TECHNIQUES OF POROSITY, PERMEABILITY AND INSOLUBLE RESIDUE ANALYSIS OF CARBONATES AND THEIR ECONOMIC SIGNIFICANCE

As based on a Study of the Ordovician and Silurian Section of the Williston Basin

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Techniques of analysis of carbonate sections were studied to find those which might be most applicable to the resolution of the problems of (1) zoning of a predominantly carbonate section, (2) correlating a section with other sections, (3) determining sources of sediments and conditions of deposition and, (4) determining character and patterns of secondary porosity and permeability developed within a carbonate section by groundwater solution. The porosity pattern, the tortuosity of the channelways, the orientation of the minerals lining the pore walls, and the mineralogy of the pore walls in contact with formation fluids and gases, are significant in connection with the problem of fluid migration and their recovery.

For the purpose of the study, the Ordovician and Silurian section in the eastern part of the Williston basin of North Dakota and Manitoba was selected. The Williston Basin is a broad, shallow feature occupying parts of Manitoba, Saskatchewan, Montana, North Dakota and South Dakota. On its east side the basin gradually deepens from the Canadian Shield to a depth of somewhat over 15,000 feet in west central North Dakota.

Originally the Ordovician section was deposited across a Precambrian terrain in the eastern part of the basin and probably extended as far east as the Hudson Bay area. Silurian beds extended eastward a similar distance. Erosion following late Paleozoic arching has separated the Hudson Bay section from that of the Williston Basin. During this period of erosion the formations were subjected to groundwater solution and leaching.

Ordovician and Silurian rocks today lie at relatively shallow depths along the eastern side of the Williston basin, and are found in outcrop in Eastern Manitoba. Because of the post-Mississippian erosion, each younger sequence of beds is found westward from the older underlying beds. The Ordovician and Silurian section has been penetrated by oil wells in various parts of the Northern Great Plains. These tests indicate that the Ordovician section underlies almost the entire Northern Great Plains area, but rocks of Silurian age are largely confined to the Williston basin.

The question of the correlation of some of the units within the Ordovician and Silurian formations long has been of importance. A means of zoning these carbonate sections and of correlating the various zones is essential. Also, for economic reasons it is important to identify the potential oil producing horizons or horizons which may develop porosity under proper conditions.

Furthermore, in paleogeological studies it is desirable to determine the source of materials, the climate, relief of the land, and distribution of streams as well as the environment in which the sediments were deposited and their history after deposition.

Carbonate rocks such as the Ordovician and Silurian formations do not record a pre-depositional history and, therefore, except by negative evidence, tell little of the terrain adjacent to the seas in which the carbonates were forming, or of the lithology of the rocks of which that land surface was underlain. Neither do they tell much about the relief of the land, the rivers or the climate. Most of this type of information must be determined from transported material. Since some of the insoluble residues found in the carbonates are of detailed origin, these give some answers to these questions.

On the other hand, the marine environment during deposition, and the post-depositional events such as recrystallization, dolomitization, mineralization, solution, reprecipitation, and the post-depositional history may be recorded by or in the carbonate formation. However, in some cases this may be more clearly determined from evidence afforded by insoluble residues, fossils, replaced carbonates, introduced cements and chert, than from the carbonate itself.

STRATIGRAPHY

The lowest member of the Ordovician section on the eastern side of the Williston basin is the Winnipeg formation of Middle Ordovician age. At its base it consists of sandstone and shale units resting unconformably on Cambrian sandstone or Precambrian crystalline rocks. Its thickness ranges from a few feet to over 200 feet. This formation was not involved in the study.

The Red River formation of Upper Ordovician age conformably overlies the Winnipeg formation. It is a limestone and dolomite which usually is somewhat more dolomitic in the upper portion of the section and is more cherty in the middle part. Its thickness ranges from a few feet to several hundred feet. At the outcrop in Manitoba it has been subdivided, from the top down, into the Selkirk, Cat Head, and Dog Head formations, although these are not always recognizable in the subsurface. The Red River formation is equivalent to the Bighorn and Whitewood formations farther west.

Conformably overlying the Red River formation is the Stony Mountain formation of Upper Ordovician age, although some of the upper part of the Stony Mountain formation may be Silurian in age. The lower portion of the formation is predominantly a red, green, or gray fossiliferous, calcareous shale with interbedded thin, shaly limestones and dolomites. The upper part is a series of alternating shales, silts, and thick-bedded crystalline dolomites which locally are quite sandy and may contain chert and evaporites. The formation has been subdivided from the top down into the Gunton dolomite with associated shale and sandstone beds, the Penetentiary dolomite, and the Stony Mountain shale. The thickness of the formation is about 100 feet along the eastern edge of the Williston basin, but it thickens westward into central North Dakota to about 1000 feet.

Conformably overlying the Stony Mountain formation is the Interlake Group of Lower or Middle Silurian age. Its thickness increases westward from its truncated edge to about 1000 feet. It is mainly a dolomite, somewhat siliceous in part, with some limestone, variegated shale, and sandstone units. Individual sand grains are scattered through the carbonates and in general become more abundant downward. Some sandstone beds are present in the lower part of the formation and some evaporites may be present. Reefs are found at several horizons.

Unconformably resting upon the Interlake Group is the Ashern formation which consists of variegated shale, limestones, and carbonates. This formation may represent in part soils which were developed upon the Middle Silurian erosion surface and which were reworked by the advancing Middle Devonian seas. Thus there is an interval of non-deposition and deep weathering extending from Mid-Silurian to Mid-Devonian time.

Samples of the Red River, Stony Mountain, and Interlake carbonate sections were collected for analysis along the ourcrop in Manitoba and from a number of wells which cored the sections in the Williston basin.

INSOLUBLE RESIDUES

Laboratory study of the samples for the purpose of establishing zones in these Paleozoic limestone beds was primarily by means of insoluble residues, although thin sections and crushed fragments also were used. Crushed fragments were effectively substituted for insoluble residue concentrates when only chert characteristics were being determined. This permitted a more rapid processing of samples. However, crushed fragments are less effective when there is need of separating fossils and are almost useless in heavy mineral analysis since they occur as very fine grains and in minute amounts. They often may be overlooked or not exposed in the crushed fragments. Therefore, solution of the carbonate was usually the technique employed when fossils and heavy minerals were to be examined.

Very weak solutions of hydrochloric acid had to be used whenever it was desired to preserve the dolomitic and non-calcareous carbonates. Gentle solution of the calcareous carbonate from around the replacing dolomite, siliceous dolomite and siliceous carbonates, preserved the patterns of replacement as casts. These replacement forms ranged from euhedral crystals to well-developed rhombs of dolomite to irregular grains. Usually the replacing mineral was less acid soluble and showed penetrations along fractures and cleavages, and into cavaties developed in the more replaceable portions of the more acid soluble host mineral.

The utilization of weak acid was essential where fragile, siliceous organic remains were present since the stronger acid destroyed the fossils or etched the markings on the fossil so as to render the fossils difficult or impossible to identify.

Strong acids digested the sample too rapidly and tended to remove all carbonate minerals, not just calcium carbonate. In addition, the vigorous action usually produced a large amount of fine "powder" which was derived from partly digested primary and secondary minerals, from fossil fragments and from clay and other fine material which had been deposited simultaneously with the limestone and dolomite at the time the formation was laid down.

The formation of the "powder" was undesirable not only because it was difficult to remove, but because it obscured or masked the remaining insoluble minerals and fossils. The significance of the origin of the fine material and its relationship to other constituents also usually was destroyed.

Light etching of polished sections followed by selective staining and peal techniques were the most effective methods of studying the mineral paragenesis of the replacing minerals and the attack of the replacing minerals upon the host mineral. This two dimensional approach supplemented the observations made on the three-dimensional "casts".

PRELIMINARY SUMMARY OF

INSOLUBLE RESIDUE OBSERVATIONS

Siliceous microfossils are fairly abundant in the samples analysed. Their identification is still in progress.

The shale and clay which are present in the residues do not seem diagonstic. However, since certain clay minerals are sensitive to certain environments which may have existed during their formation or deposition, further electron microscope studies and identification of the clay minerals may be helpful in paleogeographical interpretations. Except for the chert, most of the fine residues of silica are related to the siliceous fossil fragments and to replacement residues. No volcanic ash residues were observed.

The occasional opaque mineral grains and other heavy minerals seem to be randomly scattered through the section. Because of the tediousness of extracting them no attempt has been made to use them to establish zones, at least until other methods have proved ineffective. Indications are that their type and distribution will not be of sufficient significance to use as a zoning medium.

After the fossil clay and insoluble carbonate residues, sand grains and chert are the main ingredients of the insoluble concentrates. Three types of chert are distinguishable: (1) fresh chert, (2) leached chert, and (3) weathered chert. The fresh cherts range in color from black through shades of gray to white;

some may be sharply banded. The leached cherts are usually shades of gray, tending to become lighter as leaching is more intense. Banding tends to be lost, although in some cases weak banding appears to have developed as a result of leaching. Weathered cherts are bone white, chalky, or pink or red in color. Internal structure of the fresh cherts may be fine crystalline to almost amorphous, even under very high magnifications. They frequently show inclusions and internal structure. Only fresh cherts can be used effectively for zoning; the leached cherts mark portions of the section which were subjected to groundwater movement and solution; the weathered cherts can be used to mark minor disconformities.

The sand grains show a wide variety of types as determined by their internal structure, inclusions, metamorphic distortions, intergrowths, evidences of earlier cycles of erosion and cementation, and distinctive surficial markings such as frosting, polishing, and staining.

Sand and chert residues appear to be usable for establishing, at least locally, correlatable zones.

POROSITY AND PERMEABILITY

Since oil occurs in porous and permeable horizons in a formation, and because leaching is one method by which secondary porosity is developed, the outcrop and well samples collected were studied to determine the amount of solution porosity present. Also, examination was directed towards determing what physical-chemical properties of the formation permitted the development of porosity in certain beds and restricted development in others. The identification of these horizons in the subcrop, or the prediction of the position in the subsurface of those horizons which may be capable of porosity development, has been significant in delimiting areas in which this type of porosity trap may occur.

Polished sections impregnated with colored balsam were most effective in making these studies. These polished sections were successively ground down, etched, stained, and peels made to show serially pore and fracture pattern developments and changes.

Serial thin sections did not give enough detail as to pore patterns, although they did show to advantage cementation and recrystallization, secondary filling of channelways, and the crystallographic orientations of minerals which sometimes lined the channels through which the moving fluids in the formation must pass. The orientation of minerals in the pores may be more significant than the mineralogy itself in the control of fluid migration. Determination of these channel characteristics are especially significant in the recovery of oil since all the formation fluids must migrate through these channels to reach the well.

In the very porous carbonate samples, the pores were filled with insoluble material such as balsam. The soluble carbonate was then leaching away, producing casts of the pores which may be considered "frozen models" of the fluids trapped in them. The casts reproduced the interconnection, tortuosity, variations in diameter of the voids, and in some cases yielded information on the orientation of the insoluble mineral linings of the passageways. These characteristics of the pore passages are significant in the migration of fluids through the formation and in the ultimate recovery of the oil, gas, or water therefrom.

It was found that, although primary porosity may be present, secondary porosity is generally most important with the exception of reef and oolitic limestone areas. The secondary pore openings vary from microscopic in size to large vugs and channels three-quarters of an inch or more across. The finer porosity is more often associated with dolomitic carbonates.

SUMMARY

This is a preliminary report on some of the work being done on carbonate rocks. It is hoped that the information being developed will be useful in the

search for stratigraphic oil traps involving Ordovician and Silurian formations through the correlation of sections and localization of porosity zones. But of more importance will be the possible application of some of the results of the study to problems of migration and accumulation of oil or other fluids in rocks, and to petroleum engineering problems involving such matters as acidization and oil-water relationships. Further, some of the techniques and results may be applicable to problems dealing with the development of porosity in potential ore bearing rocks, to problems of ore replacement, to the migration of ore bearing fluids through the rocks, and to prediction of potential ore replacement zones in carbonate rocks.

REFERENCES

Pye, W. D., The Habitat of Oil--Northern Great Plains and Rocky Mountains, A. A. P. G. Symposium on the Habitat of Oil, in Press.

____________, Northern Great Plains Paleogeography and Stratigraphic traps, Second International Villiston Basin Symposium, In Press.

____________, Rapid Methods of Making Sedimentational Analyses of Arenaceous Sediments, J. Sed. Petrol, vol. 13, 1943, pp. 95-96.

Krynine, P. D., Petrology and Genesis of the Third Bradford Sand, Penn. State College Min. Indus., Exp. Sta. Bull, 29, 1940, p. 24.

Imbt, W. C., Carbonate Porosity and Permeability, In Applied Sedimentation (P.D. Trask, Editor), John Wiley and Sons, N. Y., 1950, pp. 616-32.