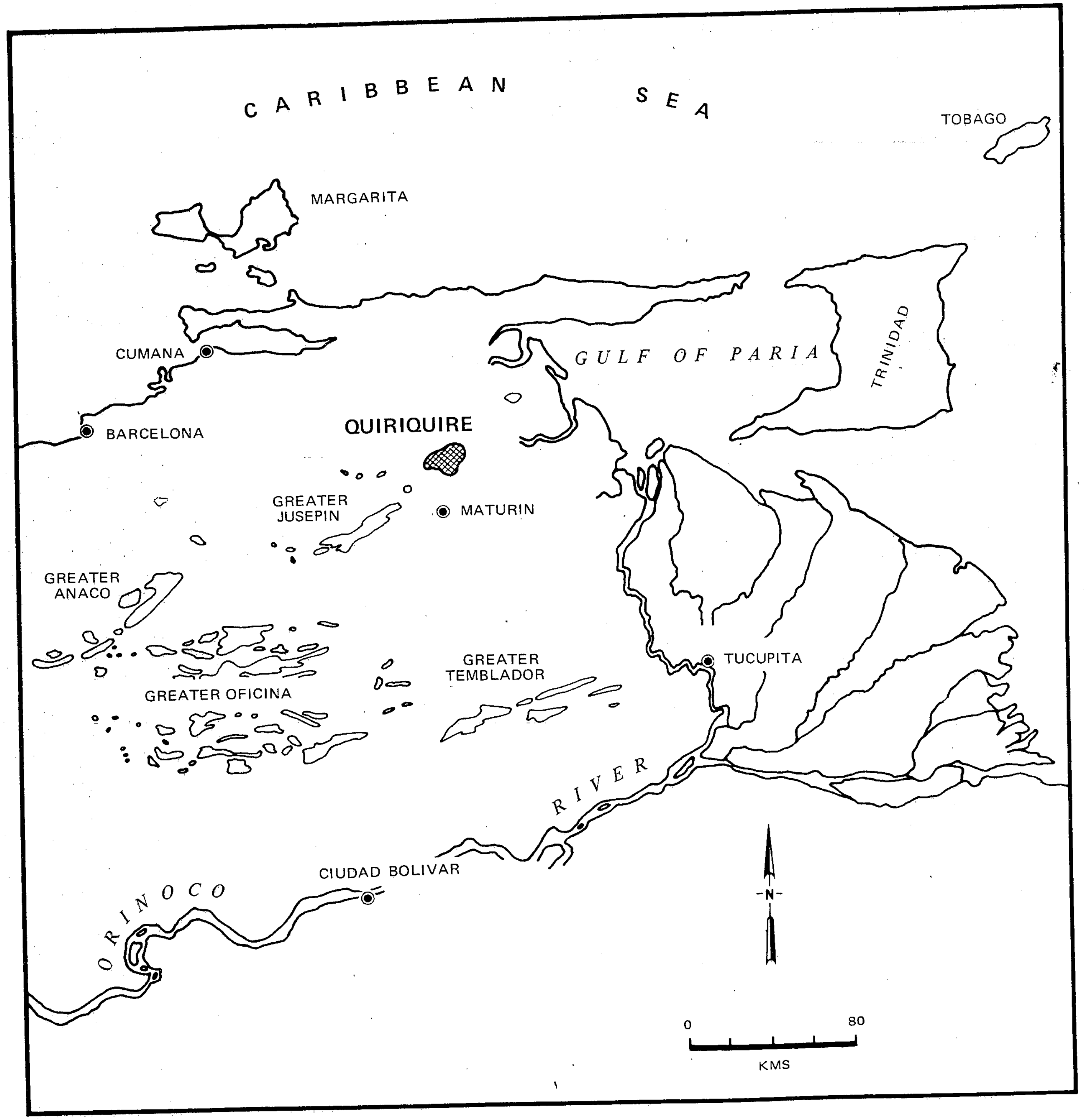


Figure 1. Location of the Quiriquire oil field, eastern Venezuela.



# DEMONSTRATION OF OVERTURNED STRUCTURE BENEATH THE QUIRIQUIRE OIL FIELD, VENEZUELA

By James L. Lamb [1)]


## Abstract

The Quiriquire oil field is situated on the north flank of the Eastern Venezuelan Basin and produces from gently-dipping Pliocene beds which rest with strong unconformity on Cretaceous to Miocene beds involved in complex structures. Various structural interpretations of these older beds have been offered, postulating simple folds and both normal and reverse faults. The final solution, in which zonation by planktonic foraminifera was the key technique, has clearly demonstrated an overturned fold in the northern sector.


## Introduction

The Quiriquire Field is located in eastern Venezuela, just south of the foothills of the Serranía del Interior (i.e., the mountain range of the interior), some 25 kilometers north of the City of Maturín, which is the capital of the State of Monagas, Venezuela (Fig. 1). The discovery well was drilled in 1928 on evidence of tar and asphalt seeps. The field has produced more than two-thirds of a billion barrels of oil. By year-end 1967 a total of 648 wells had been drilled, of which about 450 were producing 33,000 BOPD of 16.6°API oil with over 50 percent water. The proven area of the field is about 20,000 acres and more than six million acre-feet of heavy oil-saturated sand. Creole's current estimate of the oil originally in place for the Quiriquire Formation reservoir is 5.5 billion barrels. It is currently estimated that, by the end of concession-life in 1984, the reservoir will have produced 726 million barrels, which is estimated to be only 13.2 percent of the oil in place. A serious problem of water-breakthrough is being studied but water is expected to continue being a production problem because the Quiriquire Formation reservoir is a heterogeneous deposit of non-marine clays, cobbles and pebbles, unconformably overlying an older deformed rock-sequence, and it is difficult to isolate the oil zones from the water. This reservoir has often been referred to as an alluvial fan deposit, and it may be considered a good example of extensive lateral oil migration as marine source-rocks of the laterally equivalent Las Piedras Formation and underlying La Pica Formation are far removed downdip or basinward. Arguments in favor of vertical migration to account for the oil accumulation are hampered by the rather obvious intense deformation and truncation suffered by the underlying beds prior to deposition of the Quiriquire Formation. Although gas and condensate is found at depth in the older deformed

1) Esso Production Research Company, formerly of Creole Petroleum Corp.

sequence, particularly in the Los Jabillos-Caratas Formations, only a small amount of oil has been produced immediately below the unconformable base of the Quiriquire Formation.

## The Deformed Sequence

Unconformably below the Quiriquire Formation lies a deformed sequence of strata which ranges in age from Cretaceous to Middle Miocene. Figure 2 illustrates the superposition, age, and characteristics of these units. This stratal sequence was deformed during the late Early Miocene when the initial Serranía del Interior Orogeny uplifted the mountain belt to the north. In fact, the Quiriquire Field area was presumably within this primeval mountain system - prior to denudation processes - and, structurally speaking, it is separated from the less-deformed basinward sequence by a more southerly fault system. A later Middle Miocene transgression reached the southern part of the field, but most of the northern area was exposed subaerially until the Pliocene. At this time the Quiriquire Formation was deposited, following a fairly recent rejuvenation of uplift of the mountain front. An interesting feature of the pre-Quiriquire Formation erosional surface is the terrestrial Morichito Formation, shown on Figures 4 and 6, which filled in the topographic lows during peneplanation, thereby allowing the base of the Quiriquire Formation to ride evenly over the old land surface. Note how the sole of the thrust plane or point of overturning is reflected by the thick build-up of Morichito sediments (Figs. 4, 6). These deposits have reservoired minor amounts of oil.

## Structural Interpretation of the Deformed Sequence

Over the years a number of wells have penetrated the deformed sequence below the Quiriquire Formation in the search for new oil reservoirs. The progress of this exploration activity was accompanied by a succession of geological theories to account for the seemingly complex structural picture that was developing. These theories ranged from the postulation of simple folds to both normal and reverse faults of some magnitude. A paleontological study of this area was made in conjunction with a detailed lithologic study. During the early phase of this study it became evident that the Areo and Caratas Formations were lithologically so similar that it was infeasible to unambiguously differentiate them solely on the basis of lithology. Also, many early wells had no electric logs, and, due to the steeply dipping strata in the northern sector, those that did could not usually be correlated with facility.

Fortunately, however, the foraminiferal microfauna of the Areo Formation proved to be distinct from that of the Caratas Formation and planktonic foraminifera were found to be fairly common in both formations. Similarly, other formations also had characteristic planktonic species. Published results of biostratigraphic studies in Trinidad indicated that the planktonic foraminifera held the promise of chronologically precise regional faunal correlations, due primarily to their floating mode of existence, which gives them a widespread geographic distribution unhampered by the local bottom conditions. As expected, it soon became evident that the planktonic foraminiferal zones of eastern Venezuela could be matched with those of Trinidad. For this reason they were given particular emphasis in this study.



Gradually the thesis for overturning in the northern sector developed as the geologic and faunal data accumulated. At this time a key well was drilled (the Mosu-11, see Fig. 4), which penetrated an inverted sequence of beds, passed through a thrust fault, then drilled a normal repeated sequence, and finally bottomed in beds of about the same age as those found at the pre-Quiriquire Formation unconformity. This was a surprise - as it was the first time that a well drilled in eastern Venezuela had demonstrably encountered this sort of overturned structure. On the other hand the concept of inversion, or doubling over, gave a neat explanation for the twice-normal thickness of lower Carapita Formation in the synclinal areas.

Following up this lead, detailed cross sections were made in the crucial area. This was not very successful, because penetration below the unconformity was usually small and dips were steep, so that well segments did not overlap. To surmount this difficulty a subcrop map (Fig. 3) was made at the unconformity surface, and now all the data fell neatly into place. Faunal and/or lithologic units were identifiable, and a plot of their occurrence at the unconformity showed these zones subcropping in parallel bands in their correct stratigraphic sequence, successively older from south to north. The only anomalies were a regular north dip, which proved the inversion of the whole sequence, and an offset along a minor wrench fault already detected by seismic surveys.

To complete the structural interpretation, VDF seismic profiles were used to supplement the well information, and cross section (Figs. 4, 5, 6 and 7) were made across different parts of the filed. Although this picture of the Quiriquire subsurface may appear complicated, surface geology maps of the mountains to the north show many comparable structures - recumbent and asymmetric folds separated by thrust faults. The similarity emphasizes the genetic relationship of the two regions.

The final step was preparation of a contour map of the Los Jabillos sandstone (Fig. 8). This map shows the writer's interpretation of the contoured top of this unit, including all structural, tectonic, and other geologic controls. Previous efforts to contour the top of the Los Jabillos were influenced by an old gravity survey, which showed a NE-SW trend. The main structural lineaments as shown here on figure 8 are more east-westerly and the overall closure on the Los Jabillos is more southerly than had been interpreted. Also, the indication of a synclinal axis between the anticline and the overturned structure makes contouring more complicated than had been supposed. As demonstrated, the anticline is bounded on the east by a well known wrench fault and on the west by a fault and homocline. It should be emphasized that the southerly structure is contoured in such a fashion as to be in alignment with the more northerly structural elements, as the two sectors are genetically intimately related.

NOTE

AFTER THE BULLETIN WAS READY FOR DISTRIBUTION SOME CHANGES IN THIS PAGE BECAME NECESSARY. THIS WAS THE MOST PRACTICAL, IF NOT THE MOST ELEGANT, SOLUTION. WE APOLOGIZE FOR THE INCOVENIENCES CAUSED TO OUR READERS FOR CIRCUMSTANCES BEYOND OUR CONTROL.

| AGE | TRINIDAD PLANKTONIC ZONE (Bolli, 1957) | FORMATION | LITHOLOGY | DEPOSITIONAL ENVIRONMENT |
|---|---|---|---|---|
| MIDDLE MIOCENE | *Globorotalia fohsi fohsi sensu lato* | UPPER CARAPITA | SHALE AND SANDSTONE | SHALLOW TO INTERMEDIATE DEPTH MARINE |
| UNCONFORMITY | | | | |
| EARLY MIOCENE | *Catapsydrax stainforthi and Catapsydrax dissimilis* | LOWER CARAPITA | SHALE | DEEP MARINE |
| | | | | SHALLOW MARINE |
| UNCONFORMITY | | | | |
| OLIGOCENE | *Globigerina ciperoensis ciperoensis* | AREO | SHALE | DEEP TO INTERMEDIATE DEPTH MARINE |
| | *Globorotalia opima opima* | | SILTY TO SANDY SHALE-LOCALLY GLAUCONITIC | |
| | | LOS JABILLOS | HIGHLY GLAUCONITIC SILTSTONE WITH SAND STRINGERS | SHALLOW MARINE "ORBITOIDAL" |
| | | CARATAS | SHALE | FLUCTUATING SHALLOW TO INTERMEDIATE DEPTH MARINE |
| | *Globigerina Ampliapertura* | | MOSTLY GLAUCONITIC SILTS WITH SANDS NEAR BASE | |
| LATE EOCENE | *Globorotalia cocoaensis and Globigerapsis semiinvoluta* | | | |
| MIDDLE EOCENE | *Truncorotaloides rohri to Hantkenina aragonensis* | | | |
| | | VIDOÑO | SHALE WITH MINOR AMOUNTS OF GLAUCONITE | DEEP MARINE |
| EARLY EOCENE | *Globorotalia palmerae to G. rex* | | | |
| PALEOCENE | *Globorotalia velascoensis to Rzehakina epigona Zonule* | | | |
| LATE CRETACEOUS | Not determined | SAN JUAN | DOMINANTLY SANDSTONE | SHALLOW |

Figure 2. Stratigraphic sequence of formations underlying the Quiriquire Formation in the Quiriquire oil field.

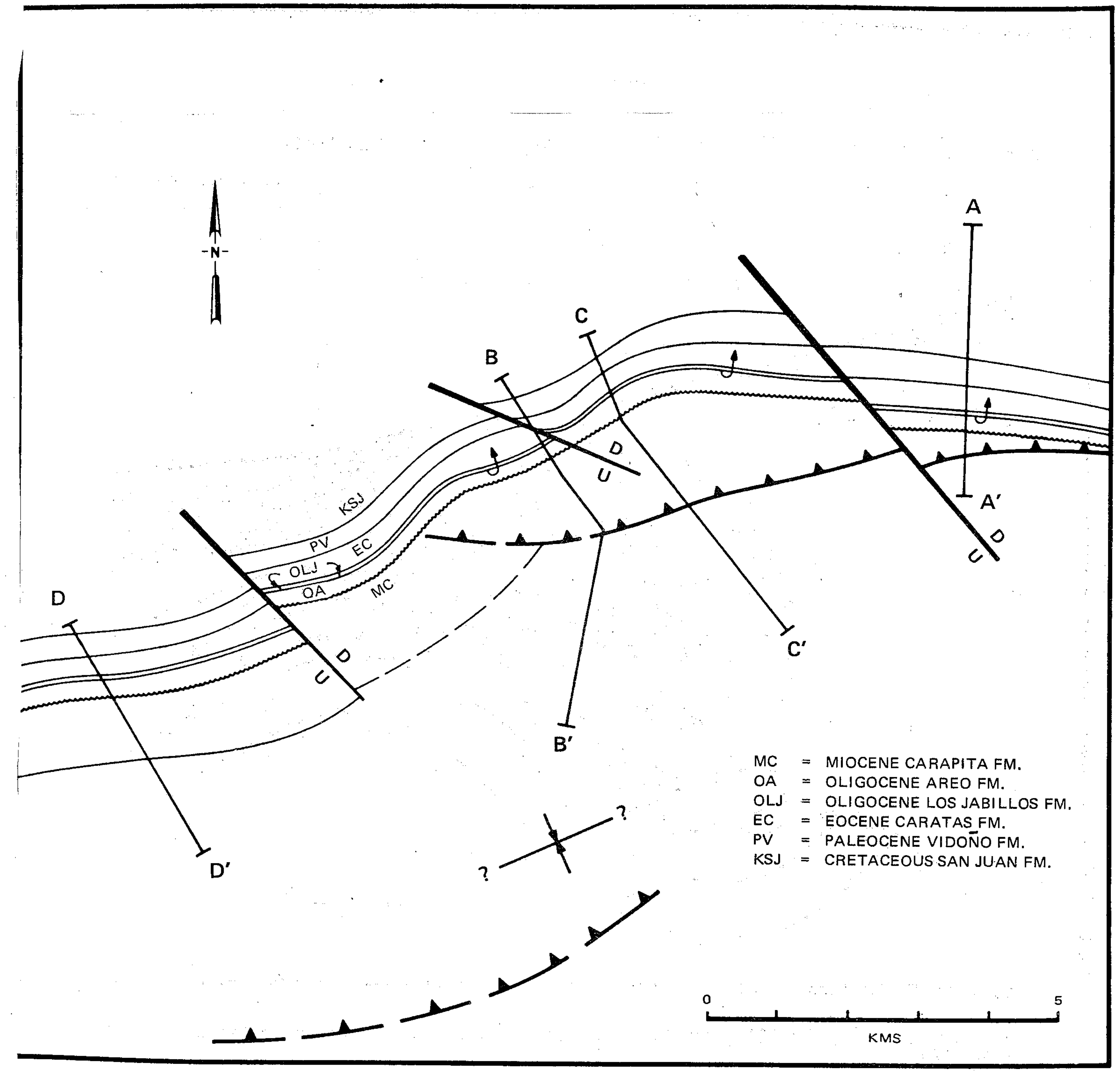


Figure 3. Subcrop pattern of formations of the deformed sequence beneath the Quiriquire Formation in the Quiriquire oil field. Locations of cross sections A-A' to D-D'.

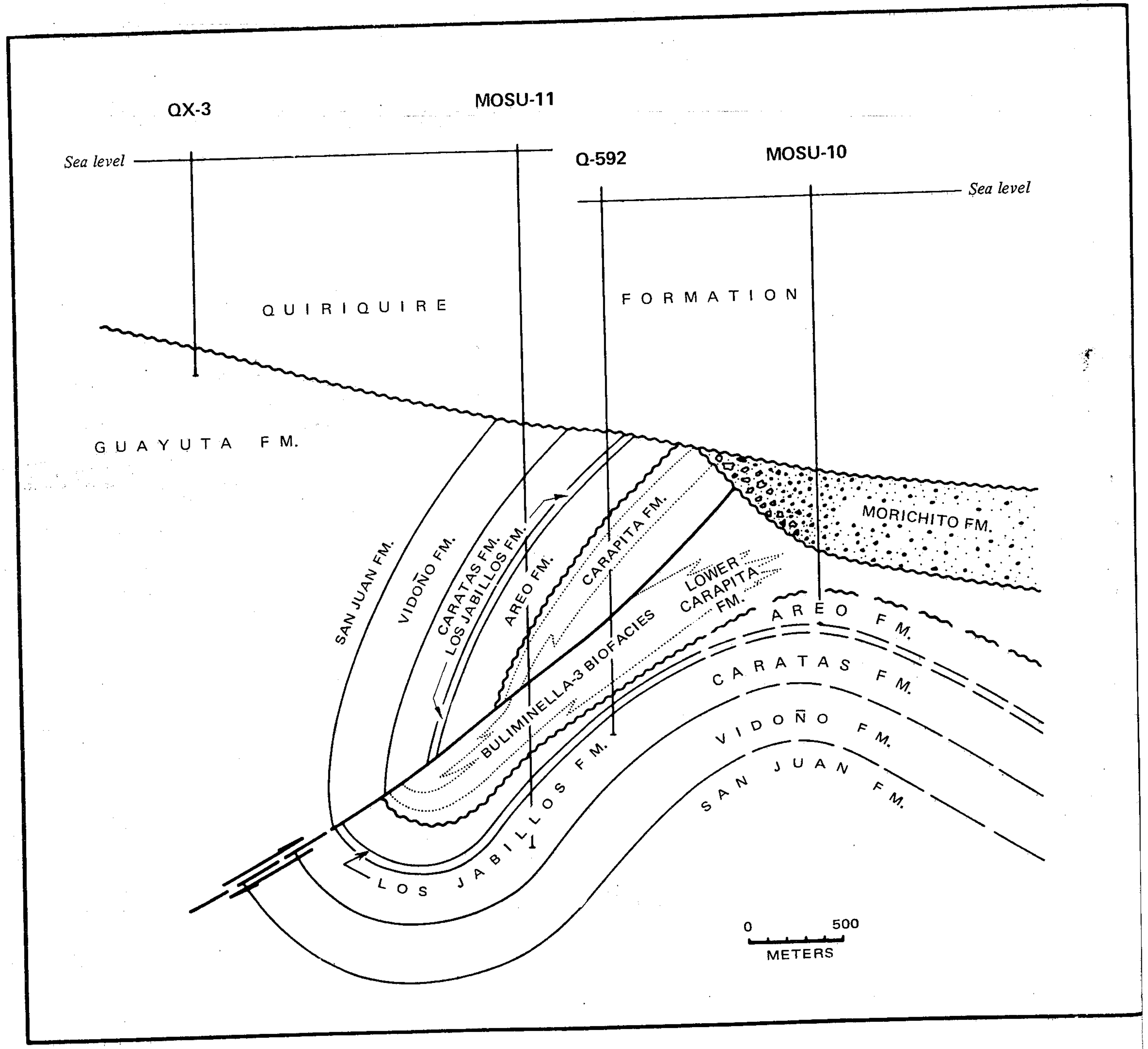


Figure 4. Cross section A-A′ from well QX-3 to well MOSU-10 illustrating complex and overturned structure north and east of the Quiriquire oil field.

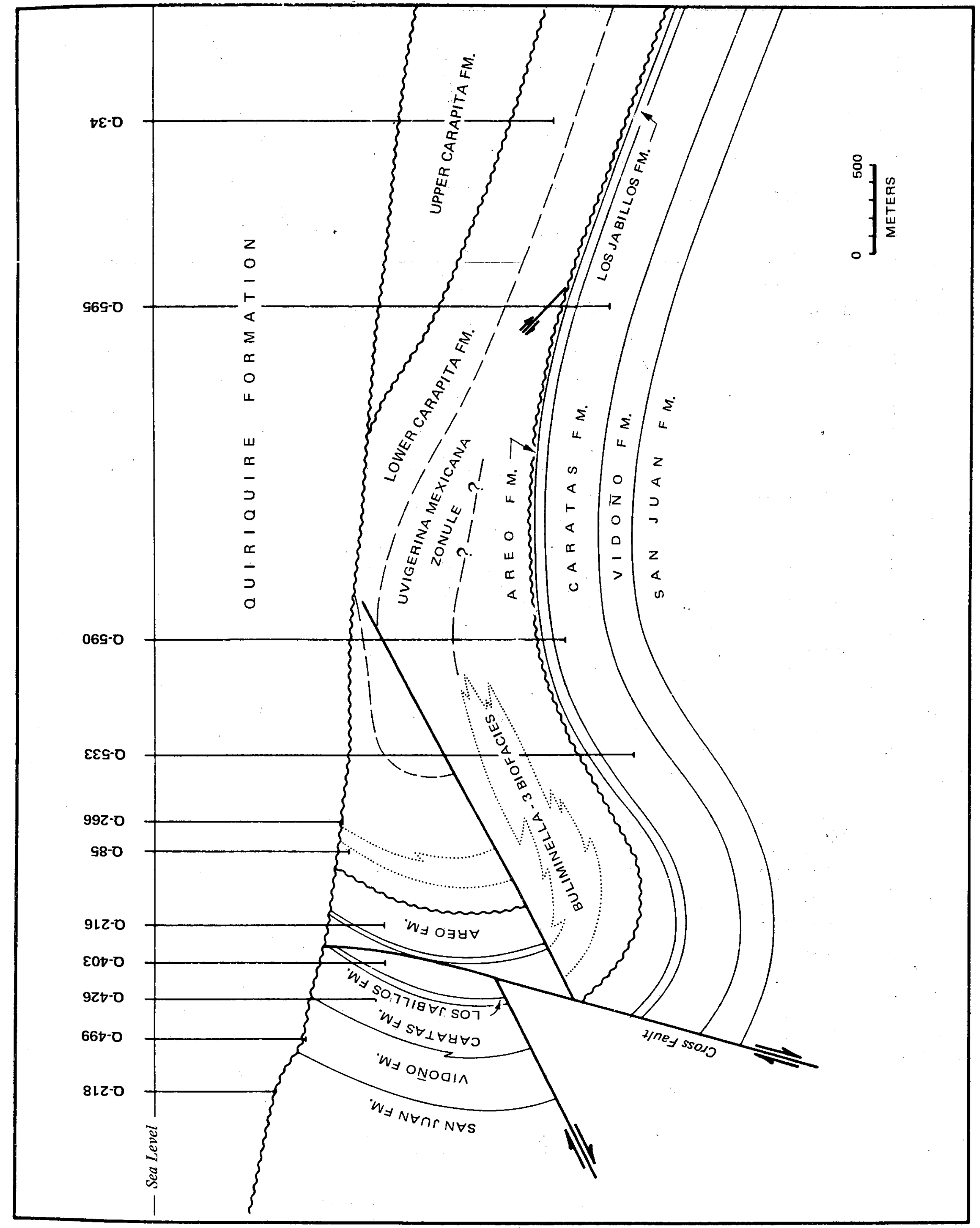


Figure 5. Cross section B-B′ from well Q-218 to well Q-34 illustrating complex and overturned structure through the central part of the Quiriquire oil field.

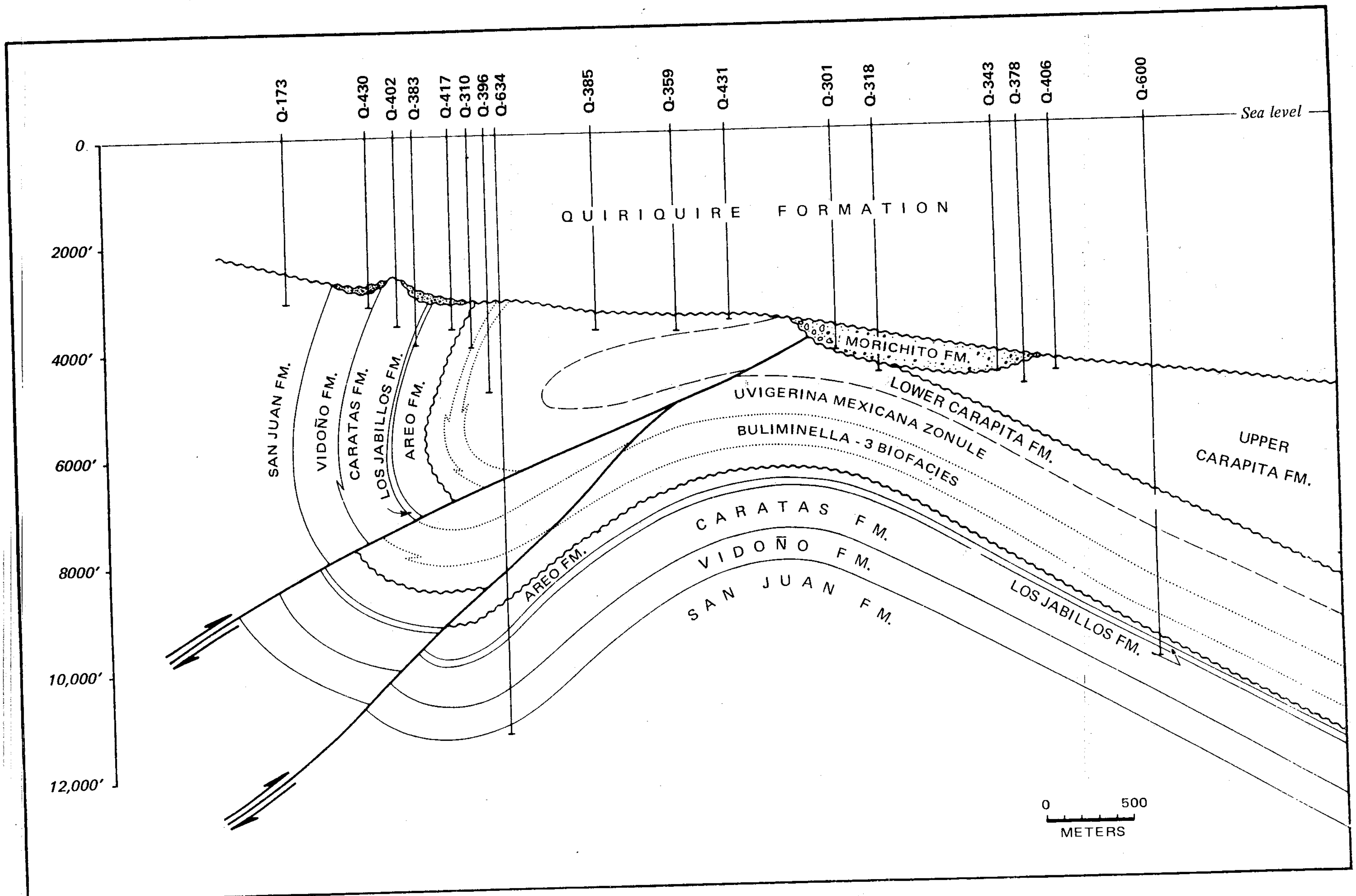


Figure 6. Cross section C-C′ from well Q-173 to well Q-600 illustrating complex and overturned structure through the central part of the Quiriquire oil field.

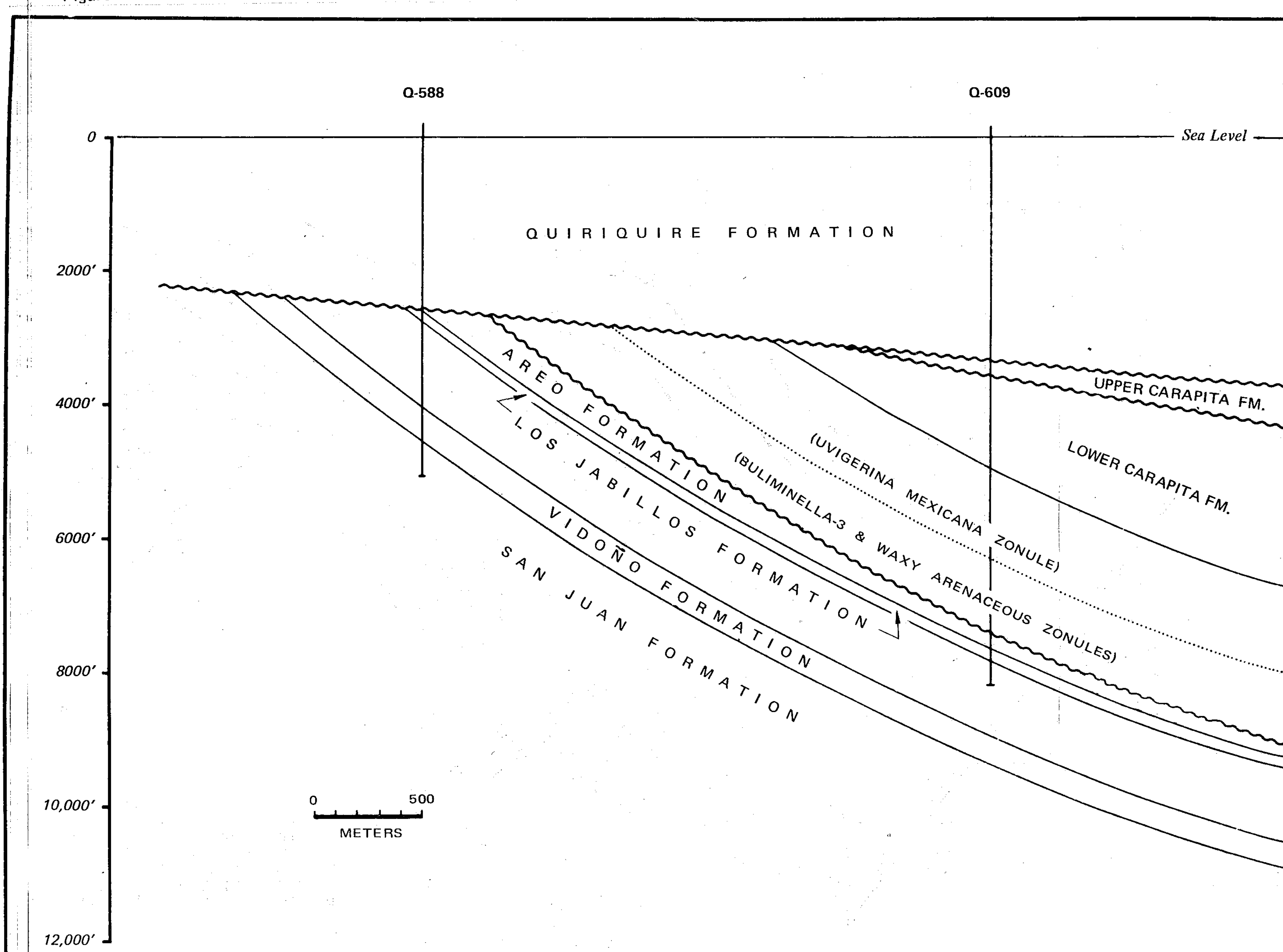


Figure 7. Cross section D-D′ from well Q-588 to well Q-609 illustrating southerly dipping strata on the western margin of the Quiriquire oil field.

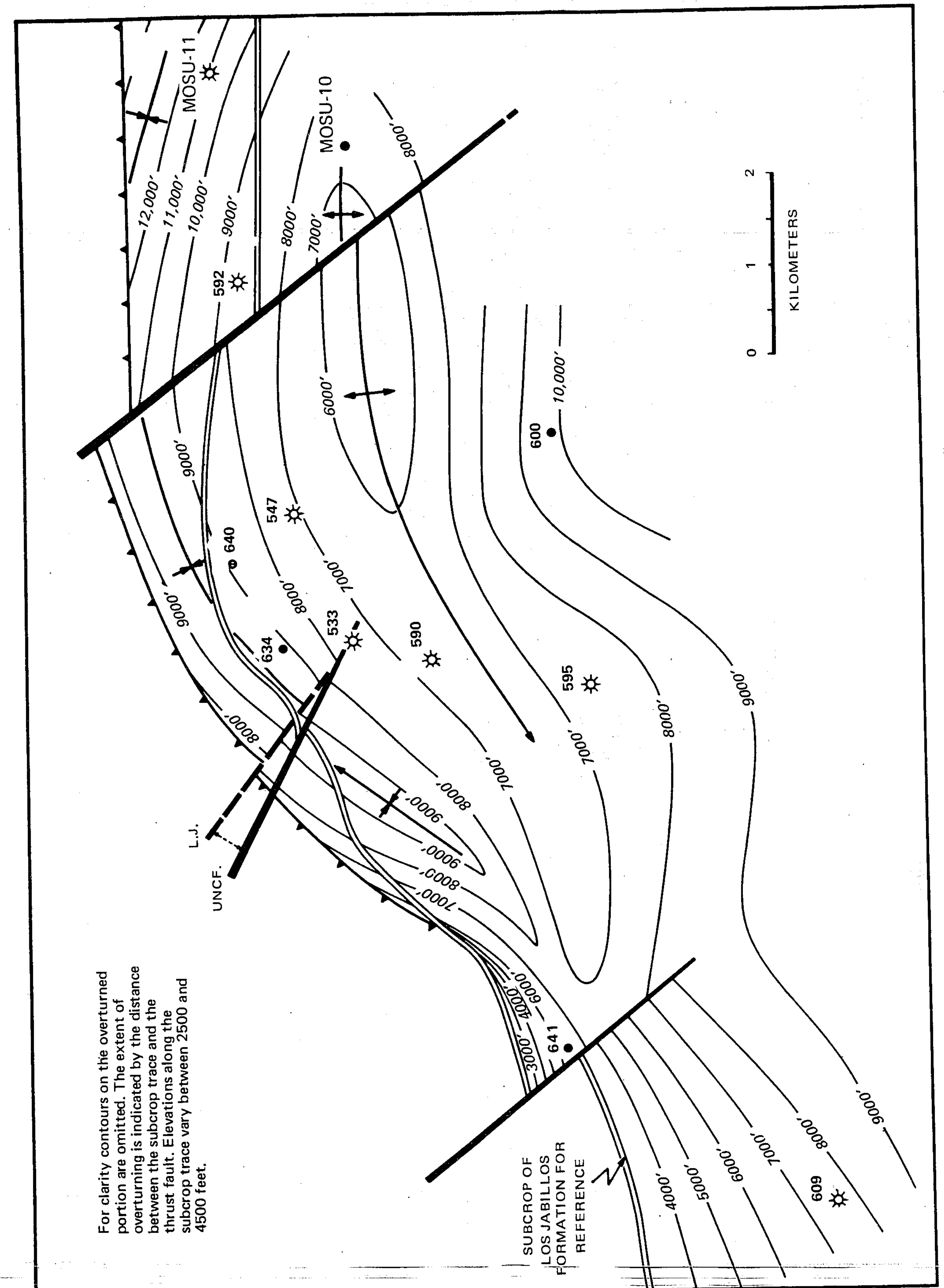


Figure 8. Subsurface structure map of the Quiriquire oil field showing contours on top of the Los Jabillos Formation. Apparent strike-slip faults are shown as heavy black lines.



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A NOTE FROM THE EDITOR,

## NEW IDEAS ON THE OCA FAULT

A recent paper by Doolan and MacDonald, "Structure and Metamorphism of Schists of the Santa Marta Area, Colombia", presented at the First Colombian Geological Congress, Bogotá, 1969, briefly deals with the Oca fault and suggests a maximum limit of right-lateral movement of twenty kilometers for this feature. In this paper, the authors describe the metamorphic complex outcropping in the Santa Marta - Guajira area of northeastern Colombia. By assuming that, 1) the Oca fault zone is younger than the metamorphic complex; 2) the metamorphics between Santa Marta and Guajira once possessed a linear trend; 3) the southeast limit of the metamorphic complex is approximately parallel to the regional foliation trend of the Santa Marta - Guajira schists, and that, 4) the Oca fault extension is located north of the Guachaca (east Santa Marta) schists, the authors attempt a fit of regional foliation trends in the schists which, in effect, suggests the above mentioned lateral displacement of twenty kilometers. They are careful to mention that although there is a possibility for error in the projection of the Guajira schists trend, the foliation attitudes of this trend are consistent over large areas, thus lending weight to their proposed interpretation.

It is our understanding that this paper will be published in the Memoirs of the Colombian Geological Congress.

Working mostly with geophysical data, G. Feo-Codecido arrives to a very similar conclusion in his paper "Consideraciones Estructurales sobre la Falla de Oca, Venezuela", to be presented at the First Latinamerican Geological Congress which will be held in Lima, Perú, in November of this year. Feo-Codecido concludes that the Sinamaica Trough and the San Carlos Block seem to represent structural units displaced away from their equivalent units south of the fault, the Dibujo synclinorium and the El Palmar uplift. On this basis, the amount of dextral transcurrence is in the range of fifteen to twenty kilometers.

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2. Feo-Codecido, G. "Consideraciones Estructurales Sobre la Falla de Oca, Venezuela". Preprint, 1970.