Comparison of Bisti and Horseshoe Canyon Stratigraphic Traps, San Juan Basin, New Mexico[1]

FLOYD F. SABINS, JR.

Chevron Oil Field Research Company
La Habra, California 90631

Abstract Bisti and Horseshoe Canyon fields produce from stratigraphic traps formed by northwest-trending linear sandstone bodies enclosed in marine shale of Late Cretaceous age. Despite these similarities, the sandstone bodies originated by different depositional mechanisms. The lower Tocito reservoir at Horseshoe Canyon is an excellent example of post-unconformity sandstone, whereas the productive "Bisti" sandstone is a marine bar sandstone. At Horseshoe Canyon field, up to 90 ft (27 m) of sandy marine shale overlies the lower Tocito sandstone and separates it from the upper Tocito sandstone. The upper Tocito, which is also productive, is apparently a bar-type sandstone accumulation formed after deposition had essentially buried the erosion surface.

The marine bar-sandstone complex forming the Bisti field reservoir occurs at the approximate stratigraphic level of the productive units at Horseshoe Canyon field. Truncation at the erosion surface beneath the lower Tocito at Horseshoe Canyon field diminishes southward, toward the Bisti field. Petrographic studies have failed to establish the presence of the erosion surface at Bisti, despite the distinctive characteristics of this surface. The "Bisti" sandstone grades downward into sandy marine shale.

The reservoirs at these two fields illustrate the fact that superficial similarities in sandstone bodies do not necessarily mean an identical origin.

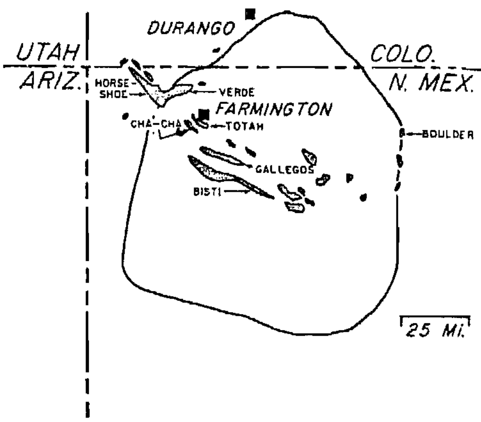

FIG. 1—Index map of San Juan basin showing location of oil fields.

INTRODUCTION AND REGIONAL SETTING

Almost all San Juan basin oil is produced from stratigraphic traps in sandstones of Late Cretaceous age. Bisti and Horseshoe Canyon fields are the largest producers and are examples of two different types of traps. Geophysics was not significant in the discovery of either field; therefore, this paper presents the stratigraphic and petrographic aspects of entrapment.

Throughout most of Late Cretaceous time, the San Juan basin was a marginal embayment of the sea that covered the Western Interior. It was not until the end of Cretaceous time that the San Juan structural basin formed as a result of marginal tectonic uplifts (Fig. 1). In the northern part of the San Juan basin, the strata are primarily offshore marine shale; in the south, continental deposits predominate. The two facies are separated by sheets of marine sandstone deposited during marine transgressions and regressions (Sabins, 1964). In the northern part of the basin, an unconformity within the Mancos Shale forms the boundary between the "upper" Mancos (Niobrara) and the "lower" Mancos (middle Carlile; Dane, 1960), as shown on Figure 2. Submarine topography on this pre-Niobrara erosion surface localized deposition of the lower Tocito sand-

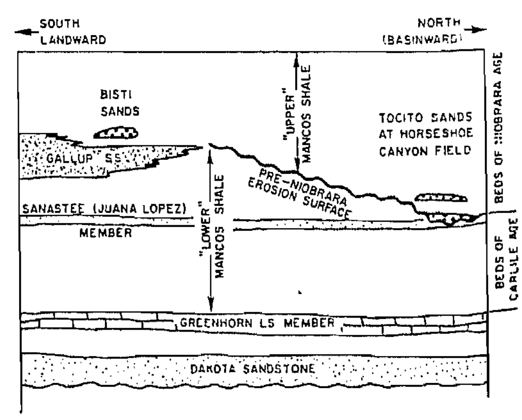

FIG. 2—Regional stratigraphic cross section of northern San Juan basin showing relation of stratigraphic traps to pre-Niobrara marine erosion surface.

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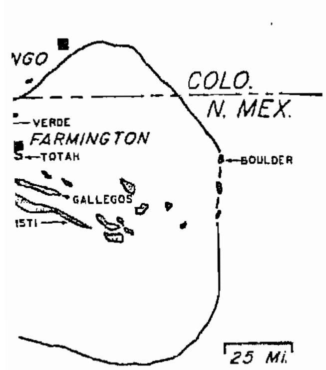
FLOYD F. SABINS, JR.
evron Oil Field Research Company
La Habra, California 90631



San Juan basin showing location of oil fields.

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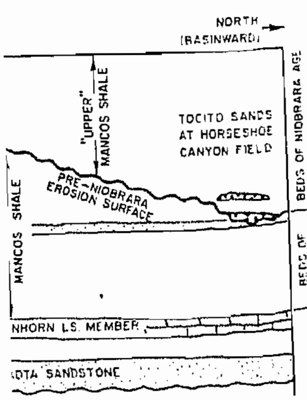

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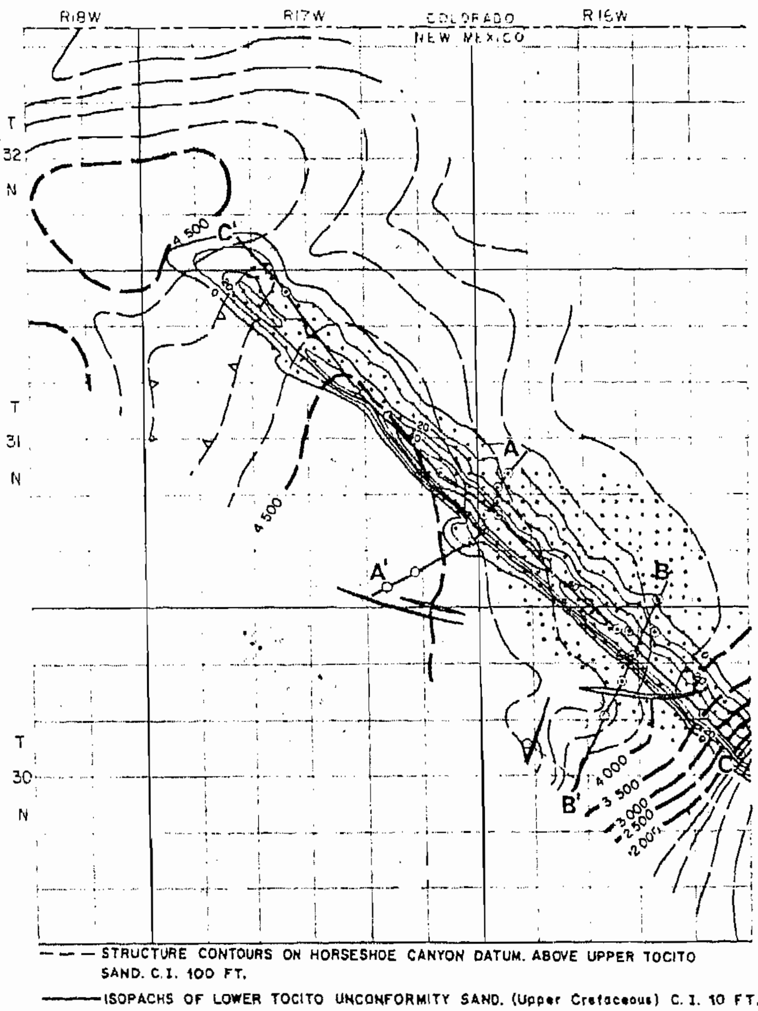


FIG. 3—Horseshoe Canyon field, structure map and isopach of lower Tocito sandstone.

stone at Horseshoe Canyon field but had little influence on the upper Tocito sandstone. The Bisti field reservoir is a marine sandstone-bar complex that was not influenced significantly by the erosion surface.

Horseshoe Canyon Field

General—The Horseshoe Canyon field in northwest San Juan County, New Mexico, produces from the upper and lower Tocito sandstones of Late Cretaceous ("Niobrara") age. The lower Tocito sandstone is an example of a post-unconformity deposit, whereas the upper Tocito represents a marine sand bar or lens. Estimated ultimate recovery is 31 million bbl of oil with an average gravity of 41° API; solution gas is the drive mechanism. The field contains 376 wells. Similar stratigraphic traps in the area are at Cha Cha and Totah fields.

The maps and cross sections were prepared by Chevron Oil-Standard of Texas Division personnel. Thin sections of Tocito sandstone cores from two Horseshoe Canyon wells were studied petrographically by the writer. Updip in southwest Colorado along the stratigraphic trend of the Tocito sandstones, Chevron Oil-Western Division and Chevron Oil Field Research drilled 11 stratigraphic coreholes. The holes were located on a northeast-southwest line 8 mi (13 km) long that crossed the Tocito

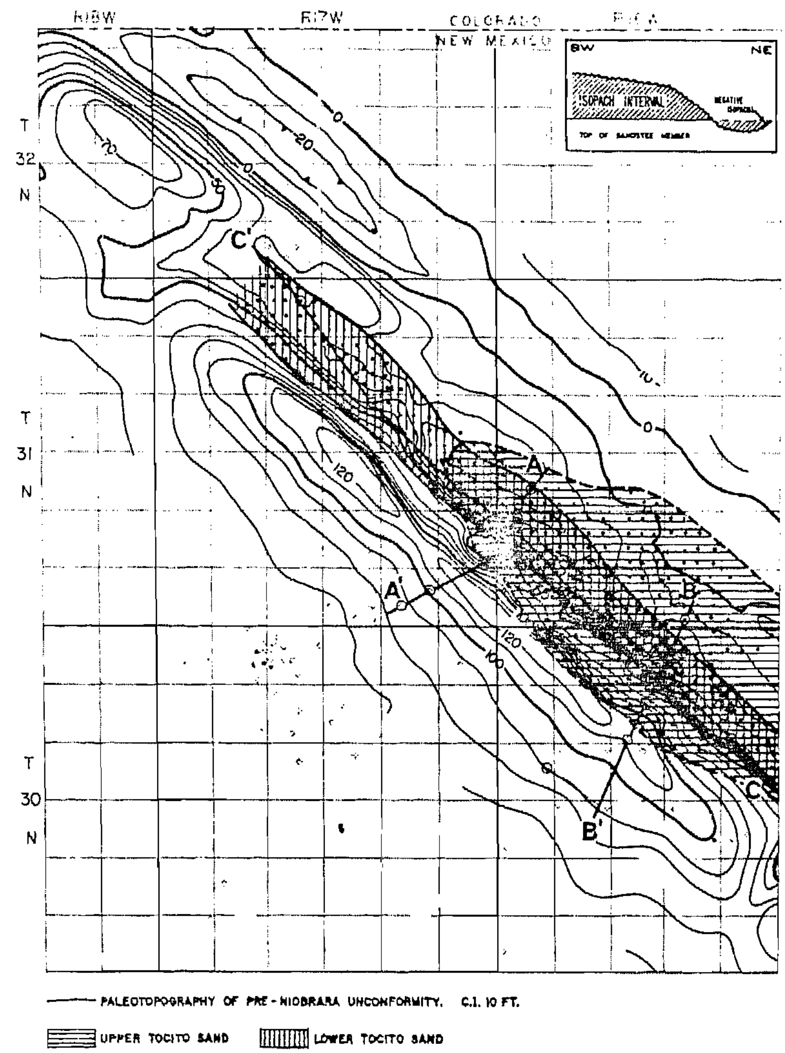


FIG. 4—Horseshoe Canyon field, paleotopographic map and distribution of upper and lower Tocito sandstones. Correct spelling is "Sanastee."

sandstones. Complete cores were recovered of the sandstones and adjacent strata and of the pre-Niobrara erosion surface.

Detailed thin-section studies of the cores were compared with petrographic data from Horseshoe canyon field. The close petrographic and stratigraphic similarity of the two sets of data enabled us to use the corehole information as a supplement to the information from Horseshoe Canyon field.

Discovery method—The discovery well was the Arizona Exploration No. 1 Petro Atlas Bolack in Sec. 9, T30N, R16W, completed October 28, 1956. This well reportedly was located on the basis of subsurface stratigraphic work. It penetrated only siltstone and sandstone stringers at the edge of the upper Tocito sandstone, which is the less productive zone, and was shut in for several years as a subcommercial well (G. M. Nevers, personal commun.). Subsequent development drilling encountered the more productive lower Tocito sandstone and led to full-scale development of the field. Apparently, geophysics did not aid in the discovery.

Relation to structure—The structure con-

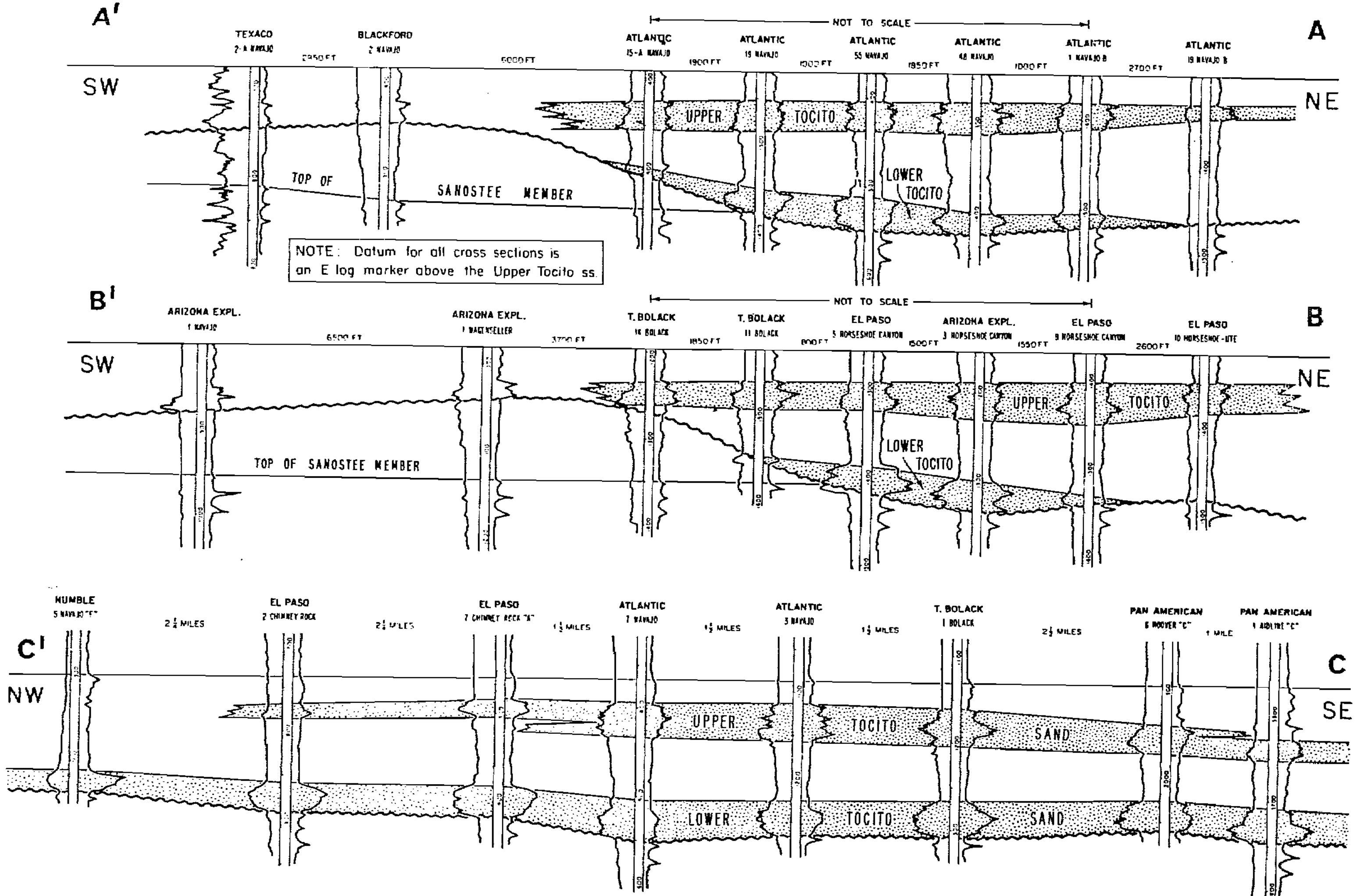


FIG. 5—Horseshoe Canyon field, electric-log cross sections. Correct spelling is "Sanastee."

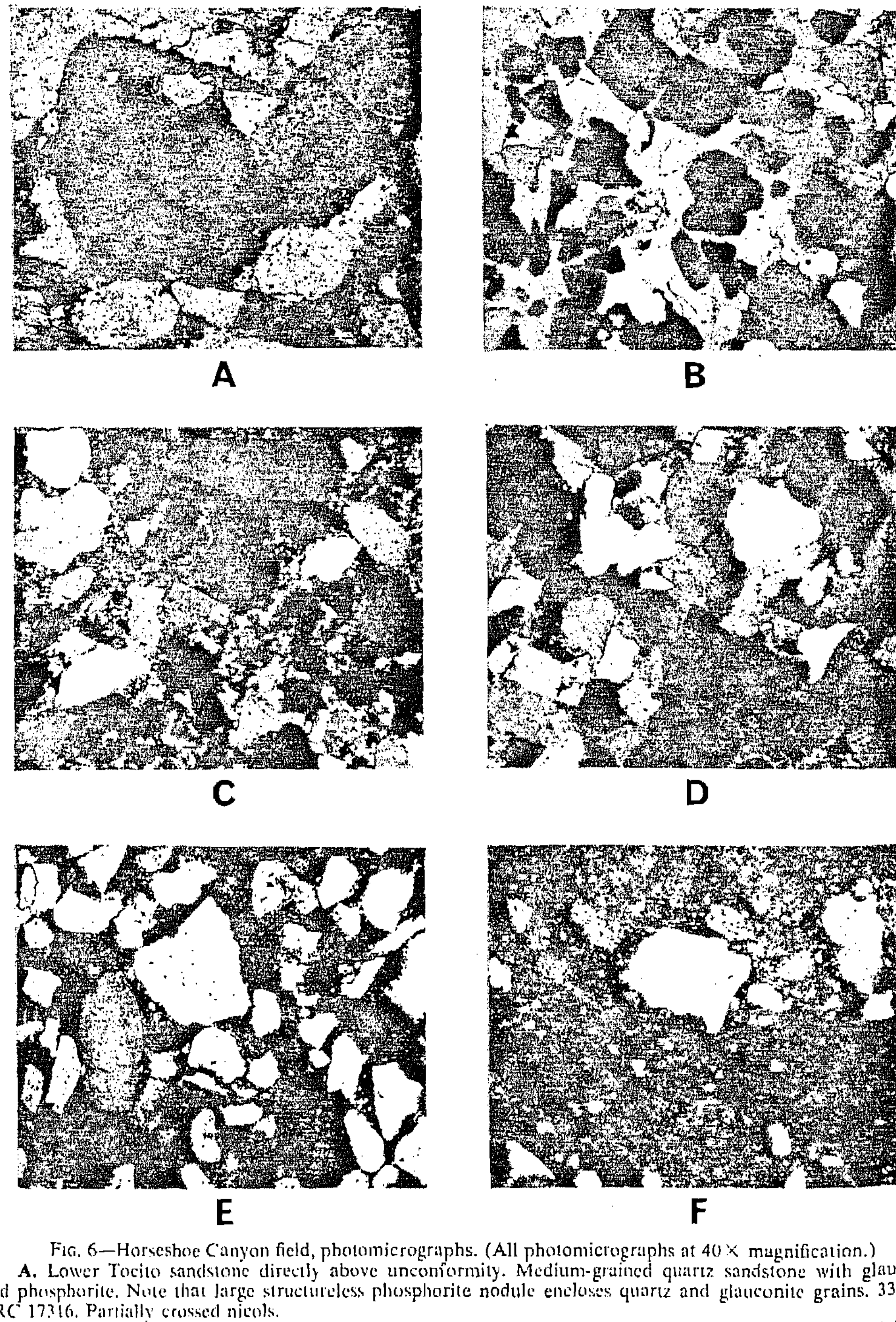
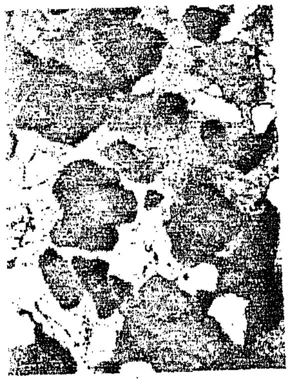


FIG. 6—Horseshoe Canyon field, photomicrographs. (All photomicrographs at 40× magnification.)

A. Lower Tocito sandstone directly above unconformity. Medium-grained quartz sandstone with glauconite and phosphorite. Note that large structureless phosphorite nodule encloses quartz and glauconite grains. 338.1 ft, CRC 17316. Partially crossed nicols.

B. Lower Tocito sandstone. Medium-grained glauconitic quartz sandstone with megacrystalline calcite cement; typical of producing sandstone. 369.0 ft, CRC 16901. Crossed nicols.

C. Lower Tocito sandstone. Medium-grained glauconitic quartz sandstone with secondary dolomite cement; a less common rock type. 367.0 ft, CRC 16901. Crossed nicols.



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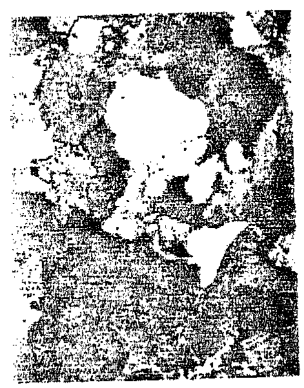

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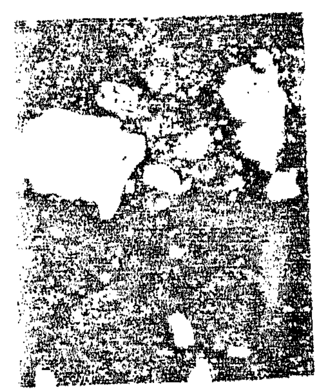

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tours of Figure 3 are drawn on a bentonite datum 50 ft (15 m) above the upper Tocito sandstone. Comparison of structure with the isopach configuration of the lower Tocito sandstone on Figure 3 shows that there is little or no structural control of the accumulation. Most of the field is located on the Four Corners platform but the southeast extension intersects the Hogback monocline, which dips steeply eastward into the San Juan structural basin. The monocline formed during the Laramide orogeny of Late Cretaceous–early Tertiary age and postdates deposition of the Tocito sandstones and associated strata.

Stratigraphy and paleotopography—The lower Tocito sandstone is localized by paleotopography of an erosion surface formed in pre-Niobrara time. Figure 4 is a paleotopographic map of the surface which demonstrates that a prominent northwest-trending ridge controlled lower Tocito sandstone deposition on its basinward (northeast) flank. Core examinations and the cross sections of Figure 5 illustrate that the lower Tocito sandstone lies directly on the erosion surface and is contained within a closed

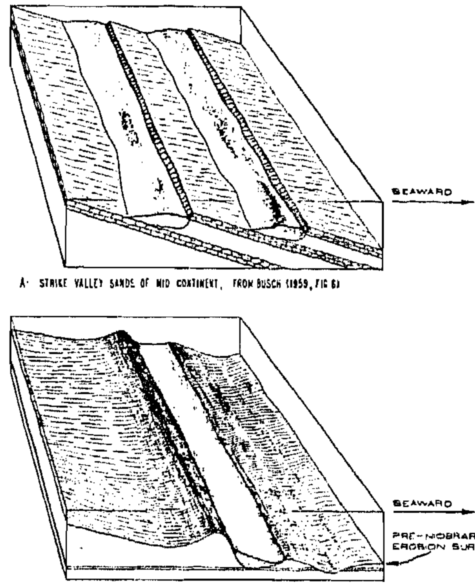


Fig. 7—Block diagrams comparing lower Tocito post-unconformity sandstones with strike-valley sandstones.

Table 1. Comparison of Upper and Lower Tocito Sandstone with "Bisti" Sandstone

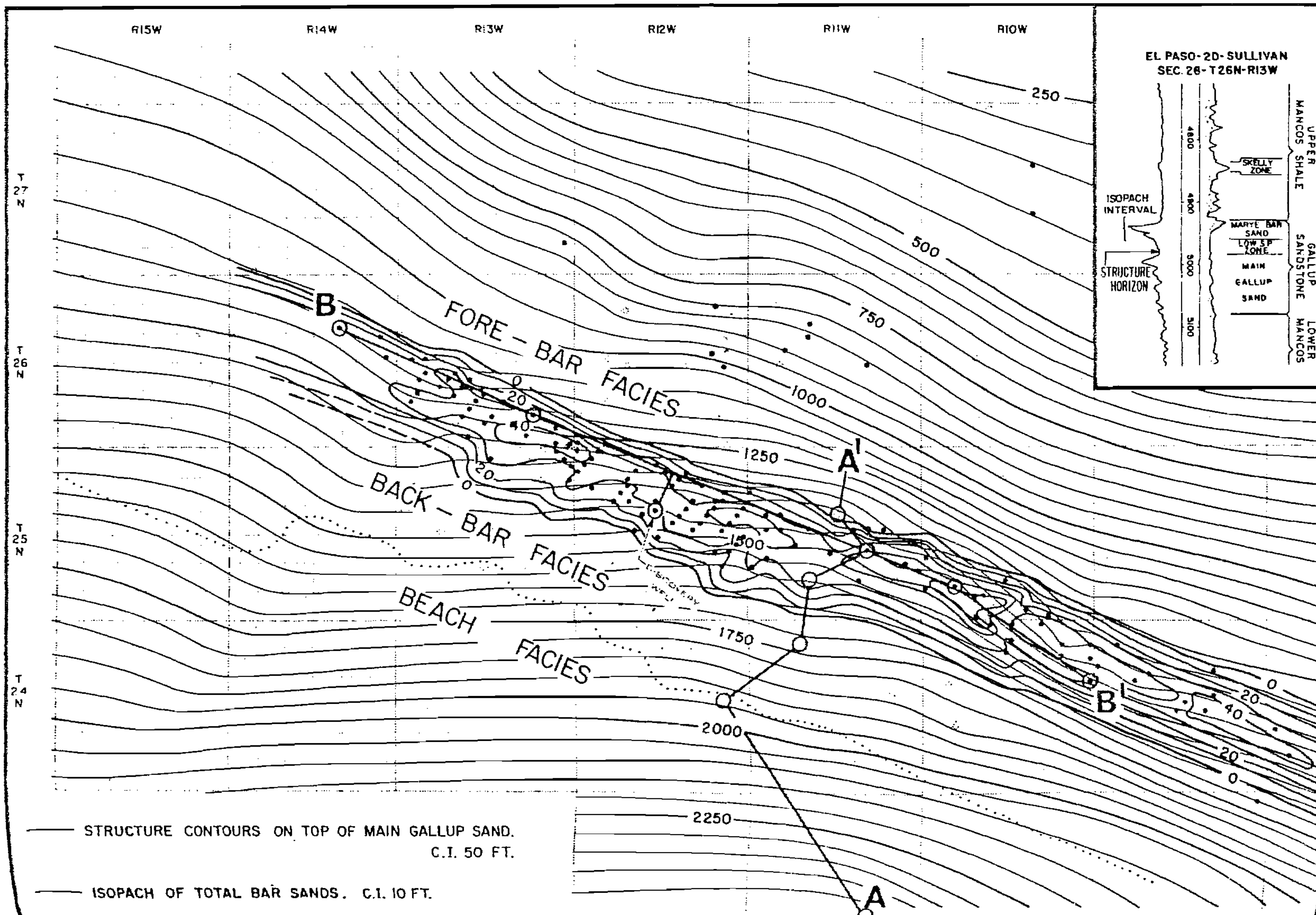
Significant Characteristics	*Horseshoe Canyon Field* *Lower Tocito Sandstone*	*Upper Tocito Sandstone*	*"Bisti" Sandstone*
Basal contact	Sharp, unconformable on pre-Niobrara erosion surface	Gradational downward into sandy shale	Gradational downward into sandy shale
Phosphorite and collophane	Abundant in basal part	Absent	Absent
Lateral facies relations	Laps out against unconformity surface in landward and seaward direction	Gradational into sandy shales	Grades seaward into forebar facies and landward into backbar facies
Vertical textural gradation	None	Coarser upward	Coarser upward
Depositional environment	Post-unconformity sand	Nearshore-marine sand bar or lens	Nearshore-marine sand bar

D. Upper Tocito sandstone. Medium-grained, glauconitic, calcite-cemented quartz sandstone. 367.0 ft, CRC 17315. Crossed nicols.

E. Landward facies of lower Tocito Sandstone. Very silty sandstone with *Inoceramus* fragments, phosphorite grains, and dolomitic cement. From thin interval directly above unconformity on crest of erosional ridge that localized sand accumulation, 274.9 ft, CRC 17319. Plane-polarized light.

F. Seaward facies of lower Tocito Sandstone. Sandy siltstone with glauconite pellets. 376.0 ft, CRC 17311. Partially crossed nicols.

Note: These samples are from a series of Chevron Oil–Western Division and Chevron Research stratigraphic coreholes drilled across updip extension of Tocito sandstones in southwest Colorado. Comparative studies show that these samples are petrographically identical to those from Horseshoe Canyon field.


R15W
R14W
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R11W
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T 26 N
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EL PASO-2D-SULLIVAN
SEC. 28-T26N-R13W
UPPER MANCOS SHALE
SKELLY ZONE
GALLUP SANDSTONE
MARYE BAR SAND
LOW S.P. ZONE
MAIN GALLUP SAND
LOWER MANCOS
ISOPACH INTERVAL
STRUCTURE HORIZON
4800
4900
5000
5100
250
500
750
1000
1250
1500
1750
2000
2250
0
20
40
FORE - BAR FACIES
BACK - BAR FACIES
BEACH FACIES
A
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B'
STRUCTURE CONTOURS ON TOP OF MAIN GALLUP SAND. C.I. 50 FT.
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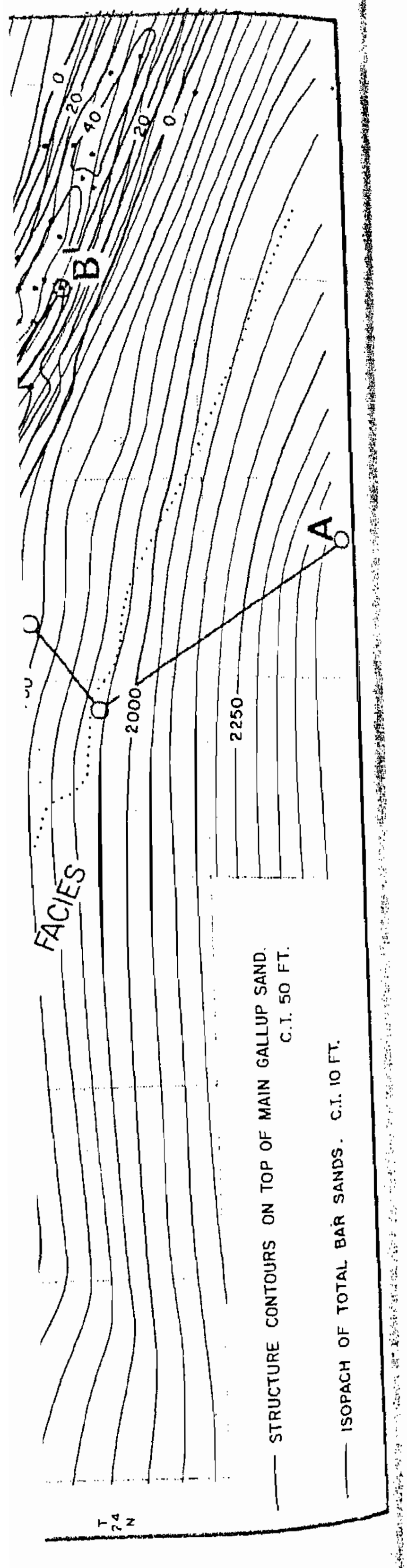

depression trending parallel with the erosional ridge. As shown by the inset in Figure 4, the paleotopographic map is an isopach map of the interval between the erosion surface and an underlying datum; therefore, differential compaction is not a factor.

The lower Tocito sandstone is overlain by approximately 90 ft (25 m) of glauconitic sandy shale with a distinctive worm-burrowed fabric; the shale grades upward into the upper Tocito sandstone, which in turn is overlain by Mancos Shale of typical offshore marine character. Relief on the erosion surface was largely blanketed by sediment before the upper Tocito sandstone was deposited; indeed, the crest of the ridge on sections *A-A'* and *B-B'* of Figure 5 is conjectured from the paleotopographic map. This lack of confining depressions and ridges probably accounts for the more widespread distribution of the upper Tocito sandstone (Fig. 5). The upper Tocito sandstone more correctly is called a lens or bar-type deposit similar to the reservoir of the Bisti field, rather than a true post-unconformity sandstone of the lower Tocito type.

Outcrop and subsurface studies show that stratigraphic truncation at the unconformity surface increases in a basinward (northward) direction; in a distance of 30 mi (48 km), 300 ft (90 m) of lower Mancos Shale section was eroded (Dane, 1960; Penttila, 1963, 1964). In this writer's opinion, erosion was submarine rather than subaerial for the following reasons.

1. The northwest-southeast trend of paleotopography is parallel with the known Cretaceous strandline and is parallel with strike of truncation. Subaerial erosion would have resulted in a drainage pattern toward the south and southwest, away from the site of maximum uplift, and the resulting paleotopography would have trended normal to the strike of truncation.
2. Collophane, glauconite, marine fossil debris, and phosphorite nodules overlie the erosion surface as illustrated in Figure 6A.
3. Residual soil profiles are absent in cores of the erosion surface.
4. Geochemical analyses do not indicate a zone of enrichment or leaching below the erosion surface.

Petrography—The lower Mancos Shale underlying the erosion surface consists of thinly laminated shale and siltstone with some interbedded very fine-grained calcareous sandstone and fragmental fossiliferous limestone. Above the erosion surface, there is an abrupt change to the medium-grained, glauconitic quartz sandstone of the lower Tocito. Collophane, fossil fragments, and phosphorite nodules (Fig. 6A, B, C) are abundant in the basal few feet of the lower Tocito. In contrast to typical bar sandstone, there is no vertical textural gradient from the base to the top of the lower Tocito sandstone. Where the sandstone is absent and the erosion surface is overlain and underlain by marine shale, the surface is marked in cores by a layer of collophane, phosphorite nodules, and fossil debris. In some cores, worm burrows filled with lower Tocito sandstone penetrate the strata below the erosion surface. The lower Tocito sandstone is not a residual product from erosion of the lower Mancos Shale, for medium-grained sandstone is lacking in the many cores and thin sections of this unit that were studied. North and south of the edges of the lower Tocito sandstone, the equivalent strata are silty sandstone and sandy siltstone (Fig. 6E, F).

The upper Tocito sandstone is petrographically similar to the lower Tocito but lacks the collophane and phosphorite nodules at the base. This fact and the gradational contact at the base of the upper Tocito are additional reasons for not considering it a post-unconformity deposit. It appears to be a marine sandstone bar or lens with an average thickness of 15 ft (5 m) and a maximum of 50 ft (15 m).

Post-unconformity vs. strike-valley sands—Busch (1959, Fig. 6) illustrated strike-valley sands as linear accumulations localized along erosional escarpments on gently-dipping resistant beds. According to some writers (Lamb, 1968, p. 827), the Tocito sandstones represent strike-valley sands, but the paleotopographic map (Fig. 4) and the cross sections (Fig. 5) show that the sand accumulation is not related to structural strike of the strata underlying the erosion surface. Instead, the topography of the erosion surface controlled distribution of lower Tocito sandstone, and the term "post-unconformity sandstone" is more nearly correct. The

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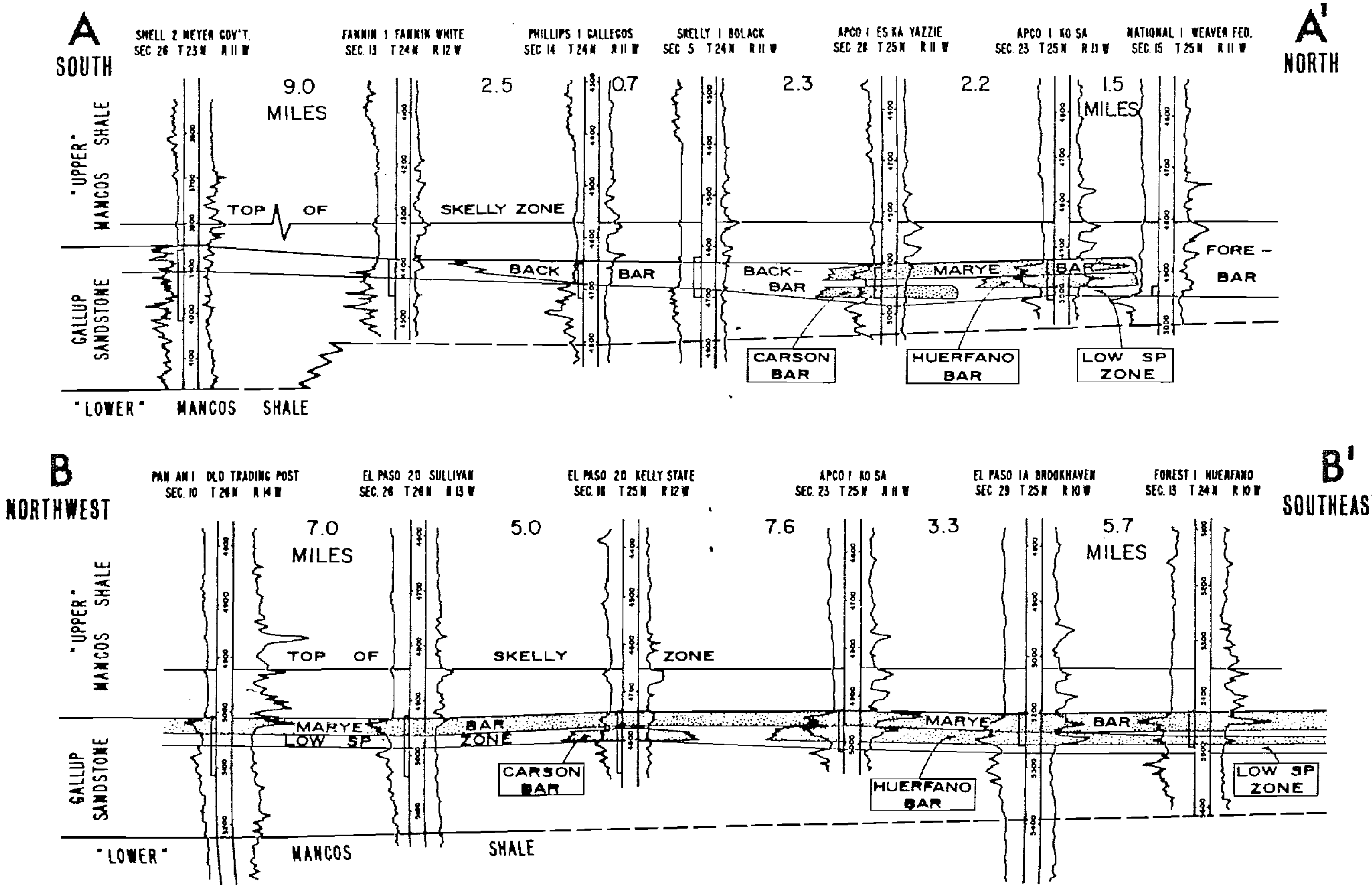
FIG. 8—Bisti field, structure map and bar-sandstone isopach. Only wells used in map compilation are shown.


A
SOUTH
A'
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PHILLIPS 1 GALLEGOS SEC 14 T24N R11W
SKELLY 1 BOLACK SEC 5 T24N R11W
APCO 1 ES KA YAZZIE SEC 28 T25N R11W
APCO 1 KO SA SEC 23 T25N R11W
NATIONAL 1 WEAVER FED. SEC 15 T25N R11W
9.0 MILES
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"UPPER" MANCOS SHALE
GALLUP SANDSTONE
"LOWER" MANCOS SHALE
TOP OF SKELLY ZONE
BACK BAR
BACK-BAR
MARYE BAR
FORE-BAR
CARSON BAR
HUERFANO BAR
LOW SP ZONE
B
NORTHWEST
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SOUTHEAST
PAN AM 1 OLD TRADING POST SEC. 10 T26N R14W
EL PASO 2D SULLIVAN SEC. 26 T26N R13W
EL PASO 2D KELLY STATE SEC. 16 T25N R12W
APCO 1 KO SA SEC. 23 T25N R11W
EL PASO 1A BROOKHAVEN SEC 29 T25N R10W
FOREST 1 HUERFANO SEC. 13 T24N R10W
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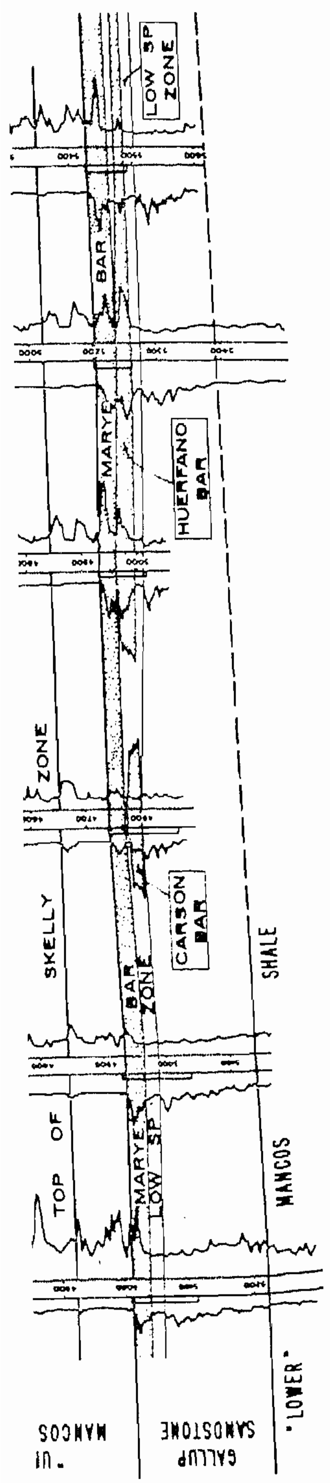

block diagrams of Figure 7 illustrate this distinction.

Bisti Field

General—The Bisti field, in the central part of the San Juan basin, New Mexico (Fig. 1), produces from an offshore-marine bar sandstone of Late Cretaceous age; the trap is stratigraphic. Estimated ultimate recovery is 56 million bbl of oil with an average gravity of 39° API. Solution gas is the drive mechanism. The field contains 232 wells. The smaller Gallegos field, north of Bisti, may be a similar accumulation, but samples and data were insufficient to evaluate this possibility. This report is condensed from a more complete study (Sabins, 1963), to which the reader is referred for details.

Discovery method—The discovery well, El Paso No. 1 Kelly State (Sec. 16, T25N, R12W), was drilled on a stratigraphic prospect with the Gallup Sandstone as an objective. It was planned as a deeper Dakota test to meet a drilling commitment and evaluate property in this area (R. A. Ullrich, personal commun., August 5, 1968). There is no reported geophysical basis for the discovery.

Relation to structure—The structure map (Fig. 8) of a horizon below the producing sandstone shows no suggestion of closure, nor does a map drawn on a stratigraphic datum above the sandstone. There is homoclinal basinward dip to the northeast at about 75 ft/mi.

Stratigraphy and petrography—As shown on the cross sections of Figure 9, the Bisti stratigraphic trap consists of three very similar bar sandstones that can be discussed collectively as the "Bisti bar complex." The bar is less than 3 mi (5 km) wide and extends more than 30 mi (48 km) in a direction slightly north of west, parallel with the Late Cretaceous strandline trend. The bar is overlain by the offshore-marine upper Mancos Shale and grades downward into sandy shale which is informally called the "low-SP zone" because of its characteristic electric-log expression. Petrographically, the low-SP zone is very similar to the sandy shale that separates the upper and lower Tocito sandstones. The low-SP zone has a maximum thickness of 25 ft (8 m) and separates the bar from the underlying Gallup Sandstone, which is a widespread sheet of marine sandstone deposited during a major regression. The Gallup Sandstone pinches out basinward into marine shale about 10 mi (16 km) northeast of Bisti field.

In a basinward (northward) direction, the "Bisti" bar sandstones grade into open-marine silty shale called the "forebar facies," and southward they grade into restricted-marine sandy shale called the "backbar facies," as shown on section *A-A'* of Figure 9.

The bar sandstones consist of subangular to subrounded, fine- to medium-grained sand with abundant pellets of microcrystalline glauconite (Fig. 10C, D), which distinguishes the bar sandstone from the finer grained, nonglauconitic Gallup Sandstone. Phosphorite nodules and collophane fragments are absent from the basal part of the "Bisti" bar sandstones. Rather, the bar sandstones become progressively more shaly toward the base and grade into the underlying sandy shale of the low-SP zone (Fig. 10B). The "Bisti" sandstones are characterized by a consistent vertical textural gradation from finer at the base to coarser at the top. This gradation apparently resulted from deposition in progressively shallower water as the bar complex was built up (Sabins, 1963, p. 215).

The forebar facies is characterized by an open-marine fauna of fish-bone fragments preserved as collophane, *Inoceramus* fragments, and calcite-filled planktonic forams (Fig. 10E). In contrast, the backbar facies lacks the open-marine fauna and contains small pyrite-filled forams (Fig. 10F). These differences are sufficient to distinguish the two facies which otherwise are very similar.

Comparison of Bisti and Horseshoe Canyon Fields

The interpretation by the writer (Sabins, 1963) and others that Bisti is a sandbar complex has been questioned by Lamb (1968, p. 849), who stated that the "Bisti" sandstone originated as strike-valley sands localized upon the pre-Niobrara erosion surface. As stated in a

FIG. 9—Bisti field, electric-log cross sections. Locations shown on Figure 8.

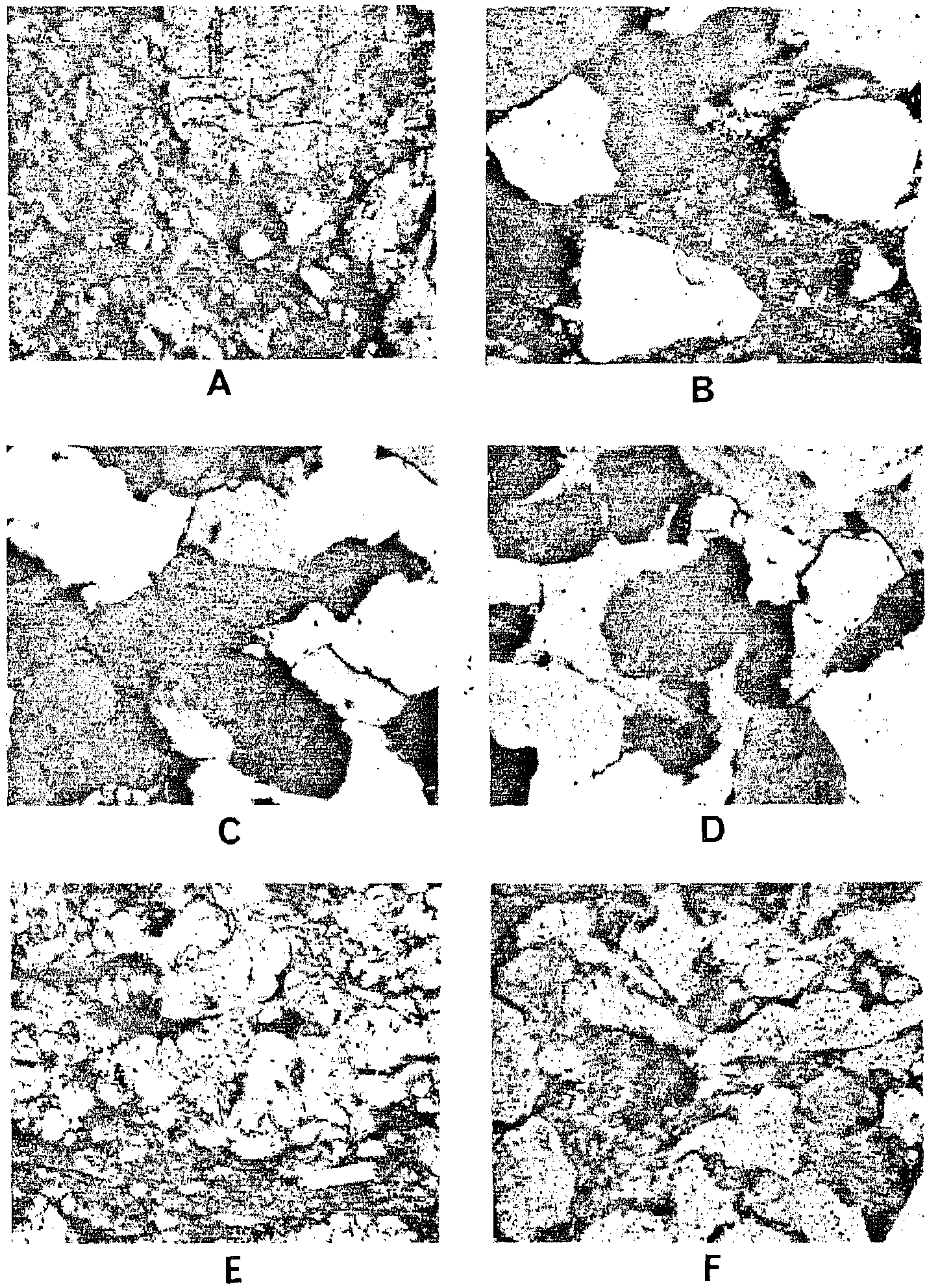

FIG. 10—Bisti field, photomicrographs. (All photomicrographs at 95× magnification.)

A. Upper Mancos Shale. Shaly siltstone with carbonaceous flakes, abundant primary dolomite grains, and fragments of *Inoceramus* (upper right). This marine shale directly overlies the "Bisti" bar sandstone but does not contain any bar-type sand. Thus, rapid burial of bar beneath marine shale with no appreciable reworking is implied. El Paso No. 9 Kelly State, 4,854 ft, CRC 14281. Plane-polarized light.

B. Low-Sp zone. Sandy shale and shaly sandstone with minor primary dolomite grains and glauconite pellets. Sand grains are of same texture and mineralogy as overlying "Bisti" bar sandstone. Wave action apparently

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preceding paragraph, even at Horseshoe Canyon field the "strike-valley sand" interpretation is not appropriate. At Horseshoe Canyon field, only the lower Tocito sandstone lies on the erosion surface and properly is called a "post-unconformity sandstone." Following deposition of the lower Tocito sandstone, the erosion surface was largely buried by as much as 100 ft (30 m) of strata before the upper Tocito was deposited as a marine sand bar or lens.

Lamb (1968, p. 849) asserted that the pre-Niobrara erosion surface is present at Bisti field; yet, the writer's (Sabins, 1963) previously published study of 650 thin sections from 39 wells failed to reveal evidence for the existence of the erosion surface. As shown on the comparative chart on Table 1, the "Bisti" sandstones lack the collophane and phosphorite typical of the basal part of the lower Tocito post-unconformity sandstones. The "Bisti" sandstones grade downward into sandy shale and do not lie on an erosion surface. Clearly, the pre-Niobrara erosion surface is not present at the base of the "Bisti" sandstones. The only other possible horizon which might be considered as the erosion surface is the contact between the sandy shale of the low-SP zone (Fig. 9) and the underlying Gallup Sandstone. Petrographic study demonstrated that this contact is marked by an upward increase in maximum and median grain size and an increase in clay content. Mineralogically, there is an upward increase in glauconite and a decrease in grains of primary dolomite (Sabins, 1963, Fig. 11). The top of the Gallup is more gradational than abrupt, and studies have revealed none of the phosphorite concentrations so characteristic of the erosion surface at Horseshoe Canyon field and in southwest Colorado.

The apparent absence of the pre-Niobrara erosion surface at Bisti should not be surprising, for all the investigators (Dane, 1970, Figs. 2, 3; Penttila, 1964, Fig. 2), including Lamb himself (1968, Fig. 3), pointed out that the amount of stratigraphic truncation at the erosion surface *decreases* progressively in a southward direction.

The "sudden change" referred to by Lamb (1968, p. 849) on the southwest margin of the Bisti field is not "sudden" but gradational (Sabins, 1963, p. 216). In the five wells from the backbar facies that were available for petrographic study, evidence for intertonguing of bar-type sandstone with the finer grained, backbar facies (Sabins, 1963, Table V) was found. In the British American No. 2 Shipp well (Sec. 11, T25N, R13W), on the southwest margin of the Bisti field, there is clear petrographic evidence of a tongue of backbar sandy shale interbedded in the middle of the "Bisti" reservoir sandstone (Sabins, 1963, Fig. 10). Thus, it has been documented that there are tongues of bar sandstone interbedded with the backbar facies and tongues of backbar facies interbedded with the main bar sandstone.

In summary, the "Bisti" sandstones were deposited in a nearshore-marine bar environment, as was the upper Tocito sandstone at Horseshoe Canyon field. The lower Tocito sandstone at Horseshoe Canyon field was deposited in a topographic depression on the pre-Niobrara erosion surface; it is classified as a post-unconformity sandstone.

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winnowed clay from low-SP zone and concentrated sand as a bar. El Paso No. 9 Kelly State, 4,916 ft, CRC 14281. Crossed nicols.

C. "Bisti" bar sandstone. Fine- to medium-grained quartz sandstone with minor feldspar and rock fragments. Abundant pellets of microcrystalline glauconite (center of view). This sand is well compacted and has some secondary quartz overgrowths. British American No. 1 Navajo, 4,893 ft, CRC 14294. Crossed nicols.

D. "Bisti" bar sandstone. Medium- to fine-grained glauconitic quartz sandstone with megacrystalline calcite cement (gray) and minor quartz overgrowths. British American No. 1 Navajo, 4,898 ft, CRC 14294. Crossed nicols.

E. Forebar facies equivalent to "Bisti" bar sandstone on seaward (northeast) side. Laminated, calcareous, silty shale with abundant primary dolomite, calcite-filled planktonic forams, *Inoceramus* prisms, and collophane (not in this view). This open-marine fauna distinguishes bar facies from backbar facies. El Paso No. 1-B Sullivan, 4,889 ft, CRC 14282. Plane-polarized light.

F. Backbar facies equivalent to "Bisti" bar on landward (southwest) side. Sandy shale with disturbed irregular structure. Presence of small, pyrite-filled, benthonic forams (center of view) and absence of open-marine fauna distinguished this from forebar facies. Anderson No. 21-29 Federal, 4,808 ft, CRC 14293. Plane-polarized light.

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