the contrast in superficial deposits of western Queensland and the recent sediments in the Gulf of Carpentaria.

4. Basin tectonism is held to influence sediment composition by determining which particles pass through the depositional interface. Crook points out that this is an over-simplification, since the mineralogy of the source area is not necessarily related to tectonism; nor indeed are source and basin tectonics necessarily related.

5. The increase in grain size is held to have tectonic implications. Crook pointed out that recent work suggests accumulations of coarse sediment reflect the detritus prepared during an earlier (arid) phase, whereas fine sediment reflects either contemporaneous source-area aridity, or long-continued humid conditions. He cited examples to show that variations of temperature and rainfall, in and near the source area, have a profound effect on the grain size and type of sediment ultimately formed.

PROCESSES OF SEDIMENTATION

In the field of sedimentation processes, the old axiom of "the present as the key to the past" is applied with gusto; and with the rapid expansion of ship-based research equipment and facilities, the means of studying "the present" are now at hand.

Fluviatile Sedimentation

"Drag" on grains A film presented at the Seventh International Sedimentological Congress in Edinburgh by Shaprou clearly demonstrated the differences in drag for differently shaped particles when the flow regime is varied. I, at least, found some of the results most unexpected.

"Blunt objects" (such as equi-dimensional pebbles or cobbles) experience considerably less drag than "stream-lined objects" (such as flattened pebbles) provided the velocity of the stream is low. The reason for this is the smaller surface area of the equant objects. However, at higher velocities the "stream-lined object" is far more easily transported than the "blunt object" - due to reduction of turbulence in the higher flow regime.

"Blunt objects with smooth surfaces" (such as water-worn equant cobbles and pebbles) experience far less drag than similarly shaped objects with rough surfaces - provided the flow velocity is low. However, the "rough-surfaced blunt object" is subject to far less drag than the "smooth blunt object" at higher velocity; this is because the roughness has the effect of producing turbulent flow conditions at a lower velocity - thus speeding up the change to higher flow regime conditions which in turn lead to a decrease in drag on the blunt object. (it is for this reason that golfballs are covered with small pits).

Orientation of shells in a current J. Newill of Liverpool University gave a talk to the British Sedimentological Research Group on experiments carried out to determine the preferred orientation of larger objects - such as shells - in the bed-load of a stream. Newill found that the large object tended to be elongated normal to the direction of stream flow, rather than parallel to the flow.

This subject was touched upon by G.V. Middleton in a paper to the Seventh Sedimentological Congress - in which he described results of flume experiments undertaken in an attempt to reproduce bedding features typical of "turbidites". Middleton placed small concavo-convex plastic segments in the sediment to be transported. These segments could be equated with brachiopod or pelecypod valves. His results are set out below:-

High-concentration "turbidite" flow - over 50% of plastic segments deposited concave side up.

Low-concentration "turbidite" flow - between 30% and 50% of plastic segments deposited concave side up.

Traction transportation - virtually 100% of plastic segments deposited concave side down.

Distinction between bed load and suspended load J.F. Prentice of the University of London gave a paper to the Seventh Sedimentological Congress on the study of a small reach of the Thames River in London, representing part of the "mixing zone", where the fresh and salt water meet and where, as a result, the clay minerals are in a state of flocculation.

Sediment is carried at all levels within the water column, but the concentration of solids increases downwards. This increase is quite slow until a point is reached approximately three feet above the bed itself; within this lowermost 3-foot of the water column, solids account for up to 180,000 pp.m. Yet it is found that the actual clay size fraction never exceeds one third of the total sediment load. It seems likely that the transport of the coarser particles is made easier by the high viscosity of the clay suspension immediately above the bottom. In this situation the usual distinction between "suspended load" and "bed-load" cannot be made; the bulk of the sediment, ranging in size from clay to sand, is transported as a fairly homogeneous mass within the lower levels of the river. Tidal action is sufficient to prevent this very viscous lower layer from settling out.

Ripple pattern in shallow fast-flowing water J.R.L. Allen of Reading University outlined to the British Sedimentological Research Group Meeting, the results of his flume studies of bed forms produced by a fast flowing very shallow stream of water. It is found that the longitudinal component of ripple marks becomes very accentuated, and finally may dominate, as the "roughness" of the flow increases. This point is reached when the ripple height equals the mean water depth.

Lower Palaeozoic blanket sands of the Sahara The Institut Francais du Petrole has made a detailed study of the Cambro-ordovician blanket sands that crop out in the southern part of the Sahara Desert, and form important reservoir beds to the north-east. A similar though less widespread sand has also been studied from the Lower Devonian. The case history as outlined by M. de Charval should be of considerable interest to Australian geologists, for the Saharan example appears to be similar, in many respects, to the Mesozoic sands of the Great Artesian Basin.

The Cambro-Ordovician sandstone ranges in thickness from 200 to 600 metres, but maintains a uniform thickness over very large areas. These sands are of fluviatile origin, and as judged from foreset festoons, the supply was from the north. Clearly, the sands originally covered an area in excess of 6,000,000 square kilometres - 2,000 kilometres in the direction parallel to the supply, and 3,000 kilometres at right angles to this. It is probable that the original gradient was only about 50 centimetres per kilometre.

Despite its enormous extent, the sandstone blanket can be divided into units as thin as 50 metres that can be traced over hundreds of kilometres with complete certainty. The following criteria have been used:-

Presence of thin shale bands

Character of the cross lamination

Presence of burrowing

Essentially the same type of sedimentation occurred in the Lower Devonian, but on a much smaller scale. However the two phases of blanket sand deposition are separated by a marked angular unconformity, a period of glaciation, and the deposition of graptolitic shales and oolitic sands.

Deltaic Sedimentation

At the Seventh Sedimentological Congress several excellent papers were presented, dealing with various aspects of deltaic sedimentation. D.M. Curtis of Shell Research, Houston, has made a detailed study of Miocene deltaic sedimentation on the Louisiana Gulf coast; she has attempted to equate her results with different hypothetical models, making only three assumptions:-

- The basin is subsiding continuously, but at varying rates
- The rate of supply of sediments to the basin may vary
- The energy level at the site of deposition may vary.

By combining these three variables, the ratio between rate of deposition and rate of subsidence can also be varied; and depending upon this ratio, deltas may prograde, build vertically or spread laterally. Either transgression or regression will result.

If the rate of deposition exceeds rate of subsidence, a delta will prograde seawards, in a regressive sequence. This is the normal condition for basin filling. The vertical sequence in a typically sandy delta will be:-

Alluvial sands (top of sequence)

Upper deltaic plain sands and clays

Lower deltaic plain sands, silts and clays

Delta-front clays, sands, silts

Pro-delta clays

This is also the order of lithofacies in a sandy delta.

<u>If rate of deposition equals rate of subsidence</u>, a delta will either build vertically or spread laterally, rather than prograding seaward. Neither regression nor transgression results, and the delta site shifts very little.

<u>If the rate of deposition is less than the rate of subsidence</u>, the result is a reworking of the regressive delta sequence, to produce a basal transgressive sand and marine clays.

It was found that the Miocene deltaic sedimentation of Louisiana closely fitted these various models. It should be possible to use this approach in the study of a wide range of deltaic successions.

J.M. Coleman, S.M. Gagliano and J.P. Morgan of the Coastal Studies Institute of Louisiana State University spoke at the Seventh Sedimentological Congress about the present day sedimentation within the Mississippi River delta. It has been found that the Mississippi River constructed in all, seven major lobes of its delta during the past 5,000 years. The latest of these has developed since 1838, following a break in a natural levee of the river. During its first 40 years this new lobe grew rapidly, because of the gradient advantage it had over the other major outlets of the Mississippi. Since that time, however, subsidence and sediment compaction have been more effective than deposition - because of the supply tailing off once the gradient advantage was lost.

In some of these areas, the accumulation of organic debris from the marsh plant assemblage has been able to keep place with the compaction and subsidence; in other places, however, this has not been possible and ponds and lakes have gradually replaced the original marsh. Thus the "landmass" produced by the break through of 1838 is already deteriorating rapidly. In this cycle, very little additional sediment can be expected; the present surface - which will be conspicuous by the abundance of roots and burrowing trails - will form the bounding surface of the presence cycle of deposition. It can be expected that continued subsidence will lead to the preservation of this sequence virtually intact.

<u>Penecontemporaneous deformation of deltaic sediments</u> J. M. Coleman, S.M. Gagliano and J.P. Morgan, of the Coastal Studies Institute of Louisiana State University, gave a paper to the Seventh Sedimentological Congress describing both the small and large scale deformation features in a portion of Mississippi River delta. The range in amplitude of folding was from a few inches up to 500 feet.

On the small scale, a wide variety of intraformational recumbent folds, and convolute laminations occur caused by the combination of unstable slopes, rapid deposition, and high speed sediment-laden currents. Most of this deformation occurs in channels, levees or at the delta front.

On a rather larger scale, bank slumping can occur, especially in the zone of strong scouring opposite point bars. On a larger scale still, flowage failure can occur where river-mouth bar-sands and natural levee deposits, overlie thick sequences of pro-delta or other marine clay sequences. Because of the overlying load, these clays become unstable; then if the river should scour into these clays during flood, the clays will tend to flow laterally into the scoured area. The deformation may affect a vertical thickness of 50 - 100 feet, and up to 1,000 feet along the river channel. This is probably one of the main reasons why deltaic clay sequences are often highly distorted and brecciated.

On a very large scale, penecontemporaeneous deformation can result in the development of diapiric clay structures - commonly referred to as "mudlumps". These mudlumps occur at the mouth of the Mississippi River, and can lead to the growth of islands. Their positions coincide with the loci of maximum sedimentation at the mouth of the major river distributaries. Relatively coarse sediments accumulating at the mouths of the active distributaries, coupled with thick underlying sections of fine-grained pro-delta or marine clays, provide the necessary conditions for mudlump formation. Studies in South Pass of the Mississippi River delta show that three diapiric folds have developed and have led to intrusion of the order of 400 feet; this figure is even more astonishing when it is realized that these diapiric structures have developed in the past 100 years. That structural rearrangements are continuing at the present time is illustrated by the movements recorded in a 495-foot string of casing, set vertically in one mudlump island; over the past 5 years to casing has been tilted 20° towards the south-west, and forced up 17 feet above its original position.

D.M. Curtis of Shell Reasearch, Houston, spoke at the Seventh Sedimentological Congress of strong faulting and folding of Miocene deltaic deposits of the Louisiana Gulf coast area. These are attributed to gravity sliding, contemporaneous with sedimentation; some shale uplifts -/"mudlumps" of Coleman and Gagliano - are sometimes associated with the folding. With very few exceptions salt domes in this province do not have linear trends that can be related to this folding, and thus seem to have developed in a different setting.

Shallow Marine Sedimentation

In both Europe and North America great attention is being paid to present day shallow marine deposits. On the European scene, the chief areas of interest are the Baltic and Mediterranean Seas and the Persian Gulf. One of the most active groups is the Marine Research Institute within the University of Kiel, West Germany.

Dr. Sarnthein of the Marine Research Institute of the University of Kiel has been working on a wide range of factors that could be of use in establishing micro-facies in the Persian Gulf:-

Grainsize distribution

Distribution of lithics and non-carbonate minerals

Distribution of pellets

Distribution of fossil (Pliestocene) carbonates

Distribution of present day foraminifera

Distribution of present day mollusca.

The present distribution of grainsizes in the recent sediments of the Persian Gulf is largely controlled by availability of material rather than current velocity and the like. The sand-sized material transported down the rivers (fine sand size) remains close to the coast. The silt and clay material tends to be swept down submarine channels, and is deposited on an old "deltaic plain", at a depth of 80-110 metres. Sarnthein believes that the fine material was transported by suspension currents, set in motion after exceptionally rainy periods. Survey work has shown that there are many potential sites of silt deposition on the deep plain, but that the only ones receiving the sediment are those close to river outlets.

The "delta plains" receiving the fine sediment generally show very little admixture with other types of sediments; perhaps because muddy bottoms are not suitable for the development of coarse shelly beds. On the other hand, the shallow areas near the coast - but away from the river mouths - are receiving no introduced sediment and as a result are most suitable for the growth and subsequent accumulation of coarse carbonate detritus.

Distribution of lithics and non-carbonate grains of sand size in the Persian Gulf, is controlled largely by two factors:-

Supply

Gradient

It seems that even much of the sand-sized material is transported in suspension rather than as bed load - for there is no apparent relation between grainsize and distribution.

The distribution of pellets is primarily controlled by organisms, since most are of faecal origin; they range up to fine sand size, but are predominantly of silt size. A few mudlumps are also present but these tend to break up. There is direct relationship between the abundance of pellets and the percentage of organic carbon - as determined chemically. There appears to be no relation between the abundance of pellets and the depth of water - similar quantities of pellets seem to be developing at water depths ranging from only a few metres to as much as 1500 metres. (In portions of the adjacent Gulf of Oman where the water depth reaches 1500 metres some of the richest accumulations of both organic carbon and pellets are found.

Deposits of Pleistocene carbonates still cover much of the Persian Gulf, and represent the ancient estuarine and tidal flat deposits of the Euphrates River. The maximum thickness of these deposits was only 10-20 metres; they are preserved because the speed of transgression since the Pleistocene is such that sea level has risen 100 metres in 8000 years.

These relict carbonates of the Persian Gulf are still composed of aragonite - additional evidence of the speed of the transgression following deposition; for it has been established that only a few days are needed to cause the inversion from aragonite to calcite or dolomite, if the deposit is exposed to air or even fresh water.

Present ~~for~~miniferal deposits are of two types. In deeper water, such as the Gulf of Oman, the foraminiferal population is primarily planktonic. In the shallower water of the Persian Gulf, a moderately successful benthonic foraminiferal fauna has developed; this cuts out well short of the head of the Persian Gulf- probably because of increasing salinity. Throughout much of the Persian Gulf, there is a high proportion of planktonic foraminifera because of the movement of surface waters. As one would expect, the planktonic forminifera tend to be concentrated in the deeper channels, while the proportion of benthonic foraminifera rises on the adjacent mud-flats.

Present day mollusca deposits are also of two types. Planktonic molluscs are common throughout the Persian Gulf, and apparently are unaffected by the wide range of salinities encountered - ranging from normal up to 399 p.p.m. The depth at which they float can differ enormously from time to time, and from one spot to another; these changes are made to adapt to changing water conditions.

Benthonic molluscs occur in fairly constant numbers to a depth of 200-250 metres; beneath this they cut out completely. The major factor affecting their concentration above that critical depth is the nature of the bottom - benthonic mollusca preferring "hard ground" composed of less than 80% fine sediment.

A paper on these micro-facies studies by Sarnthein will shortly appear in the proceedings of the First International Planktonic Conference, Geneva, 1967- published by the Archives des Sciences, Geneva.

Dr. Hartmann of the Marine Research Institute within the University of Kiel has analysed samples taken at 10 centimetre intervals within cores of sediments from the bottom of the Persian Gulf - collected by the "Meteor". His work consisted of routine analyses of nitrogen, organic carbon and carbon dioxide; in some cases, calcium, magnesium, and strontium, were also determined. Sulphur isotopes were deterined on the mass spectrograph.

It was found that the organic carbon:nitrogen ratio increased progressively away from the coast, the absolute values of both elements increasing. It is suggested that the relatively higher nitrogen content near the coast is caused by the replacement of potassium by ammonia in the clay structures.

Within the Gulf of Oman, high carbonate values were found on the shelf area associated with very low organic carbon.

D. Meischner of the University of Gottingen, Germany, presented a paper to the Fourth Meeting of Carbonate Sedimentologists outlining progress made in the close study of recent sedimentation in the north east Adriatic Sea. The area under study is of particular interest, as very little sediment is being supplied from the adjacent land areas - despite the fact that the depth of water is only 10-30 metres. This situation arises partly because of the drainage pattern along the Dalmation Coast of Yugoslavia, and partly because of the strong anti-clockwise current in the Adriatic Sea.

The sediment accumulating in this portion of the Adriatic Sea is of three types:-

Wind-blown Saharan sand (mean size 90 microns)

Rare red terrigenous clay

Carbonate debris from in situ organisms.

Of particular interest, was the high proportion of wind-blown sand - apparently blown from North Africa; however the author was primarily interested in establishing "reverse graded bedding" - thought to have developed as a result of diagenetic alteration of coarse carbonate detritus to a fine carbonate mud, within the uppermost half metre of sediment. However this interpretation involves the assumption that identical sedimentological conditions operated throughout the time during which the half metre of sediment was deposited - and no evidence to support this was presented.

Two examples are given to illustrate the problems that can be involved in determining the micro-facies to which a shallow water marine suite belonged.

The first example is from recent sediments in Manim Bay off the west coast of Eire where J. Scott and A. Buller of the University of Reading have been working. Manim Bay appears to be a closed system of carbonate sedimentation; it contains a variety of sediments all of which are commonly regarded as indicative of specific depth conditions of sedimentation. The bulk of the sediment is carbonate sand derived from the break-down in situ of the alga Lithothamnium, growing at depths of 12 to 20 fathoms. Over the same depth range, clay deposits and boulder beds both occur - but with very little overlap between the two. Nevertheless there is no doubt that both the boulders and the clays were derived from the boulder-clay that covers the adjacent headland, and presumably once covered the bay. To add to the apparent confusion, to the south of Manim Bay there is a long stretch of beach dunes - containing abundant formainifera. There is no doubt that these foraminifera have been blown from the sea during storms and retained within the dune sand.

Thus in this one small area there are deposits of carbonate, sand, muds and boulder beds all developing under identical conditions; and close by are dune sands containing foraminifera. There is no reason to believe that this small bay is in any way unique; one must expect this sort of thing to happen quite commonly in shallow marine environments.

The second example is from the Tournaisian of Southerness in south west Scotland, visited on an excursion during the Seventh Sedimentological Congress. A series of horizons consisted almost entirely of brachiopods set in a muddy matrix. The burrowing brachiopods must have been winnowed and concentrated by high energy water conditions, broken up, transported, and then re-deposited as thin horizons composed almost entirely of fossils. These horizons are up to one metre thick; the strange thing is the total absence of sand, which would have been expected in such a high energy environment.

Barrier Island A special case of shallow marine sedimentation involves the origin and growth of barrier islands. This topic has very real commercial application as it could influence prospecting for shoe-string sands, and related sand bodies.

J.H. Hoyt of the Marine Institute of the University of Georgia has made an intensive study of barrier island development off the coast of Georgia; he presented a summary of his results to the Seventh Sedimentological Congress. Hoyt suggested three possible ways in which barrier islands can develop:-

- Development from off-shore bars. He dismisses this because of the absence of open marine type sediments, between the bars and the original beach, at the time of barrier development.

- Development from emergent off-shore bars during periods of higher sea-level. Hoyt dismisses this as a general cause, because data from many areas of the world fail to confirm high sea-levels at the time of bar development (Holocene).

- Development of barrier islands from submergent dune and beach ridges. Hoyt notes that in areas of low relief, slight submergence will cause extensive flooding and will lead to the conversion of dunes and some ridges into islands. From that point the barriers may erode, prograde, or remain in place depending on the supply of sediment, tidal and current energy, and sea-level movements.

Hoyt believes that ancient barriers were formed in a similar fashion - except that in the older examples, a greater length of time was available for their development; this in turn has led to greater thicknesses in many of the older examples.

Further submergence may lead to erosion of the barrier, and cause a landward shift of the shore-line. However Hoyt maintains that this is by no means the rule; off the coast of Georgia, submergence has left some portions of the barrier intact, whereas only a few miles away the barrier and most of the lagoon-salt marsh behind have been removed.

J.R. Hails of the University of London has carried out a statistical study of sand grains from barriers now being eroded along the New South Wales coast. His general conclusion was that where polygenetic sands have deposited along a barrier coast, there may be little difference in mean grain-size and sorting values between beach and dune deposits. Differences in skewness could be significant but must be used with caution; beach sands were generally found to be negatively skewed (deficient in fine sizes) in contrast to positively skewed aeolian sands (deficient in course fraction). However in the New South Wales examples, reworking of Pleistocene barriers has confused the picture.

In Europe the leading authority on shallow marine sedimentation and barrier island development is L.M.J.U. van Straaten of State University, Groningen, Netherlands. I accompanied van Straaten to Ameland - a comparatively unstable barrier island fringing the northern part of the Netherlands. It has extensive marsh and peat deposits that have now drained; off the sheltered inner side of the island, there are very extensive mud flats that have been studied in great detail by van Straaten.

A surprising feature of the apparently very muddy tidal flats of Ameland was the great predominance of sand; the impression of high mud content is largely due to the almost continuous mat of fine faecal pellets on the surface. The flats are markedly anaerobic through the first metre of sediment, and occasionally the smell of hydrogen sulphide can be detected. Organic activity is intense especially in the higher areas of the tidal flats. Mya which can live to a depth of 10 cm. below the surface are mainly responsible for the bioturbation. Below the one metre mark the colour of the sediment changes abruptly to a normal pale grey - largely due to the change in the state of the iron from a black organo-ferric compound to pyrite.

The best way of distinguishing the different micro-facies within the tidal flats is on the basis of the Mya bioturbation. Marsh deposits are virtually un-burrowed but contain numerous rootlets; the inner tidal flat area is intensely burrowed and covered with faecal pellets; the outer tidal flat area is not greatly affected by burrowers, and the bedding ranges from massive to well-bedded. Other important organisms on the tidal flat are Corophium, a small organism that forms long narrow tubes; Cardium which lives in the top 2 cm. of the sediment; and Arenicola which forms the characteristic U-tube burrows. Mya, which as mentioned earlier is the major burrower on the flat, tends to be found in the deeper and quieter waters.

<u>Reefs</u> The development and alteration of reefs, represents a most important case of shallow marine sedimentation. Great emphasis is being placed on present day examples in interpreting the reefs of the geological column but a recent study in the Seychelles Islands clearly illustrates the dangers of generalizations and oversimplifications.

C.J.R. Braithwaite of Dundee University gave a paper to the Fourth Meeting of Carbonate Sedimentologists on the supposedly typical reef development on the Seychelles Islands. He had found that the reef proper - that is where a high proportion of framework is present - was very scarce. Framework had only been established by the corals, locally, elsewhere the deposits were mainly of reef debris, sponge material, and algae. Another surprising feature was the lack of thickness of the "reef". The "coral island" turned out to be a volcanic shell, and in many places the calcareous deposits were only a few inches thick.

Braithwaite thinks that many other supposedly thick reef developments could also turn out to be thin coatings over volcanic surfaces. He also feels that in a great many cases not studied in detail, it will be found that "framework" is very scarce, and the "reef" is simply a patchwork of prolifically growing individual colonies.

A quite different approach to the problems of reef development and dolomitization has been adopted by the Institut Francais du Petrole. The "model" that they have selected for very detailed study is a Devonian reef within the Carniques Alps. Deroo and Schmerber of the I.F.P. are carrying out the study, which is concentrating on the steps leading to the dolomitization of the reef.

In a talk given by Lloyd C. Pray of Marathon Oil Company of the United States, some of the types of reef development were discussed. Pray considered that skeletal reefs would seldom grow over a wide area, probably due to the lack of uniformity in conditions existing between the front and the back of the reef. He regarded patch-reefs as far more significant; though only about 20' x 20' x 3' thick in most present day examples, the ancient equivalents commonly formed very large masses - up to 3,000 feet thick and uniform throughout. Such a patch-reef would consist of 90% detritus and 10% material in the growth position.

<u>"Sabkha" Carbonate and Evaporite Formation</u>. The information obtained on the development of bedded carbonate-evaporite sequences from a study of the Sabkha of the Persian Gulf has led to far-reaching changes in oil exploration; for a quite new environment has been revealed to have immense hydrocarbon potential, embracing as it does both reservoir and cap rock - commonly repeated again and again up the succession.

P.R. Bush of Imperial College, London, spoke at the Fourth Meeting of Carbonate Sedimentologists, on the stages of chemical evolution recorded in the Sabkha (salt marsh) along the margin of the Persian Gulf. In the region of Abu Dhabi, on the south west margin of the Persian Gulf, the Sabkha deposits are very extensive and consist of both carbonates and evaporites. The various facies recorded - both ancient and modern - are illustrated below:-

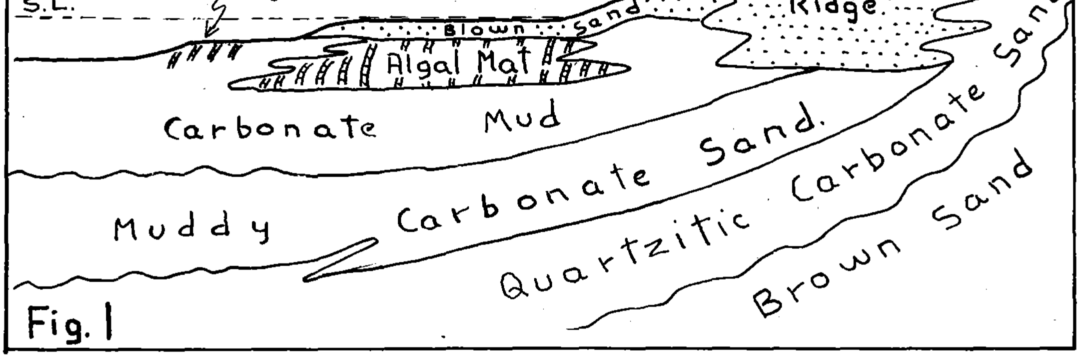

Figure 1. Ancient and modern facies recorded in the Abu Dhabi Sabkha, Persian Gulf (after Bush).

The Sabkha is in fact a supra-tidal salt flat, consisting of a belt 70-80 miles wide with a slope averaging only 1:1,000. Very extensive incursions of the Persian Gulf waters occur when strong onshore winds accompany high tides. The resultant sheets of shallow water that spread over the flats evaporate rapidly under the extreme hot dry conditions, and lead to a rapid build up in the salt content of the brine, which is always present only a few feet below the surface of the flats. Precipitation of aragonite follows this build up - and in turn leads to a concentration of magnesium in the brine itself. Further back on the Sabkha flats, gypsum will precipitate, but as the pore fluid concentration increases (water content decreases), the gypsum is replaced by anhydrite.

The Sabkha acts as a huge diagenetic machine - marine sediments containing meta-stable minerals are extensively altered to suit the changed temperature and pore-fluids conditions.

Continental Shelf Sedimentation

M.G. Grant-Gross, of the University of Washington has made an extensive study of the sediments occurring on the continental shelf off the west coast of the United States, especially off-shore from the state of Washington. He has made extensive use of radioactive waste products from a large reactor centre, to trace the movement of sediment on the shelf.

The Columbia River is the major supplier of sediment to the shelf in this region, and carries a load of approximately 5 million tons of sediment per year - rather less than one would have expected from a river of this size. Most of the continental shelf off Washington State is covered by recent sediment from the Columbia River, but there are some patches of relict sediment near the edge of the shelf. There is a marked depth zonation of the various sediments sizes:-

Sand deposits - in less than 90 metres of water

Coarse silt - in greater than 90 metres of water

Much of the recent sediment - especially the finer sizes - is sliding off the continental shelf down submarine canyons; however, a great deal of the coarser fraction is being carried northward along the shelf, for distances of up to 200 kilometres. In this long-shore transportation of sand supplied by the Columbia River, two movements have been recognised. Sands deposited in less than sixty metres of water can ~~to~~ be carried inshore as well as northward; on the other hand, sand and silt in depths greater than 60 metres exhibit a simple northward movement.

As noted above, this northward transportation of sand along the continental shelf is effective for over 200 kilometres - in fact right up to the Straits of Juan de Fuci. Quite a lot of sand actually passes through the Straits - exactly the reverse of what one would have expected. The reason for this reverse transportation of sand is the massive outflow of surface water through Straits of Juan de Fuci. This water is replaced by the deeper sand - laden water moving in from the continental shelf.

Relict Sediments on the Continental Shelves. In one of the major addresses at the Seventh Sedimentological Congress at Reading, K.O. Emery discussed the sedimentation on the present day continental shelves - especially those of North America. Emery pointed out that about ten % of the earth's surface is occupied by continental shelves; the question of how important shelves may have been in the past is open to discussion. The sources of sediment on the continental shelves are threefold:-

Erosion of the land surface, through the processes of both stream and coastal erosion.

Biogenic sediments formed on the shelf itself.

Ice-rafted material, dropped on the shelf.

The following diagram by Emery (1968) shows the approximate distribution of the various types of sediments on continental shelves at different latitudes. It will be noted that the proportion of relict sediments is much higher on the eastern continental margin than on the western.

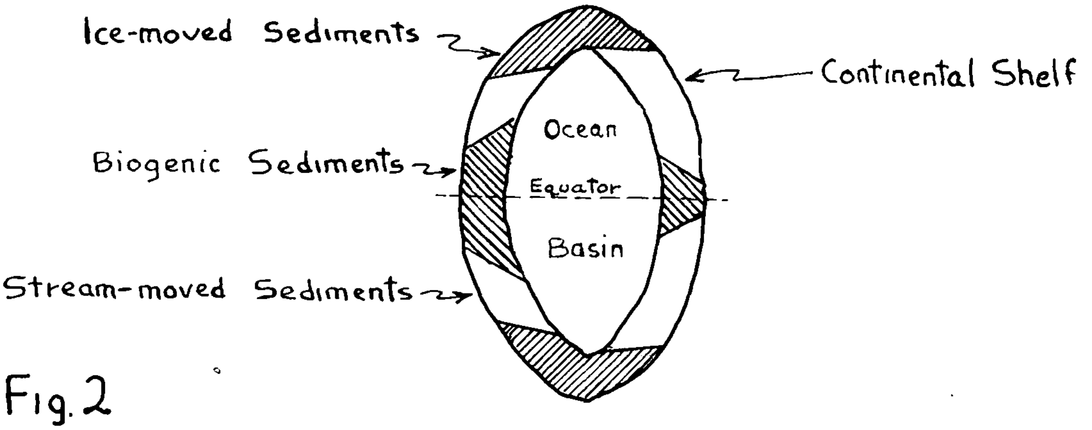

Fig. 2

(after Emery).

It is seen that a great proportion of the present day continental shelf is not receiving any new sediment whatever but is covered by relict sediment that is in some cases being eroded. It is estimated that 70% of the shelf off the east coast of the United States falls into this category.

Recent studies have also shown that the continental shelf is not as stable as was formerly thought. Carbon 14 age determinations on samples obtained from the shelf off the East Coast and the Gulf Coast of the United States, have shown that considerable vertical movement has occurred over the last 10,000 years.

Much of the relict sedimentation on the continental shelf off the eastern margin of the United States was probably deposited before the recent submergence. Peat dredged from the shelf has an identical floral assemblage to the peat occurring on the mainland United States; elephant teeth have also been recovered with the peat on the continental shelf. Recent investigations on the shelf have also revealed that much of the relict sediment off the United States that is being eroded is being transported shorewards - in some cases back towards estuaries from which presumably it had been supplied in earlier times, when the sea level was lower.

Cyclic Sedimentation.

This topic has been hotly debated for many years and naturally it was given much attention at both the Sedimentological and the Carboniferous Congresses. On the one hand these were the devotees of cycles and cyclothems, whose chief spokesman was W.P. van Leckwijck of Belgium; at the other extreme were the sceptics lead by H.G. Reading of Oxford.

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Figure 2. Distribution of sediments on the continental shelves. (after Emery).

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Van Leckwijck presented a paper at the Seventh Sedimentological Congress showing detailed correlation of Namurian sediments in southern Belgium. He regarded the succession as a good example of a "60-metre cycle", traceable for distances of up to 90 kilometres. van Leckwijck divided each cycle into three "megaphases":-

Upper part - less arenaceous than the middle, and less argillaceous than the lower part; fauna rarely fully marine and may be non-marine.

Middle part - shales, sandy shales and massive greywacke, some seat-earth and coal. Animal fossils not common.

Lower part - mainly shales becoming sandy towards top; a rich and varied marine fauna.

Van Leckwijck further divided the "60-metre cycle" in to 8 cycles of lower rank having an average thickness of 8 metres. He referred to these as "10-metre-cycles", which ideally consist of the following phases:-

- Argillo-arenaceous phase (top of sequence)
- Arenaceous phase
- Areno-argillaceous phase
- Paludal phase

The paper was severely criticized on the grounds that the correlations were forced. One of the chief critics was H.G. Reading, who urged that workers should look for natural breaks and boundaries in sequences rather that arbitarily selecting those that fit some theory of cyclic sedimentation.

H.G. Reading enlarged upon this theme in a paper presented to the Sixth International Congress of Carboniferous Stratigraphy and Geology. He urged that an initial division be made into "predictable cycles", and "random sequences" (those which on current knowledge are not predictable). Reading described four types of "predictable" sequences:-

Coarsening upward sequence - regressive conditions

Fining upward sequence - maturing fluviatile sediments

Fining upward sequence - seat earth

Fining upward sequence - transgressive condtions

Reading regarded the breaks in sedimentation as all important - and cited examples where sequences containing marked disconformities have been described as a single unit, to fit a traditional concept of cyclothems.

Red Beds.

At the Seventh Sedimentological Congress, there was much discussion about the origin and significance of red beds but little agreement on the major controlling factor, if any.

R.W. Fairbridge of Columbia University stressed the periodicity of red bed development in the geological record - well illustrated by the Old Red Sandstone (Devonian), and the New Red Sandstone (Triassic). He preferred to explain red bed development in terms of climatic characteristics of the source areas rather than a particular type of depositional environment. As pointed out by P.F. Friend of Cambridge, hematite can be stable under certain marine conditions. Well-ordered hematite is stable in the presence of hydrogen sulphide whereas hydrated ferric oxides (goethite) and amorphous gels ("limonite") are not stable. This is of considerable importance as it indicates that hematite could exist under reducing conditions - as found in present day deposits in portion of the Bay of Fundy. At the other extreme, T.R. Walker of the University of Colorado, showed that red beds were forming as piedmont deposits in the arid south west of the United States; these were derived from the red-brown covering of the mountain ranges of the region.

However Walker also found that red beds can develop through the diagenetic alteration of a wide range of sediments - deposited in equally diverse environments. He has carried out electron-probe studies of femic minerals and has found that they progressively release iron oxide during diagenesis. He feels that sedimentary rocks with only a very small proportion of such minerals can be "reddened", if the processes of diagenesis are given sufficient time to operate, in a suitable (oxidising) diagenetic environment.

P.F. Friend of Cambridge is convinced that most red beds were deposited in river or lake environments - and are thus indicative of a particular depositional environment rather than a particular source. In support of this contention, Friend has pointed out that at the time of deposition, the suspended load of most modern rivers is yellow or brown - "limonitic" rather than hematitic.

In his own paper to the Seventh Sedimentological Congress Friend discussed the significance limonite in the colouring of a red bed. He adopted two basic assumptions:-

Most reddish sediments are coloured by hematite

Most red beds were deposited in river or lake environments.

In the Devonian Wood Bay Formation of Spitzbergen that Friend was studying, there were three possible sources of the red pigmentation:-

Pink feldspars

Pigmented biotite and rock fragments

Variable degrees of limonite coatings of grains - later to form the hematite pigments.

Friend noted that evidence is accumulating that amorphous iron oxides ("limonite") are important components of many modern soils. This, combined with the fact that most of the pigment of the suspended load of rivers is yellow or brown, increases the likelihood that limonite is widespread in river deposits, and an important potential source of red bed pigmentation. In the Wood Bay Formation, Friend has followed other workers in interpreting the succession as predominantly red - but also grey to green - channel sands passing upwards into red overbank siltstones. He attributes the differences of colour in the sandstones to the changes from a reducing to an oxidising environment. The form of the colour boundaries indicates that the non-red part of the cycle was coloured as a result of alteration of a sediment that would otherwise have been red.

Friend regards the limonitic grain coatings and cement, as the principal source for the hematite that ultimately forms the pigmentation. The contribution from pink feldspar and lithic grains is small.

"Turbidites"

The name "turbidite" has been placed in inverted commas because of the present controversy as to what exactly the term meant. At the same time it was evident from the papers given at the Seventh Sedimentological Congress that there is a marked swing away from the tendency of the past 15 years to explain all graded-bedded successions in terms of turbidity currents.

In a most convincing talk at the Seventh Sedimentological Congress, J.P. Mangin of Nice, France, attacked the widespread - and commonly quite naive- use of turbidity currents to explain any layered, graded-bedded series; he also criticised the widespread use of this ill-defined term, "turbidite". Mangin called for a return to faith in facts, rather than terms.

Mangin maintains that the use of the word "turbidite" and the characteristics attached to it are based on a succession of hypotheses rather than on facts:-

1. Turbidity currents were produced in the laboratory experiments, but were extended to natural conditions without any supporting evidence. Thus the term "turbidite" was moved from the realm of the laboratory to that of nature.

2. It was then claimed that turbidity currents were responsible for the breaking of submarine cables, thus establishing a scale of magnitude for the mechanism. Mangin maintains that not only is this completely un-proved, but that enormous initial velocites would have been required - far greater than can readily be envisaged.

3. Special types of sole-markings in graded beds were simply attributed to turbidity currents and have come to be regarded as diagnostic of such currents.

4. By assuming that turbidity currents were responsible for graded-bed sequences, and knowing the minimum theoretical gradient necessary for the development of large scale turbidity currents, it was necessary to regard such graded-bed sequences as of very deepwater origin. The circular argument continued to the effect that since much of the flysch consists of graded-bed sequences, the flysch must have developed in very deep water. But Mangin has reported authentic bird footprints from parts of the so-called "flysch turbidite" formations. Also he reported that leading oceanographers are convinced that the very fine "lamintes" of turbidites cannot form in ocean deeps.

Mangin maintains that for these reasons, it is becoming increasingly popular for authors to note that "turbidity currents can be a deposit mechanism that is not linked to any specific depth"; others have written that "if a turbidity current developed in the bed of a river, a little upstream from the mouth, it would be able to travel to, and leave its deposits in, basins of very shallow depth". As Mangin points out these writers are talking about nothing more than suspension currents, in no way similar to the turbidity currents as originally postulated.

Mangin accepts that turbidity currents have operated; however, he sees no necessity to credit such currents with "the regular and endless filling of basins of enormous proportions". He stresses that the turbidity current mechanism cannot produce finely laminated beds at any depth, nor can the mechanism itself possibly operate in shallow water.

J.F. Hubert of the University of Missouri, has studied a flysch succession of graded sandstones in Switzerland, concentrating on indicators of the palaeo-currents. Preliminary results of the study were presented in a paper to the Seventh Sedimentological Congress.

Hubert found that the currents that deposited the graded sandstones consistently flowed in one direction - throughout the entire succession. At the same time it was found that carbonaceous debris (charcoal), occurring in shale beds interstratified with the graded sandstone, showed a marked parallel orientation exactly matching the current direction within the graded sandstones. However, as the carbonaceous matter occurred within a shale, its attitude could not possibly be attributed to the drag-effect of turbidity currents.

Thus we are left with two possiblities. The first is that the ocean bottom-current system oriented the carbonaceous debris in the green shales, and also deposited the graded sandstones through the winnowing effect of bottom currents. The second is that, quite fortuitously, the ocean bottom current direction exactly matched the direction of the gravity-controlled turbidity currents.

Hubert regarded the environment of deposition as comparable to that existing on modern continental rises, with a depth of 1,500 - 3,000 metres. Bottom currents capable of transporting and depositing graded sandstones through winnowing are known from oceanographic studies. Negative evidence in support of such an origin is the fact that scatter diagrams of mean size standard deviation and skewness of sandstones and siltstones in the flysch succession are all similar to comparable diagrams for sandstones and siltstones deposited by normal bottom currents in numerous continental and marine environments. As Hubert pointed out, there is a lack of distinctive textural properties at the hand specimen level to distinguish "turbidites" from "non-turbidites".

In the abstract of a paper that was to have been presented at the Seventh Sedimentological Congress by Ph. Kuenen of Groningen, Netherlands, the results of some experiments using a circular flume to produce the high density suspensions were set out. While admitting that a circular flume approximately four metres wide and less than one metre high, activated by 16 paddles reaching half-way to the bottom of the flume, could not closely match conditions in nature, Kuenen nevertheless maintained that the results would give a sufficiently close approximation to conditions of nature to be significant. Kuenen was able to reproduce current ripple marking, convolute lamination, and also horizontal laminations - by varying velocity etc.

Of particular interest were his data on the incorporation of clay and fine silt into a coarse grained turbidite. This should lead to the development of greywacke-type rocks. The experiments showed that the maximum proportion of matrix in turbidites should be about 10%. Kuenen attributes the much higher values commonly found in greywackes to the effect of slight metamorphism.

G.V. Middleton of McMaster University, Canada, also reported on flume experiments: in his case however, a straight flume five metres long was used. As far as was possible in an experiment of this small size, the results confirmed that turbidity currents could produce the various bedding features - such as graded bedding, current rippling, convolute lamination, and planar lamination - attributed to it

Of special interest were the results obtained when small concavo-convex plastic particles (pieces of plastic tubing sliced parallel to the length of the tube) were included in the sediment load. It was found that in high concentration flows - thought to be characteristic of turbidity currents - more than half of the plastic particles were deposited in a concave-up position. In the low concentration flows, between one half and one third of the particles were deposited in a concave-up position. Middleton states that if movement was by traction before deposition, virtually all of these particles would be orientated in a concave-down position.

R.G. Walker also of McMaster University, Canada, in a paper to the Seventh Sedimentological Congress outlined a system to relate the thickness of units within a turbidite succession to "proximality" within a basin. Walker regards data on the lateral variations in the thickness of turbidites as of the utmost importance. He claims that the data can be related to changes in such parameters as the thickness of the turbidity current, the rate of deceleration of the turbidity current, and to the basin geometry.

Walker's system involves the use of the ABC Index - the various letters, following the terminology of Bouma (1962), standing for the sandy divisions of a "typical turbidite". The passage from the graded division (A), through the parallel laminated division (B), into the current rippled division (C), represents a decreasing flow regime.

In Walker's index, A, B and C represent (as percentages), the number of times that a particular turbidite cycle commences with A, B or C division of Bouma (op cit). From these percentages, Walker obtains a single value called, the "ABC Index" by applying the following formula:-

$$\text{ABC Index} = A + \tfrac{1}{2}B$$

Thus the change in ABC Index from 100% to 0% represents a decrease in the average flow regime of the current depositing each group of turbidites. It is argued that the most sensitive factor is the distance the current has flowed across the basin; thus the ABC Index is used to indicate proximality. Walker has used differences in the ABC Index in interpreting basin geometry and basin evolution.

During an excursion to south-west Scotland arranged as part of the Seventh Sedimentological Congress, E.K. Walton of Edinburgh University showed an enormous variety of bed forms, scour features and tool markings in Lower Palaeozoic "turbidites"; many of these have been illustrated in Dzulynski and Walton (1965). All that needs to be added here is to emphasize that the variety of possible forms is enormous and the interpretation of these forms is often very difficult and inconclusive.

The recent field studies of J.F. Hubert of the University of Missouri, in the Ordovician of the Girvan area of south-west Scotland show that the features demonstrated by Walton must not be automatically regarded as indicative either of deep water origin or of the action of turbidity currents. Hubert was quite sure that constantly changing bottom currents on the continental rise - or perhaps in shallower water - were quite sufficient to have produced graded-bedding and the so called "Bouma cycle" (Bouma, op cit). His arguments seem especially compelling in view of the occurrence of large masses of conglomerate close to and laterally equivalent to the "turbidites".

Clays

Because of the increasing awareness of the importance of clay minerals as environmental indicators, a great deal of work is currently being directed towards a clearer understanding of the factors governing clay type, structure, and diagenesis. Again great emphasis is being placed on present day examples.

In a paper at the Seventh Sedimentological Congress, M.A. Rateev of the Academy Sciences, Moscow, gave preliminary results of his caly studies in the Indian and Pacific Oceans; these have been compared with the results obtained from the Atlantic Ocean.

Rateev found that a high proportion of kaolinite, gibbsite, and montmorillonite occur in the tropical zone, and have an equatorial distribution a definite belt exists from Australia across to South Africa. Reteev considers that the concentrating mechanism for montmorillonite is very complex, and is not dependent simply on the occurrence of volcanic ash.

A second group, consisting of chlorite and illite, develops in moderate to high latitudes forming a "bi-polar" type of distribution. The chlorite content increases from less than 10% of the total clay close to the equator, up to 80% near the poles.

Rateev thinks that in arid zones, the clay mineralogy tends to reflect the salinity of the basin; but in humid zones the clay mineralogy reflects the terrigenous origin of the caly. He is convinced that climate of the land surface is of primary importance in explaining the zonation of clay types; of course, authigenic changes will be superimposed.

In a shallow water environment, J. Lange of the Marine Research Institute, Kiel, West Germany, has studied the clay assemblage of the Persian Gulf. A typical assemblage consists of:-

Montmorillonite (smectite)

Illite

Mixed Layer

Rare kaolin and/or chlorite (very difficult to distinguish)

The chief clay mineral present in the Persian Gulf is attapulgite- though most workers currently refer to this species as palygorskite (see Brown 1961). Lange regards the attapulgite as detrital, noting that it and dolomite, tend to be concentrated close to the mouths of rivers. Passing from the Persian Gulf to the Gulf of Oman, the water depth increases greatly and the circulation is much freer; it is in this transitional zone that the attapulgite gives way to chlorite. Approaching the open ocean, the x-ray diffraction patterns of the various clay minerals become much better defined, suggesting a greater degree of crystallinity. Precisely the reverse holds when moving from the mouths of the rivers into the Persian Gulf proper - the various clay x-ray diffraction patterns become more and more diffuse. There is nothing to suggest that this is a matter of dilution, and it appears that the lattice itself is weakening.

Lange's results to date show clearly that in the rather unusual environment of the Persian Gulf no diagenetic changes of the clay minerals have occurred within the uppermost six metres of bottom sediment. (This is the maximum depth reached in the "Meteor" coring programme). Lange regards the most important phase of "diagenetic alteration" as being the first contact of the detrital clay with the marine environment of the Gulf.

There is also a consistent and strong colour change in all of the clay samples away from the shore of the Persian Gulf. Both in the northern portion of the Gulf where montmorillonite dominates, and further south where attapulgite is the main constituent, Lange has recorded this marked change in colour; the range is from pink near the shore, to a browny colour further out in the Gulf. In the Gulf of Oman the clay is predominately chlorite, and the colour a brownish green.

On the limited information available, Lange thinks that the clays forming in freely circulating deep water marine conditions consist mainly of chlorite; illite is of less importance than is generally believed. Lange thinks that much of the "illite" reported from many parts of the world is, in fact, incorrectly identified chlorite. He claims that errors of this sort date back to some of the earliest work on illite by C.W. Correns, who attempted distinctions of a greater order of accuracy than his equipment would permit.

At A.G.I.P. Mineraria in Milan, detailed clay studies are being made by S. Neglia, into the cap rock and semi-permeable membrane properties of various clay types. An immediate distinction can be made between clays formed under fresh water and saline conditions.

Fresh Water Clays - less than .4 molar per litre concentration.

The clay particle settling through fresh water will contain a very high percentage of loosely held water, but the settling process is very orderly and much of this water is lost very close to the sedimentary interface. In addition, two or three layers of water surround each clay layer - but this water that can be removed through compaction.

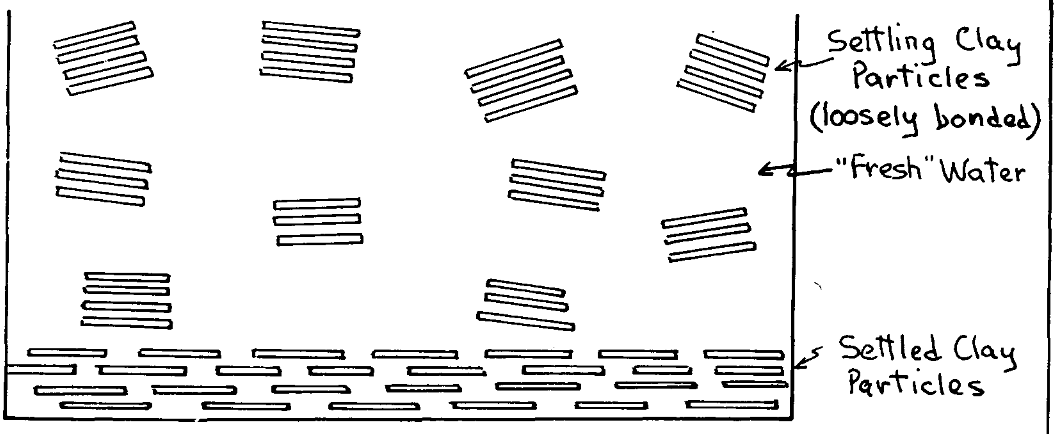

Fig.3 Salinity of water <0·4 molar concn. per litre

(after Neglia).

Salt Water Clays - in excess of .4 molar per litre concentration

Under these conditions, the clay particles settling in the water are held together by charges - the end of one particle being attracted to the middle of another. There is very little water held between the layers; one effect of this is to increase the density contrast, which leads to a much more rapid settling rate

Lange's results to date show clearly that in the rather unusual environment of the Persian Gulf no diagenetic changes of the clay minerals have occurred within the uppermost six metres of bottom sediment. (This is the maximum depth reached in the "Meteor" coring programme). Lange regards the most important phase of "diagenetic alteration" as being the first contact of the detrital clay with the marine environment of the Gulf.

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On the limited information available, Lange thinks that the clays forming in freely circulating deep water marine conditions consist mainly of chlorite; illite is of less importance than is generally believed. Lange thinks that much of the "illite" reported from many parts of the world is, in fact, incorrectly identified chlorite. He claims that errors of this sort date back to some of the earliest work on illite by C.W. Correns, who attempted distinctions of a greater order of accuracy than his equipment would permit.

At A.G.I.P. Mineraria in Milan, detailed clay studies are being made by S. Neglia, into the cap rock and semi-permeable membrane properties of various clay types. An immediate distinction can be made between clays formed under fresh water and saline conditions.

Fresh Water Clays - less than .4 molar per litre concentration.

The clay particle settling through fresh water will contain a very high percentage of loosely held water, but the settling process is very orderly and much of this water is lost very close to the sedimentary interface. In addition, two or three layers of water surround each clay layer - but this water that can be removed through compaction.

Figure 3. Stages in the settling of clay under fresh water conditions. (after Neglia).

Salt Water Clays - in excess of .4 molar per litre concentration

Under these conditions, the clay particles settling in the water are held together by charges - the end of one particle being attracted to the middle of another. There is very little water held between the layers; one effect of this is to increase the density contrast, which leads to a much more rapid settling rate than would occur in fresh water. But on settling, the criss-cross arrangement leads to a great deal of intercrystalline water being trapped between the particles. As in the previous case, two or three layers of intracrystalline water will be held very firmly by the clay particles. However the latter makes up only a very small fraction of the total water available within the clay deposit. Because the criss-cross arrangement of the clay layers is caused by quite strong bonds, the intercrystalline water is not easily removed on settling. This water will only be squeezed out after considerable pressure has been applied - such as the loading due to continuing sedimentation.-

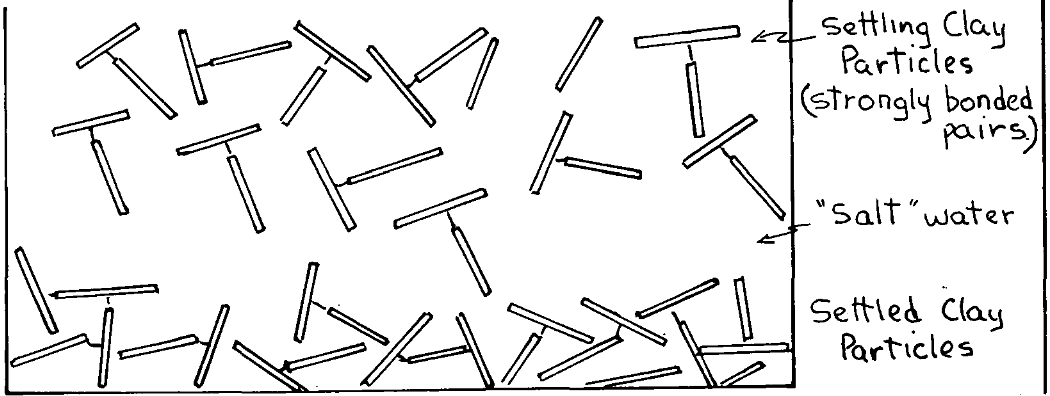

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Fig. 4 Salinity of water > 0·4 molar concn. per litre

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firmly held between two clay layers. These layers constitutes the intracrystalline water.

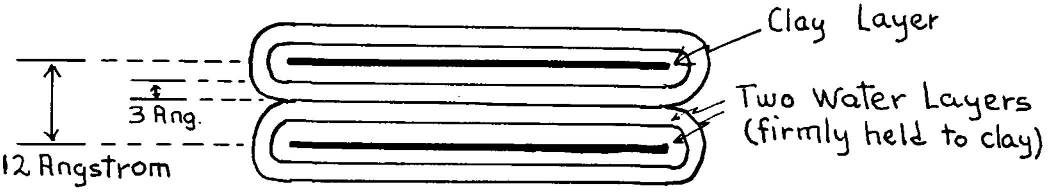

Fig. 5

Neglia)

Approximately 1,000 atmospheres pressure will remove all but the innermost layer of intracrystalline water but pressures in excess of 4,500 atmospheres are needed to remove the last layer.

The above behaviour of clays is quite general, and is in no way dependent on the clay type. The behaviour of the clay and the amount of water that can be driven from it are largely dependent on the salinity of the waters in which the clay was deposited, and the degree of loading to which the clay is subjected. Listed below are the average pressures necessary to drive off the various water layers:-

10 atmospheres - intercrystalline water of fresh-water clays

80 atmospheres - intercrystalline water of salt-water clays lost.

600 atmospheres - intracrystalline water of both clay types lost from third layer

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Figure 4. Settling pattern for clays formed under saline conditions (after Neglia).

The average thickness of the clay layers is only 10-12 Angstrom. Normally only two layers of water each approximately 3 Angstrom thick can be firmly held between two clay layers. These layers constitute~~s~~ the intracrystalline water.

Figure 5. Intracrystalline water layers between two clay layers (after Neglia).

Approximately 1,000 atmospheres pressure will remove all but the innermost layer of intracrystalline water but pressures in excess of 4,500 atmospheres are needed to remove the last layer.

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80 atmospheres - intercrystalline water of salt-water clays lost.

600 atmospheres - intracrystalline water of both clay types lost from third layer

1,500 atmospheres - intracrystalline water of both clay types lost from second layer.

4,500 - 5,500 atmospheres - intracrystalline water of both clays lost from first layer.

A.W. Skempton of Imperial College, London, addressed the Seventh Sedimentological congress on some of the processes involved in the consolidation of clays. He first noted that most of the consolidation involved the rearrangement of the clay particles, that this process was largely irreversible, and if the loading was later removed by erosion, the physical properties of the clay would remain constant, giving the appearance of over-loading.

During compaction, the relation between porosity and the load applied to the clay is consistent, down to porosity values of about 20%. One of the best measurements of compaction in clay is the Liquidity Index - which gives the liquid limit of a particular clay. There is a consistent relation between Liquidity Index and depth of burial.

Very little information is available on the actual behaviour of clays subjected to loads of 300 - 1,000 metres of overlying sediments. However, at these depths it is clear that clays formed on the ocean bottom, tidal flats, and lakes, all tend to converge as far as physical properties are concerned.

LITHOFACIES STUDIES

A.G.I.P. place much importance on lithofacies studies, combining the detailed results of petrography, x-ray diffraction, and framework analysis of the sediments. These techniques are described elsewhere in this report. Attached is a lithofacies map of the Upper Cretaceous of North East Italy at a scale of 1:500,000 (see Attachment No.1). The method of integrating surface and subsurface sections in the different part of the region is quite ingenious, and could be adopted in broad basin studies undertaken by B.M.R.

I.F.P. Facies studies within the Institut Francais du Petrole are under the supervision of M. Pelet; the work is divided into two parts - analysis and interpretation. As the major tool in interpretation is the computer, great emphasis is placed on "non-subjective" data in the analysis stage; the three broad groups of data are:-

Petrographic

Palaeoecological

Chemical

The petrographic analyses involved rather straight forward optical petrography, but very detailed and precise X-ray diffraction studies. The latter was used to give the proportions of quartz, calcite, dolomite, and aragonite, and to detect the presence of other minerals present in the whole rock. The palaeoecological studies are principally concerned with the ecological significance of the various fossil groups.

However, at this stage the main emphasis is particularly on uranium, thorium and potassium using gamma-spectrometer. One of the main aims of the study is to develop equations for the calculation of oxidation potential (Eh) based principally on trace element ratios.

CRITERIA FOR RECOGNIZING DEPOSITIONAL ENVIRONMENTS

The recognition of depositional environments is now regarded as one of the prime objectives of sedimentology. Examples given below illustrate four of the approaches adopted in this work.

Grain Size Analysis

One of the projects of the Geology Department of the State University, Leiden, is a study of present day sedimentation in the Ria de Arosa in north-west Spain. This work is under the supervision of J.D. de Jong. Perhaps the most important single conclusion reached, is that the only worthwhile method of studing grain size distribution is by means of Friedman's "Method of moments" (Friedman 1961). The quicker and simpler methods using percentiles were not sufficiently accurate enough to give meaningful results. (The same conclusion has been reached by Chappell (1967) in a recent study of fossil strand lines in New Zealand.) A major problem remains in the interpretation of bi-modal or poly-modal sands, as Friedman's Method of Moments cannot be applied to these. Approximately half of the river sand studied in Spain fell into this category. On the other hand, bi-modality is uncommon in the beach deposits.

Skewness proved to be by far the most reliable parameter in separating river and beach sand. The river sand tended to be positively skewed (cut off at the coarse end), probably due to the upward finite limit of the carrying capacity of the stream. On the other hand, beach sands tended to be negatively skewed, due to the winnowing action of waves. (However in the paper previously referred to Chappell, stresses that much care should be taken before accepting skewness at its face value; for he has shown that in many cases this can represent the admixture of two separate populations, and thus should be regarded as a bi-modal distribution.)

In the study of the Ria de Arosa, problems were caused by the shelly debris mixed with the quartz sand; it was found that the hydraulic properties (especially the fall velocity) of the shelly material and the quartz sand, differed only slightly in fractions finer than 1 mm. In fractions coarser than 1 mm., the differences in hydraulic properties became so great that bi-modality would be recorded in a sample that was formed under uniform physical conditions. For this reason it was found necessary to dissolve out all shelly material before undertaking a grainsize study.

Studies of the roundness of grains were inconclusive, except that there was a clear increase in roundness towards the beach. In this Spanish example, the stream produced maximum roundness values of .15 to .30; the Ria (estuary) had no influence on the roundness of grains; and the maximum roundness that could be attributed to wear and tear on the beach was .45 to .50.

Mineralogical distinctions between river and beach sands, were inconclusive. In the light fraction, it was found that quartz and feldspar have very similar hydraulic properties. Heavy minerals averaged less than 1% of the sands, and fell within the size range 50-75 microns. It was noted that in the adjacent marine sands the heavy minerals averaged 75-100 microns.

Matrix Studies

Using the X-ray powder camera to supplement detailed petrography, P.C. Nagtergal, of the State University, Leiden, has made a study of the significance of different types of matrix and early formed cement.

The results of his work are summarised below:-

Well crystallized kaolinite Sphero-siderite Pyrite	These are common in dark sediments of fluvial origin, and as early diagenetic products.

Abundant Chlorite Abundant chlorite replaced by arbonate Little or no kaolinite No siderite No pyrite	Characteristics of Upper Cretaceous or Permian Red Beds.

Nagtergal is convinced that the transformation of kaolinite to illite is depth controlled - citing support in Burst (1959) and Kisch (1966).

W.M. Bousch of West Germany, in a paper to the Fourth Meeting of Carbonate Sedimentologists outlined some of the uses of the insoluble residue - mainly clays - from limestone. These residues have two major uses:-

> The clay minerals of the residue tend to <u>attract</u> trace elements, to a much greater extent than the limestone itself.
>
> The source area for the clay can often be detected from the nature of the insoluble residue, since incorporation of the clay within the carbonate appears to inhibit diagenetic alteration of the clay.

Trace Element Analysis

The Geochemical Division of the Societe Nationale Petrole d'Aquitaine (S.N.P.A.) at Pau, France, makes extensive use of trace element analysis in determining environments of deposition, using the automatic optical spectrograph.

S.N.P.A. regard high values for boron, barium cobalt, nickel, molybdenum, and vanadium, and carbonaceous matter in the form of paraffin, as indicative of a marine depositional environment. Special importance is placed on the high boron value. High values for lead and copper, and carbonaceous matter in the form of aromatic compounds are taken to indicate a continental environment at the time of formation.

E. Usdowski of West Germany, in a paper to the Fourth Meeting of Carbonate Sedimentologists, outlined the way in which the proportion of strontium present in a carbonate can be used to indicate the origin of the carbonate. The amount of strontium that will be taken up by aragonite forming under marine conditions by inorganic processes, ranges from 300 to 600 p.p.m., and is about 10 times higher than the amount taken up by calcite. (Seawater currently contains about 8 p. p.m.) Aragonite formed by organic processes has a much higher amount of strontium present. Strontium analyses of numbers of aragonite ooids have shown that they contain exactly the right amount of strontium-if one assumes that they formed by inorganic precipitation in a marine environment.

Carbon Isotope Analysis

W. Sackett of Tulsa State University has been assisting S.N.P.A. to set up a mass spectrograph to determin C_{12} : C_{13} ratios on carbonaceous matter in sediments. The method is based on the fact that carbonaceous matter developed under sub-aerial conditions, will have a different C_{12} : C_{13} ratio from organic material formed under marine conditions. Some difficulty may be experienced because plant debris swept into a marine environment would carry with it a sub-aerial carbon ratio; but its association with organic material of clearly marine origin, should avoid confusion in most cases.

The only point where the original C12 : C13 ratio is likely to be modified is within one centimetre of the sedimentary interface. Once covered by later sediment, diagenetic alteration will have little or no effect.

This application of carbon isotope determinations, is still very much in its early stages; S.N.P.A. have not had time to fully evaluate their technique.

SIGNIFICANCE OF SEDIMENTARY STRUCTURES

F. von Werner of the Marine Research Institute of Kiel University, West Germany, has studied bottom cores collected by the "Meteor" in the Baltic Sea and the Persian Gulf. Sediment from very close to the sedimentary interface was studied by means of X-radiographs of slices of the cores. Werner found that in clayey sediments, U-shaped traces were much more common than straight burrows - probably because the organism needs an opening at both ends of the tube under these poorly aerated conditions. As might be expected, in sandy layers the straighter tubes are more common, because oxygen is much more abundant.

Werner has found that pyrite spheres are quite common and may replace foraminifera, burrows and tubes. The pyrite spheres can also form quite long strings that sometimes do not appear to be related to any previous organism.

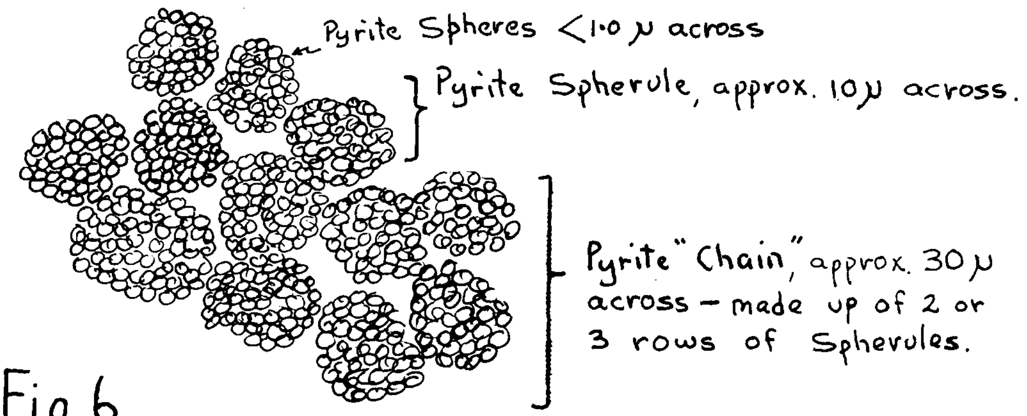

Fig. 6

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absent the major force is the direction of the prevailing winds; in this case the "oscillatory ripple", will have only one direction of dip, despite its apparently symmetrical form. In 99% of cases the dip is towards the shore.

Theoretical Configuration – not found in Baltic Sea or elsewhere.

Wind Influence only – common in Baltic Sea.

Combined Tide : Wind Pattern – common outside Baltic Sea.

Fig. 7

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Figure 6. Structure of pyrite chains (after Werner).

Newton also working within the Marine Research Institute of the University of Kiel has made a study of ripple forms of the near-shore sands of the Baltic Seas. His studies have shown that, contrary to the generally held view, oscillatory (i.e. symmetrical) ripples do not have a symmetrical internal structure, parallelling the ripple surface. Where tides are the controlling forces, the internal structure is generally of two parts (see Figure 7). In the Baltic Sea, where tides are virtually absent the major force is the direction of the prevailing winds; in this case the "oscillatory ripple", will have only one direction of dip, despite its apparently symmetrical form. In 99% of cases the dip is towards the shore.

Figure 7. Oscillatory (non-current) ripples, (after Newton)

Where ripples have developed on off-shore bars, there is a systematic grainsize variation with coarser grains being on the shoreward side of the bar. This applies regardless of profile of the off-shore bar itself.

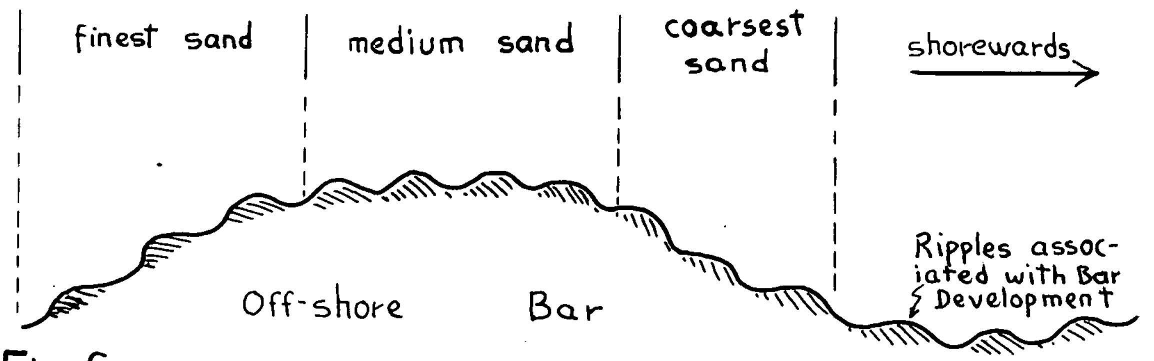

Fig. 8

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margins of the Baltic Sea give a good indication of the direction of the wind a general indication of the direction of the shore-line, but their form can be completely unrelated to the direction of sand transportation. Detailed studies using dyed sand have shown that, even in ripples parallel to the shore and having internal structures dipping towards the shore, the actual direction of sand transportation may be parallel to the shore, and thus parallel to the troughs and crests of the ripples rather than at right angles to them.

These results were obtained in the Baltic Sea, in water ranging in depth from a few centimetres down to 3 metres - below that level the Baltic waves do not normally affect the bottom surface. In a situation such as the Baltic Sea therefore, there is no way of telling a wave-formed ripple from a current ripple - even after a study of the internal structure.

Newton is very sceptical about the significance of so called giant ripples, described both in the field and experimentally by J.R.L. Allen of Reading University. In the Baltic Seas these features are up to 40 meters across, but are never more than one meter high. Newton argues that these structures would be called off-shore bars if they were found strictly parallel to the coast. He is convinced that most of them are composite structures made up of cross-beds, planar beds, and a variety of other forms, and should be interpreted as composite rather than simple structures.

On an excursion to south-west Scotland arranged as part of the Seventh Sedimentological Congress, E.K. Walton demonstrated the development of <u>sand volcanoes</u> in Lower Palaeozoic sandstone. The sand volcanoes are caused by the re-arrangement of coarse sand grains - possibly as a result of earthquake shocks. The re-arrangement leads to a less efficient packing and thus causes expansion; this takes the form of centres of upwelling and can affect the sand to a depth of over two feet

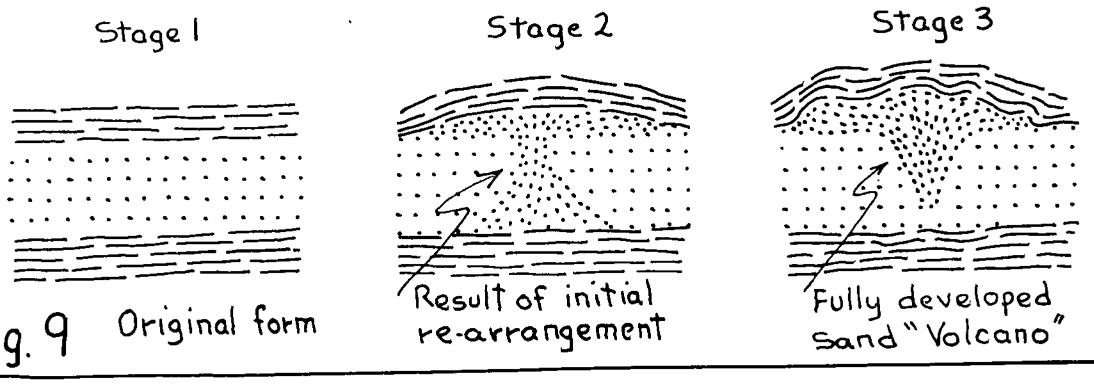

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Fig. 9

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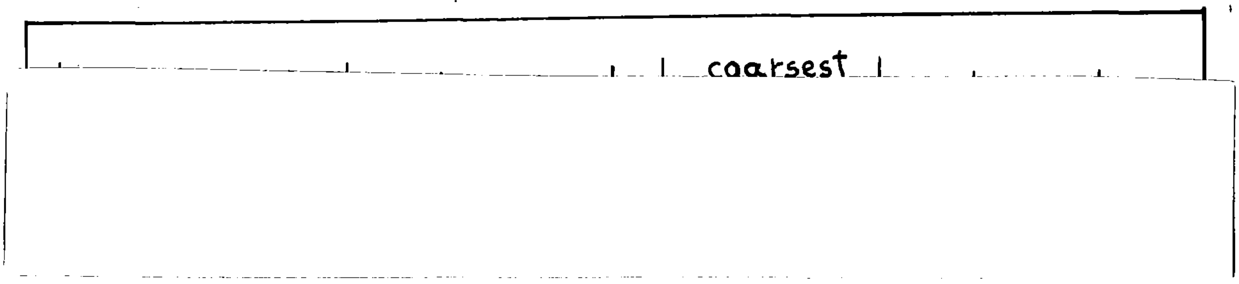

Figure 8. Oscillatory ripples on off-shore bar (after Newton)

Grainsize is all important to the development of ripples. Within the ripple-forming range of hydraulic velocity, the coarser sand will always give rise to much higher ripples than the finer sand. The ripples that develop near the margins of the Baltic Sea give a good indication of the direction of the wind a general indication of the direction of the shore-line, but their form can be completely unrelated to the direction of sand transportation. Detailed studies using dyed sand have shown that, even in ripples parallel to the shore and having internal structures dipping towards the shore, the actual direction of sand transportation may be parallel to the shore, and thus parallel to the troughs and crests of the ripples rather than at right angles to them.

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Figure 9. The development of sand volcanoes (after Walton)

The question of the significance of graded bedding in terms of depositional environment and mechanism of emplacement is wide open - many people considering that it can develop through the action of either turbidity or normal suspension currents. If this is the case, the range of environments in which graded bedding can develop is very wide indeed. (This question is discussed further in the section of "Turbidites".)

SIGNIFICANCE OF "KEY" ELEMENTS AND MINERALS

Boron

It has become very popular to regard high boron values in a sediment as indicative of a marine depositional environment. The S.N.P.A. in particular pays great attention to this in all source rock studies. However, it is clear that considerable caution must be exercised in interpreting the high values.

In an address to the Sixth International Carboniferous Congress D. Spears of the University of Sheffield summarised the results of his study of the boron content of Upper Carboniferous shales from several different facies in the north of England; he claims that the boron content is apparently independent of the depositional environment - thus precluding its use as a palaeosalinity indicator for those rocks.

In the Westphalian Coal Measures, the boron content of the shales tends to be more closely related to the relative abundance of K_2O in the shale. This is interpretated as indicating that the boron content is directly related to the amount of clay minerals present - especially illite.

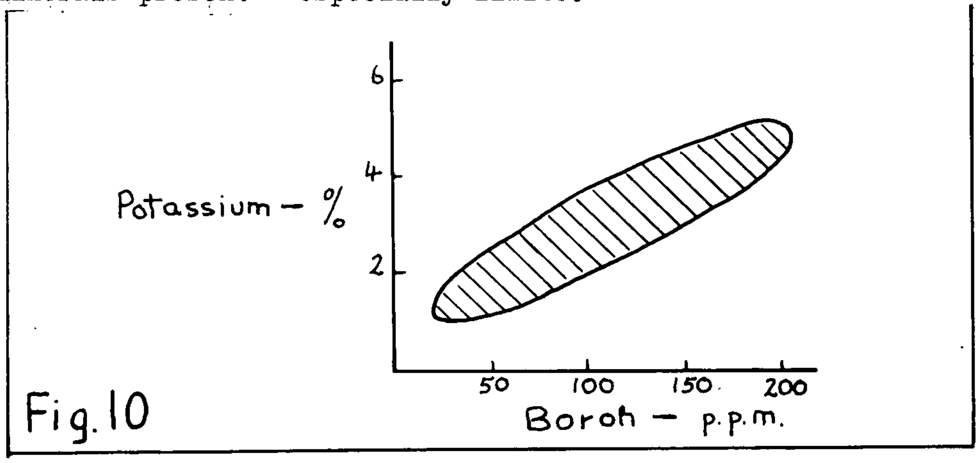

Fig. 10

(after S

n shale

Spears is convinced that detrital boron is of major importance in many sediments. In these cases, variations in the boron content can be caused by changes of provenance, or changes in the severity of chemical weathering within the one source area. As the intensity of weathering increases, the boron content of the clay minerals also increases; in other words, the boron content increases along with increasing maturity of the source area.

Spears suggests that the reason for the higher boron content in marine shales - which he does not dispute - is related to the higher clay content. If this is so, many exceptions to the palaeosalinity "rule of thumb" should be expected. Spears' work has also shown that the boron content of shale is independent of the rate of deposition. This would mean that the changes occurring in the boron percentage during transportation would be slight.

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Figure 10. Relation between B and K_2O content in Westphalian shale (after Spears).

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Glauconite

For many years now, the presence of glauconite has been regarded as one of the most **reliable indicators** of a marine depositional environment. But now questions have been raised on the validity of the concept, and the accuracy of identification.

Sarnthein, of the Marine Research Institute of the University of Kiel, West Germany, thinks that glauconite can form quite readily in a tidal flat environment - even when subjected to periodic influxes of fresh water. He regards the work of Burst (1958) as of special value. In my discussions with many petrologists - especially those concerned with X-ray diffraction studies - it became clear that they all found considerable difficulty in positively identifying glauconite. It is likely that much of the "glauconite" in the literature is a chlorite such as chamosite.

In a short paper to the British Sedimentological Research Group, R.J. Bailey of the Marine Science Laboratory, Anglesey, stressed the different conditions under which glauconite can form. In addition to forming in "well washed marine waters" Bailey thinks it can form much later by diagenesis, in sediments formed under quite different conditions.

FACTORS CONTROLLING THE DISPERSAL OF SPORES.

W.H. Zagwijn, of the Geological Survey of the Netherlands, has been making a study of the causes of vertical variation in spore and pollen population. He has found that a change in population is generally associated with a change in grain size or sorting in the enclosing sediment.

It is clear that transportation of spores and pollen by air leads to enormous dilution over very short distances; in most cases this mechanism could not produce the concentrations of spores found in many sediments. Water transport is clearly the main factor in distribution and concentration but very little is known about the behaviour of spores and pollen in water.

Shell Research is doing a lot of work on the hydrodynamic properties of spores; indications are that the vertical changes in population can be attributed to one or more of the following:-

Depositional environment

Change in type of sediment

Change of climate

SEDIMENTATION

M.E. Philcox, in a paper presented to the Fourth Meeting of Carbonate Sedimentologists, illustrated the relation between the growth pattern of stromatoporoids and the rate of terriginous sedimentation; this study was carried out in the Silurian of Cork County, Eire.

If the growth pattern of the stromatoporoid is hemispherical, then it can be inferred that terrigenous sedimentation was slow; if the growth of the stromotoporoid was conical, the indication is that there was a much greater supply of terrigenous sediment. (Obviously the stromotoporoids must be in the growth position for these interpretations to be made). The clearest examples are found in the types developed in shallow water. At greater depths a similar - though less well defined - trend could be recognised.

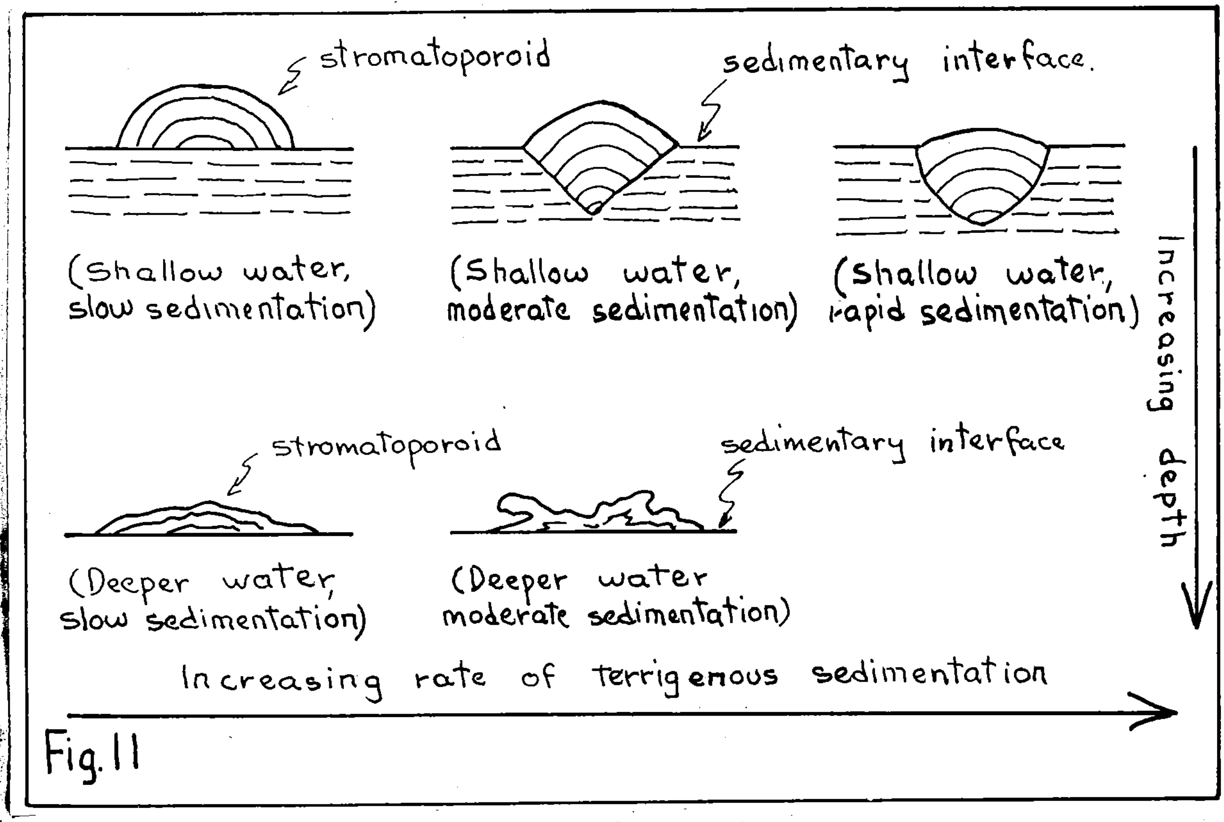

Fig. 11

Figure 11. Growth pattern of stromotoporoids with differing rates of terrigenous sedimentation, and at differing depths of water (after Philcox).

DIAGENESIS

A great deal of importance is now placed on diagenetic processes in the modification of carbonates and clays. This work is of major importance to the oil industry, because of the marked changes in porosity that can result from diagenesis.

Carbonates

H. Zankl of the University of Berlin presented a paper, to the Fourth Meeting of Carbonate Sedimentologists, dealing with the classification of diagenetic processes as they affect carbonate sediments. His work was based on his studies in the Calcareous Alps. The processes could be considered under the following headings:-

Early diagenesis

Intrastitial - insulated from the effects of compaction or solution
e.g. hard ground in chalk.

intraformational - affected by pressure and formation fluids.

bioturbation

plastic deformation

dessication

shrinkage

precipitation of calcium carbonate

solution of calcium carbonate

dolomitization

silicification

Late diagenesis

recrystallization - micrite to micrite or sparrite

recrystallization - sparrite to micrite or sparrite

precipitation of calcium carbonate

replacement by dolomite

replacement by silica

cleavage

stylolite development.

In a talk at the Fourth Meeting of Carbonate Sedimentologist, P.R. Bush of Imperial College, London, discussed the diagenetic changes that take place in the Sabkha along the margin of the Persian Gulf. He described the Sabkha (salt flat) as a huge diagenetic machine in which marine sediments containing meta-stable minerals are extensively altered to suit different temperature and pore fluid conditions.

He found that the grainsize of the original sediment has a strong influence on the rate of diagenesis; carbonate muds are rapidly dolomitized - in less than 3,000 years. Carbonate sand however, commonly remains undolomitized for much longer periods. The following minerals are produced through diagenesis in the Sabkha environment:-

halite

gypsum

anhydrite

celestite

dolomite

magnesite

aragonite

F. Koegler of the Marine Research Institute, Kiel, West Germany has made a study of the shear strength of recent sediments in the Baltic and Arabian Seas, and in the Gulf of Oman. He has found a marked increase in the shear strength of sediment that contains in excess of 20% carbonate, at a depth of approximately one metre beneath the sedimentary interface. Koegler interprets this increase in strength as marking the onset of cementation in the sediment.

B. Waugh of the University of Hull gave a short paper at the British Sedimentological Research Group Meeting on the occurrence of dolomite in the New Red Sandstone of the Vale of Eden. His work showed that the magnesium limestone is intimately associated with primary gypsum and dolomite - a situation which he equates to carbonates of the Coorong of South Australia. Waugh thinks that xerophytic plants have precipitated the dolomite - as suggested by Skinner for the Coorong accumulations.

Diagenetic alteration within patch reefs was discussed by Lloyd Pray of Marathon Oil Company at the Seventh Sedimentological Congress. The development of interlocking sparry calcite must have occured at a very early stage - certainly before compaction had reduced the high original porosity (averaging about 60%). The question arises as to whether this sparry calcite cement was original, or whether it represents original aragonite now replaced by calcite. Pray thought that if the calcite appeared "cloudy" it was possibly original - though most workers regard the sparry calcite as replaced aragonite that developed in water depths of 1 - 2 metres.

A study of the dolomitization of a Devonian reef within the Carniques Alpes was undertaken for the Institut Francais du Petrole by Schmerber and Deroo. The object was to develop a fully documented "model" that could be of use in understanding carbonate entrapment of petroleum. They found three types of dolomite present:-

Rare primary dolomite, occurring on the reefs.

Pene-contemporaneous dolomite, forming rims around calcarenite grains, that developed before the calcite cement.

Post-lithification dolomite, often associated with fault joints etc., and probably of Tertiary age.

The primary dolomite occurs as fine-grained layers, interbedded with calcite. It is commonly associated with amphipora, and tends to have a "normal marine" boron content, but high values for manganese, iron, titanium, copper and chromium. The sediments particularly rich in chromium and copper are also rich in organic matter and are thought to have formed under poorly aerated conditions in the back-reef environment.

Clays

J. Lange of the Marine Research Institute, Kiel, West Germany, has made a study of recent clay deposits in the Persian Gulf - using bottom cores recovered by the research vessel "Meteor". Lange has found no evidence of diagenetic change in the six metre thickness of sediment sampled. He maintains that the principal change in clay mineralogy occurs where the clays first come in contact with marine conditions; as an example detrital attapulgite tends to change to chlorite on entering the Persian Gulf.

The filtering effect of compacted clays and its significance in diagenesis has been closely investigated by S. Neglia of A.G.I.P. Direzione Mineraria; he is convinced that the behaviour of clays holds the key to a great number of diagenetic processes.

Neglia maintains that once all the intercrystalline and intracrystalline water has been driven off, clays that developed in either fresh water or saline environments, tend to develop a marked parallelism in their structure; at this stage they will begin to act as a semi-permeable membrane. The passage size within the membrane will depend on a number of factors, the most important of which is the external pressure being exerted on the clay layers. Initially only the large particles will be held back, but as compaction proceeds the smaller particles will also be affected - molecules, ions, and gaseous bubbles.

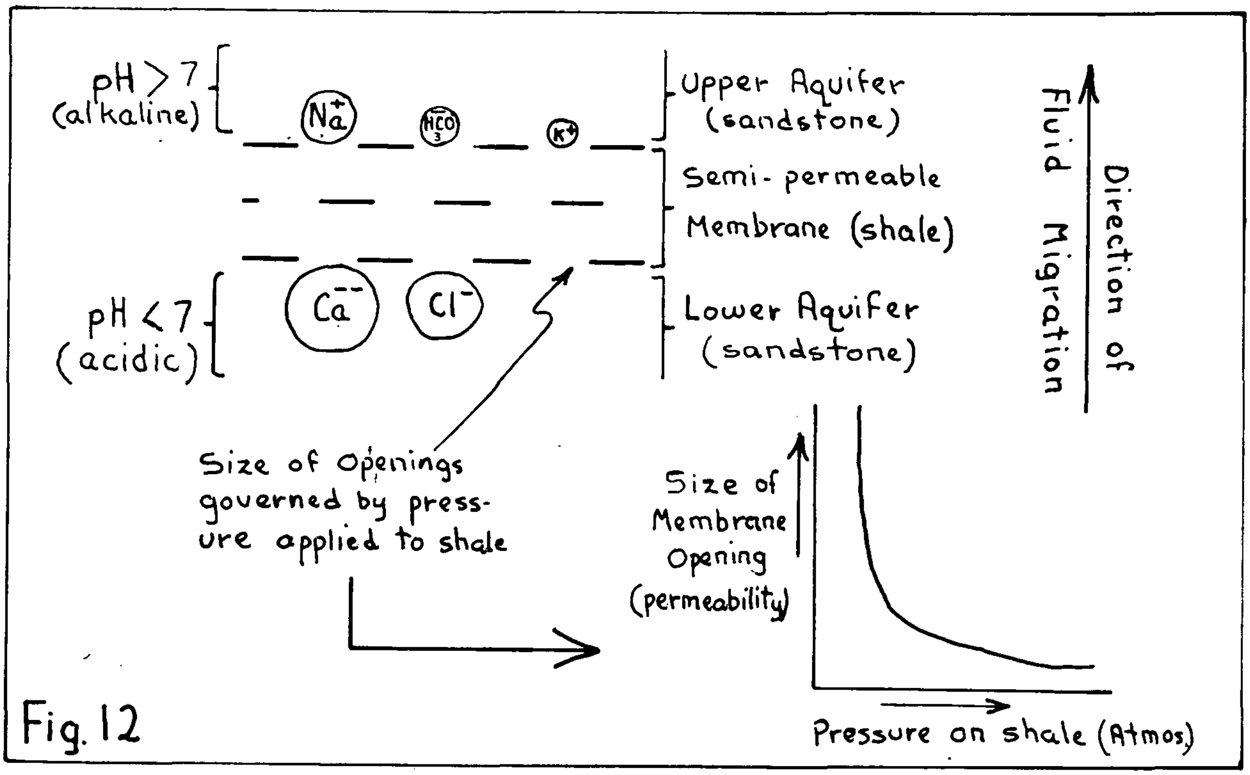

Fig. 12

Figure 12. Order in which different ions are affected by a shale membrane (after Neglia).

As seen in the above sketch, one common effect of the membrane is to produce acid conditions below and alkaline conditions above the barrier. Potassium is generally removed from the lattice of the clay at this time. These two processes bring about the diagenetic changes near the shale barrier.

The alkaline conditions immediately above the semi-permeable clay barrier will cause the solution of silica from the quartz in the adjacent sand; however, in this situation the "pressure-solution" does not lead to quartz overgrowths. An influx of water above the barrier - possibly from an upper aquifer - can lower the pH, and bring about the precipitation of the silica - previously dissolved from the quartz; the silica will precipitate both as overgrowths on quartz, and also as siliceous cement.

Further lowering of the pH to about 6 will cause the precipitation of carbonate, generally as calcite. Siderite requires a pH of about 4 before it will be precipitated. A return to slightly alkaline conditions, will lead to the resolution of carbonate - and this can bring about a marked improvement in porosity in the carbonate sequence.

Neglia maintains that all types of clays and also muscovite, can be formed from a wide range of minerals, by varying the physical and chemical conditions following deposition. He thinks that these same factors largely control the development of authigenic quartz, orthoclase, albite and carbonate.

P.C. Nagtergal working in the University of Leiden, thinks that the change from kaolinite to illite is diagenetic and controlled largely by depth of burial. He regards Burst (1959) and Kisch (1966) as the two most important references in English on this subject.

An interesting and possibly very important suggestion was made by W.M. Bousch of West Germany in a paper at the Fourth Meeting of Carbonate Sedimentologists; he claimed that incorporation of clay material within a limestone tended to inhibit diagenetic alteration of the clay. This finding could be of real importance to people studying the relation between provenance, depositional environment, and clay mineralogy.

Pyrite

L.G. Love of the University of Sheffield has made a detailed study of the diagenetic changes in the recent sediments of the Wash; these results were presented in a paper to the Seventh Sedimentological Congress. The intertidal sediments of the Wash contain up to 0.4% pyrite - and a substantial amount of iron hydroxide and monosulphide are also present and available for conversion to pyrite. From the obvious replacement characteristics of much of the pyrite, it is apparent that much must have formed after deposition of the sediment.

A clear link has been established by Love between the clay minerals deposited and the iron content of the sediments; this holds for sediments where the average grain-size ranges from 75 microns down to as low as two microns. The acid-soluble iron occurs dominantly as ferric-hydroxide, iron monosulphide, and as pyrite. These different compounds tend to occur at different levels in the sediment, and lead to a colour zonation:-

Ferric hydroxide - brown (top of sequence)

Iron monosulphide - black

Pyrite - grey

Love described some of the changes that can occur within the top few centimetres of a sediment, particularly the changes in pH that can accompany equally marked changes in Eh - signalling the using up of all free oxygen. At this stage anaerobic bacteria become intensely active, especially the sulphate reducers. The overlying seawater provides and inexhaustable supply of sulphate for downward diffusion.

Love stresses that there are definite limitations to the interpretation of pyrite-rich shale, in terms of the intertidal sediments of the Wash. Nevertheless there are consistent differences between the Black Sea sediments and those of the Wash that should be recognisable in the consolidated shale.

Caliche

A special case of alteration in situ is the development of caliche. It is commonly found in the upper part of red bed cycles, perhaps related to a soil forming process.

A unit called the Abdon Limestone, described by J.R.L. Allen from the Lower Old Red Sandstone of the Welsh Borderland, was visited during the Seventh Sedimentological Congress. The unit consists of a set of cyclothems averaging 15 feet thickness; in each cyclothem the grainsize decreases upwards, in contrast to the carbonate content which increases upwards. Apart from a few vertebrate remains, the sediments are unfossiliferous. There is much evidence of replacement by carbonate - such as explosions of former feldspars and quartz. Allen regards the development of carbonate as a form of caliche, and he thinks that it probably developed following deposition of the cycle in a few thousand years - and certainly preceded the development of the overlying cycle.

Allen attributes the development of caliche to major fluctuations of sea level which exposed the flood-plain to denudation for some thousands of years and allowed the upward migration and precipitation of carbonate from groundwater. He regards the rotation and ultimately the replacement of clastics by carbonate, as the ultimate in caliche development. Normally dolomite makes up less than 5% of the rock.

The individual caliche layers may be up to 12 feet thick - though this is exceptional - and the layers are commonly repeated up the section. In detail, three stages of caliche development can be recognized:-

Appearance of limestone nodules, up to 1 cm across, within the siltstone.

Increase in the size of nodules upwards.

Development of massive limestone, sometimes with relict clastics and sometimes with nodules.

SEDIMENTOLOGY APPLIED TO PETROLEUM EXPLORATION

PETROLEUM SOURCE BED STUDIES

A great deal of time and money has been spent in trying to determine the conditions under which hydrocarbons can be expected to develop, and in seeking "keys" to such environments. To date, results have been very disappointing on both counts.

S. Neglia of A.G.I.P. Direzione Mineraria, is sceptical of the value of many analyses, both physical and chemical, undertaken in detailed source bed studies. He doubts the validity - and even the relevance - of a number of the assumptions used in these studies.

Neglia thinks that a wide variety of organic matter can give rise to embryo-oil by the application of pressure to the different complex molecules. The molecules become progressively more flattened, and finally the "branches" of the molecules break off - removing the hydrogen.

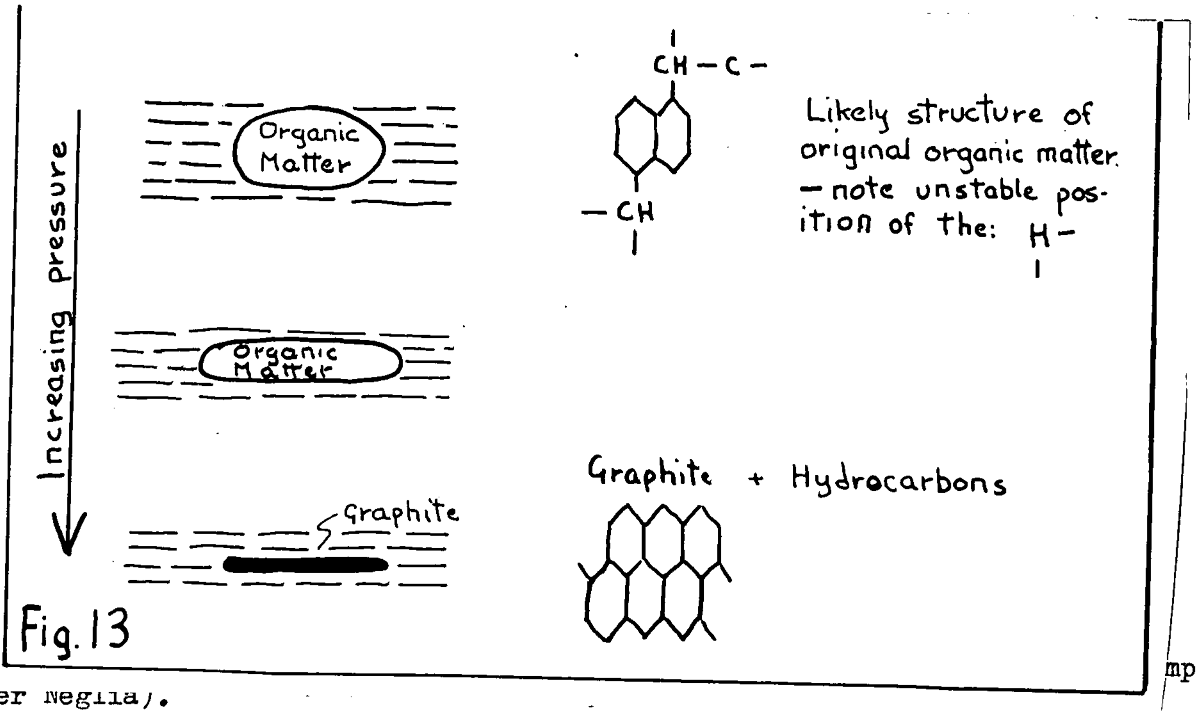

Fig. 13

mpaction

(after Neglia).

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Figure 13. Stages in the modification of organic matter during compaction (after Neglia).

Neglia regards graphite as the end product of this compaction and break up of the organic material; he would not expect to find any significant hydrocarbon accumulation in the vicinity of abundant graphite. He regards the presence of mixed-layer as reliable, "negative evidence". Neglia is convinced that mixed-layer clays are almost exclusively of diagenetic origin; as such, in this situation any hydrocarbon originally present in the shale would certainly have been lost.

As illustrated above, Neglia sees a close link between the origin of coal and oil. He thinks that some of the huge gas fields containing a little or no oil (e.g. Groningen), could be readily explained if this association was accepted because the supply of large quantities of very uniform organic matter could only develop into the simple hydrocarbons such as methane.

As noted earlier in the report, S.N.P.A. place great emphasis on boron as an indicator of palaeo-salinity - a method that has its drawbacks, as pointed out by Spears. S.N.P.A. are also using carbon isotope analysis (C_{12} : C_{13}) to determine the marine or terrestrial origin of the carbonaceous matter. However there are still some unknowns in this method and the initial outlay for a mass spectrograph, is very considerable.

FLUID MIGRATION

I was most interested to find that in Europe, great importance is being placed on compaction as a means of supplying the fluids - as well as providing the hydrodynamic gradient - to bring about the fluid migration. The views of S. Neglia of A.G.I.P. are set out in detail elsewhere in this report.

The role of compaction in defining the paths of fluid migration in a carbonate succession was considered in a paper by P. Trurnit of West Germany, at the Fourth Meeting of Carbonate Sedimentologists. He relates the role of compaction in the development of stylolites to the pattern of fluid migration. Extensive stylolites and widespread pressure solution, will effectively preven upward migration of fluids, and force migration to take place laterally beneath the stylolitic barrier. As stylolites will be much less likely to develop near the margins of the basin - where the loading is much less - the pattern of fluid migration tends to be from the centre toward the margins of the basin.

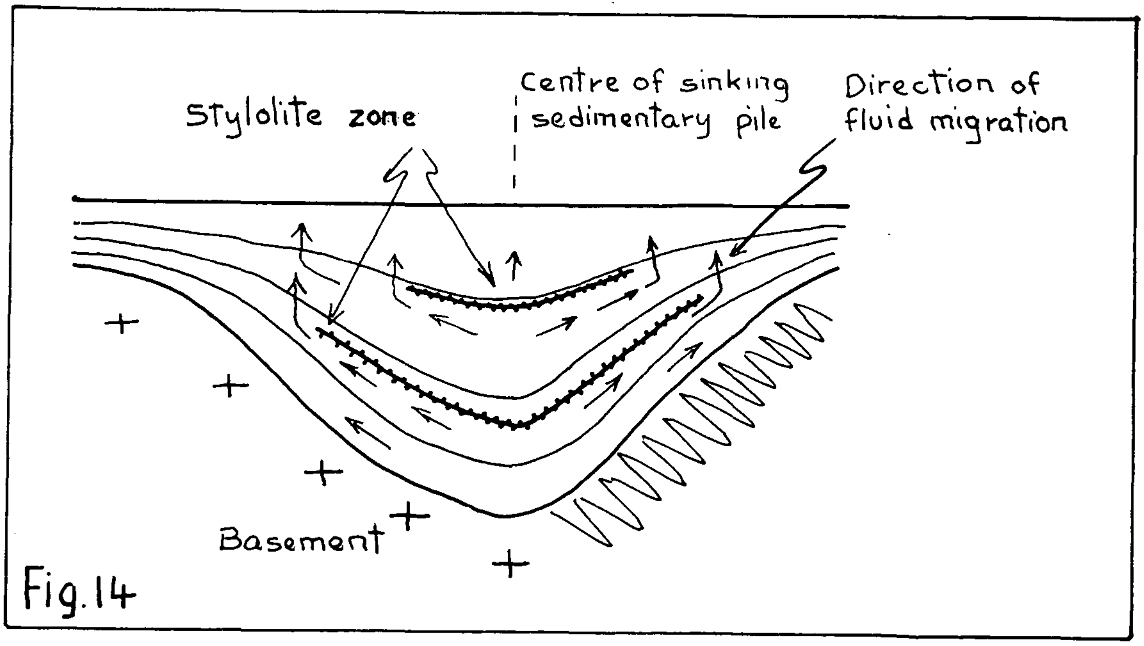

Fig.14

carbona

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Figure 14. Influence of stylolitization on fluid migration in a carbonate basin (after Trunit.)

GEOCHEMICAL PROSPECTION FOR PETROLEUM

Great emphasis is placed on geochemical prospecting within A.G.I.P. Direzione Mineraria; the group is under the control of Giordano Long, but most of the work is directed by S. Neglia.

The following is a precis of the views of Neglia on the role of geochemistry in petroleum exploration:-

1. The hydrocarbons were formed in depositional troughs in clayey sequences, both the rate of generation and release of the hydrocarbons being governed by compaction.

2. Hydrocarbons were transported with the water but as a separate phase - or possibly as two separate phases.

3. The hydrocarbons migrated updip in response to a hydrodynamic gradient. This gradient was produced by the expulsion of large quantities of interstitial water from the heavily loaded clayey sediments within the trough; the loading of the sediments at the margins of the trough was much less severe, and a higher proportion of the interstitial water was retained. (This mechanism only applies to early migration of hydrocarbons.)

4. The updip migration of hydrocarbons will be halted at the crest of a major structure; from that point, three types of further migration are possible:-

    : Migration through an outcropping aquifer, or along a fault.

    : Migration down the far side of the structure in response to the hydrodynamic gradient.

    : Migration across dip through the overlying shaley sequence - facilitated by the relatively slight compaction on the basin flank.

5. Neglia holds that the third possibility is commonly the dominant factor. In such a case of upward migration, the overlying shale acts as a semi-permeable membrane, trapping larger particles such as oil and in some cases also gas, but allowing the smaller ions to continue up through the membrane,

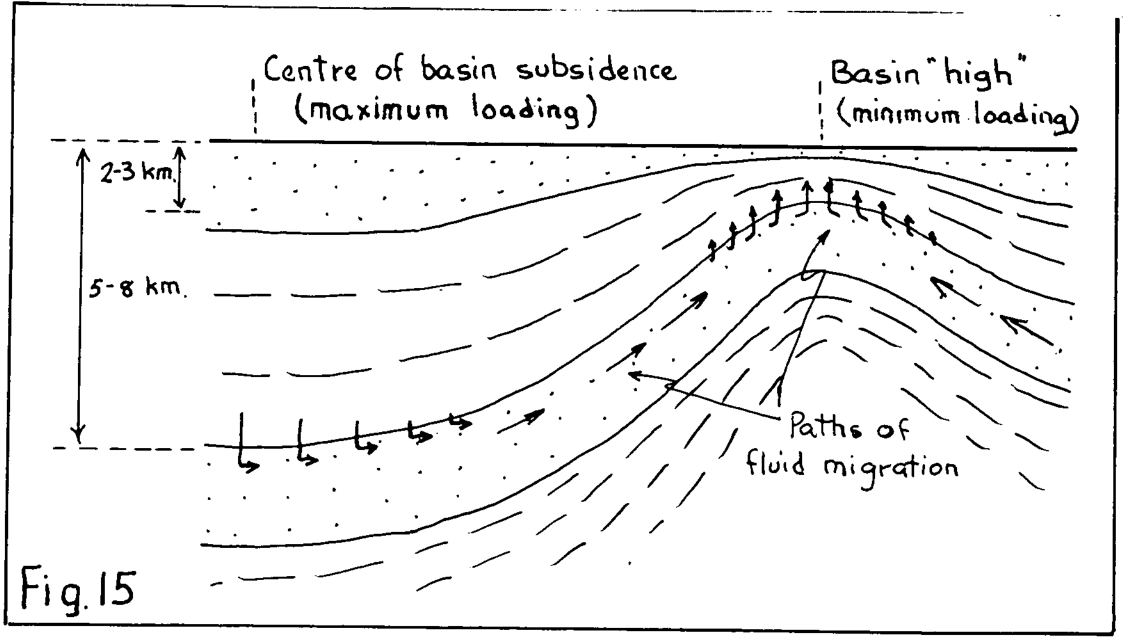

Fig.15

in a san

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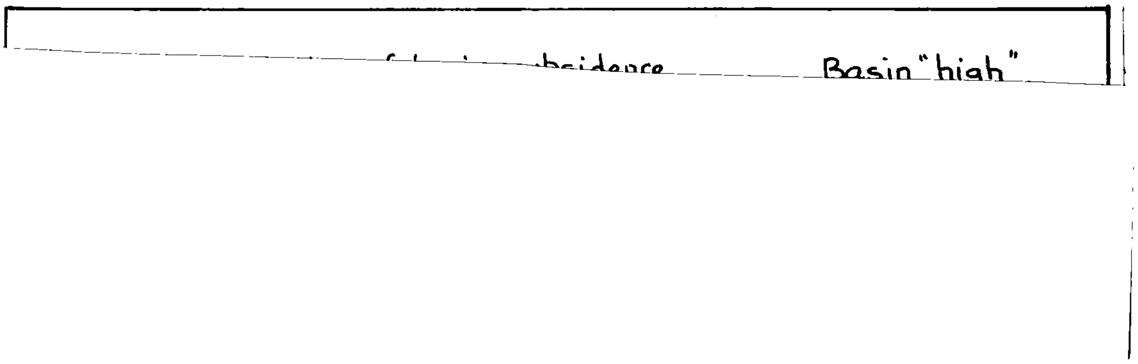

Figure 15. Influence of differential compaction on fluid migration in a sand-shale succession (after Neglia).

Neglia in supporting the conclusions of Norrish of C.S.I.R.O., maintains that clays formed under near fresh-water conditions, can be readily distinguished from clays formed in a saline environment; but that while both types of clay act as semi-permeable membranes, the compaction of a marine clay will result in the loss of a great deal more water than with a clay formed in fresh water. This point is considered in detail elsewhere in this report.

Neglia also maintains that very many structures act as closed systems as far as the interstitial fluids are concerned. This would mean that the "water drive" invoked by most petroleum engineers to explain hydrocarbon migration - could be caused by the squeezing of water from "heavily loaded shale in the areas of thick sediment accumulation. Up dip migration into areas of less compaction, where the sediment load is thin, would follow. This mechanism is an alternative to the hydrodynamic gradient developed in an open system, and necessitating migration of fluids over very long distances.

Where a closed system exists, and where migration of fluids has occurred up-dip as outlined above, there will be a high concentration of salts immediately beneath the shale barrier in the crest of the structure. According to Neglia, the build up of salts will develop because of the considerable pressure on the fluid in the crest; this will force some migration of salts across dip, through the shale "semi-permeable membrane". The result will be a "filtering out" of the larger particles. The concentration of salts will fall away as more highly compacted shales are encountered on the flanks of the structure. Thus a contouring of salinity values of the capping shale could indicate the area of greatest "fractionation" of the fluids, and thus the most likely position for oil or gas accumulation.

Where the structure does not act as a closed system, but rather forms part of a broad hydrodynamic gradient, Neglia maintains that the salts accumulating beneath the shale in the crest of the structure would be swept along the aquifer, until some barrier - such as a lateral facies change - was encountered; in this situation, the contours of salt concentration could again be used to locate oil or gas but this time in a stratigraphic trap.

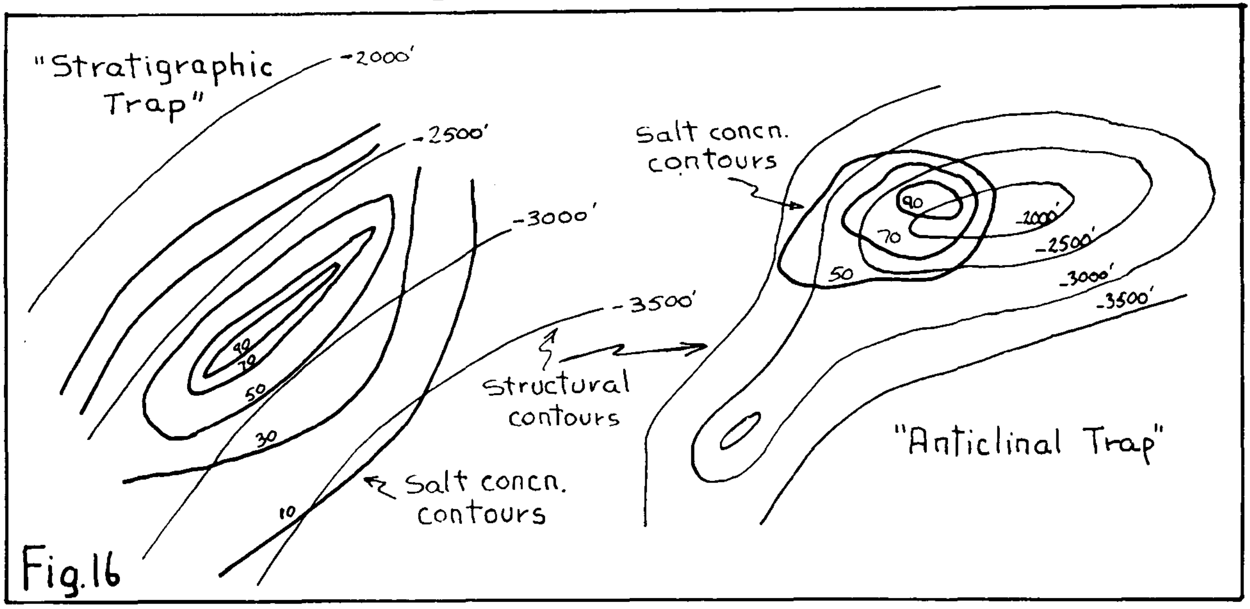

Fig.16

Figure 16. Salinity contouring superimposed on structural contours to delineate structural and stratigraphic traps (after Neglia).

It was emphasised by Neglia that with time, the ability of a shale membrane to hold back gas would gradually diminish because the globules of gas accompanying the migrating water, would gradually break up into smaller particles, and would pass up through the shale barrier. Neglia thinks that many Palaeozoic deposits of natural gas could have been dissipated in this manner.

HYDRODYNAMICS APPLIED TO PETROLEUM EXPLORATION

S.N.P.A. has closely followed the Petroleum Research Corporation of Denver U.S.A., in applying hydrodynamic data to oil exploration. M.H. Coust carries out this work in S.N.P.A.; he sees three possible applications:-

Identification of reservoirs

Correlations of reservoirs

- vertical correlation
- horizontal correlation

Assessment of traps.

It is the identification and delineation of reservoirs that is regarded as all important; one thin but continuous shale band can form a perfectly effective barrier between two reservoirs, which could each have quite distinct pressure and salinity characteristics. Criteria that are used in the type of comparison are:-

Relative salinity

Pressure data

Hydrocarbon shows

In the absence of D.S.T. data which are highly valued, S.P., sonic, gamma and neutron wire-line log results are used to calculate salinity and porosity. The initial calculation made is "thickness x porosity" (m.x%). This is the value that will be shown on the contour map; also shown on the map is a key to the type of data used in the calculations - thus enabling the likely accuracies of the various values to be quickly assessed. In S.N.P.A., the following contour maps are prepared when studying a particular reservoir:-

"Thickness x porosity" map - the major reference.

Equal pressure map (in metres)

Salinity map (sodium chloride if possible, as this is the most soluble salt; total salinity if data obtained from the logs).

Map of hydrocarbon shows. Special emphasis is placed on:-

- Iodine/chloride ratio
- Total weight of iodine
- Reduction potential

The iodine/chloride ratio and the total weight of iodine together indicate the degree of flushing of the reservoir. Coust regards the ideal reservoir situation as one with a pressure reversal - that is an upper aquifer of higher pressure than the underlying aquifer. However in view of the uncertainties involved in the calculations, Coust states that he would need recorded differences in excess of 10-20 metres of pressure, before he would consider a reversal proven.

The Aquitaine Basin is a good example of a well documented pressure reversal, caused by faulting, later sedimentation, and uplift - see sketch below.

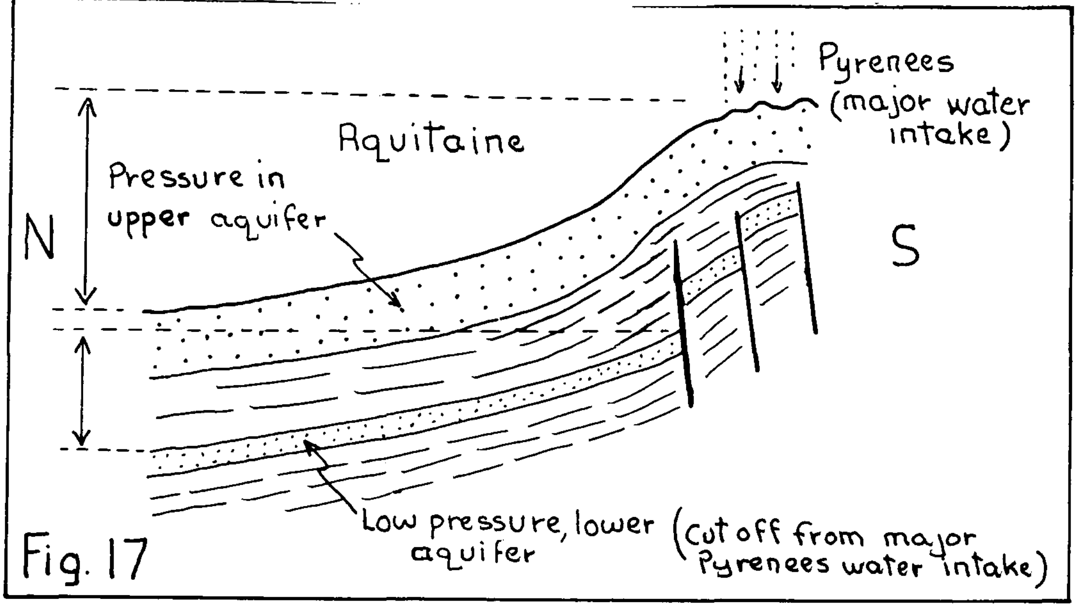

Figure 17. Example of pressure reversal in the Aquitaine Basin (after Coust).

Coust thinks that with time, separate reservoirs with different salinities and different pressures, will tend towards an equilibrium because of transverse migration. He maintains that recent work has shown transverse migration to be of much greater importance than was previously realised (Coust 1967).

SEDIMENTOLOGICAL EQUIPMENT AND TECHNIQUES

Perhaps it is easier to become outdated in the methods being applied in sedimentology than in any other aspect of the work; even when methods are described in the literature, the amount of detail supplied is seldom adequate.

SAMPLE COLLECTION

S.N.P.A. In all Societe Nationale Petrole d'Aquitaine field operations, all outcrop samples, drill core and cuttings are described systematically in the field, before they are sent to the C.R.P. (S.N.P.A. Laboratories) at Pau, France. In the case of drill cuttings, the samples are collected at 2 metre spacings, and while still at the drill site, a small portion of each sample is embedded in a cold-setting plastic - "Stratyl"; a thin section is made from each "Stratyl button". Despite this abundance of thin sections at the well site, the bulk of the well site work consists of binocular microscope examination; the thin sections are used primarily as checks, and in looking for micro-fossils. All the outcrop samples collected in a survey, will be thin-sectioned, at the C.R.P. after the petrologist has marked the required orientation on the hand-specimen.

A.G.I.P. Routine well logging is rather superficial, most of the study being based on binocular examination of cores and cuttings; but at least it is made as non-subjective as possible.

When dealing with specific problems, an entirely different approach is adopted at A.G.I.P. for example, in measured outcrop sections, samples are collected and thin-sectioned at a maximum spacing of 2-3 metres, and at closer intervals if necessary.

THIN SECTIONING PROCEDURES

S.N.P.A. As noted earlier S.N.P.A. have "unpicked" drill cuttings from each two metres, mounted into "Stratyl" thermo-setting plastic at the well site; a thin section is made from each plastic button, also at the well-site, S.N.P.A. claims that no special precautions, such as vacuum assisted impregnation, are required.

I.F.P. The I.F.P., however, adopts a very careful procedure in thin section making, to ensure uniformity of the mounting medium (and also the R.I.), and to clearly distinguish pore spaces. All samples are impregnated with "Araldite, to which a dye has been added. The technique, developed by Madame Fondeur is set out below:-

1. Araldite FCY 205 is mixed with hardener HY905 in equal proportions. Both products are made by Ciba.
2. Araldite dye DW 03 is added to the above mixture in the proportions of 100 gram of dye to 1 kilo Araldite and 1 kilo hardener. This mixing should be at 90°c.
3. The sample is then placed under a vacuum for 10 minutes, to remove as much of the air from the pores as possible. In the case of cuttings, the sample is placed in a small round cardboard box approximately 2 cm. across and .5 cm. deep.
4. The Araldite as prepared above (in 1. and 2.), is then added without releasing the vacuum.
5. A pressure of 10 kilograms per square centimetre, is then applied for 10 minutes.
6. The pressure chamber is held at 80° c. for 10 minutes.
7. After the 10 minutes of pressuring, the sample is placed in an oven at 160° c. for 5 hours, at normal pressure.

University of Reading A very simple yet effective method of impregnation has been developed by A. Tucker of Reading. It is carried out on a routine basis:-

If it is possible to cut one smooth surface on the rock chip, the following steps should be carried out:

1. Cut and polish one smooth face on the poorly consolidated rock chip.
2. Heat the chip dry on a hot plate at 180° C.
3. Plunge the heated chip into a bath of cold-Xylene - leave there until bubbling ceases (most of the air in pores will have been driven off and replaced by Xylene).
4. After bubbling has stopped, remove chip quickly and place in a beaker containing a mixture of Lakeside (1 part) and alcohol (8 parts by volume), that has been pre-heated to 180° C.

5. Leave chip in the Lakeside - alcohol mixture at 180°C. until all the alcohol has been evaporated off. (Test for this by sampling the mixture on a steel needle; when the alcohol has all gone, the Lakeside will dry quickly at room temperature, and become very brittle.)

6. Chip can now be removed and cooled. It will have been impregnated to at least 2 mm., and the previously smoothed surface can be used for a thin section in the normal way.

7. After the chip has been removed, the liquid Lakeside can be poured from the beaker into an aluminium foil "cup" where it is left to harden. The same Lakeside can be used for two or three impregnations provided that rock fragments or grains are not picked up.

<u>If the rock chip is too incompetent to be smoothed on one surface</u>, the following pre-treatment is necessary:-

1. The irregular chip should be impregnated exactly as before - set out above (3 to 6).

2. One face of the chip can now be sawn or ground to a reasonably smooth surface.

3. The smoothed rock chip should be thoroughly dried - but at a low temperature, to avoid melting the Lakeside.

4. The cool chip should be immersed in the hot (180°C.) mixture of Lakeside and alcohol as set out above in 5, to impregnate the smoothed surface of the chip.

5. After all the alcohol has been driven off at 180°C., the chip can be removed, and a thin section prepared in the normal way.

<u>Mounting of the impregnated chip</u> is as follows:-

1. Before mounting, the chip is converted to a 4 mm thick, parallel sided "biscuit".

2. Mounting medium is always the same as impregnating medium.

3. Mounting medium is spread on the glass slide and when the correct temperature is reached (140°C. for Lakeside), the gently warmed chip is inverted onto the glass slide.

4. After gently pressing together, for no more than 10 seconds, the slide and "biscuit" are removed from the hot plate, and inverted (slide uppermost) onto a flat surface. A strong overhead light is required. All the bubbles can be squeezed out by applying pressure to the glass surface.

5. The same method is used for fitting the coverslip to the mounted and ground rock slice.

PETROGRAPHY

S.N.P.A. Detailed petrological examinations are carried out at the Central Laboratories (C.R.P.) at Pau, France. A "blanket approach" is adopted, whereby all samples selected for study are given the complete treatment.

The petrologist will select the thin sections of cuttings to be studied from a particular well; in a uniform succession, this will involve a minimum of one complete thin-section description for each 10 metres. The intervening thin sections, (made at the well-site), will possibly be examined briefly, before being stored for future reference. After the decision has been made as to which thin sections will be studied - but before the study is under way - an X-ray diffraction whole rock analysis of each sample will be carried out. This will establish the percentage of quartz, and also the different types of carbonates present. It is felt that the petrographer is then in a much better position to estimate the percentages of the various textural components of a particular mineral- for instance the various forms of calcite present.

The detailed thin section descriptions will be recorded on very comprehensive work sheets, mainly by blocking in the estimated percentages of the various mineral and textural types. In addition, much emphasis is placed on fossil types, as indicators of depositional environment. The various work sheets used, together with the code to symbols used, are attached (see Attachments 2, 3 a-b).

All the above results are transferred to detailed log sheets, and blocked in by technicians, according to the percentages. Practically no writing is shown on either the work sheets or the final logs. In this way it is hoped to make the data as non-subjective as possible - and more amenable to automatic data storage on tape or punched cards. A prpject along these lines is to be introduced in the near future.

All petrological studies are carried out in the Department of Stratigraphy within the C.R.P. The Chief of the Department is M. Colo, but queries could be directed to R. Blanc who supervises the petrology.

A.G.I.P. The approach to petrology adopted by A.G.I.P. is one of applying maximum effort to a particular area, or problem that is regarded as critical. A quite superficial treatment is given to "routine" studies.

In subsurface studies, all cores are thin-sectioned, but these petrological results are not plotted separately from the binocular studies. Copies of the log sheets used are attached (see Attachments). The procedures used are quite standard, except in two regards:-

> Great emphasis is placed on the Mineral Percentage Log which is generally used instead of a Interpretation Lithological Log, in correlation work. Samples are attached (see Attachments 4, 5 a-b).
>
> Great emphasis is placed on "key fossils" that can be used as environmental indicators (see legend of Attachment 5b).

I.F.P. The Institut Francais du Petrole, is placing increasing emphasis on detailed petrographic examinations in broad reservoir studies. This work is under the direction of Madame Fondeur, and can involve geological sections up to 250 metres thick. (These studies will only be undertaken on subsurface control, if the interval has been fully cored). The routine sample spacing is 3 per metre.

Any shale interbeds within the unit being studied are ignored as for as petrography is concerned - though they will obviously be considered in other aspects of the study. The I.F.P. maintain that the clay mineralogy within the shale bed, is very similar in both type and proportions, to the clay matrix of the adjacent sandstone and siltstone.

The following features are recorded and plotted for each sample :-

Permeability (core analyses)

Porosity (estimation, and core analysis)

Quartz and lithics

Feldspars

Miscellaneous minerals

Silica (secondary)

Kaolinite

Illite

Carbonate and sulphate

Granulometry and angularity

Mode

Maximum grainsize.

The clay mineralogy is controlled where needed by X-ray diffraction analysis; however Fondeur maintains that the clay forms are often sufficiently distinctive to make this control unnecessary.

In correlation studies, great importance is placed on the relative abundance of:-

Illite

Kaolinite

Secondary silica

Carbonates

Porosity

All the above percentages are based on careful point-counting using a Zeiss "Analyser of Particle Dimensions". Details of the method are given below:-

The Zeiss "Analyser of Particle Dimensions" is a very expensive highely sophisticated point-counting machine.

The method of counting is to fit a circle - that can be expanded or contracted by turning a knob - over the grain being studied, so that the diameter of the circle equals the dimension of the grain, at right angles to its longest side.

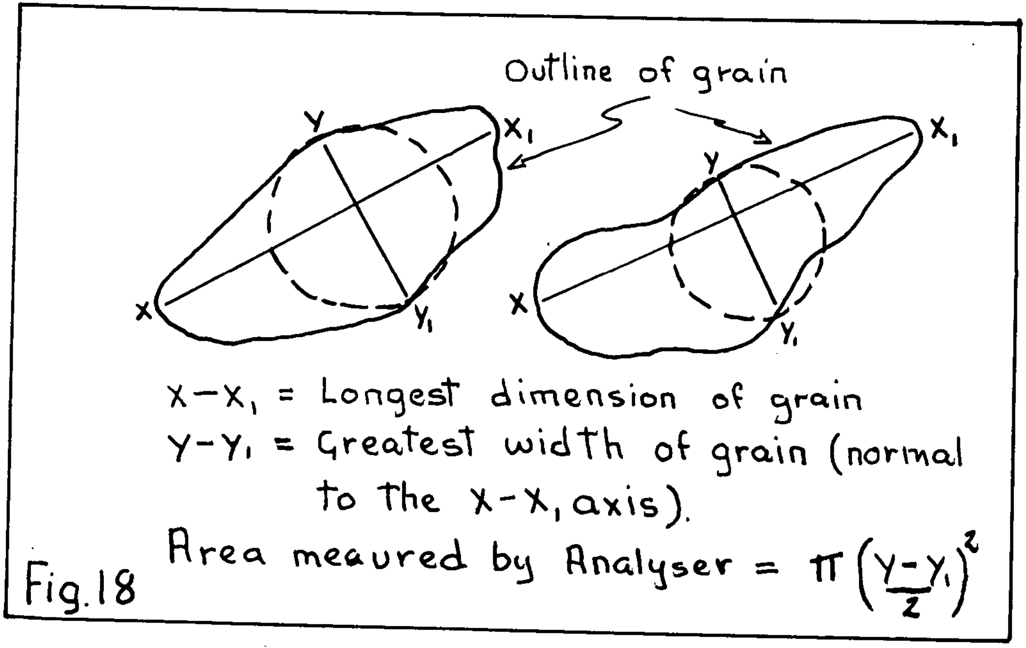

Figure 18. Method of "modal analysis" using the Zeiss Analyser of Particle Sizes (after Fondeur).

Normally 1,000 points are counted in each study; the machine can convert the granulometry or mineral estimation directly into a histogram or a cumulative curve.

University of Kiel. Staff at the Marine Research Institute at the University of Kiel, make considerable use of point counting of the more conventional variety. However they emphasized the need to watch the accuracy in this work - and suggested the use of a Reliability Chart as described by van der Plas and Tobi (1967).

University of Amsterdam. P.A. Riezebos of the Geograph Department of the University of Amsterdam, has made a special study of the 2-32 micron fraction of sediments, using phase contrast equipment. Being specially suited to the fine-silt size, this technique nicely complements the optical petrographic study of the coarser fraction, and X-ray diffraction of the clays.

The phase contrast equipment is fitted to a normal Lietz "Dialux - pol" or "Laborlux - pol" petrological microscope. A good monochromatic light source is important in order to get sufficient light through the system. Most phase contrast work is done with a X10 eyepiece and a X25 phase contrast objective. It is essential to use an immersion liquid, with a refractive index close to that of the mineral being examined. (A short cut is to examine the minerals in the coarse silt size - greater than 32 microns - with a normal petrological microscope; the mineralogy in this size range will often be very similar to that of the 2-32 micron range.) Theoretically the process of selecting the suitable immersion liquid must be repeated for each different mineral; but in most cases only 2 or 3 different immersion liquids will be needed to identify all the minerals present.

University of Leicester A new "Cambridge" Scanning Electron Microscope has been installed within the Geology Department of the University of Leicester - under the supervision of H. Sylvester-Bradley. This equipment is used primarily for the study of ostracods, but is so versatile that it could be used for a great many purposes requiring magnifications up to X40,000. The cost is approximately £17,000 Sterling.

Though the maximum magnification of this instrument is less than half that of the best electron microscopes, it has enormous advantages in requiring only very simple sample preparation, and in possessing far greater speed and versatility. No etching of the sample is necessary, and for powers of less than X20,000, the sample does not even require polishing. The machine is fitted with an oscillograph, enabling the operator to see the sample being examined at the same scale as the final photograph. In addition a "zoom lens system" is built into the equipment, enabling continuous magnification changes from X40 up to X50,000; only one control is involved, and the sample can be observed continuously through this process. The great advantage of this system is that the instrument can be quickly centred onto the portion to be studied at high power.

The output of the machine is equally versatile. A wide range of cameras can be fitted, ranging from 35 mm. up to 5" x 4" polaroid. The camera fitting is entirely external and interchanging cameras does not involve any dismantling of the equipment.

When I visited the University of Leicester in December 1967, the instrument had been running for several months continuously, without any difficulties. No "teething troubles" had been experienced. The instrument was arousing a great deal of interest amoung British scientists who required magnifications in excess of the resolving power of optical microscopes, but who only rarely required powers approaching X100,000. For these people, the "Cambridge" would prove ideal, because of its simple operation and high throughput; in most cases, a sample could be prepared and photographed in less than 30 minutes. An instrument of this sort would be of great value to the B.M.R. as it can cater for such a wide range of geological studies. At Leicester for example, revisions to the classification of Ostracoda are being made on the basis of differences of shell texture and ornament - visible with the optical microscope. Presumably many other micropalaeontological groups would be equally suited to this new approach. On the petrological side, the "Cambridge" Scanning Electron Microscope would enable rapid determinations of clay minerals and other matrix constituents.

HEAVY MINERAL ANALYSIS

Netherlands Geological Survey Within the Netherlands Geological Survey at Haarlem great emphasis is placed on heavy mineral studies in the correlation of Pleistocene sand and gravel deposits, both on-shore and off-shore. This work is under the supervision of S. Jelgersma.

Most of this material has been transported by either the Rhine or the Meuse Rivers and the heavy mineral assemblages in the two systems differ sufficiently to be diagnostic if the load has been deposited in a fluvial environment. If the sand has been transported into a marine environment, the heavy mineral assemblage is no longer sufficiently distinctive to be indicative of provenance

The heavy mineral concentration in the sands ranges from a few percent up to 15%. In each sample an average of 200 grains are counted; the vertical spacing between samples ranges from three to five metres. The various grains identified are listed below:-

Garnet - fresh

Garnet - altered

Epidote - fresh

Epidote - altered

Saussurite

Hornblende

Hornblende - volcanic

Chloritoid

Volcanic minerals - augite and titan-augite

Topaz

Other volcanic minerals

Staurolite

Other metamorphic minerals

Tourmaline

The results of these analyses are prepared so that the heavy minerals total 100%. This makes the presentation of their results simple and clear, but any significance in the varying proportions of total heavy mineral content is lost. Logs showing the method of compilation and presentation of the results are attached (see Attachment 6 a-c). The procedure for the separation of the heavy minerals is set out below:-

1. Between 100-200 gram of sample is selected - sufficient to provide a reasonable heavy mineral concentration from the 50 micron to 1 mm. fraction.

2. Samples are decanted to remove the fraction of less than 50 microns.

3. Samples are sieved to remove the fraction coarser than 1 mm.

4. Carbonate is removed from the remaining material by treatment with 25% hydrochloric acid.

5. Sample is heated to 90°C. in hydrochloric acid for 15 minutes.

6. Sample is treated with 50% nitric acid for 15 minutes, again at 80-90°C. (This will remove iron coatings).

7. Sample again thoroughly washed and dried.

8. Heavy minerals are separated using Bromoform (S.G. 2.86 - 2.87). A funnel fitted with a tap having a wide passage is used; the heavy minerals are collected in a small dish beneath.

9. A random selection of heavy mineral grains is spread over the slide, and coated with warm Canada Balsam. The grains are mixed into the balsam, using a needle. A coverslip is placed on top, and the permanent amount is then complete.

Institute of Geological Sciences. By contrast, in the I.G.S. Regional Laboratories at Leeds, heavy mineral separations are made with a specially modified shaking table, rather than with heavy liquids. Officers claim savings in both time and money with this method, and apparently obtain quite satisfactory separations.

FRAMEWORK ANALYSIS

A.G.I.P. Much importance is placed on framework analysis in A.G.I.P., and the main emphasis is on grain size distribution following the methods of Passega (1964). The work is being carried out by R. Passega and P. Bellotti, who use CM diagrams extensively for interpreting depositional environments. It is claimed by Passega (op. cit.) that the depositional environments can be determined in terms of C (one percentile in microns), and M (median in microns). The objective is a five-fold subdivision:-

Pelagic suspensions

Uniform suspensions

Graded suspensions - no rolling

Bottom suspensions - with rolling

Rolling

To date, attempts to correlate directly from C M patterns to the depth of sedimentation have failed. As a result of widespread criticism by other sedimentologists, Passega and Bellotti are now trying other values of C, higher than one percentile. If the sediments can be readily disaggregated, individual grain measurements are made; if the rocks are indurated, the measurements are made from thin-sections. No attempt has been made to utilize skewness, kurtosis or angularity in the paleogeological interpretation.

I.F.P. M. Pelet of the Institut Francais du Petrole is involved in studies of granulometry in an attempt to define and to correlate rock units. In this work "suspended material" only is used (less than 64 microns). Before analysing the grain sizes, any carbonate cement present is removed by dilute hydrochloric acid. The various size classes are referred to the "phi scale". (An example on the composite petrographic log is shown on Attachment No. 7).

It is claimed that by studying the histogram representing the suspended fraction of the sediments, very characteristic patterns for the stratigraphic units can be identified; this commonly holds, even when the gross lithologies of the units being compared are very similar.

In reservoir studies, the granulometry and angularity of the sand fraction of the sediments are determined, adopting a lower limit of approximately 60 microns. In studying the angularity of the grains, the following divisions are used:-

Well rounded	0.7 - 0.9	(shown on log as ".")
Intermediate	0.4 - 0.5	(shown on log as blank space)
Angular	0.1 - 0.3	(shown on log as "x")

PETROPHYSICAL ANALYSIS

All organizations made extensive use of petrophysical analysis in their central laboratories, for determination of porosity, permeability and density.

I.F.P. In the I.F.P. it has been found that the estimation of porosity by the point-counting method is reliable, except where illite is the common clay. In these cases, the estimation from the thin-section is always too low; for the thin-section estimation will be dependent on the degree of penetration of the dyed "Araldite".

S.N.P.A. Experiments are being carried out by M. Pochitaloff to test a Russian method developed by Sabirov and Petrik (1964) for the quantitative evaluation of porosity in the field; even drill cuttings can be used in this work. The method involves the use of an instrument called a "Picnometre".

Kerosine is the impregnating medium used. An ideal sample consists of cuttings, weighing 2-3 grams, and averaging 5-6 mm across. It is claimed that the following porosity classes can be accurately determined:-

1 - 5%
5 - 10%
10 - 20%
20 - 30%

A skilled technician is needed in this work. Although admittedly still in the experimental stage, it seems to me unlikely that the method could be simplified sufficiently to made it a satisfactory routine field technique.

A.G.I.P. place much importance on petrophysical analyses, in their special projects; when analysing drill core, readings are taken every 20 centimetres, and the results are shown graphically on the detailed lithological log of that core - at a scale of 1:100. (An example is given in Attachment No. 5a).

The practice of estimating the porosity of drill core and drill cuttings after binocular microscope study, is not encouraged. A.G.I.P. are at present experimenting with the use of coloured dyes for porosity estimations in drill cuttings.

MEASUREMENT OF SALT CONCENTRATION

A.G.I.P. S. Neglia strongly advocates the measurement of the salt concentration in shales, as an indicator of "fractionation of the shale fluid". This he relates to the likelihood of hydrocarbons being trapped behind a shale "semi-permeable membrane". He claims that the technique is much more reliable and capable of a much wider application than is possible with the analysis of water from drill stem tests, because the shale anaylses can be carried out on cores years after drilling, with complete safety. The procedure used is as follows:-

1. A core plug is cut, and total void space (Vs) is calculated from petrophysical analysis.
2. The voids occupied by intracrystalline water (V2) are not available and therefore of no significance in transmitting other water; the following relationship holds:- voids with inter crystalline water (V1) equals total void volume (Vs) less the voids of intracrystalline water (V2).

$$V1 = Vs - V2$$

3. The volume of intracrystalline voids (2) is calculated from the surface area of the clay, after crushing and x-ray diffraction analysis; voids of intracrystalline type equal surface area by 3 Angstrom.

$$V2 = \text{Surface are X } 3\text{Å}$$

4. The amount of salts present can be determined directly by X-ray fluorescence, and thus the salinity of the present intercrystalline water can be calculated.

LACQUER PEELS

Netherlands Geological Survey. Partly because of the great interest in detailed sedimentary structures within the Netherlands, and because of the lack of outcrops of well consolidated sediments, the Netherlands Geological Survey has made a great deal of use of very large lacquer peels - up to 2 metres by 1 metre. By using these peels, permanent records of sedimentary features have been obtained from "temporary outcrops" such as tunnels and quarries. The procedure adopted is quite simple, and the results can be most spectacular - as well as forming an invaluable aid in teaching. The technique is set out below:-

1. The outcrop must have a suitable surface - poorly consolidated, with appreciable porosity and low cohesion.
2. Cut the outcrop back to make a smooth inclined face.
3. Cut a horizontal channel immediately above the inclined face.
4. Apply the thinned lacquer flow evenly over the inclined face. It is all important for the lacquer to flow as a sheet, so that the depth of penetration is approximately constant throughout. Spreading of the lacquer by brush is of little help.
5. After the lacquer has soaked in and dried, a second thin coating can be brushed over the surface; a hessian strip should then be spread over the lacquered surface.
6. The hessian strip is allowed to dry in place and is then peeled off with the lacquer-impregnated sand.
7. The hessian is then fixed to a masonite sheet which in turn, is fitted with a raised wooden surround to protect the surface. Mounted peels can be stacked one on top of the other.

STAINING FOR CARBONATES

Oxford University. B.W. Sellwood of Oxford, showed an exhibit of carbonate peels at the Fourth Meeting of Carbonate Sedimentologists. The examples were superb, and a summary of the method used is set out below:-

Etching The most critical factor in the staining of carbonate peels is the quality of the etching - excessive etching being especially damaging. Sellwood suggests a 1:9 dilution of hydrochloric acid, and a maximum etching period of 15 seconds.

Staining with Alizarin Red S The staining solution should be 1 gram of Alizarin Red S dissolved in 2 ml. of distilled water. The steps are set out below:-

1. Slab is immersed in the solution, with polished side upwards, for 4 minutes.
2. Slab is immersed in distilled water for a few seconds.
3. Slab is immersed in acetone for 2-3 seconds, and an acetate film is applied.

Staining with Ferricyanide The solution is made up of 5 gm. of ferricyanide and 2 ml. of concentrated hydrochloric aicd, diluted in 1 litre of distilled water. The slab is stained as above (in steps 1-3), and the film is applied in the same way.

Combined Alizarin Red S and Ferricyanide Staining The solution is made up of 1 gm. Alizarin Red S, 5 gm. ferricyanide, 2 ml. conc. hydrochloric acid made up to 1 litre with distilled water. The steps are as follows:-

1. Stain is applied as above (in steps 1-3). The sample can be a thin section or hand specimen, instead of a peel.
2. The response of the various minerals is listed below:

Calcite (non-ferroan) - pink
Ferroan calcite - green-blue
Siderite)
Pyrite) - no colour change
Dolomite)

CALCIMETRY

S.N.P.A. Calcimetry is regarded as a field technique, and is carried out on all cuttings samples, at the well site. The times of reaction used are very small - 30 seconds for calcite and 5 minutes for dolomite.

A.G.I.P. Calcimetry is used extensively in the special studies, but not in the routine logging. The five-sample "Scheibler Calcimeter" (Carlo Erba Supplies, Italy) is used; the following, rather unusual procedure is adopted:-

1. The sample is crushed in a pestle and mortar, and 30 mg. is used for the analysis.
2. The sample is shaken vigorously with 10 ml. of 12% HCL diluted 3.3:1). The acid is never warmed.
3. The calcite reading is taken after 30 seconds, and the dolomite after 30 minutes. (A.G.I.P. claim that siderite will not interfere with the dolomite reaction).
4. Calculations of the proportions of calcite and dolomite are made directly from a chart; no correction is made for differences of atmospheric pressure.

A.G.I.P. regularly check the identification of the carbonate detected by calcimetry, with X-ray diffraction.

RADIOACTIVE AGE DETERMINATION OF SEDIMENTS

S.N.P.A. G. Kaplan working in the C.R.P. Laboratories at Pau has made extensive use of rubidium - strontium, and potassium - argon methods for obtaining radioactive ages of authigenic clays in shales. Kaplan stressed the importance of using only reliable meterial in this type of work. He will not handle any samples showing marked alteration, or where there is a lack of supporting geological information.

Kaplan maintains that it is impossible to state dogmatically, before a run, that a particular sample will show a depositional, diagenetic, or a metamorphic, age but he maintained that, with careful selection of samples, reliable ages can be obtained. He has obtained satisfactory results with sediments up to 1,000 million years old.

X-RAY DIFFRACTION

This technique - referred to subsequently as "X.R.D." - is certainly the most useful supplement to optical mineralogy, and in matrix studies it is the most effective tool. There are major drawbacks to its under-application, however:-

1. If more than two or three minerals are present in the sample, interpretation of the peaks becomes very complicated in the absence of petrological control.

2. In view of the above, it is obvious that an indurated rock - not readily disaggregated - will be very difficult to treat and to interpret.

3. Because of the preferred orientations that some minerals adopt very readily, it is very difficult to make X.R.D. truly quantitative or in many cases, even semi-quantitative. X.R.D. studies naturally fall into three categories:-

: whole rock mineralogy

: mineral identification

: clay analysis

Whole Rock Mineralogy

S.N.P.A. All X.R.D. work at the C.R.P. Laboratories is carried out within the Division of Sedimentology and Geochemistry, headed by G. Kulbicki. The work is directed by J. Stevaux.

As a routine measure in wells studies, composite samples of drill cuttings, totalling about 0.5 kilograms, are collected from each 20 metres drilled: these are "split" to the required sample size, and analysed by X.R.D. (This work is in addition to the X.R.D. carried out on the particular cuttings samples selected for detailed petrological study.) In these composite samples, no "picking" of the cuttings is attempted. Drill cores are all studies by X.R.D. on a routine basis, using a maximum spacing of one metre - and much closer spacings if the lithologies are variable.

The X-ray diffraction analysis of a crushed sample of the whole rock, is the first step in all detailed sub-surface petrological studies, and in many studies of surface sections also. Stevaux claims that a fully quantitative result for quartz, calcite, dolomite and siderite can be obtained, by use of a quite routine procedure. The equipment is geared to analyse, automatically, the smear of the crushed rock mounted on a glass slide; this work is carried out at a high sensitivity and if the peaks go off scale the sample will be re-run at a lower sensitivity. Stevaux maintains that the X.R.D. analysis of the essential mineral of a sediment will provide mineral percentages accurate to within 5% of the actual values.

If difficulty is experienced in identifying the carbonate present, a micro-sample is analysed by differential thermal analysis. This is carried out under either normal atmospheric conditions, or in a dynamic inert gas atmosphere - depending on the nature of the problem. Stevaux regards the D.T.A. results as qualitative only.

All the steps in the X.R.D. analysis of major components are carried out by technicians; the results are also plotted by technicians, by blocking in the percentages on work sheets (see Attachment 3ab). These are then passed back to the petrographer, for interpretation and integration.

I.F.P. The X-ray diffraction studies within the Institut Francais du Petrole are directed by M. Pelet. The complete study of a sample consists of three types of analyses:-

1. Powder analysis of the untreated sample
2. Powder analysis of the cement-free sample (after treatment with dilute hydrochloric acid).
3. Oriented powder analysis of clay matrix.

The cement-free X.R.D. analysis is designed to provide semiquantitative data on quartz (± 10%), and qualitative estimates of other minerals present. A comparative study of the untreated X.R.D. trace and the cement-free X.R.D. trace will show the material that has been dissolved out by the acid; the accuracy of this carbonate analysis will differ from sample to sample, but in general it could be regarded as semi-quantitative.

University of Leiden. P.C. Nagtergal has found that the 2-50 micron fraction of an arenite gives a very representative picture of the rock constituate as a whole. He did not regard the masking effects of quartz and feldspar as a problem - though most other workers would not have agreed.

Mineral Identification

A.G.I.P. The Confirmation by X.R.D. of minerals observed in a thin section can be very difficuly - especially if the mineral is not common. A.G.I.P. have developed a novel method of overcoming this problem. The cover slip of the thin section is removed and an acetate peel of the thin section is taken. This peel is then used for the X.R.D. analysis. (G.L. Morelli of A.G.I.P. could supply additional technical data.)

S.N.P.A. The analysis of feldspars by X.R.D., is supervised by J. Stevaux, and the results are regarded by S.N.P.A. as semi-quantitative only; it is carried out as a routine measure in association with whole rock X.R.D. analysis. Cuttings at 20 metre spacings, cores at one metre spacings, and many outcrop samples are all analysed for feldspar content. The results are considered by S.N.P.A. to be of major importance, and are plotted on the well log in a separate section - as shown on Attachment 3c.

Clay Analysis

Unquestionably the analysis of clay is one of the principal uses of X-ray diffraction in sedimentology. In the oil industry, the types and the ratios of the clay groups present in a sediment are the principal objectives; much attention has been given to the problem of achieving a high accuracy in the work while maintaining a high flow-through of samples.

S.N.P.A. The clay analysis work within the C.R.P. Laboratories is supervised by J. Stevaux; a standard technique is applied, on a routine basis, to all the 20 metre composite cuttings samples collected; all other cuttings samples that are studies in detail, all core samples, and a great number of outcrop samples, are also treated on this basis.

The technique is semi-quantitative, and fully automatic; the sample preparation is quite straightforward. After the rock sample is given a rough crushing in a mill, it is placed in a polythene tube and shaken vigorously in water. After allowing a few minutes for settling, the suspension - mostly less than 5 microns in size - is pipetted off; a smear of this suspension is prepared on a glass slide. The remaining suspension is stored for several months before being discarded - to provide additional material in case of queries.

With this very simplified preparation, it is obvious that in many cases precise identification of the clays will be difficult, if not impossible. The analysis is run at a high sensitivity, and if peaks go off-scale or are not clear the following steps are taken:-

1. The sample is re-run by X.R.D., at a lower sensitivity;

2. If the clay group still cannot be recognised, a micro-sample is analysed by D.T.A. (This will give a qualitative result only).

3. If the precise clay mineral is required, rather than simply the clay group, a new sample is prepared by a much more thorough and more time consuming procedure.

4. In the special case where the sample can be recognised as chloritic but the precise mineral cannot be determined, another smear is produced on a platinum plate; this is again run by X.R.D., but at controlled temperature. In this way the temperature at which the peak disappears can be found: this temperature records the dissolution of the chlorite, and is unique for the mineral species. S.N.P.A. attempt to distinguish 12 species of chlorite.

The same technique is also used to recognise talc, antigorite, vermiculite and mixed-layer clays. Thus it is of value in indicating the degree of metamorphism that has affected the sediments.

All the analytical work and much of the interpretation of it is carried out by technicians; only in special studies is the geochemist called upon to assist. The technicians plot the results on work sheets which are then forwarded to the geologist concerned; the X.R.D. traces are stored for future reference.

The very considerable investment on clay analysis equipment that S.N.P.A. has made, is applied to oil exploration in three ways:-

Identification of marker horizons It is found that some authigenic clay minerals made excellent marker horizons, even when they constitute as little as 10% of the actual content of the marker.

Indicator of depositional environment S.N.P.A. are placing increasing reliance on authigenic clay minerals in determining depositional environments. There is an obvious difficulty in distinguishing the detrital and authigenic clays, but S.N.P.A. claim that is is not a major problem in most cases. However, if authigenesis is too far advanced, the clay results are of little use in establishing depositional environment.

Basin-wide correlations The technique generally applied when attempting broad correlations, is to relate the abundances of the different clay groups throughout the basin. However, on this point Stev[illegible]aus stressed that is was essential to have extensive clay determinations from outcrop samples to supplement the subsurface information, before any correlations are attempted.

I.F.P. The oriented powder analysis of clay matrix used within the I.F.P., follows the standard procedure developed by S.N.P.A. It involves the separation of the fine fraction (less than 5 microns) but unlike S.N.P.A., the I.F.P. do not claim any more than qualitative status for this work.

University of Kiel Lange, working within the Marine Research Laboratory has carried out many X-ray diffraction studies of the 2-6 micron fraction of bottom sediments from the Persian Gulf. One common problem encountered is the overlap of diffraction lines when the sample contains a mixture of calcite, quartz, aragonite and dolomite. As an example, only if quartz makes up more than 10% of the whole can it's proportion be determined directly - by using a minor line; if quartz makes up less than 10% the whole, one must use it's strongest line and this overlaps with a strong illite line. This difficulty can only be resolved by carefully re-running the sample at a slow speed and a high sensitivity.

Lange feels that the accuracy of clay analyses determined by X.R.D. can be of the order of ± 5%, if the work is carefully controlled; accuracy is increased if samples are of roughly similar character.

University of Leiden The personnel at Leiden, had little faith in X-ray diffraction to produce reliable quantitative data; this applied to both powder camera and diffractometer results.

X-ray diffraction studies of arenites at Leiden, are almost entirely concerned with identification of matrix. Where the rock is only poorly consolidated, mechanical disaggregation is quite simple, and the analysis can proceed in the normal manner. If on the other hand the rock is well consolidated, much of the framework may be broken down in efforts to release the matrix. In these cases contamination of the matrix will be extensive, and the x-ray diffraction pattern will almost inveriably be very confused. Even greater problems are posed if the framework contains significant quantities of lithics.

University of Reading A. Parker working within the Sedimentology Research Laboratory claims that semi-quantitative clay analyses can be obtained by X.R.D. under favourable conditions; but that in some cases the answers will be v~~a~~ery wide of the mark.

The chief difficulty with quantitative work is to obtain a true randomly-oriented clay sample. Parker maintains that rapid settling of the clay suspension on a porcelain tile, under vacuum conditions, most nearly achieves this end.

Clay Sample Preparation

S.N.P.A. As noted earlier, for routine "clay group" analysis a glass slide preparation is made, after the crushed rock has been shaken vigorously in water and allowed to settle for a few minutes. Only quite rough results could be expected from such a method - though S.N.P.A. claim that the data are semi-quantitative. The following is the procedure used at S.N.P.A., if the precise clay mineral species is required:-

1. The rock sample is given a coarse crushing, to assist disaggregation
2. Splits are separated from this sample
3. One split of the above sample is used for the X.R.D. determination of the major mineral components of the rock. This analysis will be run first, and will be used as a guide to the preparation needed with the second split - ~~which will be used in the X.R.D. analysis of the second split~~ - which will be used in the X R.D. analysis of the clay.

The steps involved in the X R.D. analysis of the second split are set out below:-

1. Samples are shaken mechanically in a bath of water for differing times depending on the nature of the material:-

   limestone - 4 to 5 hours
   sandstone - $\frac{1}{4}$ to 2 hours
   shale - 1 hour
   indurated shale - 12 hours

2. If the previous X R.D. analysis (of the major mineral constituents) shows the presence of a significant amount of carbonate, a drip of carbonate, a drip of cold or warm dilute hydrochloric acid (0.1 Normal) is added to the shaking unit.

3. The coarse fraction is separated out; the suspension is shaken again and allowed to settle for a given time.

4. The fraction less than 5 microns, is collected from the suspension - the centrifuge being used to speed up the settling process.

5. A glass slide, covered with a dried smear of the suspension, is then prepared; the sample is then ready for X-ray diffraction analysis.

Essentially the same procedure is followed by A.G.I.P., and I.F.P., and the Universities of Leiden, Kiel and Reading. However at A.G.I.P., and at Reading, special care is taken to keep the chemical treatment of the clay to an absolute minimum. While admitting that additives are sometimes required to prevent flocculation of the clay. A. Parker of Reading has found that centrifuging followed by thorough washing (repeated several times if necessary) will generally achieve the same result but without any possible damage to the clay minerals. Excessive chemical treatment can markedly alter the structure of the clay and lead to the complete absence of some lines.

It is for this reason that I would recommend the Reading technique if accurate clay analysis is the goal - though it will inevitably cut down the flow through of samples. Details of the procedure as developed by Parker are set out below:-

<u>Sample Preparation - General</u>

1. Crush about 20 gm. of rock sample down to about pea size - to provide sufficient surface area for the ultra-sonic separator. Gentle hammering of easily disaggragated samples or minimal grinding in an agate pestle and mortar is recommended.

2. The broken up sample is placed in a 100 ml. beaker, and is covered by distilled water. The beaker is immersed in an ultra-sonic bath, until the water level outside matches the level of water in the beaker. Disaggregation should take about 3 hours - but should be continued until a "soupy" suspension is obtained.

3. After disaggregation, the suspension is transferred into a 100 ml. measuring cylinder; if necessary this can be topped up with distilled water, until the cylinder is full.

4. Using a mechanical stirrer, vigorously agitate the suspension for 10 minutes, after which the cylinder must be left undisturbed; Stoke's Law will govern the settling rates.

5. After 3 hours 50 minutes, a quantity of the suspension (about 5 - 8 ml.) should be pipetted off, from a depth of 5 cm. below the fluid surface. (A pipette with a 5 cm. mark on it simplifies this). The maximum grain size of the pipetted suspension should be 2 micron. The settling time of 3 hours 50 minutes applies at a temperature of 20° C. and will vary (according to Stoke's Law) with changes in pressure or temperature.

6. If after settling has continued for about 1 hour, it is apparent that flocculation has occured (total settling of the suspension), the following steps should be immediately taken:-

   (a) Add 2 drops of strong ammonia (0.880 NH_4OH), stir again as in 4) and allow to settle for 3 hours 50 minutes, as in 5).

   (b) If the procedure set out in above fails to prevent flocculation after another hour, suck off the clear liquid and discard - taking care not to disturb the surface of the flocculated sediment. Top up the measuring cylinder with distilled water, stir again as in 4) and allow to settle for 3 hours and 50 minutes as in 5).

   (c) If flocculation still persists after another hour, shake up the suspension and pour the whole into a large centrifuge tube. After balancing the centrifuge to within.5 gm., centrifuge at 1500 r.p.m. for 2 minutes. Pour off the clear liquid from the cake of sediment, and replace with distilled water. Shake sediment into suspension, and transfer to measuring cylinder, proceed with mechanical stirring as in 4), and settling as in 5).

   (d) If steps (a) to (c) still fail to stop flocculation, repeat step (c) several times. As a last resort, a few drops of calgon (sodium hexa-meta phosphate) can be added to assist the peptising.

7. After thoroughly shaking the vial containing the 5-8 ml. of suspended sediment (to ensure complete suspension), a few ml. sre pipetted off and transfered to a clean dry 1½" x 1" glass slide. The clay suspension spreads evenly over the surface and is allowed to dry on the slide, undisturbed.

8. If the resultant coating of clay is too thin, a second layer of suspension can be spread over the top - taking care to leave the first layer undisturbed. This second layer should also be left to dry, undisturbed.

9. The smear is then ready for running on the X-ray diffractometer. The slow evaporation of the water from the suspension should ensure a high degree of parallelism of the various clay flakes. Clear basal reflections should be recorded by the diffractometer.

10. If a fast result is essential, the evaporation can be speeded, by using infra-red drying lamps; however the final surface of clay is generally less regular than with slow evaporation, and therefore the parallel orientation of the particles is less consistent. This will result in some masking of basal reflections in the diffractometer, and should be avoided if possible.

Sample Preparation - Quantitative Analysis

When an accurate assessment of mineral proportions in the fraction less than 2 microns is required, it is essential that one obtains a true random-oriented clay assemblage on the glass smear. To achieve this, it is necessary to greatly accelerate the evaporation of the suspension water, and thus avoid preferred orientation of flakes during settling. At the same time, one must avoid the irregularities that develop with infra-red drying. A semi-permeable porcelain tile is used, and fast drying is achieved under vacuum. The steps are as follows:-

1. Prepare an unglazed porcelain tile 1½" x 1", and approximately ⅛" thick. Both sides should be parallel and the one surface carefully smoothed on glass plate with fine grinding powder (carborundum Grade 600).

2. The tile should have its basal surface marked; the tile should then be washed in distilled water and left to dry.

3. The tile should be placed, smooth surface uppermost, on top of vacuum system - such as a venturi operating off the water supply. When the vacuum is operating, several coverings of distilled water should be squirted onto the top of the tile and duly sucked through the base - to ensure thorough washing of the tile.

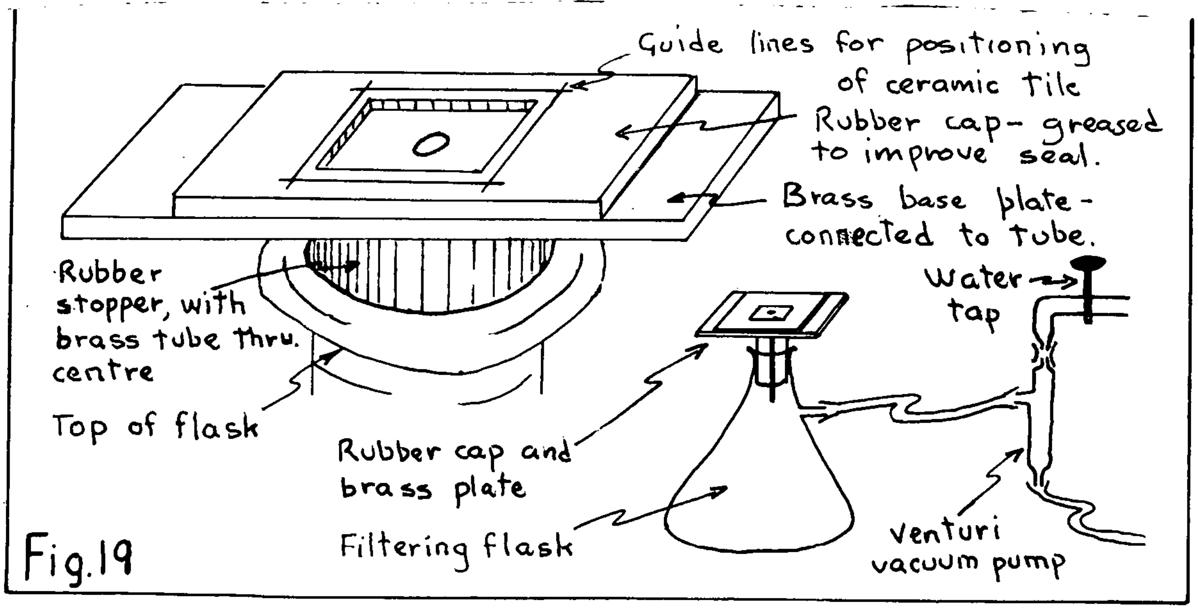

Fig.19

Figur

r).

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1. Prepare an unglazed porcelain tile $1\frac{1}{2}$" x 1", and approximately $\frac{1}{8}$" thick. Both sides should be parallel and the one surface carefully smoothed on glass plate with fine grinding powder (carborundum Grade 600).

2. The tile should have its basal surface marked; the tile should then be washed in distilled water and left to dry.

3. The tile should be placed, smooth surface uppermost, on top of vacuum system - such as a venturi operating off the water supply. When the vacuum is operating, several coverings of distilled water should be squirted onto the top of the tile and duly sucked through the base - to ensure thorough washing of the tile.

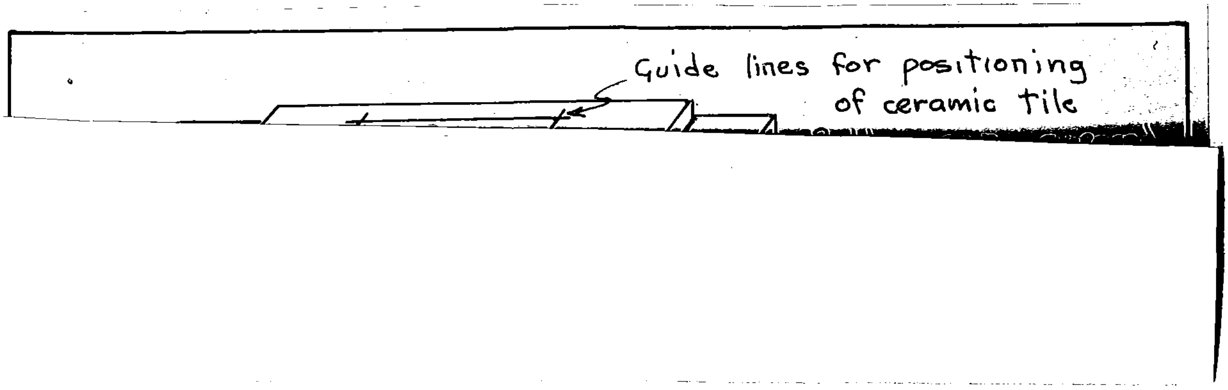

Figure 19. Vacuum fitting for preparing clay sample on ceramic tile (after Parker).

4. The clay-size suspension collected in steps 1 - 6 of the "Sample Preparation - General" is pipetted onto the tile as an even sheet. Ensure the assembly is true so that the tile is horizontal and therefore the coating of suspension as even as possible. If necessary two or three coatings of suspension can be applied.

University of Amsterdam Very intensive x-ray diffraction studies are carried out within the Geography Department of the University of Amsterdam, as part of their studies of soil development. The work is directed by P. Bakker. The following rather unusual sample preparation is adopted:-

1. The sample is dried at 60-65° centigrade for 3½ hours.
2. One portion of the sample is mechanically ground in an agate or steel mill, to approximately 4 microns size. (This will be used for whole-rock analysis).
3. The second portion of the dried sample, is crushed gently - to produce about 20 gram of sample less than 2 mm. size. This 20 gram of broken up material is placed in a beaker with hydrogen peroxide, and the beaker itself is placed in a water bath for one day; the hydrogen peroxide is topped up as required.
4. 25 mls. of hydrochloric acid (2 Normal) is added to the residue in the beaker, and left to stand at room temperature for three hours; this will dissolve any carbonate present. Keep topping up with acid until the reaction has ceased, then allow the pH to rise to at least 5.
5. In almost all cases, the clay material will have flocculated by this stage. Carefully pour off the clear liquid and wash the residue; repeat this washing several times.
6. Add a small quantity of sodium pyrophosphate, and shake for 2 minutes.
7. Add soda and shake, to peptize the clay.
8. Let suspension stand for 30 seconds to allow the sand to settle out.
9. The suspended fraction is left standing for 24 hours, after which the liquid plus suspension is drawn off; this same procedure is repeated over the next three days, after which, the claysize material only is available in the suspension.
10. The suspended clay material is flocculated with 50 mls. of magnesium acetate (2 Normal) and with 25 mls. of hydrochloric acid (2 Normal).
11. The flocculated clay is then washed with alcohol and filtered.
12. The filtrate is now ready to apply to the X-ray plate.

X-ray Diffraction Equipment

A.G.I.P., S.N.P.A., I.F.P. and the University of Reading all use diffractometers almost exclusively for X-ray diffraction, regarding the powder camera as too slow and inaccurate. Nevertheless at the university centres of Amsterdam, Leiden and Kiel the staff made considerable use of the powder camera.

S.N.P.A. The most interesting and most complex diffractometer set up was at S.N.P.A., where two units are operating virtually around the clock. The glass smears are fed into the units automatically and no corrections to the sensitivity are made during runs. The initial run is made with high sensitivity and in the event of peaks going off-sclae, the sample is later re-run at a lower sensitivity level.

University of Amsterdam The X-ray equipment is the "Enraf" camera made by Delft - Holland. Two powder cameras are fitted to operate simultaneously; each can handle a plate containing up to four different smears. Thus in a full run of six hours, eight samples can be treated; and as at least two runs are completed each day, the minimum flow through for the machine is 16 samples per day. This makes the flow through for the combined powder cameras rather greater than could be achieved than by a single diffractometer - which of course costs a great deal more to purchase, and to operate. A special fitting is used to enable single samples to be re-run at temperatures up to 1,000°C.

AUTOMATIC OPTICAL SPECTROGRAPH

S.N.P.A. make extensive use of the automatic optical spectrograph in trace element analysis, and in determining the nature of carbonaceous matter; these analyses are restricted almost entirely to source rock studies and are discussed in more detail under "CRITERIA FOR RECOGNIZING DEPOSITIONAL ENVIRONMENTS".

The spectrograph is programmed to analyse samples for any 12 of a total of 18 elements - all of which have been selected because they are influenced to some extent by the depositional environment:-

B	Va	Mb	Pb	Zn	Cu	Cr	Ni	Co
Ba	Ga	Si	Al	Ca	Mg	Mn	Ti	Sr

DIFFERENTIAL THERMAL ANALYSIS (D.T.A.)

S.N.P.A., and the Universities of Amsterdam and Kiel use D.T.A. in sedimentological studies; it is regarded as a moderately successful technique to provide qualitative confirmation of x-ray diffraction results. Multiple-sample D.T.A. runs were not popular because of the considerable technical difficulties experienced in ensuring an even and a standard heat input.

S.N.P.A. A single-sample D.T.A. unit, is operated within the geochemical section of S.N.P.A., by J. Esquevin. It has two major uses:-

> To identify minerals - especially clays and carbonates - where the X R.D. pattern is complex; thus it is a support technique to X-ray diffraction.
>
> To identify different types of carbonaceous matter - of value in source rock studies.

The D.T.A. unit consists of a "B.D.L.T. Primary Unit" - made under license from Centre Nationale de Researche Scientifique. It is fitted with a "Graphispot and Suiveur" recorder. Only micro-samples are analysed - without any dilution. Platinel cups and thermo-couples are used throughout, with a standard heating rate of 10° C. per minute. Samples can be analysed in air or an inert gas - using a dynamic atmosphere if required. A cooling curve can also be run. The recorder is designed so that it can easily be switched over to the X-ray diffractometer, when that unit is recording peak changes at pre-set temperatures (between 20° C. and 1200° C.).

University of Amsterdam The Geography Department of the University of Amsterdam makes regular use of differential thermal analysis and thermobalance results in studying soil profiles. The work is directed by P. Bakker, and the chief operator is J.J. Wensenk. It has been found that D,T,A. clay analysis is most effective with the kaolin group. This work can be semi-quantitative, providing no other group of clay minerals is present; but where other clay groups are present, qualitative results are the best that can be obtained.

The D.T.A. equipment used is a "Linseis" made in West Germany. It can be operated as either a single channel or a three channel unit; in the latter case, great care must be taken to centre the thermo-couples in the furnace. All thermo-couples are of platinum and platinum/rhodium. The thermo-cups are of a platinum, which is found to be sufficiently sensitive for soil studies. The therme-cup recommended is a tube (no base), so that if partial melting occurs the cup can still be lifted away. All samples run are first reduced to less than 1 micron size, and are placed in a dessicater for 48 hours before analysis; potassium carbonate is the drying agent used.

University of Kiel Lange of the University of Kiel has used D.T.A. in studying the bottom sediments of the Persian Gulf obtained by the "Meteor". He stressed that great care must be taken in [illegible] setting up D.T.A. equipment to minimise random peaks - which can in some cases be as large as the peaks one is trying to measure. Another major problem is centering the sample block. When dealing with a mixed sample of four or five components, some of the components will certainly make up less than ten percent of the whole. In cases such as this, Lange considers it vital to centre the D.T.A. sample block within the furnace to an accuracy of less than .1 mm., to ensure an even heat distribution. Lange's D.T.A. equipment consisted of two channels; he used two inert and two unkown samples each run.

MISCELLANEOUS

ZONAL DIVISIONS OF THE CARBONIFEROUS

In an address to the 6th International Congress of Carboniferous Stratigraphy and Geology at Sheffield in September 1967, Professor T.N. George outlined the progress made by the International Committee on Carboniferous Stratigraphic Nomenclature - which met in Sheffield just prior to the Congress.

The main problem dealt with by the Committee, concerned the integration of the old divisions of the Carboniferous - based almost entirely upon goniatites - with the rapidly expanding micro-fossil data - especially foraminifera, spores and in some cases conodonts. The detailed results of the Nomenclature Committee are set out below:-

Stefanian - Westphalian Boundary In the type area this boundary is lithological - the base of a conglomerate - and in no way faunal. Recent micro-fossil studies show that the fauna beneath the conglomerate (Holts Conglomerate) has much more in common with the overlying Stefanian fauna than the Westphalian. A French suggestion that the base of the Stefanian be lowered to a more reasonable level at a tonstein was adopted. Unfortunately this new boundary is still a lithological break but it fits the fauna much more closely - and is most unlikely to be diachronic.

Thus the old Westphalian D has been elevated into the lowermost Stefanian A. However the Committee deferred decisions on changes of nomenclature.

Westphalian Recent work has shown that some of the traditional subdivisions of the Westphalian are not very useful; for instance the top of Westphalian B. and the bottom of Westphalian C have much in common. The Committee agreed to the French suggestion to raise the base of Westphalian C, and to expand the upper most part of Westphalian B so that the boundary would coincide with another tonstein. Again the problems of nomenclature were not resolved.

Namurian The Committee agreed that the European sections used to define this stage were most unsuitable. It was agreed that the English and Irish sections be used instead, but that the name Namurian should be retained.

Tournasian It was accepted by the Committee that the base of the Tournasian posed a major problem; at present this is partly Carboniferous, and partly Devonian. Here the problem of reconciling the goniatite and micro-fossil data is most acute. The Committee was unable to make any recommendation at this time, and thus the base of the Carboniferous remains inadequately defined.

UNDERGROUND WATER RESERVOIR STUDIES

The I.F.P. is hoping to develop a new type of Overseas Mission, in the field of hydrology. With the incorporation of Fran-Corelab within the I.F.P. structure, a great deal of reservoir evaluation equipment is now available, and is rapidly being converted for this project. M. Raguenet of the I.F.P. is responsible for the project, and is working in collaboration with M. la Garde. Three types of laboratory models are being developed, to correspond as far as possible with the field situation:-

Simulation Model. This consists of an electronically controlled bank of resistors, that can provide a maximum of 150 centres for the input of information. On this model conditions can be altered very quickly, to simulate seasonal changes and variations in withdrawal etc.

Mathematical Model. This consists of a computer programme, using the data developed on the Simulation Model. It is not nearly as easily changed as the Simulation Model, but can produce much more precise results.

Scale Model. This can take a variety of forms, and be either a two or a three dimensional model; the length can also be varied, up to a maximum of three metres. The permeability is obtained by using glass beads of varying sizes. The main function of this model, is to test in as practical a manner as possible, the results of the two theoretical models.

Hydrological studies of this type would be of immense value in the artesian basins of Australia, especially in the cases where there are a very large number of control points, scattered through the basin. It could be the means of improving the present "rule of thumb" methods of calculating withdrawal and recharge rates.

NOTES ON SOME GEOLOGICAL INSTITUTES

A.G.I.P. Direzione Mineraria

A.G.I.P. Direzione Mineraria, with headquarters in Milan, is the State owned petroleum exploration, refining and marketing company of Italy. A.C.I.P. at present handles approximately 30% of all hydrocarbon sales in Italy: this figure includes virtually all the crude oil produced in Italy, at present amounting to about 3 million tons per year. A.G.I.P. supplements the local production with about 150 million tons of crude oil each year, from North and West Africa, the Middle East, and Russia. Most of the local production of oil is from Sicily, and the natural gas comes entirely from the Po Valley in north-east Italy. At the present time A.G.I.P. is concentrating its exploration effort on the northern part of the Adriatic Sea.

Overriding policy - especially financial policy - is vested in Ente Nazionale Idrocarburi (E.N.I.). This body is also a co-ordinating authority for the following interests:-

A.G.I.P.	(petroleum exploration, development, refining, marketing)
S.N.A.M.	(construction and operation of pipelines and tankers)
A.N.I.C.	(operation of refineries and petrochemical plants)

My visit to A.G.I.P. Direzione Mineraria was tremendously rewarding: the management is clearly anxious to attract visiting scientists from Australia and there is certainly a great deal to interest us in their extensive laboratories at Milan. The Chief of the Exploration Division, Dr. Rocco, and the Supervisor of the Geochemistry Laboratory, Dr. S. Neglia, proved to be most helpful.

Societe Nationale des Petroles d'Aquitaine

The S.N.P.A. is one of a number of exploration companies based in France, in which the French Government has a controlling interest. It comes within the category of a "mixed economy company" - in which both private and State capital are invested. The headquarters and laboratories of the company are at Pau in south-west France.

The Division of Exploration is headed by H. Radier; the functional groupings of the Division are set out below. One unit of the Division is the C.R.P., and this comprises all the research and laboratory groups; the detailed break down of this unit is shown in Figure 20.

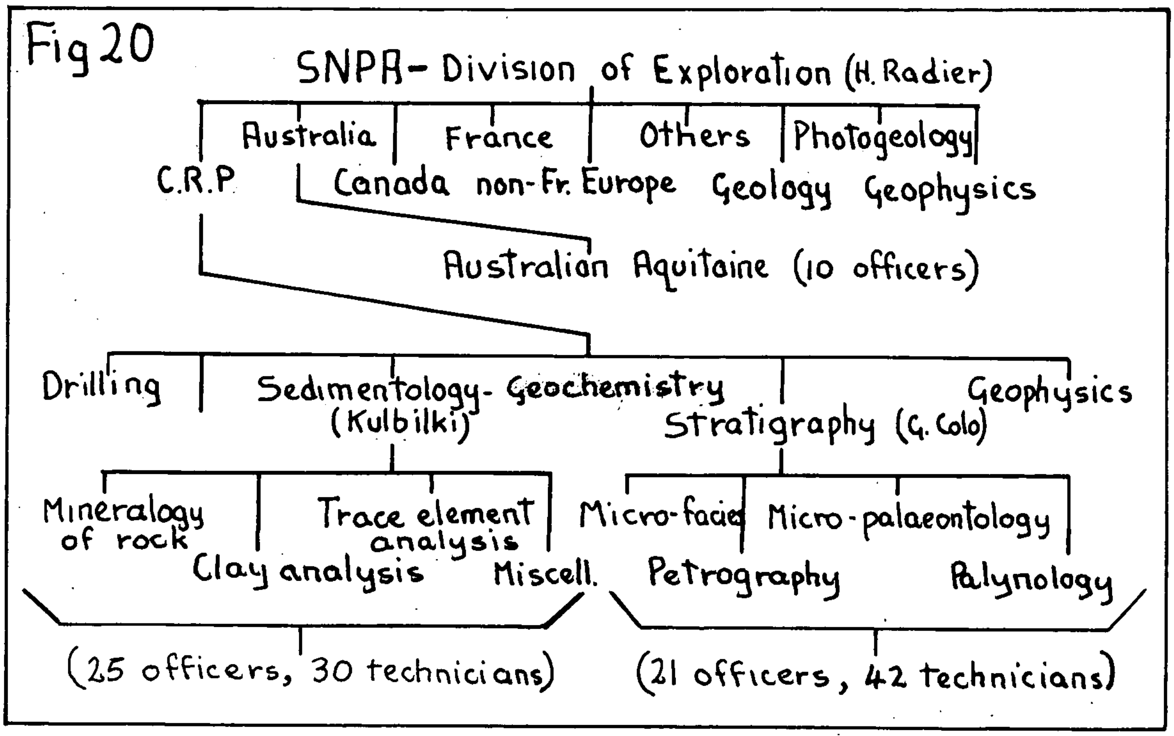

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Fig 20

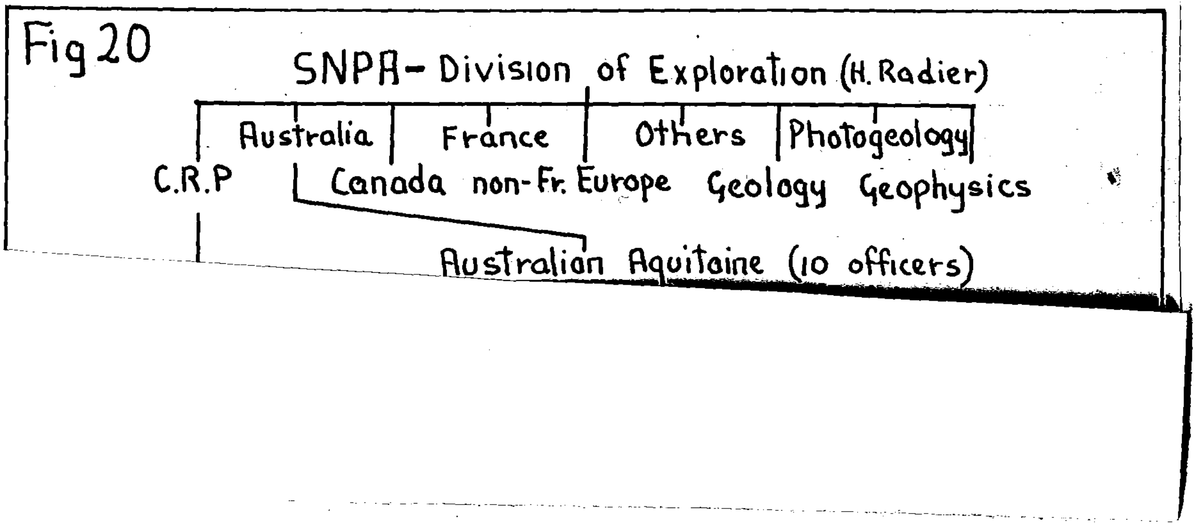

Figure 20. Organization of the Exploration Division, S.N.P.A., with detailed breakdown of the Central Laboratories (after Blanc.)

Institut Francais du Petrole

Within the past two years, both the objectives, and the organization of the I.F.P. have been radically altered. The dual objectives are now clearly to provide a pool of highly trained petroleum geologists and engineers, and to undertake long term research into some of the basic questions of petroleum generation migration and entrapment. The organization of the I.F.P. is now functional and is not governed by professional groupings:-

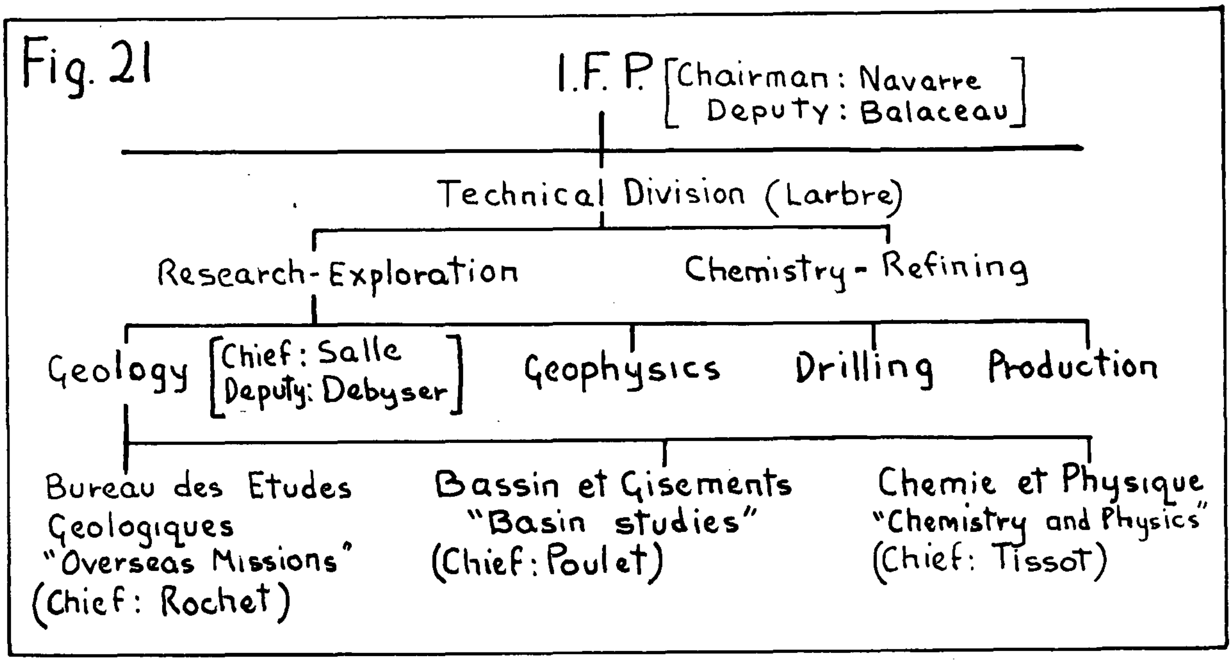

Figure 21. Organization of the Technical Division, I.F.P. (after Tissot).

A summary of the functions of Bassin et Gisements and the Chemie et Physique groups is given below:-

Bassin et Gisements (Basin studies) This group headed by M. Poulet has four main objectives:-

1. Develop new methods of stratigraphic and ecological interpretation.

2. Study particular problems of paleaogeography - especially in the sand/shale sequences of the Saharan Shield.

3. Carry out specific reservoir studies, in order to develop more accurate models; this is especially relevant to secondary recovery of hydrocarbons.

4. Undertake research into the treatment of geological information, from a statistical viewpoint. Extensive use is made of the C.D.C. 6400 computer in long term projects, such as the significance level of sampling but time is available to provide computer support for a number of unrelated short term projects.

GERMAN HYDROGRAPHIC RESEARCH

With the launching in 1965 of the research vessel "Meteor" of 2,700 tons, German scientists had ready access to one of the most modern hydrographic research vessels in the world. The vessel was built by the German Government and is operated under the dual control of the German Hydrographic Institute and the German Research Association (D.F.G.). The German Hydrographic Institute is concerned primarily with map making, and has 50% use of the vessel - normally one year's use out of every two. The D.F.G. members - including the Marine Research Institute of the University of Kiel - can use the vessel alternate years. The arrangement is that when the D.F.G. is using the "Meteor" they supply all the capital required and also pay all running costs throughout the voyage. (The D.F.G. also supplies much of the land-based equipment of the Marine Research Institute at Kiel).

Virtually all of the ship-board work of the Marine Research Institute involves the collection of bottom sediments; to date sampling has been carried out in the Baltic, Mediterranean and Arabian Seas, the Gulf of Oman, and the Persian Gulf.

Bottom samples are collected either in square-section coring cylinders of different lengths, or in grabs of different sizes. The coring tubes are in themselves quite interesting. In section they are square, 15 cm. across, and made of plastic-coated sheet steel; the tubes range in length from 2 to 6 metres. To avoid the possibility of damage to the sample when core is being removed, the tubes can be split longitudinally into two sections, by undoing a number of small screws. For special near-surface studies a special rectangular core tube is used, 50 cm. by 30 cm. in cross section, and 20 cm. long. The tube can be split in the same manner as the normal square tubes.

Obviously the core tubes described above cannot be used with sandy bottom sediment. In these cases grabs are used - with doors fitted to the top surface of the grab to enable the sample to be removed with the minimum of disturbance. A special flash camera is fitted to the grab to photograph the surface of the sediment from a height of one metre, immediately before impact with the grab.

To date, the Marine Research Institute has used the "Meteor" in waters ranging from an average of 30 metres in the Baltic Sea to in excess of 3,500 metres in the Gulf of Oman. The equipment has operated satisfactorily over this depth interval.

The team at the Marine Research Institute is led by Professor E. Seibold, assisted by F. Koegler. A summary of the pre-"Meteor" investigations up to the end of 1963 are contained in a paper by Seibold - see Sears (1963).

PREPARATION OF REPORTS - A STREAMLINED PROCEDURE

Under the guidance of Dr. A. Woodland, the Leeds Regional Office of the Institute of Geological Sciences has adopted a new procedure to speed up the preparation of geological reports. The principal feature of the scheme is that the maximum amount of work is done by the Leeds Office staff, and only the actual reproduction is left to the outside printer.

The steps involved are:-

1. Text is typed on the "Varityper 720" using the same format and margin as in the final report.
2. Plates, figures etc. are stuck in place.
3. Xerox copy of draft is run off for checking.
4. Editorial corrections are made on the xerox copy.
5. A negative of the corrected original is prepared.
6. A positive of the corrected original is prepared for the printer.

The "Varityper 720" costs approximately Aust. $4,000 and a selection of type faces would be an additional Aust. $500. The equipment is made by Adressograph-Multigraph.

All of the lettering for published maps is prepared on the "Monotype" which can prepare letters ranging in size from less than lmm. up to 3 cm. It is a photographic process, and can produce a wide range of type. The lettering can be readily transferred to waxed paper, and then stuck directly on to the map. The total cost of the equipment is approximately Aust. $6,500, and this figure includes the three drums of type, each worth approximately Aust. $650.

Further information about the overall objectives of this new procedure, and the degree of success that has been achieved, can be obtained from Dr. A Woodland. Details about the equipment used and the actual procedures followed, can be obtained from Mr. Tallis also of the I.G.S. Office, Leeds.

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APPENDIX I.

PUBLICATIONS ADDED TO B.M.R. PAMPHLET COLLECTION

The following journals, reprints and unpublished reports relevant to the topics covered by the present report were acquired in the course of my Overseas Study. These have all been lodged with the Librarian, Bureau of Mineral Resources, Canberra, and will be incorporated within the Pamphlet Colletion:-

A.G.I.P. 1959 - Studi Ed Operazioni Analitiche Che Vengono Effettuati Nei Laboratori Del Servizio Geochimico Dell'A.G.I.P. Mineraria. A.G.I.P. Direzione Mineraria, Servizio Geochimico E. Laboratori Report 3-12-195, pp 1-12, (unpubl.).

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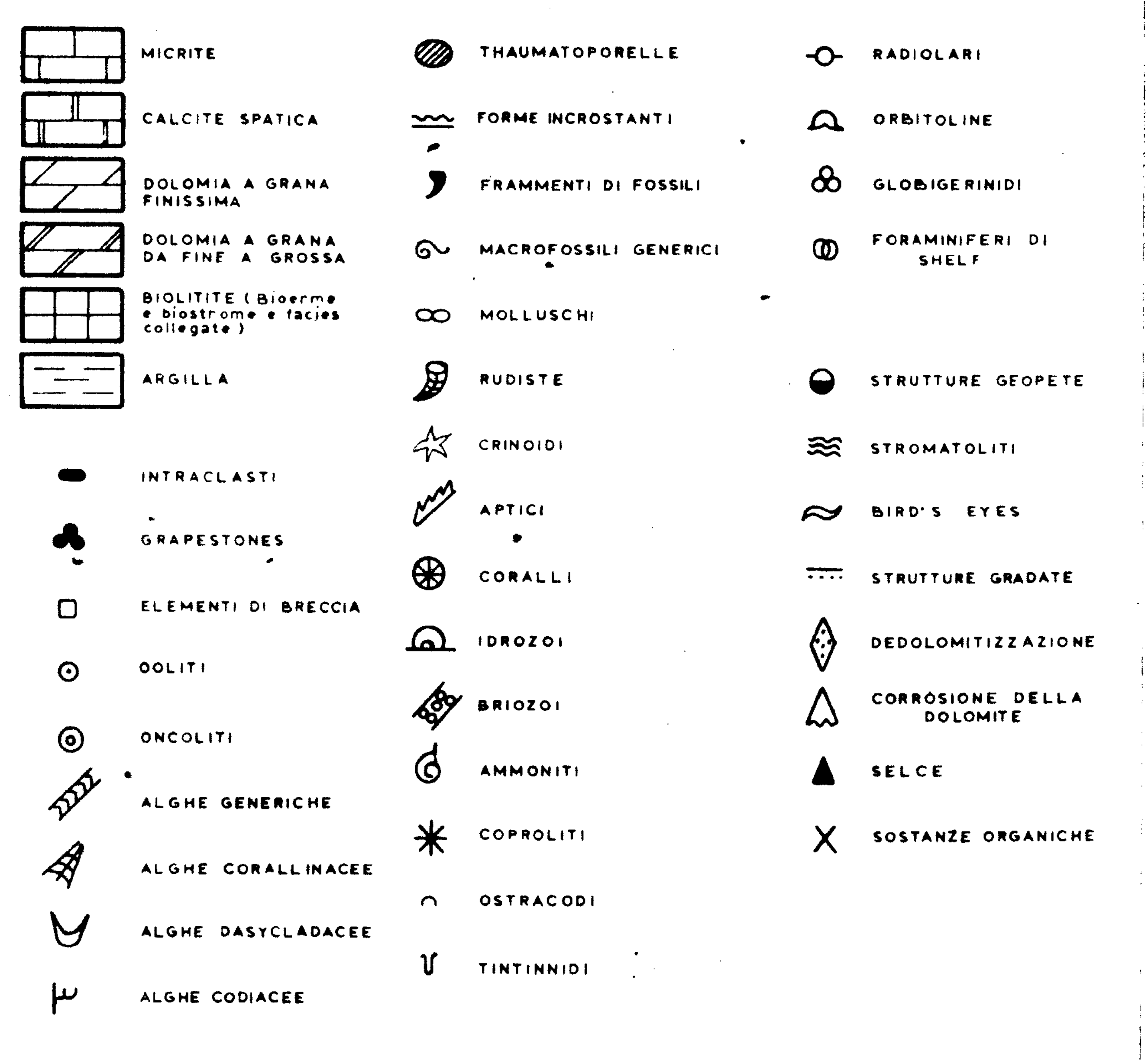
ATTACHMENT 1

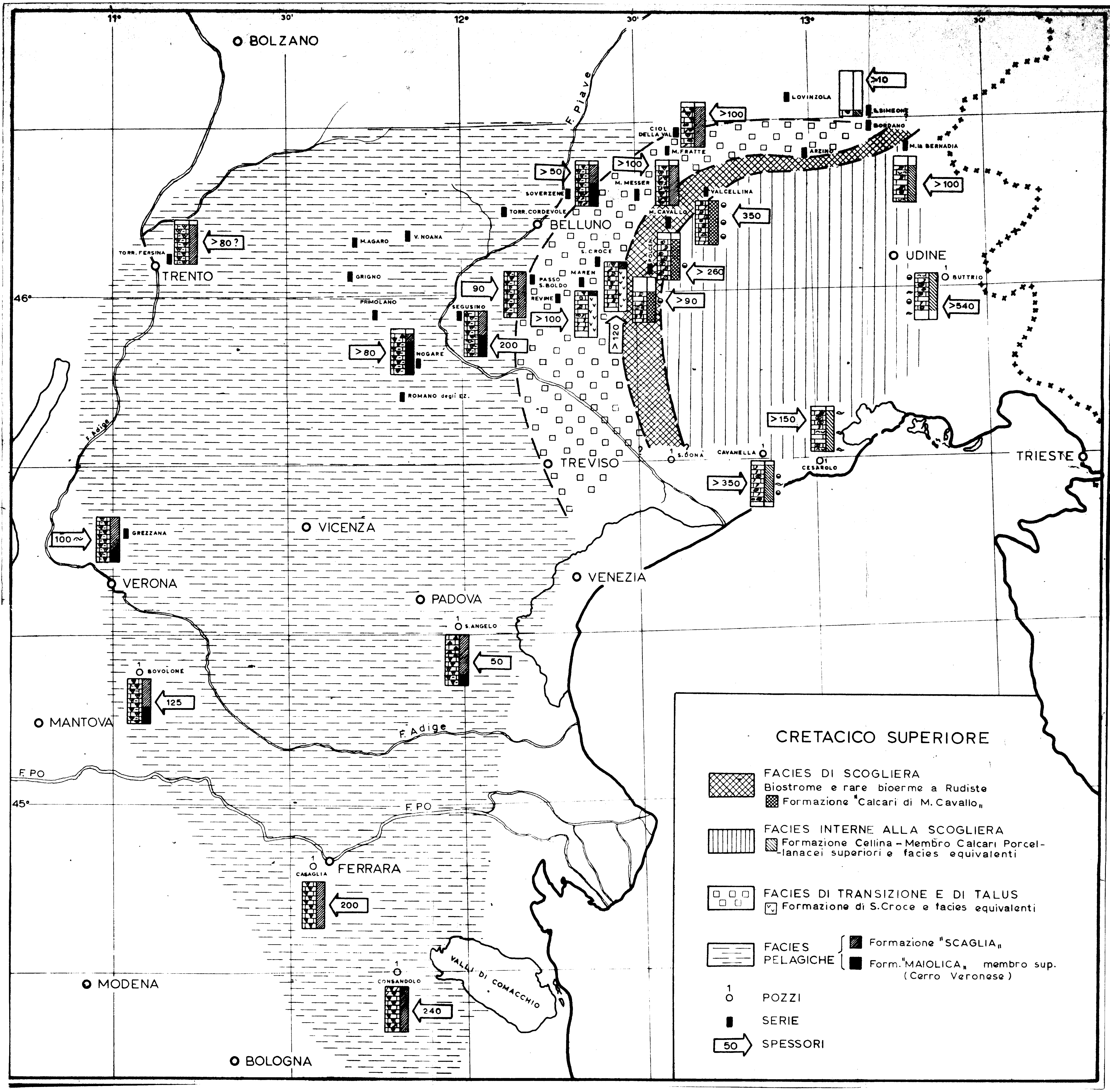
AGIP S.p.A.
DIREZIONE MINERARIA
SERVIZIO GEOCHIMICO E LAB.

CARTA DELLE LITOFACIES

SCALA 1:500'000

Autore Dr. L.MATTAVELLI M.TONNA P.M.SOZZI Disegnatore G.e D.	ALL. A «STUDIO PETROGRAFICO DI ALCUNE FORMAZIONI MESOZOICHE DEL VENETO»	Disegno N° 545 Data 8-2-67





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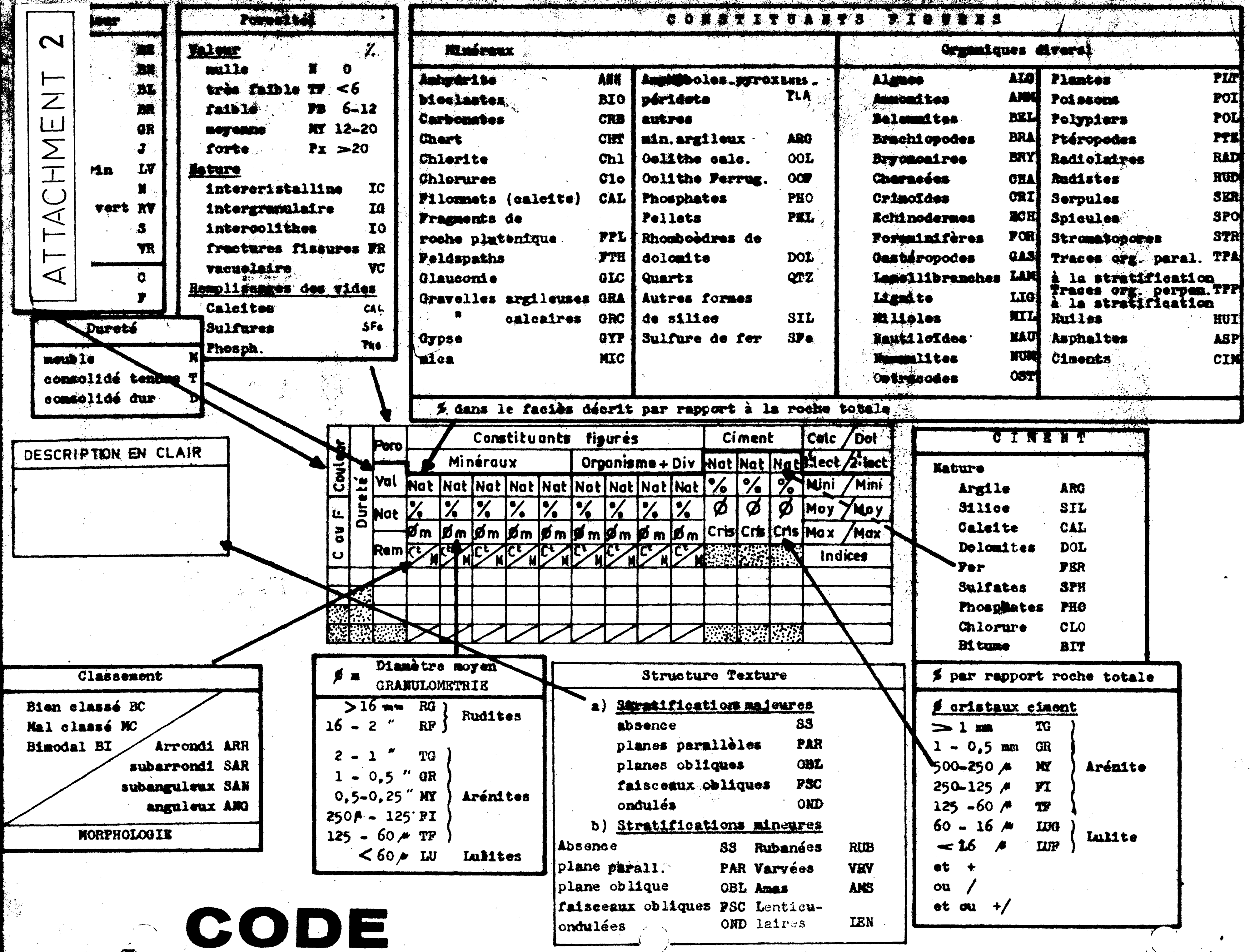


leur

	NR
	BN
	BL
	BR
	GR
	J
in	LV
	N
vert	RV
	S
	VR
	C
	F

Porosité

Valeur %

nulle	N	0
très faible	TF	<6
faible	FB	6-12
moyenne	MY	12-20
forte	Fx	>20

Nature

intercristalline	IC
intergranulaire	IG
interoolithes	IO
fractures fissures	FR
vacuolaire	VC

Remplissages des vides

Calcites	CAL
Sulfures	SFe
Phosph.	PHO

Dureté

meuble	M
consolidé tendre	T
consolidé dur	D

DESCRIPTION EN CLAIR

CONSTITUANTS FIGURES

Minéraux

Anhydrite	ANH
bioclastes	BIO
Carbonates	CRB
Chert	CHT
Chlorite	Chl
Chlorures	Clo
Filonnets (calcite)	CAL
Fragments de roche plutonique	FPL
Feldspaths	FTH
Glauconie	GLC
Gravelles argileuses	GRA
" calcaires	GRC
Gypse	GYP
mica	MIC
Amphiboles_pyroxènes_ péridots	TLA
autres	
min. argileux	ARG
Oolithe calc.	OOL
Oolithe Ferrug.	OOF
Phosphates	PHO
Pellets	PEL
Rhomboèdres de dolomite	DOL
Quartz	QTZ
Autres formes de silice	SIL
Sulfure de fer	SFe

Organiques divers

Algues	ALG
Ammonites	AMM
Belemnites	BEL
Brachiopodes	BRA
Bryozoaires	BRY
Characées	CHA
Crinoïdes	CRI
Echinodermes	ECH
Foraminifères	FOR
Gastéropodes	GAS
Lamellibranches	LAM
Lignite	LIG
Milioles	MIL
Nautiloïdes	NAU
Nummulites	NUM
Ostracodes	OST
Plantes	PLT
Poissons	POI
Polypiers	POL
Ptéropodes	PTE
Radiolaires	RAD
Rudistes	RUD
Serpules	SER
Spicules	SPO
Stromatopores	STR
Traces org. paral. à la stratification	TPA
Traces org. perpen. à la stratification	TPP
Huiles	HUI
Asphaltes	ASP
Ciments	CIM

% dans le faciès décrit par rapport à la roche totale

Couleur	Dureté	Poro	Constituants figurés									Ciment			Calc / Dol
		Val	Minéraux					Organisme + Div				Nat	Nat	Nat	1 lect / 2 lect
			Nat	Nat	Nat	Nat	Nat	Nat	Nat	Nat	Nat	%	%	%	Mini / Mini
C ou F		Nat	%	%	%	%	%	%	%	%	%	Ø	Ø	Ø	Moy / Moy
			Øm	Øm	Øm	Øm	Øm	Øm	Øm	Øm	Øm	Cris	Cris	Cris	Max / Max
		Rem	Ct / M	Ct / M	Ct / M	Ct / M	Ct / M	Ct / M	Ct / M	Ct / M	Ct / M				Indices

CIMENT

Nature

Argile	ARG
Silice	SIL
Calcite	CAL
Dolomites	DOL
Fer	FER
Sulfates	SPH
Phosphates	PHO
Chlorure	CLO
Bitume	BIT

Classement

Bien classé	BC
Mal classé	MC
Bimodal	BI

Arrondi	ARR
subarrondi	SAR
subanguleux	SAN
anguleux	ANG

MORPHOLOGIE

Ø = Diamètre moyen GRANULOMETRIE

>16 mm	RG	Rudites
16 - 2 "	RF	
2 - 1 "	TG	Arénites
1 - 0,5 "	GR	
0,5-0,25 "	MY	
250µ - 125	FI	
125 - 60 µ	TF	
<60 µ	LU	Lutites

Structure Texture

a) **Stratifications majeures**

absence	SS
planes parallèles	PAR
planes obliques	OBL
faisceaux obliques	FSC
ondulés	OND

b) **Stratifications mineures**

Absence	SS	Rubanées	RUB
plane parall.	PAR	Varvées	VRV
plane oblique	OBL	Amas	AMS
faisceaux obliques	FSC	Lenticulaires	LEN
ondulées	OND		

% par rapport roche totale

Ø cristaux ciment

> 1 mm	TG	Arénite
1 - 0,5 mm	GR	
500-250 µ	MY	
250-125 µ	FI	
125 -60 µ	TF	
60 - 16 µ	LUG	Lutite
< 16 µ	LUF	

et +

ou /

et ou +/

CODE

ATTACHMENT 3a

SIGLE

Zone DICA

N' DICA

COTE D'APPARITION	Nature échantillon	N° DE L'ELEMENT	Révision Ultérieure	VARIATIONS MINEURES	DESCRIPTION EN CLAIR	Couleur C ou F	Dureté	Poro Val Nat Rem	CONSTITUANTS FIGURES									CIMENT			Calc / Dol 1 lect / 2 lect
									Minéraux					Organiques + Div				Nat	Nat	Nat	
									Nat	Nat	Nat	Nat	Nat	Nat	Nat	Nat	Nat	%	%	%	Min / Min
									%	%	%	%	%	%	%	%	%	Ø	Ø	Ø	Moy / Moy
									Øm	Øm	Øm	Øm	Øm	Øm	Øm	Øm	Øm	Cris	Cris	Cris	Max / Max
									Ct / M	Ct / M	Ct / M	Ct / M	Ct / M	Ct / M	Ct / M	Ct / M	Ct / M				INDICES

Sonde ______ Géologue ______ Feuille ______ Eléments n° de ______ à ______ Cote : de ______ à ______

SNPA

ATTACHMENT 3b

COTES	ND 1e lect/2e lect D 1e lect/2e lect	Fraction partant au débourbage lame mince	% ELEMENT ET N°										OBSE (ND, couleur, indices, etc) (Microfaune - microfaciès)

SNPA

Sonde ____

Géologue ____

Date ____

Feuille n° ____

Profondeur de ____ à ____

Sondage :
Coupe :

ATTACHMENT 3c

Cote ou référence plaque	ELEMENTS TERRIGÈNES												Phosphates	Glauconie	Fer { oxyde réduit		MATRICE OU CIMENT										ELÉMENTS ALLOCHTONES																						TYPE DE ROCHE	OBSERVATIONS
	Quartz					Feldspaths		Micas		Chlorite	débris de roches	Min.x lourds					Argiles				So4=	Calcite		Dolomite		autres Co3=	Intraclasts	Oolithes	Pellets	Bioclasts																	déb. ligniteux			
	%	Nourrissage	Ø max.	Ø moy.	Morphoscopie	Orthoclases	Plagioclases	Muscovite	Biotite								Illite	Kaolinite	Chlorite			Micrite	Sparite	Micrite	Sparite					% total	déb. indet.	Spongiaires	Polypiers	Echinodermes	Bryozoaires	Serpules	Brachiopodes	Gasteropodes	Lamellibranches				Foraminifères	Ostracodes	Radiolaires	Algues				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48		

SONDAGE ou COUPE :

ATTACHMENT 3d

NUMERO DE FICHE	COTE OU REFERENCE PLAQUE	CAROTTE	DOSAGES R.X						QUARTZ 0 à 100%				PHENOMENES DIAGENETIQUES			
											GRANULOMETRIE QUARTZ		CRISTALLINITE de la DOLOMITE		CRISTALLINITE de la CALCITE	
			SILICE	CALCITE	DOLOMITE	SULFATE			QUARTZ	SILICE SECONDAIRE	Ø MOYEN	Ø MAXIMUM	Ø MOYEN	Ø MAXIMUM	Ø MOYEN	Ø MAXIMUM
			1	2	3	4	5	6	7	8	9	10	11	12	13	14

ROCHES CARBONATEES 100% à 0																															
DOLOMITE																CALCITE															
DOLOSPARITE					DOLOMICROSPARITE					DOLOMICRITE						SPARITE					MICROSPARITE					MICRITE					
																>80μ					20-80μ					<10μ					
	□	⊙	○	△		□	⊙	○	△		□	⊙	○	△	−		□	⊙	○	△		□	⊙	○	△		□	⊙	○	△	−
TOTAL	Lithoclasts	Oolithes	Gravelles	Intraclasts	TOTAL	Lithoclasts	Oolithes	Gravelles	Intraclasts	TOTAL	Lithoclasts	Oolithes	Gravelles	Intraclasts	Pellets	TOTAL	Lithoclasts	Oolithes	Gravelles	Intraclasts	TOTAL	Lithoclasts	Oolithes	Gravelles	Intraclasts	TOTAL	Lithoclasts	Oolithes	Gravelles	Intraclasts	Pellets
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46

POROSITES ET FRACTURES						POURCENTAGE ET TAILLE DES ALLOCHEMS												MINERAUX													
POROSITE		FRACTURATION				53 □ Lithoclasts 54 ⊙ Oolithes 56 ○ Gravelles 56 △ Intraclasts												MICAS													
Géodes (+ ou rien)	Intercristalline 1 = 5% 5 = 25%	Epaisseur en μ	Mineralisation (Do, F, Ca, An)	Tailles des cristaux (+ ou −)	Vacuoles (+ ou rien)	0 à 250μ		250 à 900μ		> 900μ		0 à 250μ		250 à 900μ		> 900μ		Muscovite	Biotite	Chlorite	Fer	Glauconie	Lignite	Anhydrite							
						%	Ta	%	Ta	%	Ta	%	Ta	%	Ta	%	Ta														
47	48	49	50	51	52	1	2	3	4	5	6	1	2	3	4	5	6	57	58	59	60	61	62	63	64	65	66	67	68	69	

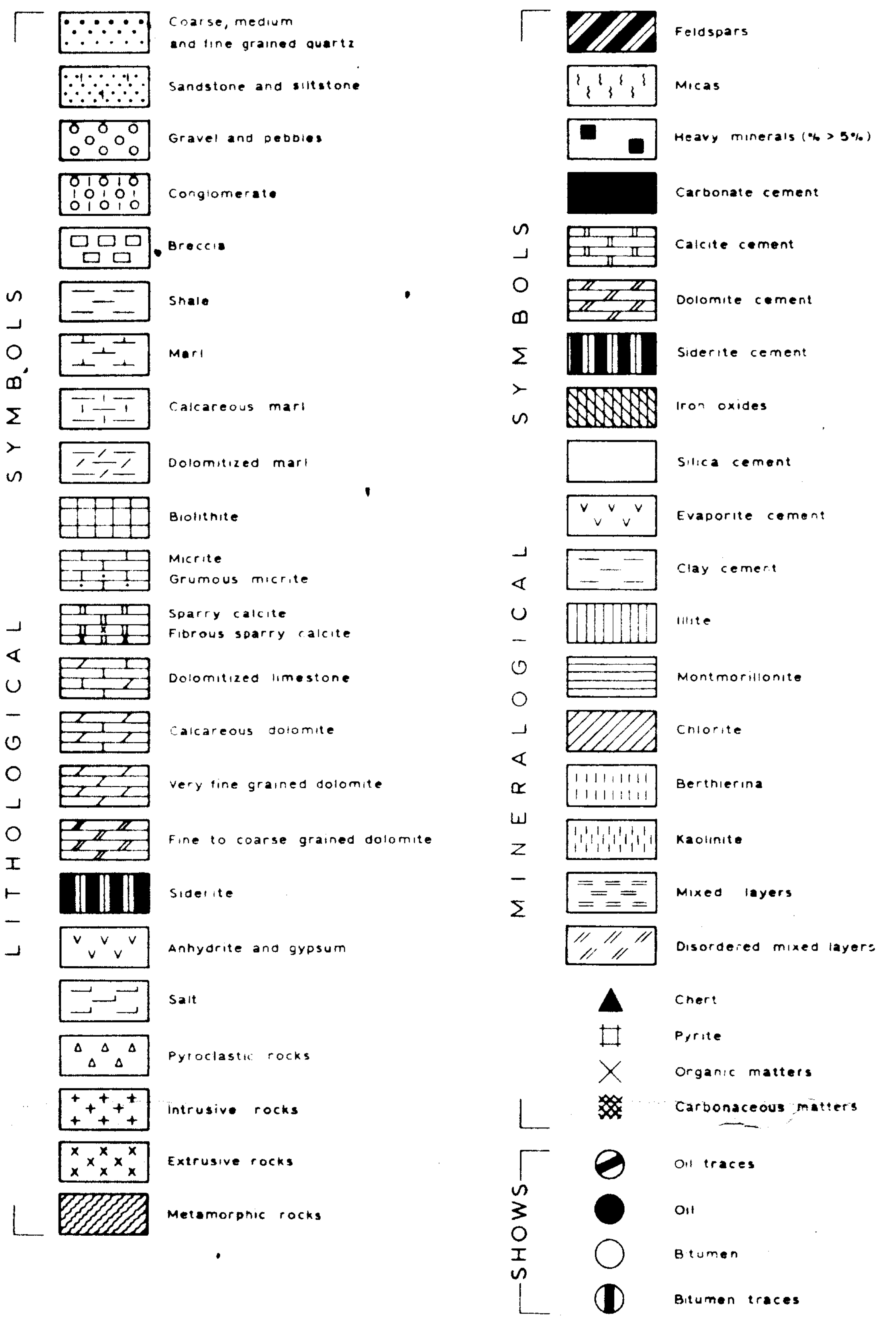
ELEMENTS ALLOCHTONES																																																																	OBSERVATIONS	NUMERO DE FICHE	COTE OU REFERENCE PLAQUE	CAROTTE
POURCENTAGE TOTAL	BIOCLASTS																																																																				
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65				
20																																																																					

ATTACHMENT 4

AGIP S.p.A
DIREZIONE MINERARIA
SERVIZIO GEOCHIMICO E LABORATORI

WELL
No
STATE
CONCESSION
R.T. mts
S.L. mts
N.

AUTHOR
ANNEX TO
TRACED by
DATE
SCALE 1
DRAWN N.



LITHOLOGICAL SYMBOLS

- Coarse, medium and fine grained quartz
- Sandstone and siltstone
- Gravel and pebbles
- Conglomerate
- Breccia
- Shale
- Marl
- Calcareous marl
- Dolomitized marl
- Biolithite
- Micrite
- Grumous micrite
- Sparry calcite
- Fibrous sparry calcite
- Dolomitized limestone
- Calcareous dolomite
- Very fine grained dolomite
- Fine to coarse grained dolomite
- Siderite
- Anhydrite and gypsum
- Salt
- Pyroclastic rocks
- Intrusive rocks
- Extrusive rocks
- Metamorphic rocks

MINERALOGICAL SYMBOLS

- Feldspars
- Micas
- Heavy minerals (% > 5%)
- Carbonate cement
- Calcite cement
- Dolomite cement
- Siderite cement
- Iron oxides
- Silica cement
- Evaporite cement
- Clay cement
- Illite
- Montmorillonite
- Chlorite
- Berthierina
- Kaolinite
- Mixed layers
- Disordered mixed layers
- Chert
- Pyrite
- Organic matters
- Carbonaceous matters

SHOWS

- Oil traces
- Oil
- Bitumen
- Bitumen traces

ALLOCHEMS

- Oolites
- Onkolites < 4 mm
- Onkolites > 4 mm
- Little rounded intraclasts and pellets
- Intraclasts in general
- Intraclasts like grapstones
- Micrite granules not determinable
- Coprolites
- Microfossils in general
- Macrofossils in general
- Fossils fragments
- Planktonic microfossils
- Benthonic Foraminifera
- Macroforaminifera
- Globigerinides
- Tintinnids
- Radiolaria
- Sponge spicules
- Ostracoda
- Orbitolinas
- Mollusca
- Rudistes
- Corals
- Hydrozoa
- Briozoa
- Cephalopoda
- Aptychus
- Saccocoma
- Mollusca, Rudistes etc. in fragments
- Leached fragments of mollusca
- Fragments of recrystallized mollusca
- Crinoids
- Pelagic lamellibranchs
- Algae in general
- Dasycladaceae
- Solenoporaceae
- Codiaceae
- Encrusting algae
- Corallinaceae
- Thaumatoporellae

PETROGRAPHIC TEXTURES

- Secondary overgrowth of silica
- Leaching of quartz
- Leaching of quartz and its replacement by carbonates
- Leaching of quartz and its replacement by evaporites
- Pressure solution s.l.
- Long contacts
- Concavo - convees contacts
- Tangential contacts
- Sutured contacts
- Neogenic illite after quartz
- Neogenic Kaolinite after quartz
- Leaching of carbonates
- Corroded dolomite rhombohedrons
- Rhombohedrons with leached nucleus
- Zonated rhombohedrons
- Rhombic vugs
- Dolomite spots with dolomite rhombohedrons
- Calcite with dolomite rhombohedrons
- Pseudomorph calcite after dolomite
- Geopetal textures
- Bird's eyes
- Stromatolitic structures
- Inward collapse

POROSITY

- Chalky porosity
- Intergranular porosity
- Vuggy porosity
- Intercrystalline porosity

SEDIMENTARY STRUCTURES

- Bedding
- Massive bedding
- Laminations
- Graded beddings
- Wavy laminations
- Convolute laminations
- Disturbed beddings
- Burrows and bioturbations
- Erosional channels
- Cross bedding
- Ripple marks
  - simmetrical
  - asimmetrical
- Flow marks
- Load casts
- Groove casts
- Mud cracks
- Stylolites
- Nodular structures

ATTACHMENT 5a

ALL N° 2

AGIP - Direzione Mineraria

SERVIZIO GEOCHIMICO E LAB
SEZIONE PETROFISICA E MINERALOGICA

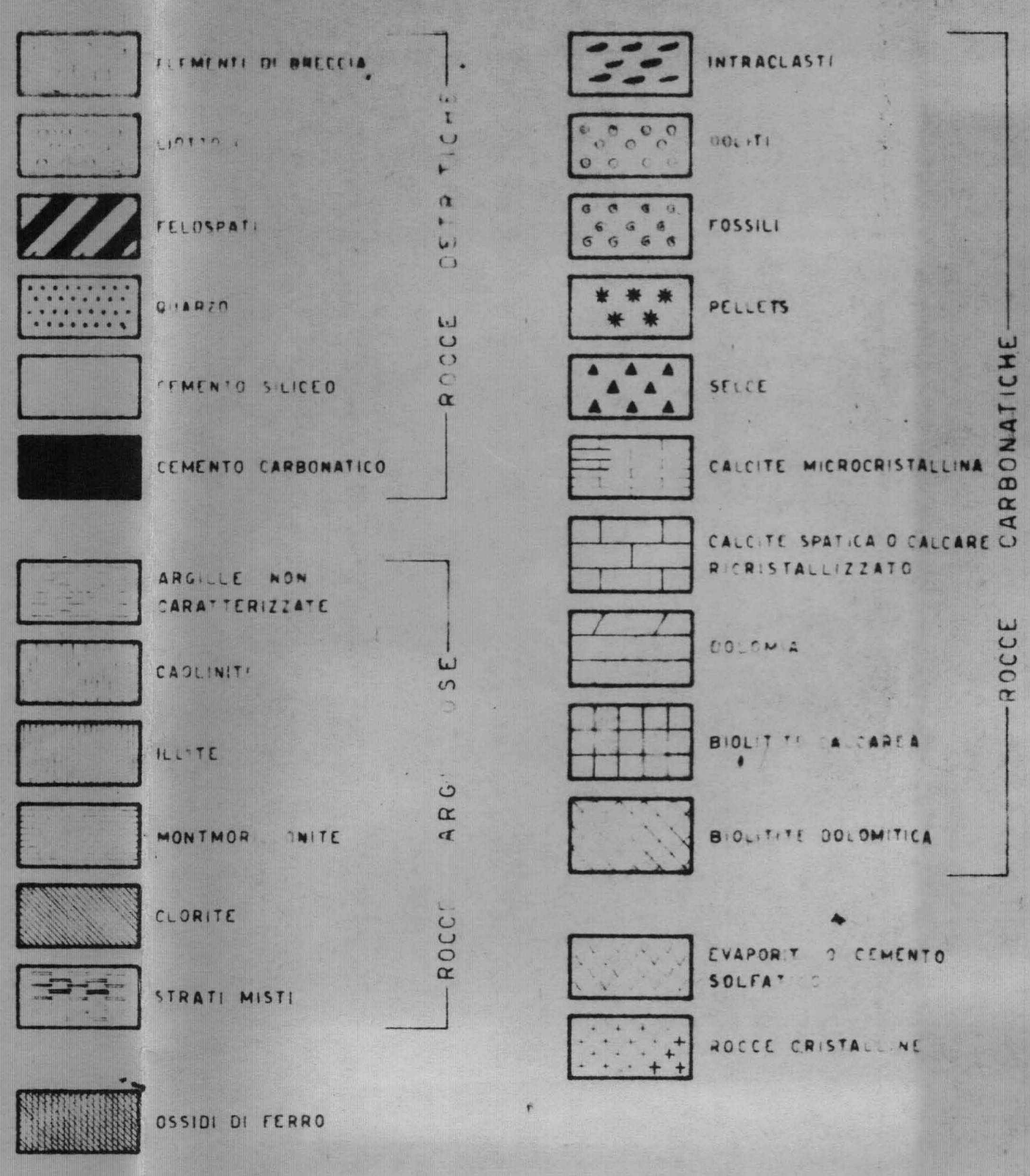
POZZO EL BORMA 15
Carotaggio meccanico continuo
da m 2401 a m 2462

LOG PETROFISICO

Scala 1:100

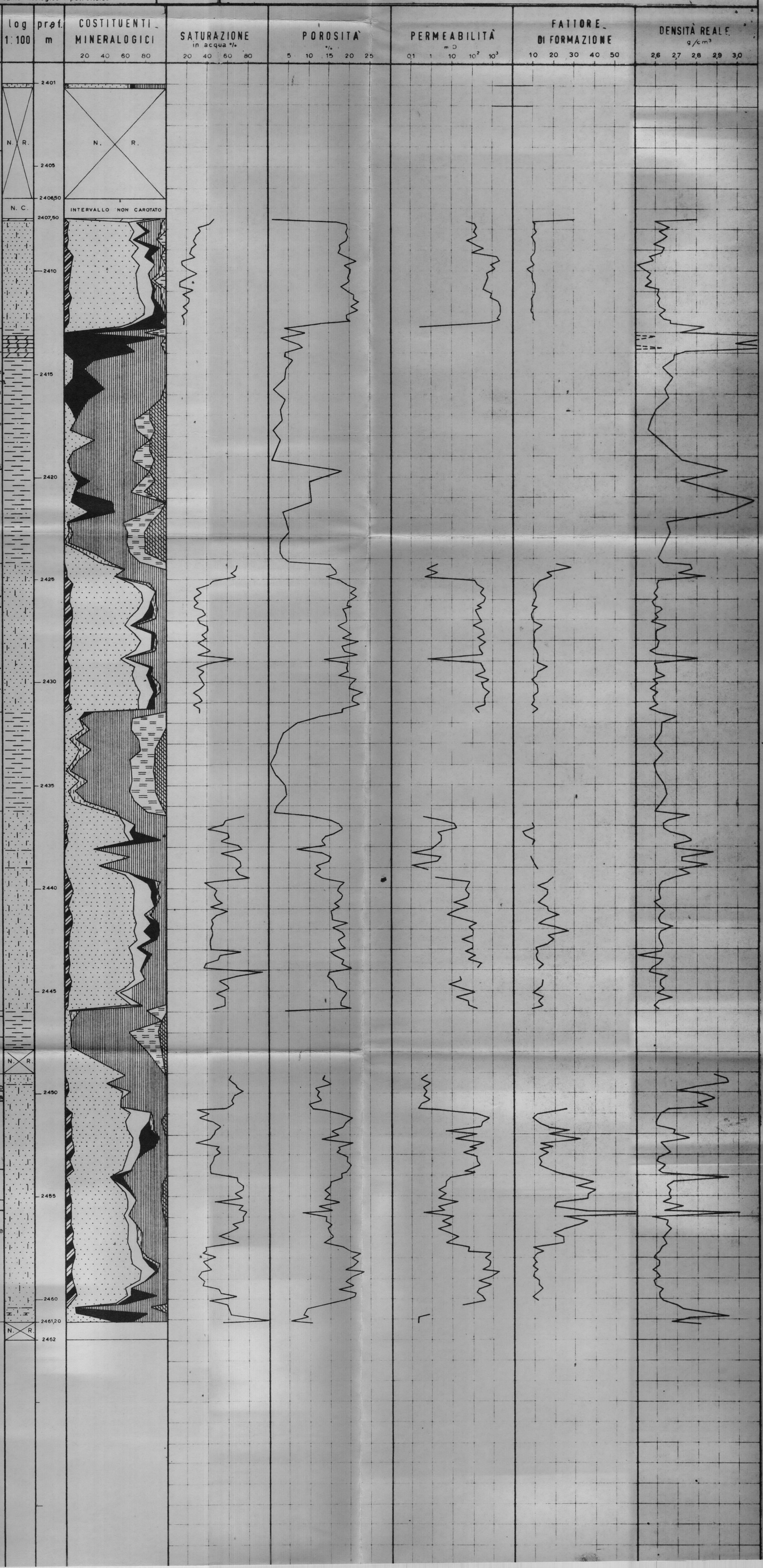
AUTORE: Dr. G. Taronna Dr. Morelli P.M. Cenedese DISEGNO DI: V. D.	ALLEGATO A: Pozzo EL BORMA 15. Carotaggio meccanico continuo da m 2401 a m 2462 Esame litologico – petrofisico	DISEGNO N° 502 DATA 26-9-66

COSTITUENTI MINERALOGICI DELLE ROCCE



Per gli altri simboli si veda il MANUALE DIREZIONALE – Norme Tecniche – Servizio Geologico – 41.1 – Settori di Esplorazione –

ETÀ	FORMAZIONE	Descrizione litologica
TRIAS	KIRCHAOU	Arenaria quarzosa di colore nocciola scuro, a grana variabile da finissima a media, interessata da numerosi veli argillosi verdastri e da rare lenticelle nerastre carboniose. La frazione detritica è costituita da quarzo, feldspati, miche detritiche, tormalina e zircone. Il cemento è costituito da silice, carbonati, illite, scarsa caolinite ed argilla. Tra m 2407,50–2407,60 presenza di dolomia afanitica argillosa includente plaghette di siderite. Sedimentazione incrociata.
		2412,80
		Argilla verde e rossa, a tratti leggermente siltosa, includente noduletti costituiti da dolomia e, talora, da siderite. L'esame roentgenografico mostra che le argille sono costituite da illite, strati misti e caolinite. Tra m 2413,10 e m 2414,20 presenza di siderite di colore nocciola scuro, costituita da grossi cristalli sfrangiati con periferia limpida di neoformazione, leggermente siltosa verso la base. La siderite presenta numerose fratture cementate da argilla illitica.
		2424,20
		Arenaria quarzosa di colore nocciola, a grana fine-finissima, interessata da numerosi veli argillosi verdastri e, a tratti, da lenticelle carboniose. La frazione detritica è costituita da quarzo, feldspati, miche e minerali pesanti. Il cemento è prevalentemente siliceo-illitico con minori percentuali di carbonati e caolinite. Sedimentazione incrociata.
		2431,50
		Argilla verde e rossa, leggermente siltosa, con ossidi di ferro diffusi. La composizione mineralogica delle argille è: illite-strati misti-caolinite.
		2436,30
		Arenaria quarzosa di colore nocciola chiaro, a grana fine-finissima e talora media, interessata da numerosi veli e livelletti di argilla verde e, a tratti, da lenticelle carboniose. La frazione detritica è costituita da quarzo, feldspati, miche e minerali pesanti. Il cemento è prevalentemente siliceo-illitico associato a minori percentuali di carbonati e caolinite.
		2446
		Argilla verde e rossa per ossidi di ferro diffusi, leggermente siltosa, costituita da illite, strati misti e caolinite.
		2449
		Arenaria quarzosa di colore nocciola e grigio verdolino, a grana fine-finissima interessata da numerosi veli e livelletti argilloso-sabbiosi verdi ed a tratti da lenticelle carboniose nerastre. La frazione detritica è costituita da quarzo, feldspati, miche e minerali pesanti. Il cemento è prevalentemente illitico-silico con minori percentuali di carbonati, caolinite ed ossidi di ferro. A m 2460,80, l'arenaria include noduli costituiti da siderite.
		2461,20



ATTACHMENT 5b

AGIP SpA
DIREZIONE MINERARIA

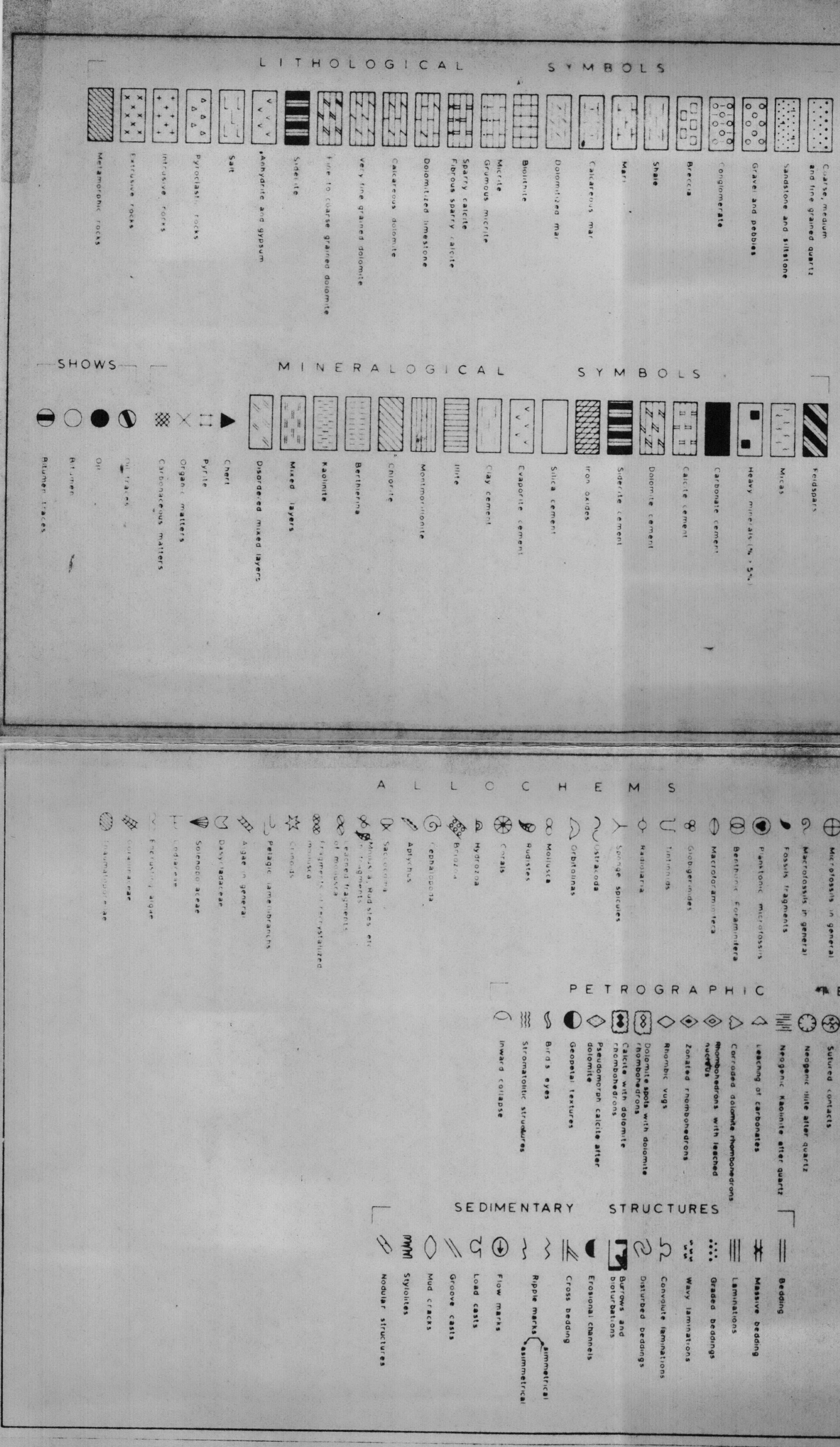
WELL IM-T N. 2
STATE IRAN
CONCESSION IMINOCO
7
R.T. 35'
S.B. - 302' (ref. R.T.)

PETROGRAPHIC WELL LOG

AUTHOR Dr. G. Taronna
P. M. A. Piaia

ANNEX TO IRAN PERSIAN GULF. DISTRICT N°1- AREA 2 F.
WELL IM-T2 (IMINOCO).

TRACED by V. D
DATE
SCALE 1:2500
DRAWN N. 602



LITHOLOGY

Whitish to grey brownish and dark grey dolomite, very fine to fine grained, white benthonic microfossils, vuggy to very dense, with some anhydrite nodules and veins. From 3120' to 3225' dolomitic limestone, slightly shaly. Interbeddings of shale with chert nodules.

3225'

Whitish to brown fossiliferous dolomitic limestone (biomicrite), slightly shaly, with interbeddings of some grey to greenish marl. In the lower part medium grained dolomite.

3450'

Whitish to light brown fossiliferous limestone (biomicrudite), with aboundant Nummulites, slightly shaly, with interbeddings of red marl. From 3700' the biomicrudite is dolomitized.

3900'

Cream to light brown fossiliferous shaly limestone (biomicrite) and grey fossiliferous marl. In the upper part, the biomicrite includes chert nodules. Sometimes the rock is dolomitized.

4950'

Grey to grey brownish fossiliferous marl with interbeddings of fossiliferous limestone (biomicrite), sometimes intraclastic limestone. Grey shale laminations are present.

5341'

Grey fossiliferous marl formed by pelagic microfossils sometimes filled with glauconite and pyrite. Interbeddings of shaly biomicrite.

5484'

Whitish fossiliferous shaly limestone (biomicrite) formed by benthonic microfossils and macrofossils fragments; intercalations of dark grey brownish fossiliferous marl.

5652'

Brown fossiliferous marl with interbeddings of thin whitish biomicrite.

5770'

Whitish, dense to porous, fossiliferous limestone (biomicrite) formed by benthonic microfossils sunk in a micritic matrix. The biomicrite is interbedded with micrite and grey marl.

6180'

Grey-green, soft, sometimes pyritic marl passing gradually to dark grey and chocolade brown shale. Traces of white, fossiliferous, chalky limestone.

6342'

Light hazel to dark hazel chalky fossiliferous limestone (fossiliferous micrite) formed by benthonic fossils sunk in an aboundant shaly micritic matrix. The chalky limestone is interbedded with grey marly levels.

7155'

Grey cream shaly limestone (micrite) with rare fossils.

7362'

Dark hazel vuggy dolomite.

7409'

8110'

Dark brownish, fine to medium grained, dolomite sometimes including oolites and fossils. The rock is vuggy because of leaching. Spots and levels anhydrite are present.

8335'

Hazel, medium grained dolomite with a mosaic texture, with spots and levels of anhydrite.

8560'

Light tan, fossiliferous dolomitized limestone (dolomitized biomicrudite) sometimes with intraclasts, including anhydrite nodules in the upper part and slightly shaly in the lower one.

8950'

Light tan to grey dolomitized fossiliferous limestone, slightly shaly.

9226'

Tan green fossiliferous shaly micrite, slightly dolomitized in the upper and lower part. Sometimes the rock includes rare intraclasts and oolites.

ATTACHMENT 6a

1659

GEOLOGISCHE DIENST - HAARLEM

1659

PLAATS

Mander Reide
Pompput 67- 8
28 F/41

Det.: juli '67 J. L. D

PLAATS	Prep.:	toermalijn	zirkoon	granaat				rutiel	anataas	brookiet	stauroliet	distheen	andalusiet	sillimaniet		topaas	chloritoid		epidoot	saussuriet s.s.	alteriet		hoornblende				baz. hoornblende	augiet	hypersteen	olivijn e.d.	titaniet		pumpellyiet	buiten telling		
Diepte				kleurloos + rose	rood tot geelbruin	Maas-	overige troebele							korrel	fibroliet		heldere	Maas-			groen	s.l.	Vogezen	alkali	bruin	groen					Eifel type	s.l.		chloriet	biotiet	muscoviet
0.50 - 1.50	21753	6	2.5	5				0.5			3.5	2	1		2	1			23	1.5		28				21		2	0.5				0.5			
3.50 - 4.50	21754	4	3	4.5				0.5	0.5		6	0.5	0.5		2.5	1.5			22.5	2.5		32.5				17		1	0.5				0.5			
6.50 - 7.50	21755	10	1	3.5							3.5	1.5	1		2	1.5			30	1.5		27.5				16.5		0.5								
8.50 - 8.75	21756	7.5	2.5	5				0.5			2	2.5	3	0.5	0.5	0.5	0.5		33.5	0.5		21				17		1	1.5		0.5					
9.00 - 10.00	21757	11.5	5	0.5				1.5			7	0.5	1	1	0.5				36	1		27				7.5										
11.00 - 12.00	21758	10	5	2				1	1		4	2	2		2				26			35				10										
13.00 - 14.00	21759	13.5	2	0.5				2			6	3	2.5			0.5			36.5	0.5		25.5				6	0.5	0.5			0.5				0.5	
15.50 - 16.50	21760	11.5	3	3				2	1		6	1	3	0.5	1.5		0.5		29	1.5		26				8.5		0.5	0.5			1.5				
17.50 - 18.50	21761	14.5	6	3				1.5	1		8.5	1.5	3		0.5				35			15.5				9	0.5					0.5				
19.50 - 20.00	21762	10.5	10.5	4				3	1		4.5	2.5	2	1					37			16				6.5		0.5	0.5				0.5			0.5
22.00 - 23.00	21763	12.5	5	1.5				2	1		4.5	3	2				0.5		29	0.5		26				11.5	0.5				0.5				0.5	
25.30 - 26.50	21764	14.5	1.5	5.5				3	0.5		5.5	1.5	2.5		0.5				30	0.5		27.5				6.5							0.5			
28.50 - 29.50	21765	5.5	9	10				1.5	1		5	0.5		0.5	0.5	0.5			27.5	0.5		26				11	0.5		0.5							
31.00 - 32.00	21766	9.5	6	15.5				3.5	0.5		7	1	0.5						26			22.5				7.5		0.5								
34.00 - 34.75	21767	11	7	13				1.5	0.5		2.5	1.5	1	0.5	0.5				24	0.5		22.5				10.5	1	2	0.5							
36.75 - 37.00	21768	11	1	19.5				0.5			4.5	1	2.5			0.5			25			23.5				5	1.5	4.5								
38.00 - 39.00	21769	9	1.5	13				1	0.5		7	3	4		1				15			31				6	2	5.5					0.5			
39.00 - 40.00	21770	8.5	3.5	20							13.5	6.5	4.5	2.5	0.5	2.5			15.5			15				6	0.5		0.5	0.5						
41.00 - 42.00	21771	14	3	19				5.5			9.5	12.5	5	5	1	2			11			6				5.5				1				0.5		
43.75 - 44.75	21772	14	4	18				1			11	7	4	2.5	1.5	1			15.5			13.5				6.5			0.5					0.5		
46.75 - 47.75	21773	4.5	1.5	33				0.5			16	9	5	2.5	1	3			8			11.5				3.5		0.5	0.5							
49.75 - 50.75	21774	2.5	1.5	33.5							10.5	2.5	0.5	1		1.5			13			22				11		0.5						0.5		

LEGENDA ZWARE MINERALEN

Genormaliseerd d.d. 2 - 1 - '64 Sed. Petr. Lab.

ATTACHMENT 6b

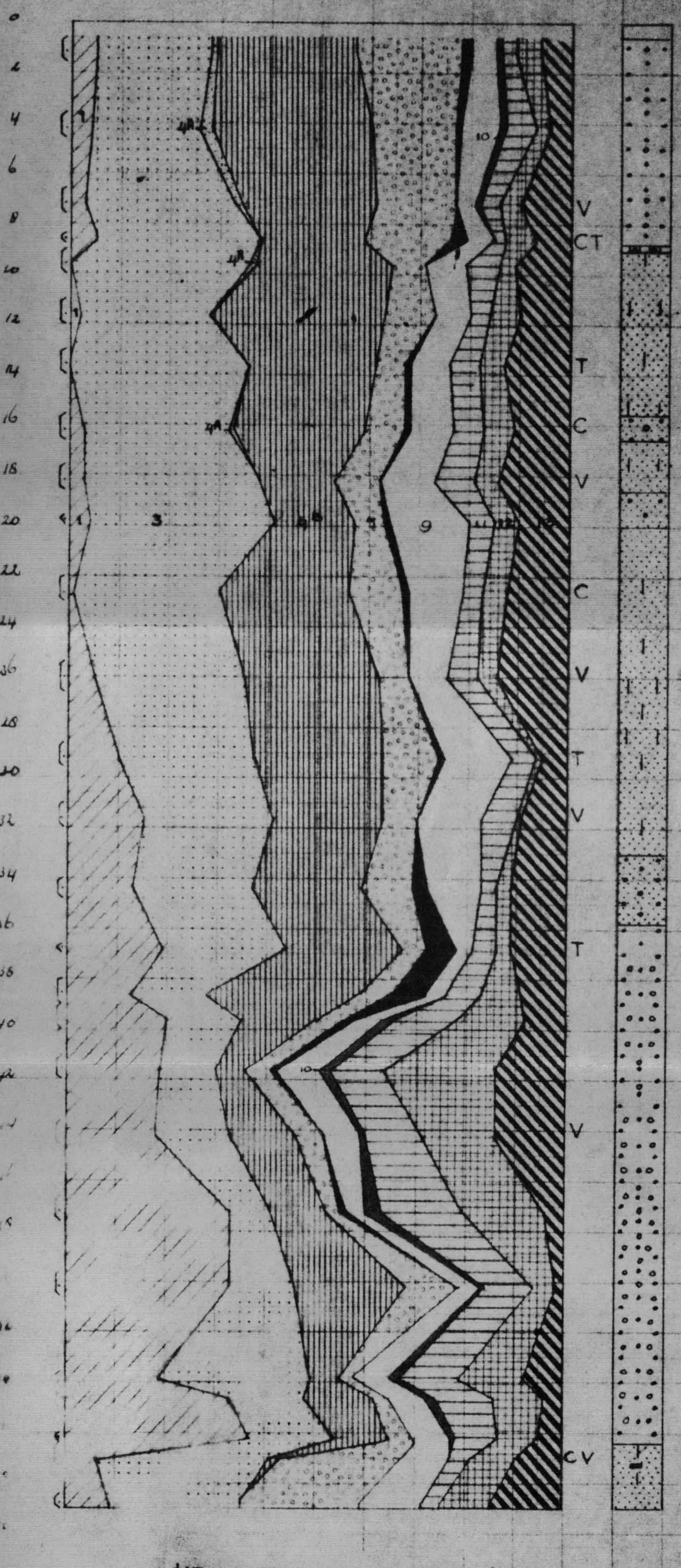
1	▨	207	granaat	
2	⬚	St. 8740	maasgranaat	
3	░	00	epidoot	
4ᵃ	░	353	saussuriet s.s.	
4ᵇ	▥	200	alteriet	
5	▒	003	hoornblende s.l.	groen bruin alkali
6	⬚	St. 0745	Vogezen _ hoornblende	
7	□	St. 8763	chloritoïd	Helder Maas
8	■		vulkanische mineralen	augiet hyperstheen baz. hoornblende Eifel - titaniet olivijn
9	□		rest	zirkoon rutiel anataas brookiet titaniet s.l. spinel pumpellyiet e.a.
10	□	St. 0731	topaas	
11	▤	266	stauroliet	
12	▦	302	metamorfe mineralen	distheen andalusiet sillimaniet
13	▧	216	toermalijn	

vertikale schaal van de diagrammen 1 : 200

1% = 1 mm

ATTACHMENT 6c

·MANDERHEIDE, POMPPUT 67-8. 28F/41



J ... '67 ...D VERZ:1659

INSTITUT FRANÇAIS DU PETROLE
DIVISION GEOLOGIE

ATTACHMENT 7

Rb1

LOG PETROGRAPHIQUE

ECHELLE VERTICALE 1.200

Mars 1965