EXPLORING FOR STRATIGRAPHIC TRAPS IN THE OFICINA AREA, VENEZUELA

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ABSTRACT

The exploration for oil accumulations in the Greater Oficina area, which is located in the State of Anzoátegui, Eastern Venezuela, has utilized most of the exploration tools as soon as they became available. Early exploratory locations were based on structural information derived from field surveys, torsion balance, gravity surveys and refraction seismograph data. Later, as more was known about the structure of the basin, reflection seismograph mapping, modified by structure drill data, became the most effective method to locate the faults along which oil may have accumulated. The latest method for finding oil accumulations is a combination of stratigraphic mapping and reflection seismograph data in order to locate areas of good lensing sand development that might favor the accumulation of oil. Wherever lenses or "channel" sands abut against a fault, or wherever lateral sand pinchout of "areal" sands can form barriers that abut against a fault, a trap is provided that merits investigation by drilling. Then, stratigraphic drilling is used to evaluate these accumulations and to trace the trends of the sands.

Considerable success has been attained by the stratigraphic test programs utilizing these methods; during the past ten years, about 700 stratigraphic holes have been drilled, discovering hundreds of millions of barrels of new oil in combination stratigraphic and structural traps.

RÉSUMÉ

Pour exploiter les accumulations de pétrole dans la région de "Greater Oficina" qui se trouve dans l'Etat de Anzoátegui" à l'Est du Vénézuéla, on s'est servi de la plupart des moyens d'exploration, dès qu'ils sont devenus disponibles. Au commencement, les lieux d'exploration se localisaient à base d'informations de structure qui s'obtenaient des observations des champs, par balance de torsion, par des investigations de gravité et par des données sismographiques de réfraction. Plus tard, au fur et à mesure qu'on obtint plus d'information de la structure du bassin, l'établissement des cartes par reflexion sismographique, modifié par les données de perforation de structure devenait la méthode la plus efficace pour localiser des failles où le pétrole pourrait être accumulé. La dernière méthode pour trouver des accumulations de pétrole consiste en une combinaison d'établissement de cartes stratographiques et l'obtention de données de réflexion sismographique à fin de localiser les régions de bon développement de sables lenticulaires, susceptible à favoriser l'accumulation de pétrole Là où des sables lenticulaires ou des "sables de canal" s'appuient sur une faille, il se produit une trappe qui vaut bien la peine d'être étudiée en perforant. Dans ce cas, la méthode de perforation stratigraphique pour évaluer ces accumulations et repérer les tendances des sables est utilisée.

Un succès considérable a été obtenu par les programmes d'épreuve stratigraphique. Pendant les dix derniéres années, les épreuves stratigraphiques ont permis la perforation d'environ 700 trous stratigraphiques. Ces trous ont donné comme résultat la découverte de centaines de millons de barils du nouveau pétrole d'une combinaison de trappes stratigraphiques et structurales.

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INTRODUCTION

The Greater Oficina area is situated in the south-central part of the State of Anzoátegui, about 100 kilometers north of the Orinoco river and about 150 kilometers south of the Caribbean Sea (Figure 1). The area covers about 18,900 square kilometers and at the present time includes 97 oil fields, 20 of which are Class A fields (over 50 million barrels). Since the discovery well, Oficina N° 1, was completed in 1937 by the Mene Grande Oil Co., a total of 5,560 wells have been drilled and the cumulative production, as of 30 June 1970, is 3,610 million barrels, with current production slightly more than 436 thousand barrels per day. The oil fields discovered in the Greater Oficina area before 1947 have been described in detail by Hedberg, Sass and Funkhouser (1) and later information on the area has been reported by E. Mencher <u>et al</u> (2), G. A. Young <u>et al</u> (3) and H. H. Renz <u>et al</u> (4).

The Greater Oficina area is located on the southern flank of the Eastern Venezuela Basin, in the flexure zone or hinge belt of the structural basin. Consequently the area is complexly faulted, resulting in a mosaic of E-W, NE and NW striking normal faults. These normal faults, with fault displacements varying from a few feet to more than 700 feet, are of fundamental importance, together with the lenticular sand development, in controlling the accumulation of oil. Most of the oil occurs in the sandstone beds of the Oficina formation. The sandstones are part of a cyclic series of siltstones, lignites, sandstones, shales and claystone deposited in deltaic and paralic environments through repeated alternation of lagoonal-swamp, brackish-water and shallow-water marine conditions. Oil also occurs in the underlying Merecure formation containing interbedded sandstones and shales which were deposited under fresh and brackish-water conditions. The stratigraphic section in the Oficina area is illustrated by Figure 2.

The Oficina sands are extremely lenticular, relatively thin (2 to 40 feet as a rule, but can be up to 200 feet thick) and effectively separated into discrete reservoirs by the underlying and overlying shales. The term "channel sand" is used generally by everyone for these lenticular sands but the true origin of any one sand is not really known. With continued study, the sand patterns are being developed but it is still difficult to determine, with the information available, whether a sand was a point-bar, lunate bar, levee, crevice deposit or part of a barrier beach. The Oficina section contains over 100 sands, most of which are productive in one or another part of the Greater Oficina Area.

EARLY METHODS OF EXPLORATION

The search for new accumulations of oil is the primary responsibility of the geologist and his success depends entirely on the tools and data available, plus the time and ingenuity to utilize them. In Venezuela over the years, geologists have used geophysics, structure drill, stratigraphic testing and recently detailed mapping as tools. The search for traps was, and still is, a continual process of re-study and appraisal. The results of old surveys, re-studied in the light of new research and ideas, continue to reveal bases for finding new traps.

Early exploratory wildcats searched primarily for structural traps but as more data became available, and it was apparent that the oil had accumulated in stratigraphic traps, the geologists devised new techniques to look for accumulations not directly related to structure but rather for traps formed in combination with sand development and porosity changes. Before describing these newer techniques, I would like to review briefly the past techniques as they provide to key to the basic exploration for stratigraphic traps.

Refraction Seismograph

The basic tools during the early days of exploration in Eastern Venezuela were a combination of surface geology, refraction seismograph and torsion balance. The oil fields found during this early period, 1930-1939, in the Greater Oficina area are shown on Figure 3, after Spencer (4). However, it was quickly realized that refraction seismograph and torsion balance were ineffective in locating faults in the Oficina Area, and that surface geology was useless as the plains were covered with thick Quaternary mesa sediments.

Fortunately, the early drilling provided considerable geological information and indicated the conditions for entrapment of oil. The characteristic features of the Greater Oficina area that guided the future exploration were:

1. A general northward dip of the sediments, less than 5°.
2. Little folding.
3. Common normal faulting, with fault planes dipping 40° to 45°.
4. Accumulation of oil in fault traps.
5. Multiple productive sands.
6. Excellent electric log correlation for short distances.

Magnetometer Surveys

The magnetic surveys carried out during the years showed pronounced northeast-southwest magnetic trends but the interpretations made at the time did not help to discover oil accumulations. Only recently, through the use of trend maps, has the magnetic picture been clear enough to correlate with the known subsurface fault pattern.

Gravimeter Surveys

Gravity surveys also failed to provide any practical data on faults. However, with the development of residual trend maps, the gravimetric data shows a fault mosaic similar to the known subsurface pattern.

Reflection Seismograph

Reflection seismograph, which was introduced into the Greater Oficina area in 1939, appeared to fill the requirements for a tool to locate faults. Although the early work was rudimentary, methods of interpretation and the mechanical equipment improved rapidly so that reflection seismograph became established as the most effective tool to locate faults. However, small branch faults, which were needed to provide entrapment, were not identifiable on the reflection profiles, so a method of structure drilling was devised to overcome this deficiency.

Structure Drill

Structure drill holes were used to verify faults found by reflection seismograph and to obtain additional structural details, such as small branch faults, fault splits and small changes in the strike of the faults, that are necessary to cause entrapment of the oil. The method of using structure drill was to drill a series of shallow holes to a correlatable horizon beneath the surface mantle and map the structure. The shallow structure would, hopefully, reflect the structure at depth. Holes were drilled on one kilometer spacing to depths ranging from several hundred to four thousand feet.

As an example of the branch faults found by structure drill, Figure 4 shows the seismograph interpretation of the Areo area with a strong ENE trending fault, (the Merey fault) and weak indications of two barrier faults that might provide closure for a trap. A structure drill project was carried out to verify the faults at shallow depths. The resulting map, projected to the same horizon, shows the structure to be similar to, but slightly more complex, than the original seismograph picture.

Although structure drill was not practical as an initial means of exploration

due to the high cost per acre explored, the combination of reflection seismograph and structure drill was the most effective method used in the Greater Oficina area, finding most of the major fault trends and the largest number of fields (Figure 3).

DEVELOPMENT OF STRATIGRAPHIC METHODS OF EXPLORATION

During the development of the fields in Greater Oficina, the subsurface mapping showed that the sands were very lenticular and that they appeared to pinch-out in an east-west direction (Figure 7). Whether or not these lenticular sands were actually north-south trending channel sands was not determinable at the time, but it was realized that new methods would have to be devised in order to seek out these combination stratigraphic-structural traps.

Two methods were introduced at this point to overcome the problem: 1) the stratigraphic test technique and, 2) the semi-regional isopach mapping project (6). The first was to drill holes along the major east-west seismograph faults so as to locate and evaluate new sand lenses, i.e. channel sands; and the second was to draw semi-regional isopach maps on each sand, connecting the known parts of lenticular sands along each fault, in an attempt to delimit and to trace the trend of each channel sand. It was believed that where these channel sands were crossed by faults would provide traps with excellent possibilities for oil accumulation.

Stratigraphic Testing

The concept of strat hole testing combines two related objectives. One objective is to trace the positions of faults, particularly small branch faults not shown by seismograph or structure drill, any one of which may control a major trap. The other objective is to refine stratigraphic information on channel sand development, shape and areal distribution. Some channels contain major reservoirs despite an east-west width of only a kilometer or so.

As the wells have to be drilled rapidly and economically, a portable rig is used that is capable of drilling through the Oficina formation to 12,500 feet. The spacing of the holes is flexible, but they are usually spaced 1 to 1.5 kilometers apart, as any wider control could straddle a prospective channel.

This stratigraphic test hole technique was introduced in the Oficina area in 1954 and has been highly successful in finding stratigraphic traps (Figure 3). The Ostra project is a good example of the technique and it is typical of the many projects that have been carried out in the Greater Oficina area. As shown by Figure 5, the Ostra project was designed to trace the Ostra seismograph fault and investigate any associated oil-bearing sands. The original project contained 23 holes spaced at one-kilometer intervals along the fault. After drilling the first few holes, revisions were made in the structural interpretation at the western end of the project and the locations of several strat holes were changed accordingly. The project was successful in that it extended the productive area 12 kilometers eastward from the discovery wildcat, Ostra-1, and 9 kilometers to the west. Major accumulations were found to be in thin channel sands controlled by the Ostra fault (shown by Figure 7, a cross-section parallel to the fault) and by a general pinch-out of sands to the west. A total of 28 wells were drilled and eleven were successful, finding over 18 million barrels of recoverable reserves. The wells were drilled in an average of 7.8 days to an average depth of 5,560 feet.

This same approach is also used to trace extensions of known faults beyond the productive limits of fields in the hope of finding new sand channels which require only an updip fault for accumulation. It is also used to investigate shallower sands, or deeper sands, along the barrier faults in the middle of large fields in which the wells are dedicated to one or two productive sands.

Stratigraphic Mapping

About the same time that stratigraphic drilling was started, semi-regional map-

ping was also introduced. Prior to 1950, sand mapping by isopachs of net sand or percentage of sand was generally restricted to the field areas, primarily because there was so little information between fields.

However, a project of semi-regional mapping was set up and the net-sand isopachs for each sand in one field were extrapolated and connected to equivalent sands in all other fields. These maps brought out the existence of long north-south trending channel sands. Figure 6 shows a typical sand map, in a generalized form, of the I5 sand. When the sand map was combined with a fault map, it pointed up many locations to drill where the sands abutted against barrier faults. Where one sand channel is overlain by two or three other sand channels and the possibility of faulting is good, a location would be considered as attractive for strat drilling.

It should be mentioned that the locations derived from the initial mapping project were not particularly successful for two reasons: it was found that the actual sand channels were not straight, nor particularly long, but meandered and were truncated abruptly, as might be expected; and faulty regional correlation showed erroneous trends between fields.

A more successful stratigraphic mapping technique at that time was to extrapolate the position of eastern or western pinchouts of sands along faults that ran diagonally to the dip of the sediments, as indicated by Figure 4. Thus oil that had migrated updip along the fault was entrapped by the pinchout of the sand. Between adjacent fields, or adjacent points of well control, channel pinchouts could be estimated with some certainty and this method of mapping was used in conjunction with strat drilling for many years.

The regional approach to channel mapping, as mentioned previously, was undoubtedly the best one to use to locate any interfield channel sand traps, but it was obvious that the basic data had to be correct. It was also obvious that to correct the data would involve two time-consuming stages of data preparation. First, all of the sands in the area would have to be recorrelated on a regional basis and then the fields would have to be re-mapped on a detailed lens-by-lens basis. Only after completing such a detailed mapping project would it be feasible to re-map the areas between the fields so as to show the areal distribution of the channel sands.

It was decided that such a detailed mapping project would be worthwhile and the project was started about four years ago in 1966. Numerous new segment traps and channel extension prospects were indicated by the maps and immediately drilled as either exploratory or development wells. No detailed record was kept as to the number of traps found by the project, but it is estimated that over a hundred of such traps have been drilled with a success ratio of over 45%, which attests to the quality of the mapping project.

As there is now such a wealth of data in the Oficina area, it has become difficult for geologists to thoroughly process and evaluate it. This where the role of the computer becomes important because it can compare, analyze and map large amounts of data. At present the computer is being used as a new tool to search through all of those blank areas between existing fields and provide an indication, by maps and data print-outs, as to whether or not a sand trap is there and what the prospects are for oil accumulation.

The computer approach is still in its infancy but several computer locations have been found and drilled with moderate success.

As an example of the mapping methods now being used for channel sand exploration, Figure 8 shows four maps over the area of the 1969 channel sand discovery in Isla field. For comparative purposes, Map A (Figure 8) shows the seismic picture, on the J_2 sand horizon, as it was in 1966. From a structural standpoint, a trap is formed by the juncture of the Yanes fault and indications of branch faulting, marked

by a circle on the map and labled as an area of interest.

By using the data stored in the well file of the computer data bank, the computer can plot a net sand map for any of the hundred sands in the Oficina formation. In this case Map B shows a computer plotted map of a third-degree polynomial surface on the net-sand isopachs of the O_2 sand, which is one of the prospective channel sands. One sand trend appears to extend south-eastward from well - 101 and another from near well-6. The computer can also plot maps showing regular net sand, sand percentage and interval thickness, or maps of various degrees of polynomial surfaces and residual surfaces.

With the trend of the channel indicated by the net-sand map, the next step is to obtain a computerized map of the structure, in order to look for faults that cross the channel trends. Map C shows a third-order polynomial least-squares residual trend surface drawn on the U_2 sand, which is the base of the Oficina formation and which provides a good indication of structure. Note that one easterly fault appears to cross both sand trends, and another fault farther south appears to cross the extrapolation of the sand in the area of interest. Thus by using the fault pattern derived from well data (Map C) or by using seismic fault data (Map A), we can locate prospective traps where faults intercept trends of sand thickening.

In 1969 Strat Well - 601S was drilled in the area of interest (Map D) and found three prospective channel sands: the O_2, R_0 and R_1. The area was quickly developed and other strat wells were located to extend the trend southward. Wells 802S and 806S found the sands but were in the downdip portion of the sands due to the eastward dip of the sediments.

At this point it may be well to review some of the difficulties encountered in searching for and in developing channel sands, regardless of the methods used.

First, the exploration problem. To locate a channel accumulation, a channel sand must be extrapolated from some adjacent field and this meandering sand body must be cut by a fault to form the accumulation. The area around Well - 6 (Figure 8D) showed sand thickening and oil accumulation, two important elements. The thickening could be projected southward as a trend parallel to the 601S channel. The southern boundary fault of the 601S area could be projected eastward to form a trap. Farther south a seismic fault also crossed the sand to form a trap.

During 1970, two strat wells were drilled on this trend to test these traps and both were dry: 211S found the channel sands but no fault, and therefore no accumulation; 255S found a fault but no sand channel, and therefore no oil accumulation.

Development drilling also poses problems. In the 601 area two holes were dry because they are downdip in the water leg due to the dip of the sand toward the east. In the 802 area, an outpost hole, in an effort to step updip, stepped out of the sand channel and was dry.

In spite of many problems, the channel sands are worthwhile pursuing because they are prolific producers. During 1970 two stepouts from Well -101 for the O_2 sand were completed for 1,500 BPD and 2,500 BPD of 40° - 43° oil. Other strat test holes, such locations E-20 and Y-28, are planned to further delineate this group of channel sands.

Although the Oficina area has been explored repeatedly by different techniques and the best traps have already been found, it is felt that there is still a large amount of oil to be found in channel sands. As the oil will be in small pools, however, a major drilling effort, such as lines of strat tests, cannot be justified economically. The exploratory sites must be pinpointed by careful mapping and new methods, such as those utilizing sand trends and fault patterns.

SUCCESS OF STRATIGRAPHIC TESTING AND MAPPING

As all methods of exploration are used together in combinations, it is difficult

to assign a measure of success to any one method. However during the period 1966-1969 most of the exploratory locations drilled by the Mene Grande Oil Co. have been based on a combination of subsurface mapping and seismograph; that is, extrapolation of faults and sand thickening into areas adjacent to fields. The exploratory success ratio for this type of stratigraphic-structural mapping, averaged 51% over the 4-year period, drilling an average of 12 exploratory wells per year. During 1970, 12 wells were drilled for channel sands distant from field control with a resultant success ratio of 33%. As wells producing from channel sands are generally good producers, 300 to 2,500 BPD initial potential, and the wells are relatively inexpensive to drill, $85,000 for a completed well, the success ratio could fall as low as 20% and still provide an attractive return on investment.

Another measure of success is the number of locations generated by the mapping project. During the same 4-year period, over 250 new locations, both exploratory and development, were found in the fringe areas of the existing fields due to the mapping and exploratory programs.

During the past fifteen years in which stratigraphic drilling has evolved, over 700 strat holes have been drilled in the Greater Oficina area. Twelve major fields have been discovered as well as numerous small fields, most of which have been incorporated into larger known fields for ease of nomenclature. Success ratios have ranged from year to year between 33% and 63%. These strat holes have discovered over 800 million barrels of recoverable reserves, primarily in combination stratigraphic and structural traps of the types described. As the exploratory phase is about over in the Greater Oficina area, the area provides a good history of the use of exploration tools and techniques, which may be applied to other areas with deltaic environments. Many of these methods have already been described individually in other professional papers, but I feel that the successful use of combinations of techniques is not always known nor published, and that discussion of these techniques may aid exploration in new areas and provide ideas that can be applied to old methods in a new sense.

ACKNOWLEDGEMENT

Information included in this paper on the Greater Oficina area has been gathered during the past 30 years through the combined efforts of the many geologists and geophysicists of the Mene Grande Oil Co. Credit for the imaginative use of new tools and methods goes to many geologists, among whom I would like particularly to mention H. D. Hedberg, H. J. Funkhouser, and H. A. Guntz. Among those who have contributed especially to stratigraphy may be mentioned H. H. Renz, George Pardo and J. DeSisto. This paper is presented with the permission of the Mene Grande Oil Co. and the Creole Petroleum Corp., joint owner of many of the concessions in this area.

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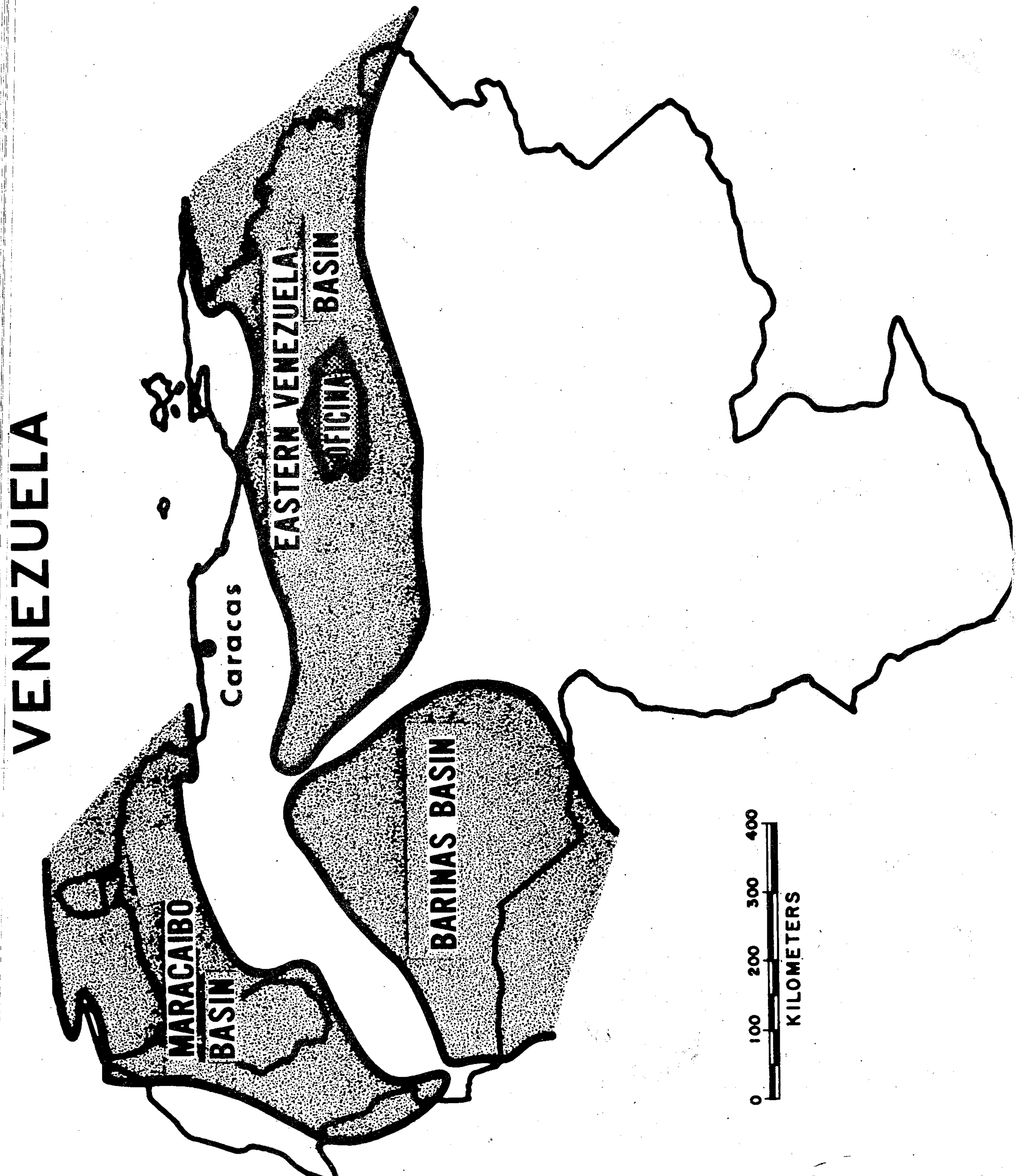
Illustrations



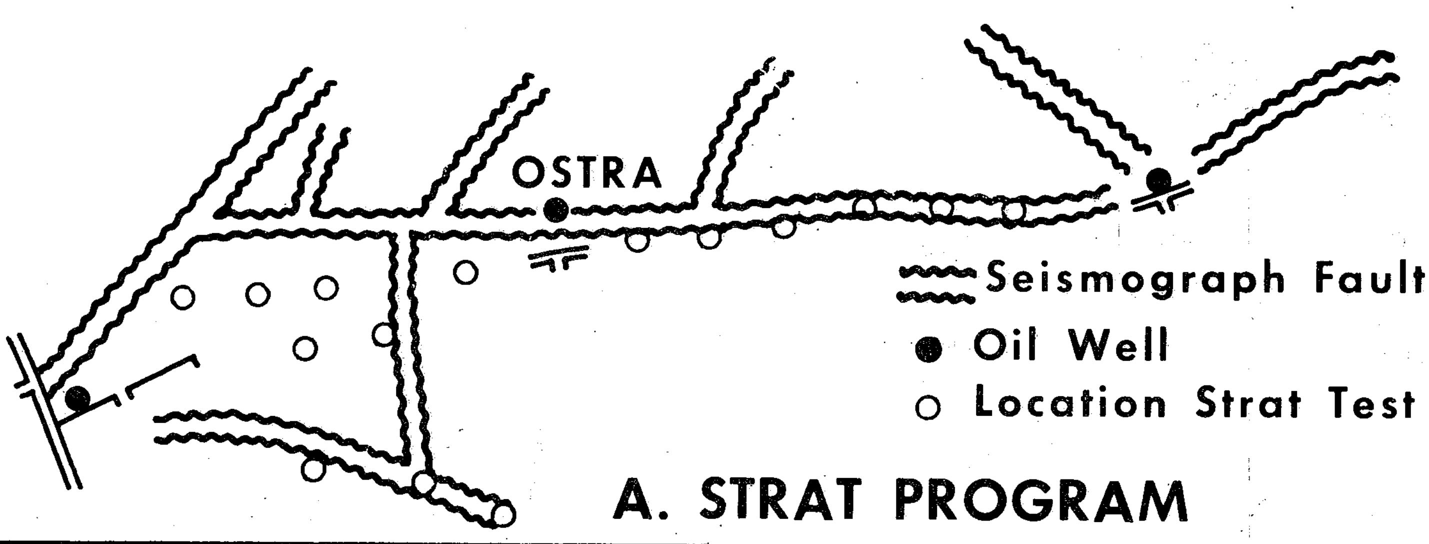
STRATIGRAPHIC COLUMN
GREATER OFICINA AREA

AGE	FORMATION		THICKNESS
PLEIST.	MESA FM.		0'-250'
MIO-PLIOCENE	LAS PIEDRAS FM.		400'-4,000'
OLIGO-MIOCENE	FREITES FM.		1,100'-3,600'
	OFICINA FM.		2,000'-5,000'
	MERECURE FM.		200'-1,400'
CRETA-CEOUS	TEMBLADOR GRP.		600'-2,000'
	BASEMENT		

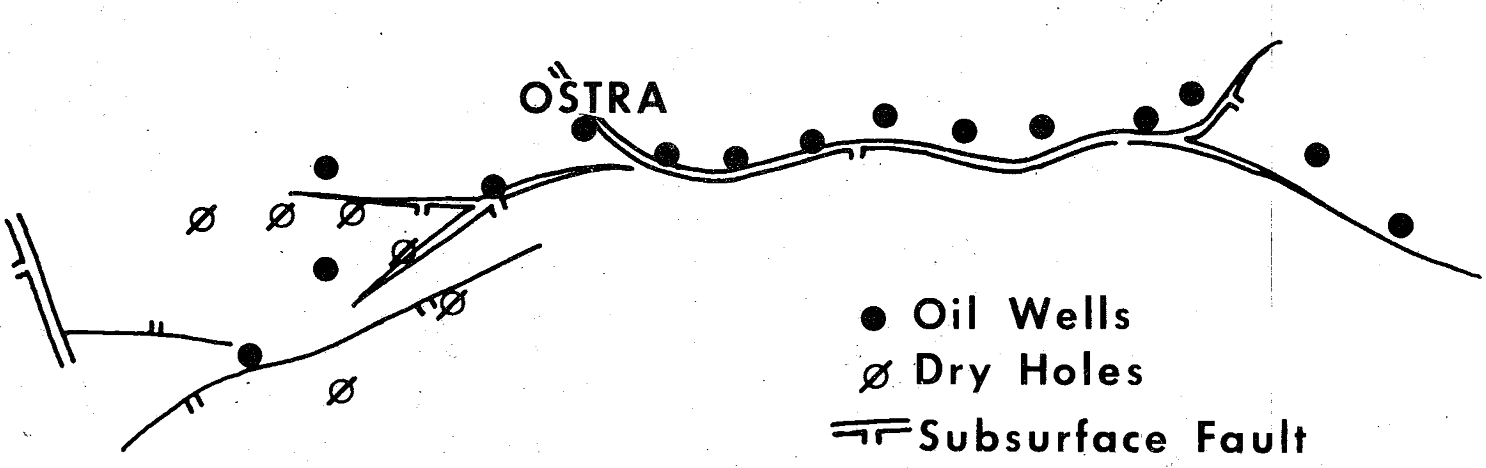
GREATER OFICINA

OIL FIELDS

- Refraction Seismograph
- Reflection Seismograph and Structure Drill
- Stratigraphic Drilling

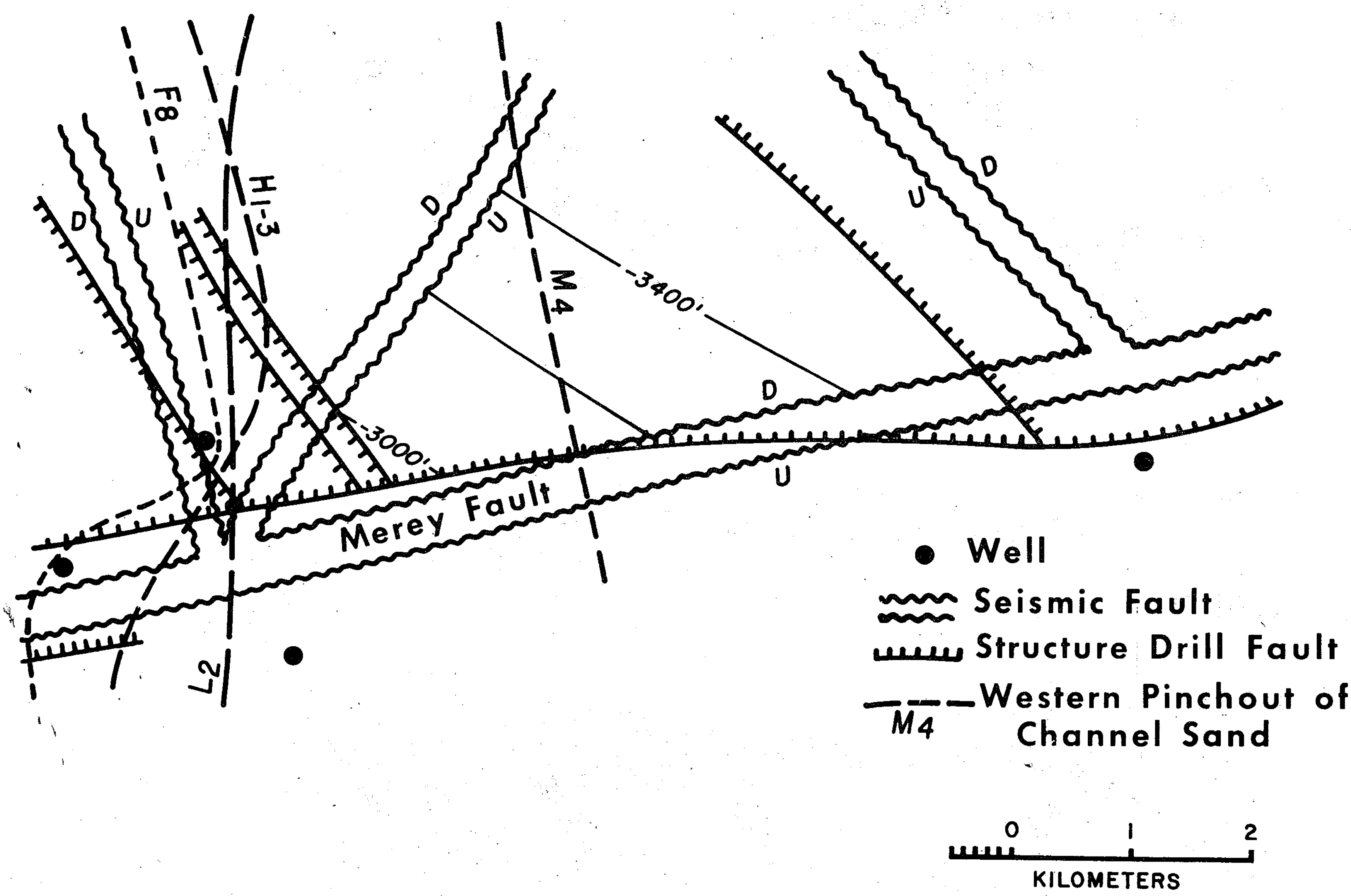


A. STRAT PROGRAM



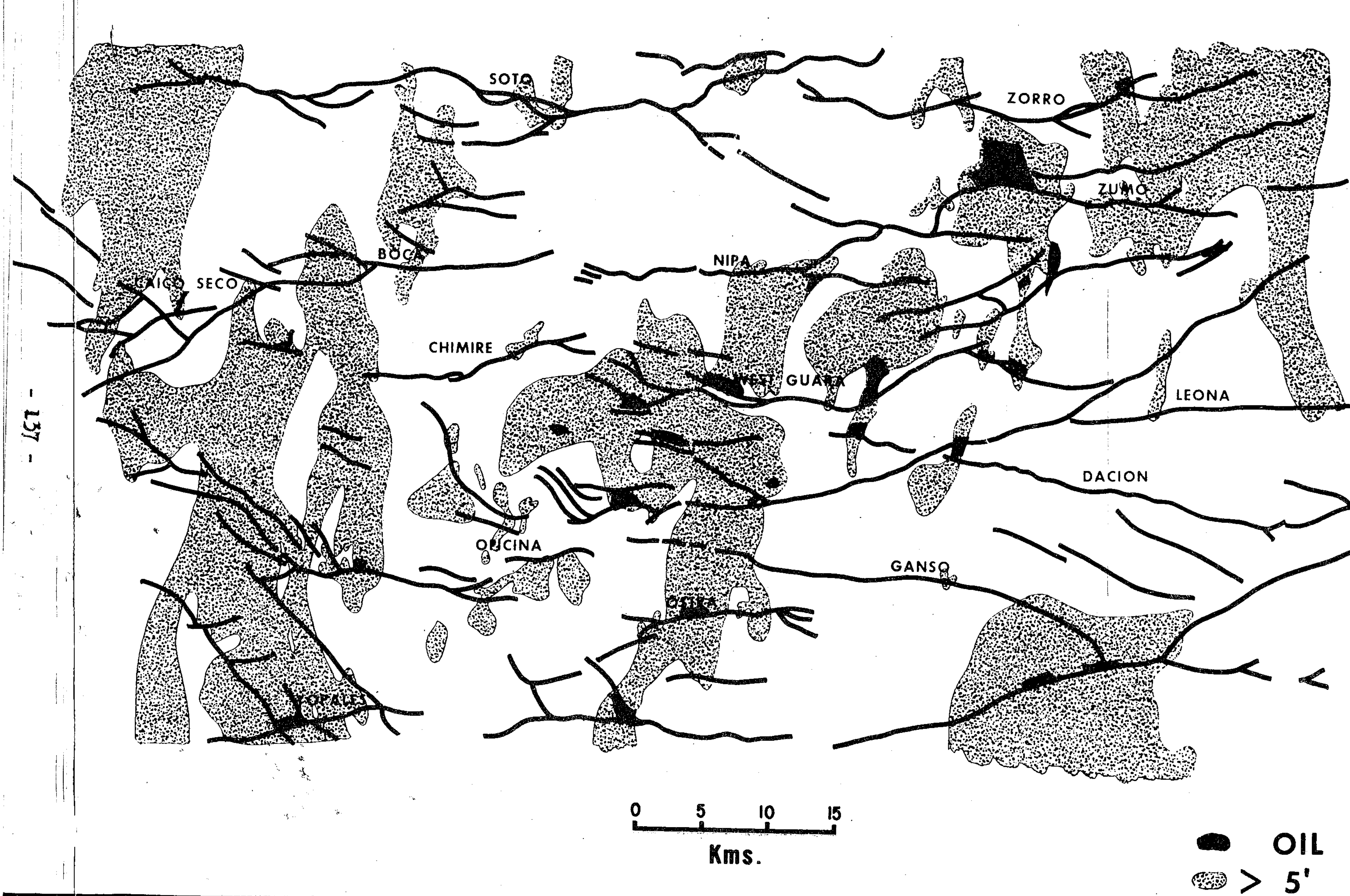
B. RESULTS STRAT PROGRAM

FAULT AND SAND PINCHOUT TRAPS

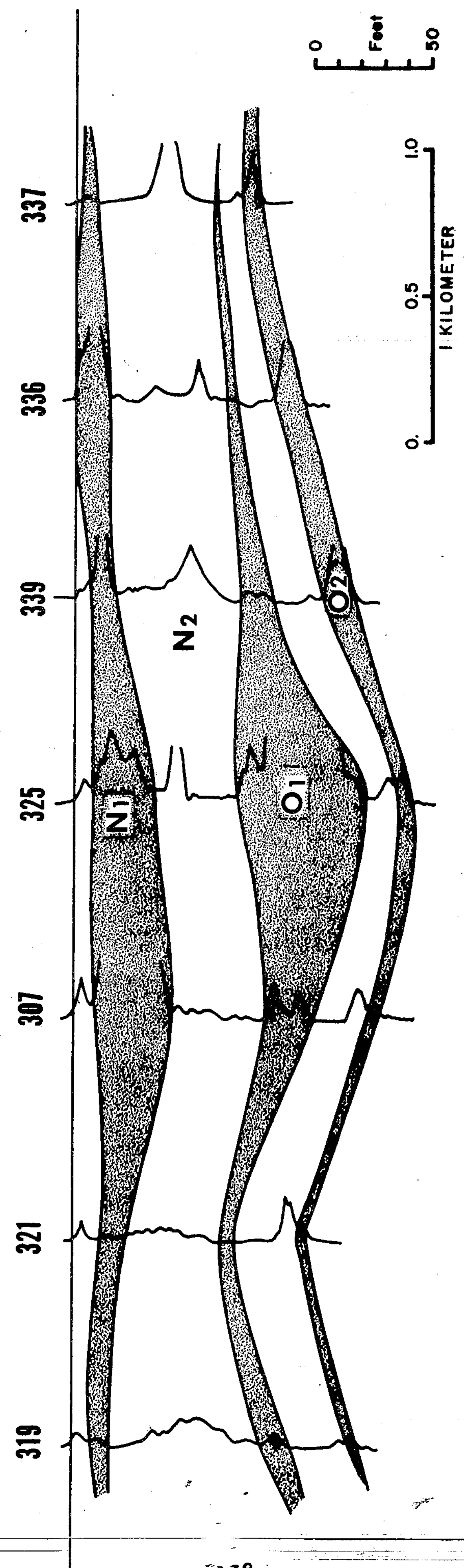


CHANNEL SAND EXPLORATION

I_5 Sand



CHANNEL SAND DEVELOPMENT - OSTRA FIELD



CHANNEL SAND EXPLORATION