COMMONWEALTH OF AUSTRALIA.

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BUREAU OF MINERAL RESOURCES GEOLOGY AND GEOPHYSICS.

RECORDS.

1961/141

VISIT TO UNITED STATES OF AMERICA, APRIL-AUGUST, 1961.

by

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SUMMARY

Methods used in the search for oil in the United States of America have changed since 1945 from exploring structural traps to studying and drilling stratigraphic traps. This is a report on studies of some of the subsurface stratigraphic methods used. As part of my programme preparation of detailed graphic lithological logs was learnt at the American Stratigraphic Company. The importance of such detailed logs was seen in the subsurface work done by the Stratigraphic Research Section of the Pure Oil Company and the Paleotectonic Map Group of the United States Geological Survey. The approach used by these organisations is as follows:

(a) All available literature and well logs are studied (punch card recording is very useful in this stage);

(b) subsurface framework maps are prepared using best available information;

(c) stratigraphic units are chosen;

(d) maps (tops and bottoms of units, isopachs, percent sand in clastics, lithofacies, etc.) are drawn;

(e) a brief report on the stratigraphy is prepared.

The oil companies have also encouraged research in recent sedimentation for a better understanding of stratigraphic traps. I therefore undertook some studies in sedimentation to supplement my other work. A background on modern theoretical ideas was obtained from the Convention of the Society of Economic Palaeontologists and Mineralogists held at Denver in April, 1961. Later, about a month was spent working on a project in the Sedimentation Laboratory of the United States Geological Survey. I also attended a course on Recent Sedimentation presented during the Second Summer 5-week Period at the University of Colorado, Boulder.

Some field trips in connection with my studies were undertaken and I have included some brief notes of interest on these. Other observations of interest made during my stay in America are also included in the report.

Although oil exploration in Australia is still only in the stage of searching for structural traps, processing of new information into a form which may be used later for subsurface stratigraphic studies should be done now.

INTRODUCTION

The Commonwealth Government has allocated certain funds since 1958 for sending officers overseas for experience and training in various aspects of the search for oil; the object is to train our officers in the up-to-date techniques being used in countries with most experience in the petroleum industry. In 1959 J.N. Casey visited the United States of America and Canada to obtain a general picture of the oil industry and methods used in the search for oil in those countries. W.J. Perry (1961) specialised in 1960 in techniques of photo-geology both in the United States of America and in Europe. The purpose of my visit to the United States was to examine methods used in subsurface stratigraphy and studies in recent sedimentation.

My itinerary was as follows:

April 18-23	Denver - arranging a programme of studies to be undertaken, and registering for Convention of American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists, and Rocky Mountains Association of Geologists.
April 24-28	Convention meetings and field trip to Colorado Springs and Canon City.
April 29-May 7	Denver - studies of subsurface stratigraphic methods used by Pure Oil Company; visit to the United States Geological Survey.
May 8 - 17	Field trip with Dr. E.D. McKee to study carbonate sediments of the Mississipian (Lower Carboniferous) Series in the Grand Canyon, Hell Canyon, Salt River and Black River Canyons in Arizona; younger sediments and structures were examined en route.
May 18 - 21	Denver - continued work at Pure Oil Company.
May 22 - 30	Visited Lisbon Valley, Big Flat, Desert Lake areas in south-east Utah with Pure Oil Company - observed aspects of drilling, handling of cuttings, gas and electric logging, and well completion.
May 31-June 2	Visited Pure Oil Company exploration group at Durango, Colorado.
June 3 - 19	U.S.G.S. Federal Center, Denver - work in sedimentation laboratory under Dr. McKee; visit to Ohio Oil Co. Research Laboratory, Denver.
June 20 - 28	Field trip with Mr. S. Oriel of U.S.G.S. to examine sediments and structures in Wind River Canyon and Bighorn Basin, Tertiary lake deposits in western Wyoming, with brief visit to Yellowstone National Park.
June 29-July 9	U.S.G.S. Federal Center, Denver, continued work in sedimentation laboratory.
July 10 - 23	Denver - American Stratigraphic Company - logging cores and cuttings.

July 23-Aug.23	Attending second summer school at Colorado University - lectures on "Recent Sedimentation" by Dr. Tj. H. van Andel; also visits to U.S.G.S., Denver, Phillips Petroleum Company, Petroleum Research Corporation, Denver.
Aug. 23-27	La Jolla, California, visited Scripps Institution of Oceanography.
Aug. 28-29	Union Oil Company of California, Los Angeles - visited research and palaeontological laboratories.
Aug. 30-31	Richfield Oil Corporation, Los Angeles, visited research laboratories.

I would like to thank the Director for the opportunity of making the overseas trip, Dr. Fisher, Messrs. M.A. Condon and J.N. Casey for their suggestions and help in arranging my programme, and various members of the staff for their help in organising the trip. Acknowledgement to the various institutions and companies and their staff who gave me so much attention and hospitality in the United States has been made by personal letter; I refer in particular to the Pure Oil Company, United States Geological Survey, American Stratigraphic Company, Scripps Institution of Oceanography, Richfield Oil Corporation, Union Oil Company of California, Phillips Petroleum Company, Petroleum Research Corporation and Ohio Oil Company. I am grateful also to Dr. W.F. Schneeberger and Messrs. L. Brundall and W. Bloodworth for their help.

During visits to oil companies and other organisations I obtained a lot of literature and other material which will be referred to in the text of this report. This is currently being used in reporting techniques used in America but will be deposited later in the Bureau of Mineral Resources Library.

THE WESTERN UNITED STATES OF AMERICA – LOCALITY MAP

Bureau of Mineral Resources, Geology and Geophysics, September, 1961.

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SUBSURFACE STRATIGRAPHIC METHODS AND THEIR APPLICATION

Each company dealing with logging of wells, subsurface correlation and mapping has its own approach. Some, for example, do not bother with lithologic logs for subsurface correlation and use only electric or similar types of logs (although in at least one case this was due to staff shortage in the research group); others prefer to have very detailed lithologic logs of the type prepared by the American Stratigraphic Company. I propose to outline the type of information logged by the American Stratigraphic Company, show how similar types of logs are used in the Pure Oil Company Stratigraphic Research Group and how subsurface mapping is done by the United States Geological Survey in their Paleotectonic Map Project.

1. American Stratigraphic Company (Amstrat), Denver.

I spent two weeks with Amstrat undertaking a course instructed by Mr. James Mitchell. He employs 30 stratigraphers, 3 draftsmen, 2 typists, 4 laboratory assistants and some clerical staff, and does contract well-logging for private oil companies, both in the United States and in Canada.

Under an agreement with Amstrat, companies who obtain the lithologic logs send a cut of their samples to Amstrat. When the material arrives at Amstrat it is all hand-washed (except those samples which contain salt or other solubles). The method of drying is shown in Figure 1 - sample is stacked on the side of saucepan away from burner so that water drains out of it and evaporates over flame. In this way, cuttings will not disintegrate so readily and will remain cleaner.

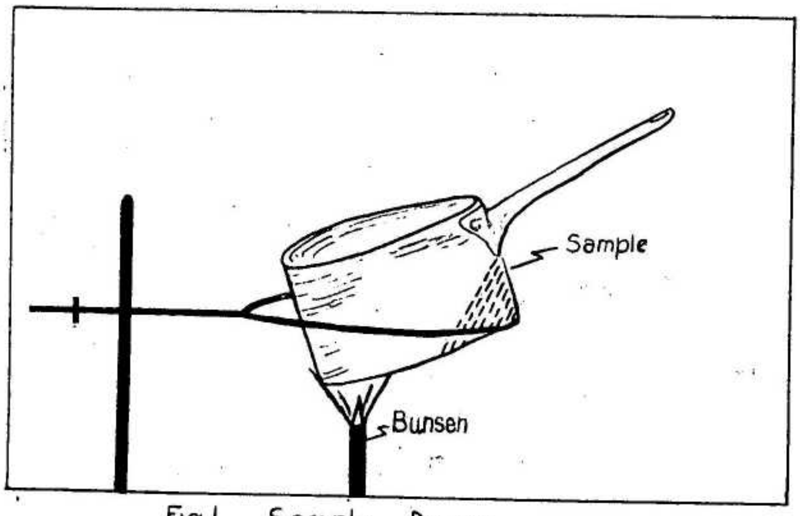


Fig I. Sample Drying

The cuttings are stored in paper envelopes with metal folding tops (as used in our own palaeontological laboratory), and then placed in long cardboard boxes. Other companies store cuttings in glass phials with screw or cork tops, or set in small clear-plastic blocks.

The equipment used by the stratigraphers is as follows: 1 binocular microscope with mm scale in one ocular,* pliers, probe-needle, tweezers, small sable-hair paint brush, watch-glasses, black pad for viewing thin sections, coloured pencils, dark box with ultra-violet light, xylene or carbon tetrachloride, 1:1 and 1:8 hydrochloric acid, oil of cloves ** and eye-dropper bottles.

The stratigraphers also use notes, colour chart, graphic log form, lithologic symbols, abbreviations prepared by Mr. Mitchell and visual porosity chart of Terry and Chilingar (1955). A sand gauge folder (prepared by Geological Specialty Company, P.O. Box 8337 Britton Station, Oklahoma City) is also useful. Copies of the lithological log key and symbol legend chart, and of the standard colour chart with a generalised log attached are included in this report as Figures 2 and 3. The colours were not reproducible for this report but a coloured chart has been included in the Chief Geologist's copy.

* the scale is 10 mm. long and divided into 100 parts. A conversion chart is available so that grainsize can be determined from the size as shown by microscope.

** oil of cloves has the same R.I. as sparry calcite and aids in finding this mineral as cement or infilling.

Preparation of the lithologic log:

The following notes have been prepared from Mr. Mitchell's latest circular dated 22nd December, 1958.

Column 1.

A. Stratigraphic relationships - Formation tops are presented in abbreviated form and summarised at the bottom of the log.

B. Footnotes - For elaborating on formations, lithology, fossils, etc.

C. Shows - Fluid contents of sediments are graded as shown on the log key.

Column 2.

Porosity types are shown on the symbol legend chart.

Column 3.

Porosity grades:

slight - trace to 6%
poor - 6 to 12%
medium - 12 to 20%
good - more than 20%

Column 4.

Detailed plotted graphic lithology based on forty-seven rock type symbols and thirty-six accessory symbols. Use of multiple accessory symbols per interval reflects observable percentages as follows:

very rare	- one symbol per thirty-foot interval
rare	- one symbol per twenty-foot interval
5 to 20%	- one symbol per ten-foot interval
20 to 40%	- two symbols per ten-foot interval
40 to 50%	- three symbols per ten-foot interval
more than 50%	- becomes the rock type and use five symbols per ten-foot interval.

Column 5.

Crystal, grain or fragment size - Wentworth Scale is used and applied both to carbonate and non-carbonate clastics. Sand gauge folder contains example samples.

Column 6.

A. Rounding of non-carbonate clastics - Sand gauge folder contains examples.

B. Types of alteration of carbonates after lithification.

Column 7.

A. Sorting of non-carbonate clastics:

P	poor	- five or more grain sizes
M	medium	- three to five grain sizes
W	wellsorted	- less than three grain sizes

B. Degree of alteration of carbonates after lithification.

With reference to carbonate rocks, Mr.Mitchell uses the word "alteration" instead of "diagenesis" because the classification includes the changes which take place after lithification and excludes compaction, submarine weathering, recrystallisation and replacement which occur during lithification. His discussion (1958, pp 5-10) on alteration of carbonates is too large for inclusion in this report.

Column 8.

Percent of framework - ratio of framework (coarse fraction) to void filler (primary cement).

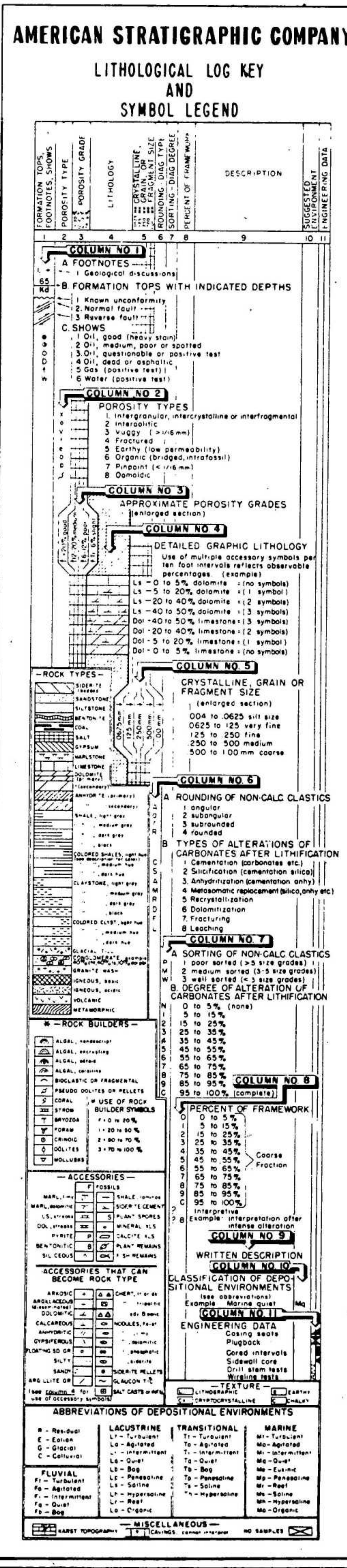
Definitions for this classification:

A. The framework is formed of material greater than 1/16 mm. in diameter. Lithic types which have a detrital framework are : conglomerates, gravels, detrital breccias, orthoquartzites, arkoses, greywackes and the calcareous fragmental sands - calcarenites and calcirudites.

B. Voids or interstices are the empty spaces in the framework.

C. Void filler (primary cement) is functionally defined as that binding material of a grainsize less than 1/16 mm. in diameter which infills the interstices of the framework.

FIGURE 2



AMERICAN STRATIGRAPHIC COMPANY
LITHOLOGICAL LOG KEY
AND
SYMBOL LEGEND
FORMATION TOPS, FOOTNOTES, SHOWS
POROSITY TYPE
POROSITY GRADE
LITHOLOGY
CRYSTALLINE, GRAIN, OR FRAGMENT SIZE
ROUNDING - DIAG TYPE
SORTING - DIAG DEGREE
PERCENT OF FRAMEWORK
DESCRIPTION
SUGGESTED ENVIRONMENT
ENGINEERING DATA
1 2 3 4 5 6 7 8 9 10 11
COLUMN NO 1
A FOOTNOTES
1 Geological discussions
B FORMATION TOPS WITH INDICATED DEPTHS
1 Known unconformity
2. Normal fault
3 Reverse fault
C. SHOWS
1 Oil, good (heavy stain)
2 Oil, medium, poor or spotted
3 Oil, questionable or positive test
4 Oil, dead or asphaltic
5 Gas (positive test)
6 Water (positive test)
COLUMN NO 2
POROSITY TYPES
1. Intergranular, intercrystalline or interfragmental
2 Interoolitic
3 Vuggy (>1/16 mm)
4 Fractured
5 Earthy (low permeability)
6 Organic (bridged, intrafossil)
7 Pinpoint (<1/16 mm)
8 Oomoldic
COLUMN NO 3
APPROXIMATE POROSITY GRADES
(enlarged section)
>21% good
12-20% medium
6-12% poor
1-6% slight
COLUMN NO. 4
DETAILED GRAPHIC LITHOLOGY
Use of multiple accessory symbols per ten foot intervals reflects observable percentages. (example)
Ls - 0 to 5% dolomite = (no symbols)
Ls - 5 to 20% dolomite = (1 symbol)
Ls - 20 to 40% dolomite = (2 symbols)
Ls - 40 to 50% dolomite = (3 symbols)
Dol - 40 to 50% limestone = (3 symbols)
Dol - 20 to 40% limestone = (2 symbols)
Dol - 5 to 20% limestone = (1 symbol)
Dol - 0 to 5% limestone = (no symbols)
- ROCK TYPES -
SIDERITE (bedded)
SANDSTONE
SILTSTONE
BENTONITE
COAL
SALT
GYPSUM
MARLSTONE
LIMESTONE
DOLOMITE (primary)
(secondary)
ANHYDRITE (primary)
secondary
SHALE, light grey
medium grey
dark grey
black
COLORED SHALES, light hue (see description for color)
medium hue
dark hue
CLAYSTONE, light grey
medium grey
dark grey
black
COLORED CLYST, light hue
medium hue
dark hue
GLACIAL TILL
CONGLOMERATE
GRANITE WASH
IGNEOUS, basic
IGNEOUS, acidic
VOLCANIC
METAMORPHIC
COLUMN NO. 5
CRYSTALLINE, GRAIN OR FRAGMENT SIZE
(enlarged section)
.004 to .0625 silt size
.0625 to .125 very fine
.125 to .250 fine
.250 to .500 medium
.500 to 1.00 mm coarse
COLUMN NO. 6
A ROUNDING OF NON-CALC CLASTICS
1 angular
2 subangular
3 subrounded
4 rounded
B TYPES OF ALTERATIONS OF CARBONATES AFTER LITHIFICATION
1 Cementation (carbonates etc.)
2 Silicification (cementation silica)
3. Anhydritization (cementation anhy)
4 Metasomatic replacement (silica, anhy etc)
5 Recrystallization
6 Dolomitization
7. Fracturing
8 Leaching
COLUMN NO. 7
A SORTING OF NON-CALC CLASTICS
1 poor sorted (>5 size grades)
2 medium sorted (3-5 size grades)
3 well sorted (<3 size grades)
B. DEGREE OF ALTERATION OF CARBONATES AFTER LITHIFICATION
N 0 to 5% (none)
1 5 to 15%
2 15 to 25%
3 25 to 35%
4 35 to 45%
5 45 to 55%
6 55 to 65%
7 65 to 75%
8 75 to 85%
9 85 to 95%
C 95 to 100% (complete)
COLUMN NO 8
PERCENT OF FRAMEWORK
0 0 to 5%
1 5 to 15%
2 15 to 25%
3 25 to 35%
4 35 to 45%
5 45 to 55%
6 55 to 65%
7 65 to 75%
8 75 to 85%
9 85 to 95%
C 95 to 100%
Coarse Fraction
? Interpretive
? 8 Example: interpretation after intense alteration
COLUMN NO 9
WRITTEN DESCRIPTION
COLUMN NO 10
CLASSIFICATION OF DEPOSITIONAL ENVIRONMENTS
(see abbreviations)
Example Marine quiet Mq
COLUMN NO 11
ENGINEERING DATA
Casing seats
Plugback
Cored intervals
Sidewall core
Drill stem tests
Wireline tests
* - ROCK BUILDERS -
ALGAL, nondescript
ALGAL, encrusting
ALGAL, oolitic
ALGAL, coralline
BIOCLASTIC OR FRAGMENTAL
PSEUDO OOLITES OR PELLETS
CORAL
STROM
BRYOZOA
FORAM
CRINOID
OOLITES
MOLLUSKS
* USE OF ROCK BUILDER SYMBOLS
F = 0 to 20%
1 = 20 to 50%
2 = 50 to 70%
3 = 70 to 100%
- ACCESSORIES -
F FOSSILS
MARL, limy
MARL, dolomitic
LS, streaks
DOL, streaks
PYRITE
BENTONITIC
SILICEOUS
SHALE, laminae
SIDERITE CEMENT
PLANT SPORES
MINERAL XLS
CALCITE XLS
PLANT REMAINS
FISH REMAINS
ACCESSORIES THAT CAN BECOME ROCK TYPE
ARKOSIC
ARGILLACEOUS (disseminated)
DOLOMITIC
CALCAREOUS
ANHYDRITIC
GYPSIFEROUS
FLOATING SD GR
SILTY
SANDY
ARGILLITE GR
CHERT
tripolitic
NODULES
limy
dolomitic
phosphatic
siderite
SIDERITE PELLETS
GLAUCONITE
SALT CASTS
(see column 4 for use of accessory symbols)
- TEXTURE -
LITHOGRAPHIC
CRYPTOCRYSTALLINE
EARTHY
CHALKY
ABBREVIATIONS OF DEPOSITIONAL ENVIRONMENTS
R - Residual
E - Eolian
G - Glacial
C - Colluvial
FLUVIAL
Ft - Turbulent
Fa - Agitated
Fi - Intermittent
Fq - Quiet
Fb - Bog
LACUSTRINE
Lt - Turbulent
La - Agitated
Li - Intermittent
Lq - Quiet
Lb - Bog
Lp - Penesaline
Ls - Saline
Lh - Hypersaline
Lr - Reef
Lo - Organic
TRANSITIONAL
Tt - Turbulent
Ta - Agitated
Ti - Intermittent
Tq - Quiet
Tb - Bog
Tp - Penesaline
Ts - Saline
Th - Hypersaline
MARINE
Mt - Turbulent
Ma - Agitated
Mi - Intermittent
Mq - Quiet
Me - Euxinic
Mp - Penesaline
Mr - Reef
Ms - Saline
Mh - Hypersaline
Mo - Organic
- MISCELLANEOUS -
KARST TOPOGRAPHY
CAVINGS, cannot interpret
NO SAMPLES

FIGURE 3

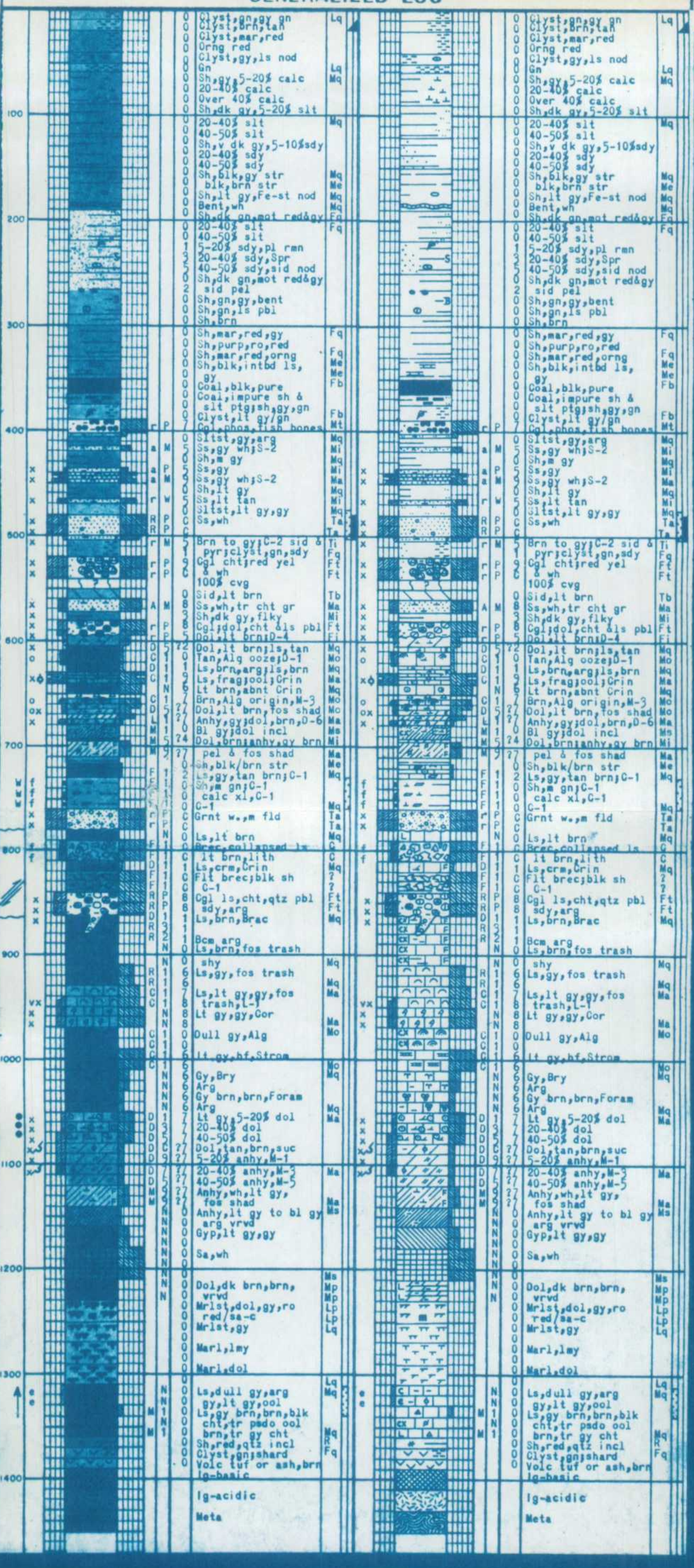
AMERICAN STRATIGRAPHIC COMPANY

— STANDARD COLOR CHART —

COLORED		BLACK & WHITE
	CLAYSTONE gray	
	red	
	green	
	brown	
	SHALE light gray to black	
	red	
	green	
	brown	
	SHALE, green mottled red	
	SILTSTONE	
	SANDSTONE	
	LIMESTONE *(clastic ratio from 7 to C)	
	LIMESTONE *(clastic ratio from 0 to 6)	
	MARLSTONE	
	DOLOMITE secondary	
	DOLOMITE (primary?) chemically precipitated	
	MARLSTONE, dolomitic	
	SIDERITE	
	ANHYDRITE	
	ANHYDRITE secondary (metasomatic)	
	GYPSUM	
	SALT	
	volcanic, metamorphic, basic, acidic — IGNEOUS	

* Percent of framework (coarse fraction)

— GENERALIZED LOG —



For operational reasons 1/16 mm. has been chosen as the grainsize break between framework and void filler because

(a) fractions of clay and silt size tend to nullify porosity for economic production of fluids;

(b) this is the grainsize division point between siltstone and sandstone, as well as between calcilutites and calcarenites;

(c) this is the grainsize at which dominant transportation by suspension ceases and transportation by saltation becomes dominant.

It is realised, however, that calcareous dust and fragments of silt size may be produced by abrasion of shell debris and that quartz silt grains are commonly of detrital origin. Therefore the definition of void filler is arbitrary and is functionally related to producible primary porosity.

Shales, claystones, mudstones, silty claystones, etc., and evaporites will be classified as 0. If evaporites are observed as crystals greater than 1/16 mm. it will be assumed that this is alteration after lithification and therefore a form of recrystallisation.

Where carbonates have been altered by dolomitisation, recrystallisation, silicification, etc., to such an extent that original relation of framework to void filler is obscured, a question mark (?) is used in place of the ratio figure. However, in many instances the stratigrapher studying the samples finds evidence which allows him to make an interpretation concerning the framework ratio of the carbonate before alteration:

(a) shape and abundance of relic structures;

(b) shape and abundance of voids after fossils;

(c) texture and arrangement of dolomite crystals;

(d) relationship to overlying and underlying beds;

(e) known lateral stratigraphic relationships;

(f) distribution of calcic content in a dolomite.

Such an interpretation is reported as a question mark (?) followed by a ratio.

The relationship between framework and porosity is discussed later.

Column 9.

Written description -

The main properties remaining to be described are :

A. Colour

B. Fauna

C. Miscellaneous significant data such as degrees of alteration etc.

Column 10.

Classification of depositional environments in thirty-seven units which can be determined from well cuttings and cores. (see Appendix I).

Column 11.

Engineering data showing positions of casing seats, cored intervals and drill-stem test intervals.

Relationship of framework to void filler.

(1) Pettijohn (1957) shows that with hand packing of perfect spheres so that they form a cube, a porosity of 48% may be obtained. This is the maximum possible porosity with spherical particles of the same size. With natural packing of clean, clastic sands, 30 to 35% maximum primary porosity is generally obtained. The maximum porosity figure used in consideration of framework and void filler is therefore 33±%. Where the framework of a sand is 100% (i.e. no void filler) it is called C (complete) and has maximum primary porosity of 33±%. When framework is 90% of sediment (=9), primary porosity is reduced to 23±%.

For 80%	framework	(=8),	porosity	=	13±%
For 70%	"	(=7),	"	=	3±%
For 67%	"	(=7),	"	=	0
For 60%	"	(=6),	"	=	0
For 50%	"	(=5),	"	=	0, etc.

This means that for framework 7 up to C, sediment has had some kinetic energy applied to winnow out fine material; from 6 to 0 means quiet environment where not enough kinetic energy to remove fines.

(2) For sediments in any particular area, the properties of grainsize, shape and sorting have a small effect on their porosity. This may be determined by experience with the rocks of that area. For sedimentary rocks in the Rocky Mountains area, the following factors were applied :

(a) grainsize -

very fine to fine-grained	+1%
medium-grained	0
coarse to very coarse-grained	-1%

(b) shape -

angular	-2%
sub-angular	-1%
sub-rounded	+1%
rounded	+2%

(c) sorting -

poorly-sorted	-2%
medium-sorted	0
well-sorted	+2%

(3) In subsurface logging, a balance is possible between observed porosity, properties of sediment and degrees of alteration. This is best shown by example :

If a sand from the Rocky Mountains region is medium-grained, rounded, medium-sorted and has a framework ratio of 9:1, primary porosity is determined as

0 + 2 + 0 + 23±% = 25±% ;

but observed porosity is only 10% ;

therefore 15% by plugging (e.g. by silicification) should have also been observed, and in this example an "S1" or "S2" symbol included in column 9.

(4) In the case of carbonate rocks (calcarenites etc.) the framework ratio will give no indication of porosity; these may have primary porosities from 0 to 61%.

References :

I have the following literature from Amstrat for reference:

James T. Mitchell's notes on

"New Method of Recording and Presenting Stratigraphic Data";

"Alteration of carbonates after lithification";

"Ratio of framework to void filler";

"Classification of depositional environments for subsurface studies";

"Hypothetical succession of beds to illustrate logging practices".

Much of this was written in January, 1958 and revised in December, 1958. To the notes I have added some new and different ideas developed by Mr. Mitchell since then. The "Classification of depositional environments for subsurface studies" has been included as Appendix I of this report.

Stratigraphers at Amstrat also use the abbreviations in

MITCHELL, J.G. & MAHER, J.C., 1957 - Suggested abbreviations for lithologic descriptions. Bull.Amer.Ass.Petrol.Geol.,41(9),2103-2107.

and the porosity chart of

TERRY, R.D. & CHILINGAR, G.V.,1955 - Summary of "Concerning some additional aids in studying sedimentary formations" by M.S. SHVETSOV. J.Sediment.Petrol., 25(3), 229-234.

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FOLK, R.L., 1959 - Practical petrographic classification of limestones. Bull.Amer.Ass.Petrol.Geol., 43(1), 1-38.

HAUN, J.D. & LeROY, L.W., 1958 - Subsurface geology in petroleum exploration. Colorado School of Mines, Golden, Colorado.

HEDGPETH, J.W.,1957 -Treatise on marine ecology and paleoecology. Mem.geol.Soc.Amer.67, Vols.I and II.

PETTIJOHN, F.J.,1957-Sedimentary Rocks,2nd Ed.Harper and Bros.N.Y.

SHIMER, H.W. & SHROCK, R.R., 1944 - Index fossils of North America. N.Y., Wiley.

2. Pure Oil Company, Denver and Durango, Colorado.

Between April and June, I spent some time with the Pure Oil Company studying their approaches to subsurface stratigraphy in both the stratigraphic research office, Denver and the exploration group center in Durango, Colorado. I also visited their field drilling section which is centred in Moab, south-east Utah, to observe logging and drilling techniques in their Lisbon Valley, Big Flat and Desert Lake fields (south-east of Moab to just south of Price).

Oil search in a region is approached in the following stages :

(1) preliminary regional geological and geophysical investigations and exploratory drilling to determine the regional strudtures;

(2) more detailed investigations including drilling to define smaller possibly important structural features within the main structures; approach still related to closure of structures;

(3) stratigraphic research to determine possible pinch-outs, permeability barriers, and other stratigraphic traps.

Stage (1):

The main regional units to be studied are generally decided after literature and logs of old wells in the region have been examined. These units are then investigated in the following way :

(a) aerial photograph interpretation of the areas involved (cheapest way is by contract);

(b) geophysical traverses - magnetic method may be used first to determine basement structure; gravity surveys are sometimes run to find main structural trends;

(c) comparison of results of (a) and (b) and determination of relative importance of the subsurface structures.

(d) some long reconnaissance seismic lines may be run across strikes to define main subsurface structures more precisely.

Some wildcat drilling may accompany Stage (1). Particular attention is paid to collection of cuttings and to coring of tops of formations. (Some notes on well logging are given in Appendix II). At the end of Stage (1) possible producing formations and the more important large structures of the region are known.

Stage (2):

The more important large structures are subjected to detailed seismic surveys. Reflection methods are preferred but refraction methods are more useful where faults are suspected. Further wells are drilled on medium and small-scale structures as they are discovered.

As part of the Stage (2) programme, special studies on good producing formations may be started, and continued into Stage (3). A contour map of the top of the formation on a regional scale is prepared - it will show areas where the formation is shallow enough to warrant further drilling for economic exploitation. Other important or useful maps are the isopach, hydrodynamic, salinity (see Edie, 1958), porosity, and lithofacies (see Sloss, Krumbein & Dapples, 1949) maps. The lithofacies map, however, is more commonly prepared in Stage (3).

Stage (3):

Stages (1) and (2) are generally undertaken by well-site and exploration groups of the company; Stage (3) is done by the Stratigraphic research group. Their procedure is as follows:

a. All available literature is studied and stratigraphic detail noted for preparing and dividing sections; important detail for report noted; bibliography prepared;

b. Wells in the area are examined with respect to depth, spacing and available information, and the best are used in forming a subsurface framework; cuttings and cores from these wells are logged in detail and the graphic lithologic logs are combined with any other types of available logs to form "composite interpretive logs" at vertical scale 100 feet to the inch (see Maher, 1959);

c. Other useful data from literature and well logs are filled into framework; sections at vertical scale 200 feet to the inch - but at no set horizontal scale - are drawn for comparison and division into stratigraphic units; data are extracted from composite interpretive logs and placed on stratigraphic analysis sheets, (see Appendix III);

d. The next step is map preparation - first a map showing well localities and oil and gas occurrences, then maps prepared from the stratigraphic analysis sheets as required; they may include maps of tops or bottoms of units, isopachs, percent sand in clastics, percent lime in non-clastics, lithofacies, etc. ;

e. A brief report on the stratigraphy is prepared to accompany and explain the series of maps.

The sample log prepared by Pure Oil Company is similar to that detailed by Maher (1959) and entails more written description but less columns that the Amstrat log. The samples are examined, described, and plotted on the log in one operation. Maher carefully describes the preparation of composite interpretive logs - equipment and materials, their arrangement for logging, the procedure, and systematic description of samples. The abbreviated description of the sample is lettered with a crow-quill pen and drawing ink at the right of the well column. Symbols both in black ink and colour are plotted in the well column and to the left of the column.

Both the Amstrat type of log and Maher's log are interpretive and are a combination of the driller's type of log, where only predominant rock symbols are shown, and the percentage log.

References :

EDIE, R.W., 1958 - Mississippian sedimentation and oilfields in south-eastern Saskatchewan. Bull.Amer.Ass. Petrol.Geol., 42(1), 94-127.

MAHER, J.C., 1959 - The composite interpretive method of logging drill cuttings. Oklahoma Geol.Surv.Guide Book VIII.(I obtained a copy of this publication).

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SLOSS, L.L., KRUMBEIN, W.C. & DAPPLES, E.C., 1949.- Integrated facies analysis. Mem.geol.Soc.Amer. 39.

3. The United States Geological Survey Paleotectonic Map Project.

I have prepared some notes on this project because a similar approach might be one of the most useful contributions which the Bureau of Mineral Resources can make to oil search in Australia in addition to its programme of regional mapping. We would not be able to do this yet in as much detail as the United States Geological Survey; however, frameworks of the type mentioned in Stage (3) b.above have been started by the Institut Francais du Petrol for Australian basins and continuation of this work could lead to preparation of palaeotectonic maps at a later date. Drilling in Australia is not beyond the closed-structure exploratory stage and there is no immediate need for subsurface stratigraphic maps; but this need will also eventually arise.

The following notes were prepared after discussion with Mr. S.S. Oriel of the United States Geological Survey; Mr. Oriel has spent 8 years working on the Palaeotectonic Map Project under Dr. E.D. McKee. Dr. McKee also contributed some comments to these notes.

To prepare maps and figures used in the folios of the Palaeotectonics of the Jurassic, Triassic and Permian Systems, more than 20,000 control points were established in each system. Six to sixteen geologists have been employed at various times during the compilations, and each project has taken from 2 to 3 years. These facts give some idea of the large amount of work and time required for such projects.

In order to decide how many men will be needed on a project, an idea of the amount of data available is first obtained. It must be remembered, however, that at the small scale at which maps are drawn for the project, only selected data are used in some areas. An estimate is also made of how much data one man can process in 2 to 3 years. The country is then divided into a number of areas on the basis of the amount of the particular geological system in the area and the density of its available data, each area being capable of completion in 2 to 3 years by one man.

Each man is introduced to his work by giving him a copy of a completed folio to study - this will show him the scope of the report and the small scale at which he will be preparing maps. His next step will be to learn the punch-card system used for recording data. Instruction sheets explaining the use of the punch cards, and lists of standard symbols, abbreviations etc. to be used are issued to each person. The first step in the project is then commenced.

(i) General review. During the first six months of the programme each man tries to get a general idea of the work to be done. The necessary steps, outlined below, may be undertaken concurrently or as opportunity arises.

A. Reading. Articles to be studied must be sought from all sources: Federal surveys, state surveys, field trip guide books (although private company reports are not available from many sources, some of their information may be found in guide books), bulletins and journals of geological societies; university theses may be useful for some localities, etc. Very useful tools for American projects are the correlation charts which their National Research Council is preparing for each system (for example see Imlay, 1952 - Jurassic.) Well logs may also be briefly examined at this stage to see how much detail is available, what kinds of units are represented and how they compare with measured surface sections in nearby or distant places. A small author index card is used for literature to be recorded in Bibliography; punches may be made in these cards for the systems covered by the report. Samples of this type of card and of other punch cards used are available for reference.

B. As important information is found, it is recorded on punch cards. If conducted properly, it should not be necessary to refer back to any specific publication. Punch cards are prepared for localities where measured sections are available and for wells whose logs are used, and special cards are used for other important information. Each locality for which a section is available is treated as follows:

(a) it is given a number according to which state it is in (i.e. each state is numbered separately), and in the order in which it is found in the literature;

(b) cards are prepared for each formation in the section at the locality, and each card bears the number of that locality;

(c) the cards for each formation show the system to which it belongs, the author and source of information, total thickness of formation, types of rock in the formation and their individual thicknesses, overlying formation and underlying formation, (see McKee, 1954).

An improvised card has been prepared to include all formations and their lithologies for well log sections, because they generally have many more formations represented than outcrop localities; this is an expedient to speed up the programme. Special cards may record acknowledgements, ideas on thickness and lithofacies trends, origin and source of sediments, palaeogeography, palaeotectonics, climate etc.

C. All points from where measured sections are recorded or wells whose logs are available are plotted on a base map (published at 1 : 5,000,000, compiled at 1 : 1,000,000 or 1 : 2,500,000) which is included as a locality map. This base map should be available for plotting at the start of reading. Not only will this show where data are available but also where too much information is being accumulated. Various symbols are used for different types of data.

D. A field trip into the area to see the rock types and sections is considered desirable within the first six months of the project. A visit to local geological authorities is also useful, and one may obtain

(i) new ideas about genetic interpretations, information of newly-found fossils etc., which have not been published;

(ii) details of other available data (much unpublished) and how long it would take to obtain copies.

A quick examination of cores and cuttings of chosen wells in the area should also be undertaken during the first stage of the project to provide a basis for evaluating and interpreting available sample descriptions.

When examination of the amount and quality of data available and problems of the area is completed, the information which has been recorded may be processed in detail.

(ii) Selection of Intervals. In the second stage of the project only the most complete and correct data at well-spaced localities are used; more general data is on punch cards for later use. The system is divided during this stage into a number of "intervals".

The selection of intervals is done in 4 steps :

A. (a) Prepare strip logs of selected surface sections
   (b) Obtain some well logs of subsurface sections
   (c) Try to obtain correlations between adjacent sections (This may be done simply by using a metal-backed wall and attaching strip logs to wall with magnets.)

B. Draw a number of stratigraphic cross-sections for the area; good control has been obtained by having sections for small parts of the area greater than 40 but less than 100 square miles.

C. Choose the best intervals; the more subdivisions the better as far as preparation of lithofacies maps and determining geological history of the area is concerned. However, the greater the number of boundaries, the more problems arise in correlation on a country-wide scale.

D. Compare and match the intervals chosen with the intervals in neighbouring areas, and when agreement is reached, finalise division of sections.

The number of intervals chosen for each system in palaeotectonic maps in the U.S.A. to date has varied from 3 to 6.

This is a very important stage because the validity of the whole project depends on the validity of the intervals chosen and of their correlation across the country. Distinctive tops and bases are essential for the system and each of its intervals. (The intervals are not necessarily "series" as defined by the Stratigraphic Nomenclature Committee - they include strata between recognisable lithologic horizons which, it is hoped, approach but need not coincide precisely with equal-time horizons).

(iii) Map Preparation. Maps to be prepared are decided on basis of data available, and whether their inclusion will contribute more knowledge of the system. Different types may be superimposed, provided that the resultant map is clear. A manual of mapping conventions is provided for each geologist engaged in the project.

Before each map is prepared, the relevant punch cards are grouped - all data are included in this stage of the programme, and this allows interpolation between those selected localities used in preparing sections in the second stage. (Alternatively, data required for maps of the system, and for maps of the intervals may be extracted and listed on separate sets of punch cards.)

Maps which may be prepared are as follows :

A. for the system - isopach, palaeogeologic (rocks below system), suprageologic ;

B. for each interval - isopach, lithofacies (a block of 24 patterns, and some special patterns for lithofacies maps are included in the mapping conventions) ;

C. other types for system or interval depending on available data -
detrital ratio, ratio of sandstone to mudstone, ratio of limestone to dolomite, ratio of carbonate to sulphate; special maps may show amount of coal to aggregate thickness of section, relations of different properties of sediments (e.g. ratio of carbonaceous to other mudstone, distribution of different coloured mudstones), etc.

Because of their genetic and potential economic implications all such maps make valuable contributions if they can be included.

The maps prepared above are of rocks and units as they are known; it should also be possible to prepare interpretive maps from them: e.g. interpretive isopach map based on isopach and lithofacies trends - restoring thicknesses known to have been reduced by erosion since deposition, map of source areas - from directions of cross-bedding, changes in grainsize of detritus, etc., and, inferred margins of deposition.

These maps are very useful in showing the geological history of the system and its intervals.

(iv) Report.

This explains why and how the maps have been prepared and the significant results thereof. It should enable any reader to reproduce the results himself if he wishes to continue the mapping as additional information becomes available. The text describes the stratigraphic limits of units used. Trends and their significance are also discussed. Some space is devoted to important local problems in the areas allocated to the contributing geologists.

The purpose of such a project is to synthesize all of the vast amount of available stratigraphic information (published and unpublished) for each geological system and to present it as an up-to-date summary reference for further scientific research (in both academic and economic fields.)

(v) References.

IMLAY, R.W., 1952 - Correlation of the Jurassic formations of North America, exclusive of Canada. Bull.geol.Soc.Amer., 63, 953-992.

(v) References contd.

McKEE, E.D., Paleotectonic map project. A brief outline of the undertaking for the U.S. Geological Survey (unpubl.)

________, 1954 - Use of revised stratigraphic punch card. Memorandum to geologists of Paleotectonic Map Project. (unpubl.)

McKEE, E.D., ORIEL, S.S., SWANSON, V.E., MacLACHLAN, M.E., MacLACHLAN, J.C., KETNER, K.B., GOLDSMITH, J.W., BELL, R.Y. and JAMESON, D.J., 1956 - Paleotectonic maps of the Jurassic system. U.S. geol.Surv., Misc.geol.Inv., Map I, 175.

McKEE, E.D., ORIEL, S.S., KETNER, K.B., MacLACHLAN, M.E., GOLDSMITH, J.W., MacLACHLAN, J.C. and MUDGE, M.R., 1959 - Paleotectonic maps of the Triassic system. U.S. geol.Surv., Misc.geol.Inv., Map I, 300.

U.S. GEOLOGICAL SURVEY - Guide for organizing data in preparation of text for Permian folio. (unpubl.)

________ - Manual of conventions for geologists on the paleotectonic map project. (unpubl.)

Copies of publications and articles listed above, except Imlay (1952), were obtained for reference.

STUDIES IN RECENT SEDIMENTATION

A tremendous amount of research in recent sedimentation has been undertaken in the U.S.A. since World War II; this is because of the interest by oil companies in stratigraphic traps instead of structural traps as reservoirs for oil. (Dr. van Andel in lectures at Colorado University during July, 1961 stated that research in modern sediments was stimulated by American Petroleum Institute Project 51 in which 40 scientist man-years and $1,000,000 have been spent; this project has been possible mainly through the efforts of the American Association of Petroleum Geologists and the American Petroleum Institute.) The studies which I made in recent sedimentation while in America were therefore undertaken to supplement my studies in subsurface stratigraphy.

My programme in America allowed me to study recent sedimentation both in a theoretical sense, first at the convention of the Society of Economic Paleontologists and Mineralogists in April, and later at lectures at Colorado University, and in a practical sense at the Sedimentation Laboratory of the United States Geological Survey. In addition, I was able to visit the Ohio Oil Company Research Centre near Denver where work on recent sediments is being undertaken, and also to spend two days at Scripps Institution of Oceanography at La Jolla, near San Diego, southern California.

1. S.E.P.M. Convention.

The convention of the Society of Economic Paleontologists and Mineralogists was held in conjunction with the American Association of Petroleum Geologists, and the Rocky Mountains Association of Geologists in April at Denver, Colorado. The main theme of the S.E.P.M. meetings was sedimentation:

April 24 p.m., 25 p.m. - Symposium - Water movements and sedimentation.

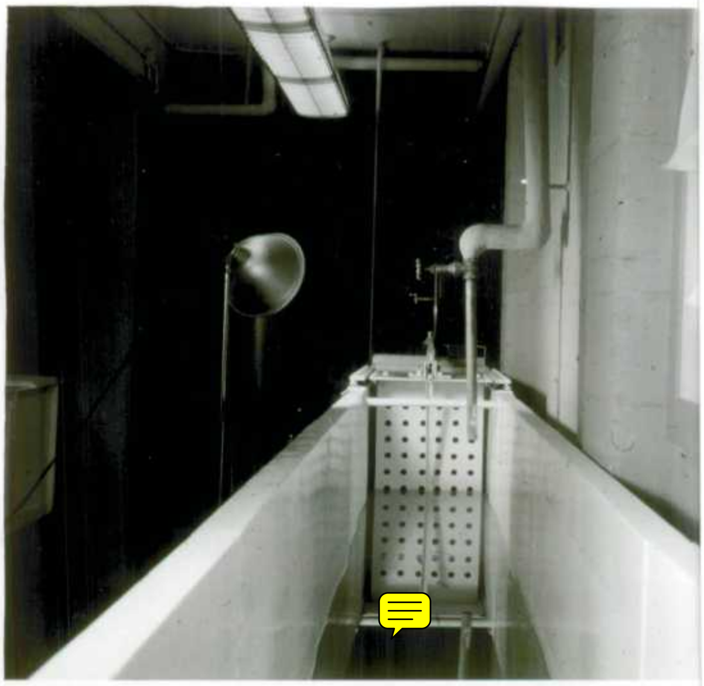
April 26 a.m., p.m., 27 a.m. - Sedimentation and Sedimentary petrology.

April 27 p.m. - Symposium - Classification of carbonate rocks.

Forty papers were given during these meetings. The two symposia produced the most interesting discussions; many good papers were presented on sedimentation and sedimentary petrology but some others were too restricted in their scope. No attempt will be made to summarise any of these papers in this report; this has been done in the handbook of the meetings, a copy of which is available for reference.

2. Sedimentation Laboratory, United States Geological Survey.

Work in the Sedimentation Laboratory was done during various intervals in June, July and August under the supervision of Dr. E.D. McKee. The laboratory is equipped with three tanks: wave-tank, delta-tank (see Plates 1 and 2) and another tank in which stream movement of sediments may be simulated. The project on which I worked was conducted in the delta-tank; I was helped by Mr. C. Baker, Dr. McKee's assistant, who was also engaged in wave-tank experiments while I was there. Mr. Y. Nir of the Israel Geological Survey participated in the first part of the delta-tank project.



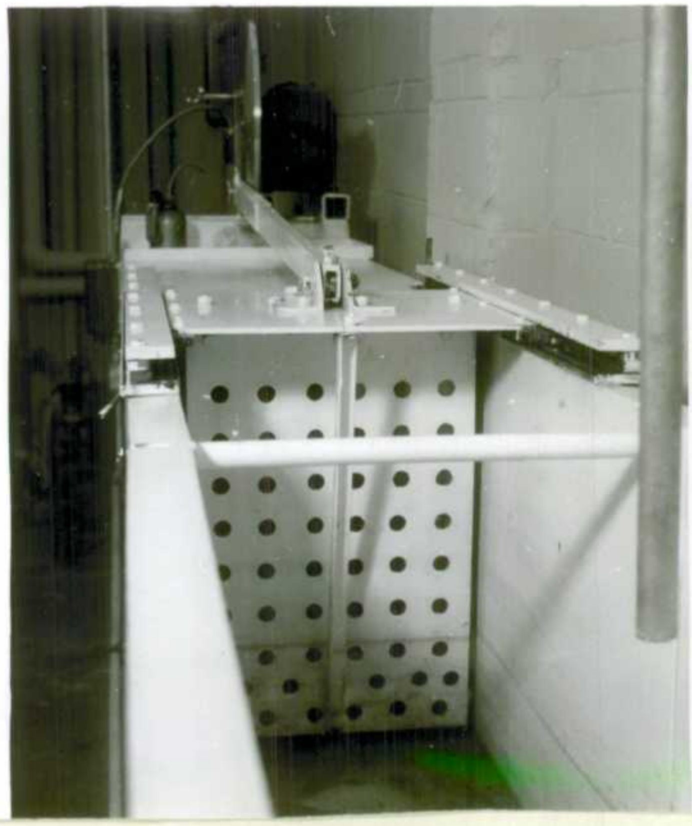
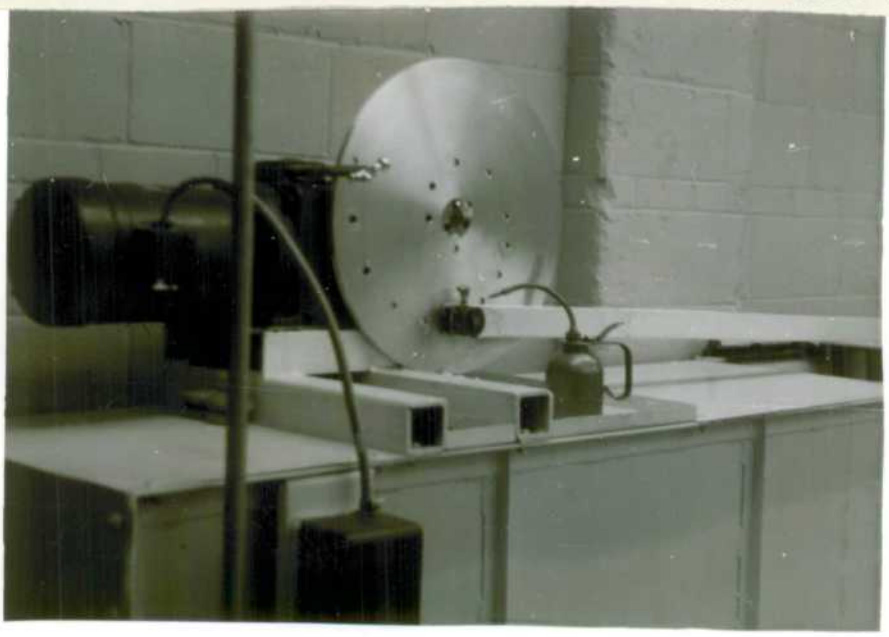
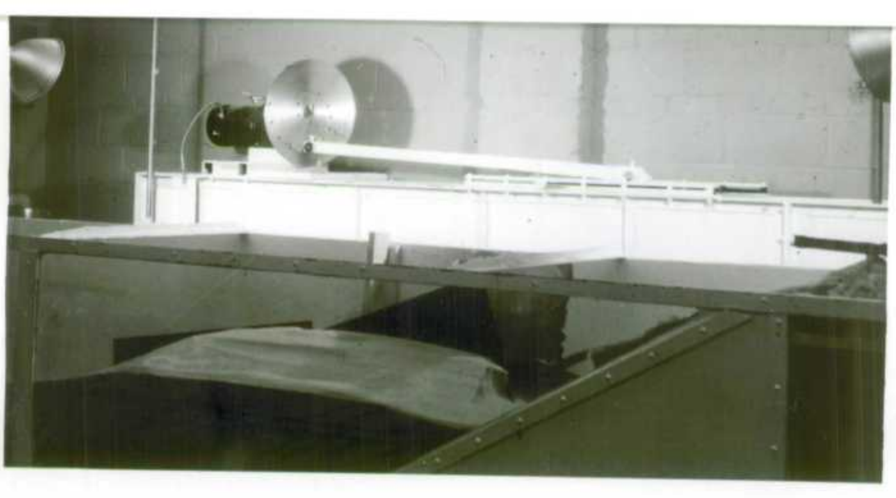


Fig.1. Baffle plate to generate waves:
1a. With water in tank.

1b. Tank empty.



2a. Close-up.



2b. Distant shot showing arm to baffle plate. (Delta Tank in foreground)

Fig.2. The motor and circular disc drive of the baffle plate. Position of arm attachment may be varied to different holes of disc to change wave length.

<u>PLATE 1.</u> Wave tank, Sedimentation Laboratory, United States Geological Survey, Denver.
(Figs. 1b and 2a by courtesy Mr. J.N. Casey.)

Fig.1. Side view. Delta slope at right is at 30°.

Fig.2. Sand is hosed into tank from shelf in foreground. Water level in tank controlled by valve outlets in far end of tank (one outlet is hidden by bar).

PLATE 2. DELTA TANK, Sedimentation Laboratory,
United States Geological Survey, Denver.

(Figs. 1 and 2 by courtesy Mr. J.N. Casey).

During experiments in the tanks, Dr. McKee (1957) has developed satisfactory methods of recording any structures which formed. Stratification planes are marked as they are developed by sprinkling fine magnetite grains on the sediment surface. The attitude of the strata at any one time may be permanently recorded :

(1) by marking the magnetite lines on the glass window of the tank with a grease pencil and subsequently tracing on to a sheet of transparent paper;

(2) by photography;

(3) by draining off the water, cutting through the deposit with a long knife to form a smooth vertical section, impregnating the freshly exposed surface with liquid rubber spread on a thin board which is wedged against the surface, and finally after 2 or 3 days slicing the impregnated face of sediment free from the mass and allowing it to dry on the board.

A. Delta-tank experiment.

Projects in the delta-tank are generally devoted to producing sedimentary structures. We were engaged in trying to form apparently "overturned" recumbent folds in sand strata in normal flat-bedded or cross-bedded sets of strata. These have been reported from Recent sediments as well as from sandstones in the geological column in different parts of the world. An understanding of how they were formed may give a clue to the environment of their deposition, and hence an idea of how big the sandstone units might be, their other properties, and of their possible economic importance. A report on the methods used and the results is currently being prepared; only a brief summary is given here :

The delta-tank is shown in Plate 1, Figure 2b and Plate 2. It is 15 feet long, $2\frac{1}{2}$ feet wide, and 2 feet high for about 11 feet of its length; beyond this point the bottom rises along a 30° slope to a platform at the top of the tank. To commence experimental work, water was added to the deep part of the tank until its level was high enough to allow formation of fairly long sand strata over the 30° slope. Water level may be altered by using any of the four outlet valves. When required water level was obtained, sand was piled on the high platform at the end of the tank and washed with a hose down the slope. This process was stopped at regular intervals to spread magnetite on the sediment surface. The slope of the strata formed depended on the speed with which the sand was added; the more slowly the sand was washed in, the steeper the strata. Strata formed were tested as follows :

(a) by piling heavy weights on the topset part of the strata;
(b) by dragging a heavy bag of sand across the strata;
(c) by pushing a flat board horizontally through them;
(d) by allowing "groundwater" to seep from a high level "lake" through the strata and undercut the lower part of the foreset strata;
(e) by undercutting the foreset strata with a slowly rising water level and also with a faster increase in water level height.

Where possible these tests were performed on saturated sand (i.e. under water), on wet sand (water drained out of tank), and on dry sand. Although some of the methods are artificial, it is believed that if an effect can be produced artificially, a clue is available as to how the effect may be produced by a more natural process.

The best results were obtained by using saturated sand strata with low dip and by dragging a heavy sand bag across them. It was found, however, that strata from which water was drained and later re-saturated reacted differently to this force; newly formed strata were therefore needed before "over-turning" occurred. The results of one successful experiment are shown in Plate 3. Subsequently, Mr. Baker caused a large mass of sand to slide over a set of saturated strata and "overturn" them. The effect is actually one of "dragging over" rather than of "turning over" in the normal sense. It is probably produced in nature by rapid piling of sediment above topsets of deltaic-type sand strata, overloading and sliding of the unstable mass of sediment over the strata. The most logical environment seems to be the deltaic zone built at the mouths of large active streams which occasionally suffer torrential flooding.

B. Stream-flow tank.

The stream-flow tank was not used during my visits to the laboratory but has been used in the past to produce some interesting results. The tank is 15 feet long, 2½ feet wide and 1 foot high. McKee (1957) produced in this tank cross-stratification which appeared to be upside down; it consisted of festoons that were convex upward, and formed by coalescing lobes at the front of deltas advancing ahead of two stream sources.

C. Wave-tank - Experiments on the form and structure of offshore bars and beaches.

The wave-tank is 45 feet long and equipped with a baffle run by a small electric motor to generate waves, (see Plate 1). Factors which may be varied for experimental work are the wave length (altered by changing hole in rotating disc to which baffle plate arm is attached), height of water, and type of sand. A series of experiments was started by McKee and Sterrett (1961) and is being continued by Mr. C. Baker under Dr. McKee's supervision.

Some useful references to Dr. McKee's work may be found in:

McKEE, E.D., Form for describing sedimentary rocks. Type written report. Copy available for reference.

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McKEE, E.D. & STERRETT, T.S., 1961. Laboratory experiments on the form and structure of longshore bars and beaches. Amer.Ass.Petrol.Geol., "Geometry of Sandstone bodies".

McKEE, E.D. & WEIR, G.W., 1953 - Terminology for stratification and cross-stratification in sedimentary rocks. Bull.geol.Soc.Amer., 64, 381 - 390.

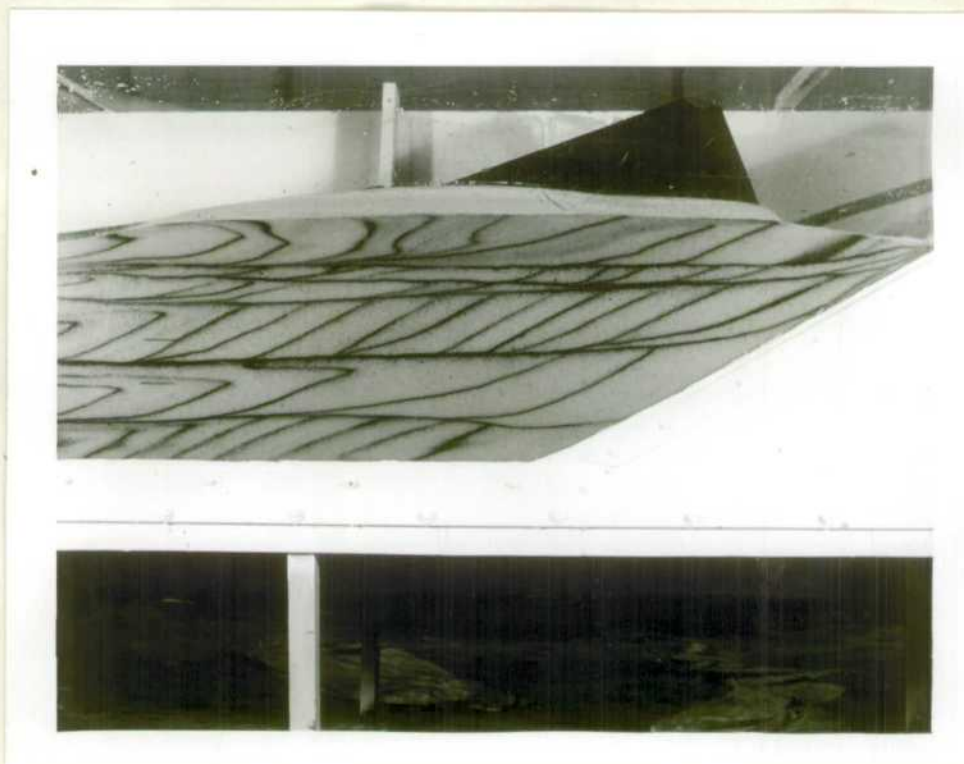

PLATE 3. Sets of strata some of which were successfully "overturned" during experiments in delta tank at Sedimentation Laboratory, United States Geological Survey, Denver.

3. Lectures on Sedimentation by Dr. Tj. H. van Andel.

Dr. van Andel opened his course with some general remarks on the organisation of his course, principles of scientific method and the history of sedimentology. He pointed out that not even the specialist could hope to keep up with the amount of literature being written on sedimentology at the present time. Over 150 references were listed by Dr. van Andel as worth reading in conjunction with the course. His set of lectures was an attempt to synthesize much of the available material and may some day be used as the basis of a text-book on sedimentology.

Earliest work in this field was mainly descriptive - - "sedimentary petrography". The name "sedimentary petrology" was used in the 1920's to describe the study, description and ideas on genesis of sedimentary rocks. Since 1945 the study has become more interpretive and is now called "sedimentology". The historical development actually occurred in two separate fields : mineralogical to petrological, and sediment texture. The growth may be seen in both fields from purely descriptive (qualitative) work to more rigorous methods of analysis, and from there to study of basic processes which determine the observed characteristics.

Sedimentary processes and their products were described in a general way. The following factors were listed as important in events leading to sediment formation :

(a) source material;
(b) physical and chemical processes;
(c) energy levels;
(d) duration of process;
(e) life history;
(f) interaction of processes;
(g) geological setting.

Some of these were then discussed in more detail. The composition of source areas, both local and regional, were considered with respect to heavy mineral suites which they produced. Examples were given in detail of the Gulf of Mexico, the Gulf of California, the Eifel and Rhine Rivers, Germany. Modifications to the parent material were discussed from the aspects of the limitations of the source rock and of the modifying forces.

The lectures given may be summarised by listing their headings and sub-headings :

Terrigenous sediment sources

(1) Composition of source areas and mineral suites
(2) Modifications of parent material
(3) Weathering and mineral stability
(4) Sources and diastrophism
example - Venezuelan Cretaceous and Lower Tertiary

Transportation and deposition

(1) Effects of transportation on texture
(2) Transportation and abrasion
(3) Transportation and composition
(selective mechanical and chemical destruction, selective sorting, and, contamination and dilution)

(4) Oceanography
(Temperature, salinity, oxygen content, ocean currents)

Classification of depositional basins

Sedimentary facies of depositional basins

(1) Unrestricted stable basins with high terrigenous supply (Gulf of Mexico type)

(2) Unstable basins with high terrigenous supply (Gulf of California)

(3) Areas of low sediment supply (Persian Gulf, the Bahamas, Gulf of Batabano)

A few selected reports are listed hereunder as references:

A.A.P.G., 1947 Fundamental research in sedimentology. Research Committee, Amer.Ass.Petrol.geol. Houston, Texas.

ALEVA,G.J.J., 1956 The grain size distribution of quartz in granitic rocks.Geol.en Mijnb.18(6), 177-187.

van ANDEL,Tj.H.,1950 Provenance, transport and deposition of Rhine sediments. Wageningen.

——————,1955 Sediments of the Rhone delta; sources and deposition of heavy minerals. Verh.geol.Mijnb.Gen.Ned., 15(3), 515-556.

——————,1958 Origin and classification of Cretaceous Paleocene and Eocene sandstones of western Venezuela. Bull.Amer.Ass.Petrol.geol., 42(4), 734-763.

——————,1959 Reflections on the interpretation of heavy mineral analyses. J.sediment.Petrol., 29(2), 153-163.

van ANDEL,Tj.H. and POOLE, D.M., 1960 Sources of recent sediments in the northern Gulf of Mexico. J.sediment.Petrol. 30(1), 91-122.

van ANDEL,Tj.H. and POSTMA, H.,1954 Recent sediments of the Gulf of Paria,Venezuela. North.Holland Publ., Amsterdam.

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DAPPLES, E.C., KRUMBEIN, W.C. and SLOSS, L.L., 1953 Petrographic and lithologic attributes of sandstones.J.geol.,61(4), 291-317.

DOEGLAS, D.J., 1946 Interpretation of the results of mechanical analyses. J.sediment.Petrol.,16(1),19-40.

FOLK, R.L., 1951 Stages of textural maturity in rocks. J.sediment.Petrol.,21(3), 127-130.

——————, 1954 The distinction between grain size and composition in sedimentary rock nomenclature. J.geol., 62(4), 344-359.

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____________, 1942 Differential sedimentation and its products during one complete geosynclinal cycle. Proc.1st Panama Congress Min.Eng. and Geol., 2, 537-581.

KUENAN, Ph.H., 1950 Marine geology. N.Y.

____________, 1955 Experimental abrasion of pebbles,wet sand blasting. Leid.geol.Meded., 20, 142-150.

____________, 1956 Experimental abrasion of pebbles, rolling by currents. J.geol.,64(4), 336-368.

____________, 1959 Experimental abrasion, 3, fluviatile action on sand. Amer.J.Sci., 257, 172-190.

____________, 1960 Experimental abrasion, 4, aeolian action. J.geol., 68(4), 427-449.

LEOPOLD, L.B., 1953 Downstream change of velocity in rivers. Amer.J.Sci., 251, 606-624.

McKEE, E.D., 1957 Primary structures in some recent sediments. Bull.Amer.Ass.Petrol.geol., 41(8),1702-1747.

____________, 1959 Storm sediments on a Pacific Atoll. J.sediment.Petrol., 29(3), 354-364.

McKEE, E.D., CHRONIC, J. and LEOPOLD, E.B., 1959 Sedimentary belts in lagoon of Kapingamarangi Atoll. Bull.Amer.Ass.Petrol.geol.,43(3), Pt.I, 501-562.

MOORE, D.G. and SCRUTON, P.C., 1957 Minor internal structures of some recent unconsolidated sediments. Bull.Amer.Ass.Petrol.geol., 41(12),2723-2751.

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4. Scripps Institution of Oceanography.

Two days only were spent at Scripps at La Jolla,California. This time was spent in discussing the various aspects of oceanography being studied by those officers who were present. The emphasis at the present time is on studies in the Gulf of California as part of A.P.I. Project 51. A summary of activities January - June, 1961, is given by van Andel (1961). He was in charge of the Vermilion Sea Expedition - a gulf marine study.

My discussions were with Dr. J.R. Curray who is studying sediments and morphology on the coastal plain and eastern continental shelf, Mr. R.W. Thompson - Colorado tidal flats, Mr. S. Calvert - diatomite deposition in deep basins, and Mr. J.S. Bradshaw - studies of foraminifera. I also met Dr. R.H. Parker who works on distribution of macrofossils in recent marine environments, and Dr. M.N. Bramlette who earlier studied diatomites but is at present working on coccolithophorids. Recent phosphate deposits which occur down to depths of 60 fathoms were discussed very briefly with Messrs. Bruno d'Anglejan and M. Nicholls.

van ANDEL, Tj.H., 1961 - Study of recent sediments and their environments in the Gulf of California. Ann.Rep. 1960-1961. A.P.I. Research Project 51, Report 39, Univ. of California, San Diego.

BRIEF NOTES ON FIELD TRIPS.

Visits to the Front Range and Ancestral Front Range areas in Colorado, into northern Arizona, south-east Utah and western Wyoming, proved very interesting in the wide variety of sediments and structures (tectonic, salt-dome and sedimentary) seen. Travelling from Denver to Canon City, for example, we passed through over 8,000 feet of Upper Jurassic to Paleocene sediments with steep to shallow dips, 5,000 feet of steeply dipping to overturned Pennsylvanian - Permian red beds which lie unconformably over a thin Lower Palaeozoic section or directly on the Precambrian (see Plate 4). Structures are due to anticlinal folding in the Front Range, and some thrust faulting; they are related to the Laramide Orogeny. The Rocky Mountains which rise to over 14,000 feet above sea-level in western Colorado result from these movements, as do the prominent lines of Permian and Lower Cretaceous sandstone hogbacks along the eastern side of the Front Range. This excursion ended west of Canon City at a Precambrian - Ordovician contact; a small sample of red shale with fish fragments was obtained from the Harding sandstone formation which crops out in this area (see Appendix IV). Of interest during the excursion was a visit to Oil Creek and the site of the second producing well in the United States; it was drilled in 1862 and the production was 1 barrel per day from a depth of 50 feet !

Further reference to the geology of Colorado may be found in the Guide to the geology of Colorado published by the Geological Society of America and associated societies in 1960.

In May, I travelled with Dr. E.D. McKee and Professor Gutschick to Shiprock (north-west New Mexico) and Flagstaff (Arizona) where we met two palaeontologists of the U.S.G.S. (W. Sando and T. Dutro). This party spent the next few days examining the Mississippian Redwall Formation and establishing the validity of four proposed subdivisions. Sections visited were in the Grand Canyon, Hell Canyon and Salt River Canyon and nearby areas. Some younger sedimentary rocks and structures were also examined. Plates 5 to 8 show various aspects of this excursion.

Fig.1. Precambrian mountains (Pikes Peak) in west faulted against vertical to overturned beds of Pennsylvanian (Fountain Fm.) and Permian (Lyons Sandstone) age in middle distance, and steeply dipping Mesozoic formations in foreground.

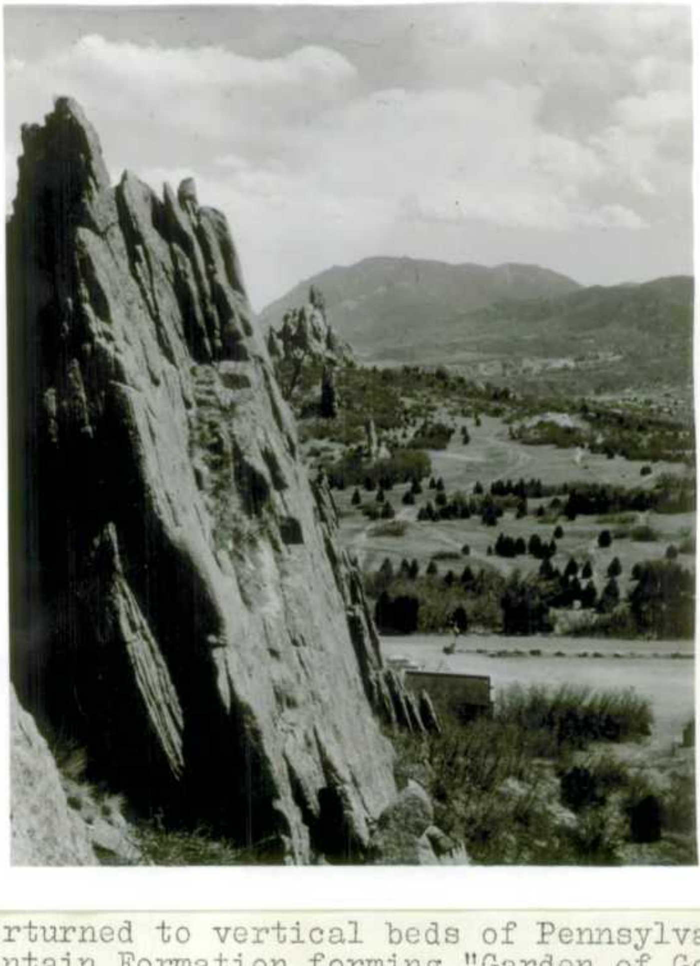

Fig.2. Overturned to vertical beds of Pennsylvanian Fountain Formation forming "Garden of Gods"; Rampart Fault Zone along west (right) edge of valley.

<u>PLATE 4</u>. "Garden of Gods" area between Colorado Springs and Canon City: Rampart Fault Zone along east side of Front Range, Colorado.

I was interested in the use of the term "flat-irons" which was applied to erosional residuals of steeply dipping beds on the flanks of a monocline (see Plate 7). A very interesting sedimentary structure, which was described as "fucoid" and produced by burrowing, was seen on the base of a ledge of projecting dolomitic siltstone (Plate 8, Fig.2); similar structures were later examined in grey shale and it was noted that the "burrow" parts were infilled with fine-grained sandstone.

Samples were obtained of Tertiary basalt from the Shiprock Dyke, sedimentary (Jurassic) uranium ore and some Mississippian oolitic limestone and corals. Specimens collected during this and subsequent field trips are numbered and described in Appendix IV; unless otherwise noted, they are stored in the Bureau of Mineral Resources Museum, Canberra.

Later in the month I was able to visit the Pure Oil well-geologists whose headquarters are at Moab in south-east Utah. Their rigs which I visited were in the Lisbon Valley and Big Flat areas (Paradox Fold and Fault Belt), and at Desert Lake, south of Price (on west side of San Rafael Swell). Surface geology in these areas is mainly Permian - Mesozoic, largely affected by structures which are attributed to salt dome movements from the thick evaporite section in the underlying Hermosa Formation (Pennsylvanian). Intrusives of Tertiary volcanics occur in the Paradox Basin area. These features are shown in Plate 9. The Pure Oil Company has produced oil and gas from Mississippian and Devonian formations in structures which are apparently quite different from those formed by the evaporites in the overlying Pennsylvanian. Producing formations are tight in some areas and have to be either acid or sand-fractured. Uranium mining is also carried out in this area; the mineral occurs in sedimentary deposits. Another mining development had commenced near the Colorado River south of Moab - a shaft was being sunk down to the salt beds of the Hermosa Formation (which in this area carry large amounts of the potash mineral sylvite) below the Cane Creek anticline shown in Plate 9, Fig. 1).

From Moab I went to Durango where I spent two days with the exploration group of Pure Oil Company. This stay included a field trip, mainly north of Durango, to see structures and sediments along the Silverton road. The age of the sediments ranged from Lower Cretaceous to ?Cambrian (Ignacio sandstone beds). The Pennsylvanian Hermosa Formation crops out in this section and a collection of brachiopods and other fossils was obtained. Some glacial features were also seen on this trip: roche moutonnees of Precambrian granite (Plate 10, Fig.2); nunataks (Plate 10, Fig.1) of Tertiary volcanics and Precambrian rocks; and near Durango, old glacial deposition surfaces and a terminal moraine through which the Animas River slowly meanders and below which the river is fast flowing.

A good reference for the two field trips mentioned above is the "Geology of the Paradox Basin fold and fault belt" by the Four Corners Geological Society for their 3rd field conference in 1960.

A wide variety of sedimentary rocks and tectonic structures was seen during the visit to Wyoming with Mr. S. Oriel of the U.S. Geological Survey. The main features of interest were :

(1) Klippen-like masses of Ordovician rocks resting on Mesozoic sediments - they may have been large blocks which had slipped down from up-faulted Lower Palaeozoic rocks to the north - Wind River Canyon ;

Fig.1. Cretaceous beds, Mesa Verde Group over Mancos Shale, on west side of Mesa Verde, south-west Colorado.

Fig.2. Professor R. Gutschick and Dr. McKee on aeolian deposits of Navajo Sandstone (Lower Jurassic), Mexican Water, Arizona.

<u>PLATE 5</u>. Mesozoic sediments in south-west corner of Colorado (Fig.1) and north-east corner of Arizona (Fig. 2), Four Corners Area. Field trip to Grand Canyon in May 1961.

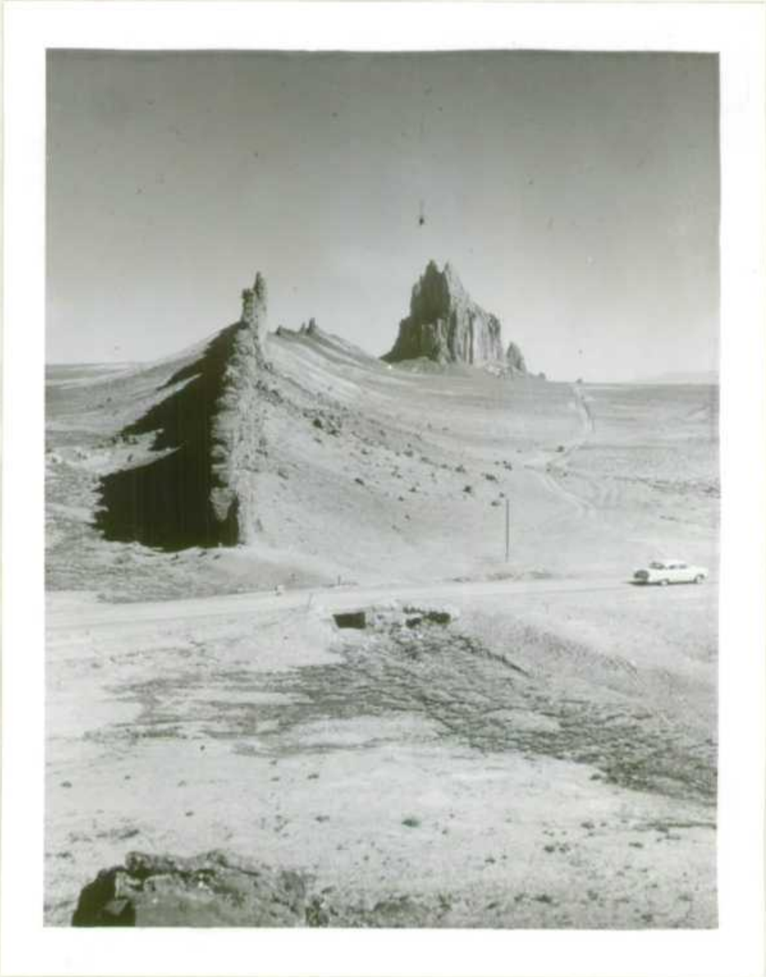

PLATE 6. "Shiprock" (at right) and dyke:

Tertiary basalt intruding Mesozoic sediments,
north-west corner of New Mexico
(Four Corners area). May 1961.

Fig.1. Steeply-dipping Mesozoic sediments (with Navajo Sandstone-Lower Jurassic on top) of monoclinal limb. View to south-west.

Fig.2. Eroded monoclinal limb shown in Fig.1 with resistant Navajo Sandstone forming "flat-irons". Juniper and Binyon trees in foreground.

PLATE 7. Monoclinal fold and formation by erosion of "flat-irons" west of Marsh Pass, about 10 miles south of Kayenta, Arizona. May 1961.

Fig.1. Yavapai Point, Grand Canyon, view to north-west, showing Permian beds at top of 5,000 feet of Palaeozoic sediments.

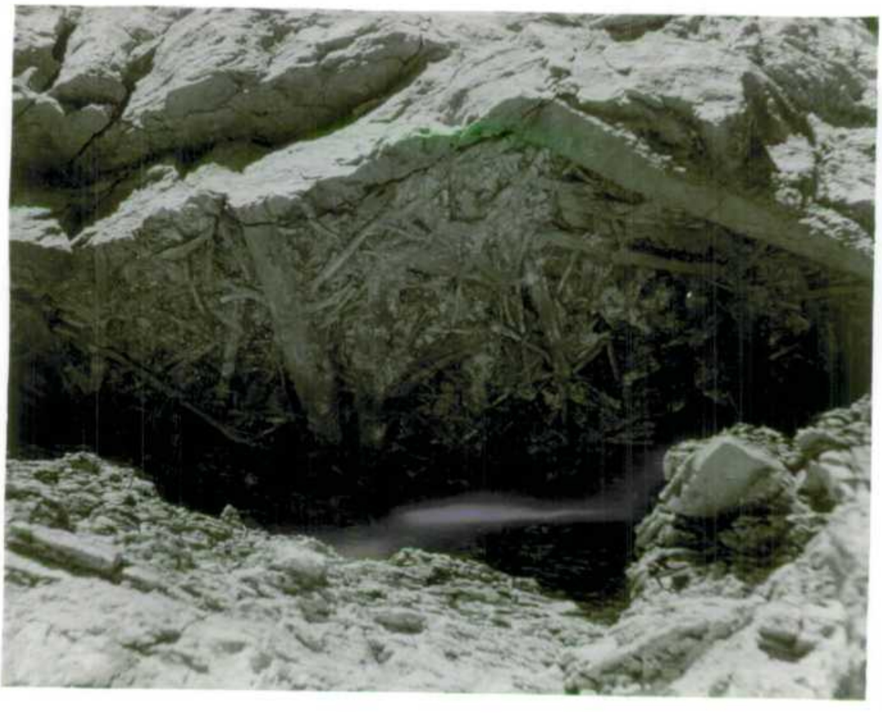

Fig.2. Looking up at base of ledge of Devonian dolomitic siltstone with well-developed "fucoid" (worm burrow) structure, Salt River Canyon.

PLATE 8. Palaeozoic beds in Grand Canyon (Fig.1) and Salt River Canyon, Arizona. May 1961.

Fig.1. Cane Creek anticline in Permian (Cutler Group) to Jurassic (Navajo Sandstone) sediments formed by salt doming. View to south-east from Dead Horse Point towards snow-capped La Sal Mountains (Tertiary intrusives).

Fig.2. Jurassic sediments with Navajo Sandstone at base at left on downthrow side of fault and domed Permian Cutler Group to right; salt dome tectonics west of Moab.

PLATE 9. Salt dome tectonics in Paradox Basin, south-east Utah. May 1961.

Fig.1. Engineer Mount - Tertiary intrusives through Permian Cutler Group - forming nunatak (and monadnock in later San Juan peneplain) during Pleistocene-Recent glaciation. View from Highway 550, near Cascade River.

Fig.2. Roche moutonnee of Precambrian granite, near Animas River.

PLATE 10. Glaciation features along the Animas River and Highway 550, north of Durango, south-west Colorado. May 1961.

(2) Many tectonic features including some well-exposed overthrusts, and effects of Tertiary volcanics and a visit to some of the thermal areas in Yellowstone National Park, see Plate 11;

(3) More effects of glaciation - cirque valleys in Red Rock and Sheep Mountains in the southern corner of Montana;

(4) Fossiliferous Permian black shales, limestone, chert deposits - Phosphoria Formation - at the Raymond Canyon phosphate-vanadium mine; samples were collected;

(5) Some good Mesozoic sections - a sample was obtained from oyster beds in the Hilliard Formation of Cretaceous age;

(6) Tertiary alluvial and lacustrine sediments (samples were collected of algae, gastropods, ostracod limestone, and some oil shales containing the mineral shortite), and the "diamictite" facies - heterogeneous deposits with two dominant sizes (rudite and lutite) but with arenaceous material intermixed; the sediments are shown in Plate 12.

A field trip of two days was undertaken during the course at Colorado University to visit the Ancestral Front Range area in western Colorado. Sedimentation features in the Pennsylvanian Minturn Formation were studied.

Some sedimentary structures are also well-exposed in Cretaceous and Eocene rocks along the coast near La Jolla, California; these were briefly examined while visiting Scripps Institution of Oceanography, (see Plate 13).

OTHER OBSERVATIONS OF INTEREST

The discussion so far has been devoted to the main aspects of my visit to America. I was also able to briefly visit oil companies and other people who showed me some techniques and items of interest.

1. Petroleum Research Corporation.

Mr. J.W. Knight briefly explained the Corporation's work on how hydrodynamics affects oil and gas accumulation; the effect is well illustrated by models in their laboratories at Littleton, Colorado. The principles involved are briefly described in Perry (1961)* and no further elaboration is needed here.

* Perry, W.J., 1961 - Observations on Photogeology overseas. Report on study tour July to December 1960. Bur.Min.Resour.Aust.Rec.1961/45.

Fig.1. Thumb Paint Pots, West Thumb, with Yellowstone Lake in background. Mud volcanoes formed by steam and gas escape through highly viscous mud. Mud fragments thrown to about 10 feet into the air.

Fig. 2. Grotto Geyser, near Old Faithful. Rounded travertine mounds around mouth of small geysers.

PLATE 11. Yellowstone National Park, Wyoming.
June 1961.

Fig.1. "Diamictite" marginal Tertiary lacustrine facies - pebbles to boulders of sedimentary rocks from nearby hills in fine red muddy sediments (hammer in upper left for size comparison) - formed by mud flows ? Wasatch Formation. Interfingering of finer Wasatch sediments and Green River Formation occurs in white hills in back-ground - see Fig.2.

Fig.2. Intertongueing fine sediments (sands, silts, algal limestone, laminated oil-shales) of Wasatch and Green River Formations.

PLATE 12. Tertiary lacustrine beds in basin north-east of Kemmerer, Wyoming. June 1961.

Fig.1. Convolute siltstone bedding, riddled with burrowings, in strata of Cretaceous age. Cliffs on beach south of La Jolla. (These contortions were formed before burrowing occurred).

Fig.2. Bed of Eocene siltstone intensely deformed by slumping in small platform along beach north of Scripps Institution, La Jolla. Dr. J.R. Curray at left.

PLATE 13. Contorted strata exposed in beach sections near La Jolla, California. August, 1961.

The literature which I have for reference is as follows:

Hydrodynamics - its effect on barrier-trap oil-holding capacity.
Hydrodynamics - an aid to exploration.
Answers to commonly asked questions on hydrodynamics.
Areas and examples of hydrodynamic control of oil and gas production.
List of clients.
Petroleum Research Corporation - Principal executive and Technical personnel.

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2. Phillips Petroleum Company - Research Group.

The operation of this group was studied in some detail by Mr. J.N. Casey in 1959. This is a special group of 35 persons located in Denver, who handle research problems for the whole of Phillips organisation. It is divided into :

(i) photogeological section which examines a region qualitatively to find its form and structure, and quantitatively by local detailed contour mapping;

(ii) stratigraphic section which does regional mapping, maps facies changes, locates reservoir conditions, identifies source beds and other stratigraphic mapping; the section includes a hydrodynamic and fluid study unit.

I am grateful to Mr. Orlo Childs who operates the Research Group for explaining these functions to me.

3. Union Oil Company of California - laboratories.

Mr. W. Moran kindly arranged for me to visit the head office of the Union Oil Company in Los Angeles and, with some of his associates, visits to the Research Laboratory at Brea, and Paleontology Group at Compton. The activities of the Research Department at Brea are as follows : production research, refining research, chemical research, design, process engineering, patents, commercial development, general services. These functions are briefly outlined in a booklet given to me after the visit. Two aspects of the work being done at Brea are discussed later. It is interesting to note that the company has developed a method for extracting oil from oil shale commercially.

Microfossils, spores and pollen are handled at the laboratory at Compton and some aspects of techniques used there are also discussed hereunder.

(i) Thin section preparations at Brea.

A note was made here of successful preparation of sections of porous or friable rocks by using Epoxy resins and hardening additives. The addition of a dye, Fluorol 7GA, was found useful for showing porosity. More details can be obtained if required.

Small vacuum pumps are used in the laboratory to handle the glass blocks holding the rock sections both in cutting and polishing procedures.

(ii) Microfossil extraction and indexing, Compton.

Here the microfossils are needed quickly and need not necessarily be in as good condition as necessary for detailed descriptions of species. Cuttings and broken core: of soft material (60 ccs) is placed in 1 pint bottles with rollers (cores of steel encased in rubber hose) and rotated. The material is then washed through 20 and 150 mesh sieves; only that portion retained by the fine mesh is saved. After drying, the microfossils are removed by flotation in carbon tetrachloride, or more successfully, in potassium mercuric iodide.

Chert is broken down by boiling in caustic soda. Other hard samples may be broken by using a Waring (similar to Mixmaster) blender with hardened blades. Fair results have been obtained in this manner if the sample is only churned for less than one minute, but hollow well-preserved forms are usually ruined.

Specimens are stored in glass phials, labelled, and placed in a small stoppered bottle of untreated sample, also labelled. The bottles are kept in strong cardboard boxes which are stored on wooden shelves in a galvanised iron shed.

Slides of sorted specimens and index cards, reports, etc. are kept in a concrete vault.

Two series of index cards are kept at Compton. One is a set kept in alphabetical order of oil companies and shows well name, location, elevation, depth, general file number, and columns for sample number, shed storage file number, bottle file number. The other series has three sets of coloured cards for each locality ;

white well sample card with columns numbered for samples and a corresponding open column for depth range,
or,
white surface sample card which is open for details;

blue card for letters, references, etc., on stratigraphy and fossils - it has a column on the back for recording stratigraphy briefly;

yellow card for lithological section.

More detailed information may be recorded on files on a "generalized graphic log and foraminiferal chart" and a "well sample sheet". Samples collected in the field by a geologist are recorded on a special sheet which is forwarded to the micropalaeontologist with the samples. Appendix V is a copy of this sheet; information in "Locality or map, sample number, organic content of original material, formation or age" columns is supplied by the field geologist - the rest is supplied by the palaeontologist.

Samples of cards and other sheets used are available for reference.

(iii) Routine analysis of cores, Brea.

The best method of keeping cores before analysis is to seal them in a tube of Saran (polyethylene) plastic, wrap in aluminium foil and apply a wax coat. At Brea, 22 cores may be analysed at the one time; porosity and permeability for each sample is determined in ½ hour, saturation may be determined for all samples overnight by toluene extraction or, for an individual sample, in a core extractor in 4 hours. These are routine tests. More complicated tests may be run if required. These are outlined in A.P.I. Report No.40 (1960):

"A.P.I. recommended practice for core-analysis procedure".

A copy of this report and a reprint :

ARNOTT, E., 1958 - Observations relating to the wettability of porous rock. Petroleum transactions, A.I.M.E.

are available for reference.

Recommended reference books for core analysis studies are :

CALHOUN, J.C., 1955 - Fundamentals of reservoir engineering. Univ. of Oklahoma Press.

CRAFT, and HAWKINS, 1959 - Applied petroleum reservoir engineering. Prentice Hall Inc., Englewood Cliffs, N.J.

PIRSON, S.J., 1950 - Elements of oil reservoir engineering. McGraw-Hill, N.Y.

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4. Richfield Oil Corporation - research laboratories.

By kind permission of Mr. Mason Hill, I was shown the Richfield research laboratories at Anaheim and Long Beach and other interesting features in Los Angeles by Mr. L. Brockett of the Foreign Exploration Group.

Research undertaken at Anaheim is similar in many respects to that at Brea. Richfield also have perfected means of oil extraction from oil shale and they use the residue as source material for light-weight concrete. The laboratory at Long Beach houses the district geological staff, off-shore drilling group, geophysical, palaeontological and palynological sections. The work done by these sections was discussed briefly with personnel working at the laboratory.

5. United States Geological Survey - study of Cretaceous shales.

In 1956, Messrs. W. Rubey and J. Gilluly initiated a study of a regional crustal unit in the United States. The unit chosen was the Cretaceous Pierre Shale because -

(i) it is fairly continuous over a large area up to 800 miles wide;
(ii) it appeared to be uniform;
(iii) it is very thick in parts (ranges from 500 to 3000 feet);
(iv) the stratigraphy and fauna are well known.

Mr. Harry Tourtelot was placed in charge of the project; he is assisted by one regional stratigrapher and a clay mineralogist. Mr. Tourtelot was able to discuss the approach with me while I was at the Federal Centre, Denver.

The more uniform marine (eastern) part of the deposits was chosen for study first. Five divisions were made in the marine sequence and isopach maps prepared for each. Regional maps of the Pierre Shale will be prepared later when studies of interbedded freshwater and marine, and freshwater marginal facies are completed.

The clay samples were collected wherever necessary rather than on any grid system; they were 10-15 lb samples of as pure clay as possible. The samples are subjected to :

(a) complete rock analysis;
(b) quantitative spectrographic and chemical analysis for 20 minor elements;
(c) quantitative X-ray analysis.

(a) and (b) are done in the chemical laboratories which were only able to handle a limited number of samples (in this case 70).

The results are handled statistically. The details will be published in a series of reports of the U.S.G.S. -

No.390. General Reconnaissance.
No.391. Methods -
  A. of chemical analysis and precision;
  B. of spectrographic analysis and precision;
  C. of X-ray analysis and precision.
No.392. Eastern marine area (including a chapter on concretions)
No.393. Western area.
No.394. Final report.

The analytical methods used are also discussed in the following papers:

FAIRBAIRN, H.W. and others, 1951. - A co-operative investigation of precision and accuracy in chemical, spectrochemical and modal analyses of silicate rocks. Bull. U.S.geol. Surv. 980.

STEVENS, R.E. and others, 1960. - Second report on a co-operative investigation of the composition of two silicate rocks. Bull.U.S.geol.Surv. 1113.

This work is mentioned because the conclusions of the research may later warrant similar work being undertaken on a similar project - the Cretaceous shales of the Great Artesian Basin.

CONCLUSIONS AND RECOMMENDATIONS

1. Since 1945, the oil industry in the United States has directed its search for oil gradually away from study of structures towards study of sub-surface stratigraphy.

2. In order to understand stratigraphic traps better, many companies and organisations have initiated research projects on recent sedimentation.

3. Research into recent sedimentation by the Bureau is probably not warranted at this stage; so much is being done in the United States which will be of general environmental application, that we should await the results of this work. On the other hand, our geologists should note or record any features of recent sedimentation which they observe - a common file for such information would be very valuable for reference; any new information on little known environments such as the New Britain Trench investigated by Mr. W.C. White recently, should be published.

4. Sub-surface stratigraphy, as practised in America, is not possible in Australia yet because we do not have enough control. Nevertheless, well logs should be watched to ensure that enough information is available on them to prepare such maps as lithofacies, ratio of sand in clastics, ratio of limestone to dolomite, etc., in the future.

5. Well logs available at present should be used in conjunction with measured surface sections for building up frameworks of the various basins. Locality maps of wells, bore and sections in each basin would be particularly useful at this stage of our exploration work.

APPENDIX I.

CLASSIFICATION OF DEPOSITIONAL ENVIRONMENTS FOR SUBSURFACE STUDIES

by James G. Mitchell.

Abstract.

A classification of depositional environments that is based upon data that are readily available from the lithologic character of the sediments is desirable for use as a tool in subsurface exploration for oil and gas.

Kinetic energy, chemistry and organisms, the basic factors affecting deposition, may be used to classify environments. Their influence upon deposition is readily interpreted from lithologic characteristics of the sediments. Sorting and modal size of clastic sediments reflect the kinetic energy level effective during deposition. Evaporites represent deposition that is dominated by chemical processes with a minimum of kinetic energy. Reefs indicate that deposition is dominated by growth of organisms.

Geography, physiography and depth may influence kinetic energy, chemistry and organisms in a variety of ways, but do not directly affect deposition. Depositional environments should be separated, in subsurface studies, from larger, more inclusive domains (Marine, Transitional, etc.) because available data reflect an instant in geologic time and a point in space.

Source and supply of materials are responsible for the mineralogy of sediments, but are essentially unrelated to depositional environments.

CONTINENTAL (domain of wind, weathering, ice, etc.)

R Residual - chemical and mechanical products of air, water, weathering and organisms.

E Eolian - deposition from moving air.

G Glacial - deposition from moving ice.

C Colluvial - deposition by the action of gravity alone.

FLUVIAL (domain of moving fresh water)

Ft Turbulent - deposition from moving water of high kinetic energy; Detritus exceeding 2 mm in modal diameter. Characteristic of high gradient streams.

Fa Agitated - deposition from moving water at moderate kinetic energy. Sand deposits with modal diameters from 1/16 to 2 mm. Poor mineral and size sorting of sands.

Fi Intermittent - deposition alternately from moving and quiet water. Interlaminated silt, sand and mudstone. Characteristic of flood plains of streams of youth and early maturity.

Fb	Quiet	- deposition from relatively quiet water, resulting in structureless mudstone and claystone with flaky minerals unoriented. Characteristic of broad, mature and old age flood plains.
Fb	Bog	

LACUSTRINE (domain of continental water impoundment)

Lt	Turbulent	- deposition from water of high wave and/or current energy. Detritus exceeding 2 mm in modal diameter.
La	Agitated	- deposition from water of moderate wave and/or current energy. Sands from 1/16 to 2 mm in modal diameter.
Li	Intermittent	- deposition from alternately quiet and moving water. Interlaminated mudstones, claystones, siltstones and sandstones.
Lq	Quiet	- deposition from quiet (low energy) water, mudstones and claystones.
Lb	Bog	- deposition under anaerobic conditions from stagnant water. Swamp deposition.
Lp	Penesaline	- deposition at salinities suitable for precipitation of carbonate.
Ls	Saline	- deposition at salinities suitable for precipitation of sulfates and chlorides.
Lh	Hypersaline	- deposition at extreme salinity. Playa lakes, etc.
Lr	Reef	
Lo	Organic	

TRANSITIONAL (domain of transition from continental to marine conditions)
includes deltaic, lagoon, barrier island environments
- forams less variable compared with marine environment and more arenaceous types.

Tt	Turbulent	- deposition from water of high energy. Detritus exceeding 2 mm modal diameter. Coarse sand and gravel beaches and deltas.
Ta	Agitated	- deposition from water of moderate energy. Sand deposits with modal diameters from 1/16 to 2 mm. Beaches and deltas.
Ti	Intermittent	- deposition from alternately quiet and moving water. Interlaminated silts, sands, mudstones and claystones. Tidal flats, etc.
Tq	Quiet	- deposition from quiet (low energy) water. Claystones, mudstones. Tidal lagoons, tidal marshes, etc.

Tb	Bog	- deposition under anaerobic conditions in shallow stagnant water. Coastal swamp deposition.
Tp	Penesaline	- adaptable, highly ornamented fauna of ostracods, molluscs; encrusting algae (and pseudo-oolites).
Ts	Saline	- minimum fauna - may find moulds preserved.
Th	Hypersaline	- in hypersaline environment - fossils may be present from rafting or spores may be present.

MARINE (domain of oceanic waters and marine organisms) - highly variable fauna; presence of crinoids and brachiopods used as positive indication of marine environment.

Mt	Turbulent	- deposition from water of high wave and/or current energy. Mechanical and organic Detritus exceeding 2 mm modal diameter.
Ma	Agitated	- deposition from water of moderate wave and/or current energy. 1/16 to 2 mm modal diameter.
Mi	Intermittent	- deposition from alternately quiet and moderate energy levels. Interlaminated sediments of quiet and agitated types.
Mq	Quiet	- deposition from quiet (low energy) waters. Fine muds with some disseminated coarser material.
Me	Euxinic	- deposition from water at extremely low energy levels that allow stagnation and development of chemical and biological relationships fostering deposition of pyrite.
Mp	Penesaline	- chemical deposition from waters of salinity and pH below those prevalent within evaporitic conditions. Precipitation of primary carbonates.
Ms	Saline	- chemical deposition from waters of salinity and pH requisite for deposition of sulfates and chlorides.
Mh	Hypersaline	- chemical deposition from waters of extreme salinity and pH resulting in deposition of soluble magnesium salts, etc.
Mr	Reef	- building and deposition by organisms. Organic material relatively in place. Reefs and reef-like bodies.
Mo	Organic	

Envir.	Absence of Terriginous Material	Moderate Terriginous Material	Abundant Terriginous Material
Mt	Coarse bioclastics such as reef talus and pisolitic carbonates.	Coarse bioclastics with detritus pebbles, etc. of terriginous origin. Distinctly clean.	Gravels, coarse detritus. May be mixed with marine organic debris but is distinctly clean.
Ma	Crinoidal limestones and similar bioclastic rocks if organic material is available. Salinity conditions may dominate and oolitic carbonate rocks may be formed. Clean.	Admixture of biologic, terriginous and chemical sediments possible. Such types as the slightly argillaceous and sandy oolitic limestones, etc.	Sandstones. Relatively clean, well sorted and may exhibit rounding. Primary carbonate and bioclastic material may be present.
Mi	Interbedding or interlamination of bioclastic or chemically aggregated materials with fine chemical or biologic muds. May be slightly argillaceous.	Interbedded bioclastic or chemical limestones with fine carbonate muds and shale or mudstone and silt.	Interbedded or interlaminated sandstones, siltstones, and shales, showing intermittent sorting and removal of fine muds.
Mq	Fine carbonate muds of chemical or organic origin. May be slightly argillaceous and have disseminated coarse fossil or chemical material.	Argillaceous carbonates and limy mudstones, claystones, etc. Marls, etc.	Shales, mudstones, claystones with scattered or disseminated silt and sand possible.
Me	Probably non-existent.	Black or dark pyritic shales. May contain depauperate or exotic faunas. May be slightly calcareous.	Dark pyritic shales. Generally non-calcareous.

Mp	Clean carbonates. May vary between pisolitic, oolitic and chemical oozes, depending upon energy conditions.	Argillaceous chemical carbonates. silty or sandy chemical carbonates.	Shales, silts and sands with chemically deposited primary cement. Dependent upon energy level for size of terriginous material.
Ms	Clean, massive anhydrites, gypsums, salts.	Argillaceous, anhydrites, gypsums, salts. May become silty or sandy.	Very argillaceous, silty, sandy, anhydrite or gypsum. Terriginous components of salt rarely exceed clay size.
Mh	Clean salts of magnesium, potassium etc.	Probably no appreciable influx of terriginous sediments unless eolian.	Non-existent.
Mr	Reef, reef talus, etc. Clean carbonates with essentially no terriginous material.	Reef, reef talus, etc. with associated terriginous mud silt and sometimes disseminated sand.	Probably very rare. No known examples.

APPENDIX II.

SOME NOTES ON WELL LOGGING, PREPARED WHILE WORKING WITH THE PURE OIL COMPANY

1. Collection of Cuttings. This is generally done by rough-neck but should be carefully supervised by well geologist. The samples are cleaned, dried and bagged. Ensure that salt samples which need washing are washed in saturated salt solution. Shale shaker should be washed clean before sample for next interval starts to accumulate.

   The interval at which cuttings are taken depends on the well (whether wildcat or in an area with many wells), and the importance of the formation being drilled. In wildcat wells, or where porosity of formation is to be determined, or if drilling is slow, cuttings are usually taken at 10-foot intervals (or at 5-foot intervals for very important formations). In areas with good subsurface control and where relatively unimportant formation being drilled, cuttings may be taken every 30 feet.

   The well geologist takes a cut of the samples for his own logging; the rest is sent to the Company's central store. After news of the well has been made public, cuts of the samples are sent to organisations who work with cuttings (such as Amstrat) or to other companies who have requested cuts.

2. Before logging samples, the well geologist prepares a graph of drilling time at the same scale as his sample log form; it is prepared from a Geolograph (or other drilling time) chart. The chart revolves on a drum operated by a clock - a mechanical pen unit makes a mark on the chart as the drill penetrates each one foot of depth.

   Drilling time is one of the best indicators of change in formation at the time of drilling - cuttings cannot be used because of time lag in their reaching the surface. The rate of penetration increases in soft and often in porous formations, but decreases in hard formations. Certain features shown on the chart, however, may lead to incorrect interpretations: increasing lags may indicate a worn-out bit, irregularities occur when trips are made out of the hole, etc.; but these may be recognised if the driller makes the appropriate notations on the chart.

   The chart of the Geolograph may also give a good indication of the time lag between when samples are cut and when they reach the surface. Certain formulae (e.g. lag = 10 to 15 feet per 1000 feet of depth) and slide rules are designed for determining time lag but are only applicable if hole perfectly cylindrical. Another method of determining time lag is to add something distinctive to the drilling fluid at the head of the hole and to time its return.

3. The well geologist prepares a daily geological report on a printed form with the following columns: depth, drilling time, lithologic column (illustrated by symbols), drilling data (bits, trips, etc.) and sample description. (I have a copy of the form used by Pure Oil Company for reference). The sample description is not detailed; the main information wanted at this stage are lithology, porosity, permeability, oil and gas shows. Procedure is generally as follows:

(a) chips placed in cups in a porcelain tray and tested under fluoroscope; high gravity oil is light yellow colour and may be confused with mineral fluorescence - addition of carbon tetrachloride shows difference by flushing oil out of chips; the rate of flushing gives an idea of permeability; another source of fluorescence in a dry sample may be oily material used on pipe joints or other contamination - this may be distinguished because it occurs on surface of chips only and not within them and will affect "foreign" fragments within the sample as well;

(b) chips with oil content are placed in water; flotability gives an idea of saturation;

(c) lithology is briefly described using low-power microscope; wet sample gives better idea of colour and texture; immersion in 10% hydrochloric acid shows nature and amount of carbonate present;

(d) dry samples are used to describe porosity; "pinpoint" porosity shows as small holes which may have jagged edges in carbonate rocks, "intercrystalline" is shown by crystalline calcite and sucrosic dolomite, "vuggy" caused by large jagged gaps filled in part by crystals; fractured formations as porous media may be difficult to recognise in cuttings - drilling speed may give an indication.

APPENDIX III.

TYPE OF STRATIGRAPHIC ANALYSIS SHEET USED BY PURE OIL COMPANY.

STRATIGRAPHIC ANALYSIS

SHEET NO. ______

COMPANY ______ NO. ______ OWNER ______ LOC. ______ SEC. ______ T. ______ R. ______ COUNTY ______ STATE ______

ELEV. ______ T.D. ______ LOG ______ SOURCE ______ COMPUTED BY ______ DATE ______ REMARKS ______

UNIT	DEPTH (TOP)	ALTITUDE (TOP)	THICKNESS	I.P., D.S.T. SHOWS	POROSITY	CLASTICS				TOTAL	NONCLASTICS					TOTAL	RATIOS		
						SH.		SS.			LS.	DOL.		EVAP.					

APPENDIX IV.

REGISTER OF SAMPLES OBTAINED FROM AMERICA FOR REFERENCE AND SUBMITTED TO MUSEUM

NO.	LITHOLOGY	FOSSILS	AGE	LOCATION
F21950	Clayey limestone, greenish brown.	Ostracods (rich), fish fragments.	Bridger Formation, Tertiary (post-Wasatch and Green River Formations).	North side of Highway 189, 29 miles N.E. from Kemmerer, Wyoming in road-cutting
F21951	Black petroliferous shale and limestone, with black chert.	Brachiopods, Crinoid stems.	Lower Hermosa Formation (Pennsylvanian)	Cutting west of road, U.S. Highway 550 (Durango to Silverton), 3 miles south of Cascade River, Colorado.
F21952	Light buff to grey fossiliferous limestone.	Snail shells (gastropods), freshwater.	Buckman Hollow Formation, Paleocene.	4 miles west of La Barge, 1 mile north of LaBarge Creek road, western Wyoming.
F21953	Light buff oolitic limestone.	Microfossils?	Redwall Fm., upper part of Mississippian.	Bridge Canyon (west part of Grand Canyon National Park), Northern Arizona.
F21954	as above	2 specimens of <u>Homalophyllites</u> (corals)	from lower part of Redwall Fm.	
F21955	Coarsely crystalline grey-brown limestone or calcarenite.	coral <u>Vesiculophyllum</u>; Microfossils?	"C" member of Redwall Fm. Mississippian.	Quarry south side of Hell Canyon and west of the old bridge road, (Arizona).
F21956	Finely crystalline grey-brown limestone or calcarenite.	corals <u>Homalophyllites</u>; Microfossils?	"	"
F21957	Oyster shell fragments including hinge area, from oyster bed.		Hilliard Formation, Upper Cretaceous.	13 miles north of Kemmerer, Wyoming, along unpaved road to north of Phosphate.

APPENDIX IV contd.

NO.	LITHOLOGY	FOSSILS	AGE	LOCATION
F21958	Some fossil samples presented by Mr. R. Munger, Amstrat, Durango, Colorado - mainly brachiopods.		Hermosa Fm., (Pennsylvanian).	Exact locality not given - south-west Colorado area.
F21959	Diatomaceous Chert	Diatoms	Monterey Shale,* Miocene.	From coastal section south of Monterey Bay, California.
R9408	Greenish medium-grained, friable sandstone.	-	Saltwash member of Morrison Fm., Jurassic(Upper).	Mine at Cove, north-east Arizona. On loan to Dr. Walpole.
R9409	Black basalt	-	Early Tertiary	Shiprock dyke, north-west corner of New Mexico. On loan to Dr.Walpole.
F21960	Black limestone and chert, phosphatic and with vanadium.	Brachiopods, etc.	Phosphoria Formation, Permian.	Raymond Canyon Phosphate Mine, 1 mile east of Highway 89 along Idaho-Wyoming boundary. On loan to Mr. W.C. White.
F21961	Red fossiliferous shaly rock.	Fish remains	Harding Sandstone, Ordovician.	Road cutting 6miles from Canon City west along Route U.S.50, Colorado. On loan to Dr. Opik.
F21962	Algal limestone - growth around gastropods, twigs, pebbles.		Buckman Hollow Formation, Paleocene	Buckman Hollow, about 1 mile north of La Barge Creek road and 5 miles west of LaBarge, Wyoming.
R9410	Pisolitic limestone	Algal?		Road cutting near turn-off to Buckman Hollow, west of LaBarge, Wyoming
R9411	Algal limestone		Upper tongue of Green River Formation, Eocene.	South side of road, 32 miles by road north-east of Kemmerer, Hwy. 189.
R9412	Algal limestone growth around wood.			South side of Hwy.189, 14 miles north-east from Kemmerer, Wyoming.
F21963	Brown oil shale with mineral shortite.	Fish remains, ostracods.	Lower part of middle tongue of Green River Formation, Eoc.	Just north of McGinnes ranch, about 27 miles (direct) north-north-east of Kemmerer, Wyoming.

* Refer: BRAMLETTE, M.N., 1946 - The Monterey Formation of California and the origin of its siliceous rocks. U.S.Dept.Int.Prof.Paper 212.

APPENDIX V.

FORM USED BY UNION OIL COMPANY FOR RECORDING
FIELD AND LABORATORY INFORMATION ON MICROFOSSIL SAMPLES.

DATE SUBMITTED TO PALEO. LABORATORY ________

SUBMITTED BY ________

TO ACCOMPANY REPORT NO. ________

AREA

____

COUNTY STATE

FORM 136
PRINTED IN U.S.A.

RESULTS OF MICROSCOPIC EXAMINATION OF SURFACE SAMPLES BY PALEONTOLOGY LABORATORY

REPORT NO. ________

DATE EXAMINED ________

MICROPALEONTOLOGY DETERMINATIONS BY ________

LOCALITY OR MAP	SAMPLE NUMBER	ORGANIC CONTENT OF ORIGINAL MATERIAL	FORMATION OR AGE	LAB. NUMBER	MICROORGANIC CONTENT OF ORIGINAL MATERIAL	FORAMINIFERAL ZONE OR SUBZONE	FORMATION OR AGE	CERTAINTY OF CORRELATION (POOR, FAIR, GOOD)	BASIS OF CORRELATION (LITHOLOGIC OR FORAMINIFERAL)	REMARKS OR CORRELATION WITH ADJACENT AREAS AND SAMPLES