Sedimentology of the lower part of the Upper Triassic, Chinle Formation and its relationship to uranium deposits, White Canyon area, southeastern Utah

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Open-File Report # 83-459

1983

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ABSTRACT

Closely spaced measured stratigraphic sections of the lower part of the Late Triassic Chinle Formation in the White Canyon area of southeastern Utah depict a fluvial-deltaic-lacustrine depositional sequence that hosts uranium deposits in basal fluvial sandstones. The basal Shinarump Member consists of predominantly trough-crossbedded, coarse-grained sandstone and minor gray, carbonaceous mudstone and is interpreted as a valley-fill sequence overlain by deposits of a braided stream system. The overlying Monitor Butte Member is composed of cyclic- and foreset-bedded siltstone, sandstone, and mudstone and is interpreted as a succession of low-energy fluvial, deltaic and organic-rich, lacustrine-marsh sediments. The overlying Moss Back Member is composed of a laterally extensive, coarse- to medium-grained, conglomeratic sandstone and is interpreted as a braided-stream system that flowed north to northwest. The entire sequence was deposited in response to changes in local base level associated with a large lake that lay to the west.

Isopachs of lithofacies indicate distinct lacustrine basins and a correspondence between these facies and modern structural synclines. Facies changes and coincidence of isopach thicks suggest that structural synclines were active in the Late Triassic and influenced the pattern of sediment distribution within the basins. Uranium mineralization appears to be related to certain low-energy depositional environments in that uranium is localized in fluvial sandstones that lie beneath organic-rich lacustrine-marsh mudstones and carbonaceous delta-front sediments. The reducing environment preserved in these facies may have played an important role in the localization of uranium.

INTRODUCTION AND PREVIOUS WORK

The Chinle Formation in the White Canyon area has been studied extensively, in part due to the economic importance of uranium located in basal fluvial sandstones. Stewart and others (1959, 1972a, 1972b) made regional stratigraphic correlations of the Chinle and related formations, which include the White Canyon and adjacent areas. The geology and ore deposits of the White Canyon (Thaden and others, 1964), Elk Ridge (Lewis and Campbell, 1956), Deer Flat (Finnell and others, 1963), and Monument Valley areas (Witkind and Thaden, 1963) have been investigated in some detail; each report describes local stratigraphy and ore controls. Regional studies of uranium deposits (Finch, 1959; Johnson and Thordarson, 1966) were concerned with large-scale trends, controls, and distribution of uranium ore.

The present study investigates in detail the stratigraphy, sedimentology, facies relationships and depositional enviroments, and their possible relationship to uranium occurrences in portions of the White Canyon, Henry Mountains, and Green River uranium districts (fig. 1) (Johnson, 1959; Johnson and Thordarson, 1966). Measured sections were chosen for completeness of section and exposure; included were areas of uranium occurrences, prospects, and mines, and areas that contain no known uranium occurrences.

Fifty-five stratigraphic sections of the Shinarump, Monitor Butte, and Moss Back Members of the Upper Triassic Chinle Formation were measured at approximately 5 mi (8 km) intervals in and adjacent to the White Canyon uranium district (Johnson and Thordarson, 1966) of southeastern Utah (fig. 1). The sedimentology and facies relationships of this series of continental

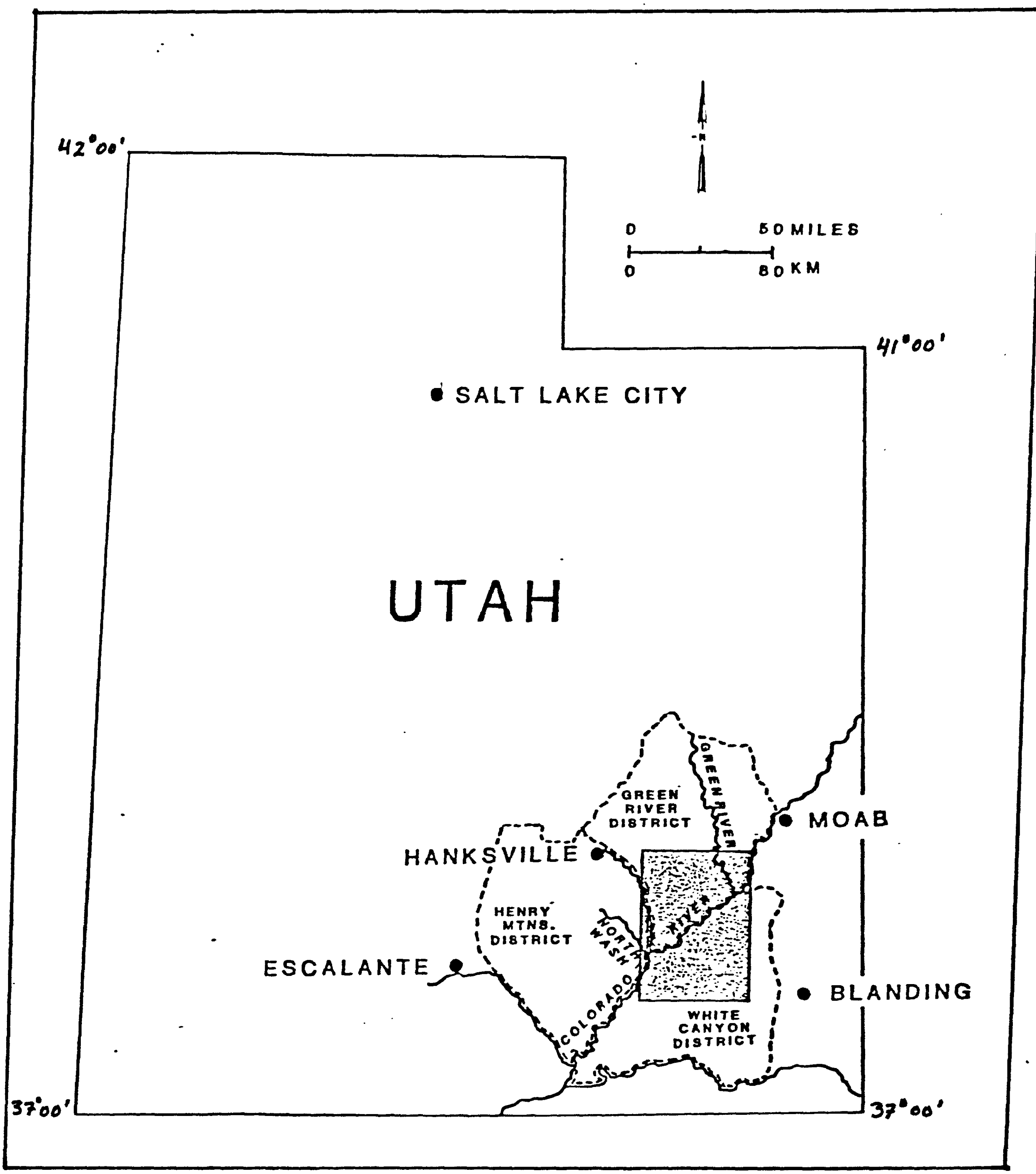

Figure 1.--Index map showing location of study area and uranium mining districts in southeastern Utah.

beds (Stewart and others, 1972a) were examined to determine if localization of uranium could be related to specific facies or depositional environments. The Petrified Forest Member and upper (red-bed) part of the Chinle Formation (Stewart and others, 1972) were not studied, as uranium in the White Canyon and adjacent areas is restricted to fluvial sandstones of the Shinarump and Monitor Butte Members that directly overlie the Moenkopi Formation (Finch, 1959; Finnell and others, 1963; Lewis and Campbell, 1956; Thaden and others, 1964). The Moss Back Member was included in this study because it contains uranium in the northern Elk Ridge (Lewis and Campbell, 1965) and the Lisbon Valley areas (Huber, 1980) where it directly overlies the Moenkopi Fm. and because it's lithology and sedimentary structures are more similar to the underlying units than the overlying units. Measured sections, stratigraphic cross sections, and isopach maps of units and parts of units were used to delineate vertical and horizontal facies relationships, as well as their areal distribution.

Depositional environments were inferred from bedding and sedimentary structures, the distribution and geometry of lithofacies, fossils and trace fossils, and vertical and horizontal facies relationships. The distribution of facies shown on the maps and sections suggests there was a structural control on depositional enviroments.

STRATIGRAPHY

The Chinle Formation in the study area is underlain by red-brown, micaceous and rippled siltstone and fine-grained sandstone of the Lower and Middle(?) Triassic Moenkopi Formation (Stewart and others, 1972b). The Moenkopi Formation is interpreted as mudflat deposits with a regional, erosional unconformity separating it from the overlying Late Triassic Chinle Formation (Stewart and others, 1972b). The Chinle Formation in southeastern Utah consists of six members (Stewart and others, 1972a): Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock, in ascending order.

The Shinarump Member is a yellow-orange to gray, very coarse- to fine-grained conglomeratic sandstone with minor siltstone and gray mudstone that can be described as two units. The lower unit occupies scours up to 20 ft (6 m) deep that were eroded into the Moenkopi Formation. The upper unit forms a broad sheet. Occurrence of the Shinarump in the study area is widespread. It generally forms a pronounced cliff or ledge, but it is absent locally, and was not deposited north of a line that trends northwest approximately through North Wash (fig. 2).

The Monitor Butte Member generally overlies the Shinarump Member. Where the Shinarump is absent, the Monitor Butte Member directly overlies the Moenkopi Formation. The Monitor Butte Member pinches out to the northeast, along a northwest line that extends northwest through the Orange Cliffs in the vicinity of Elaterite Butte (fig. 2). Within the study area, the Monitor Butte Member is composed of a variety of lithologies, some of which differ from those exposed at the type locality in southeastern Utah (Witkind and Thaden, 1963). White to yellow and gray, coarse-grained fluvial sandstones interfinger with red, gray, and green bentonitic mudstones. Isolated lenses of nodular limestone and fibrous calcite; thin discontinuous limestones; calcareous intra-clast conglomerate; poorly sorted burrowed and bioturbated

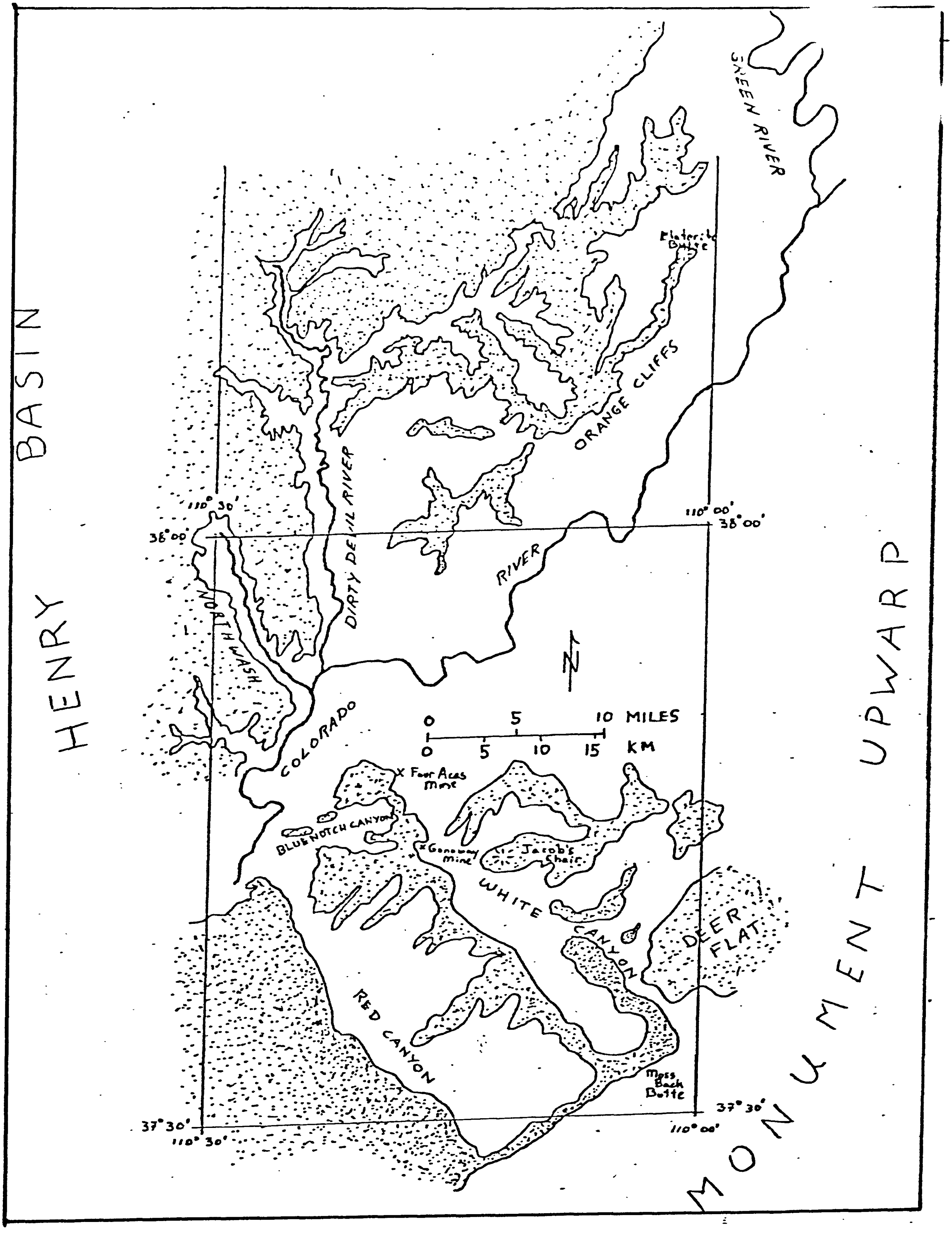

Figure 2.-- Index map showing location of geographic features referred to in text.

sandstone; siltstone and very fine-grained sandstone that exhibit large-scale foresets; coarsening-upward, cyclically bedded mudstone, siltstone, and sandstone; and black, organic-rich mudstone comprise the remainder of the Monitor Butte Member.

The type-section of the Moss Back Member was described by Stewart (1957) for exposures on Moss Back Butte, near the eastern end of White Canyon (fig. 2). The brown, coarse- to medium-grained, locally conglomeratic Moss Back sandstone generally overlies the Monitor Butte Member and forms a broad ledge. Northeast of the Shinarump and Monitor Butte pinchouts the Moss Back Member unconformably overlies the Moenkopi Formation. Locally, the Moss Back changes facies into micaceous siltstone and sandstone of the Monitor Butte and Petrified Forest Members. Where the Moss Back is absent, the Monitor Butte is overlain by sandstone or calcareous units of the Petrified Forest Member. Where the Moss Back Member is present, it is overlain by sandstone, mudstone, or calcareous units of the Petrified Forest Member. The remaining members of the Chinle Formation, the Petrified Forest, Owl Rock, and Church Rock, were examined but are not discussed in this study.

METHODS

Sections were measured using a Brunton compass and tape. Measured sections were correlated using the top of the Moss Back Member as a datum. Despite the fact that this is a fluvial sandstone, the Moss Back was chosen as a datum because of it's lateral continuity and essentially flat upper surface, and the lack of any other laterally continuous, recognizable, horizontal bed or surface. In many cases a white, medium-grained, well-rounded, tabular-planar crossbedded quartzose sandstone unit immediately overlying the Moss Back allowed correlation between sections where the Moss Back was absent. In areas where the Moss Back fluvial sandstone grades laterally into extensive overbank sandstone and sandy mudstone of the Monitor Butte Member, the tops of these deposits were used to correlate sections.

In the study area (fig. 2), outcrop observation is limited north of the Colorado River by beds that dip below the level incised by the Green River and its tributaries. On the west, observation is limited by beds that dip toward the Henry Basin and by the lack of dissection of the Chinle west of Red Canyon. To the south, observation is limited by erosion to Permian rocks along the Monument Upwarp. Within the study area vegetative cover is minimal, erosion and dissection is extensive and only talus and large landslide blocks limit observation.

Data from measured sections (fig. 3) were used to construct stratigraphic cross sections and isopach maps of units. The cross-sections, isopach maps, and other field observations were combined to produce an interpretation of facies, environments, and depositional history for the study area.

LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS

SHINARUMP MEMBER

The Shinarump Member is predominantly yellow-orange to gray, very coarse-grained, well-rounded and well-sorted, conglomeratic quartzose sandstone that can be separated into distinct units, which were originally identified by

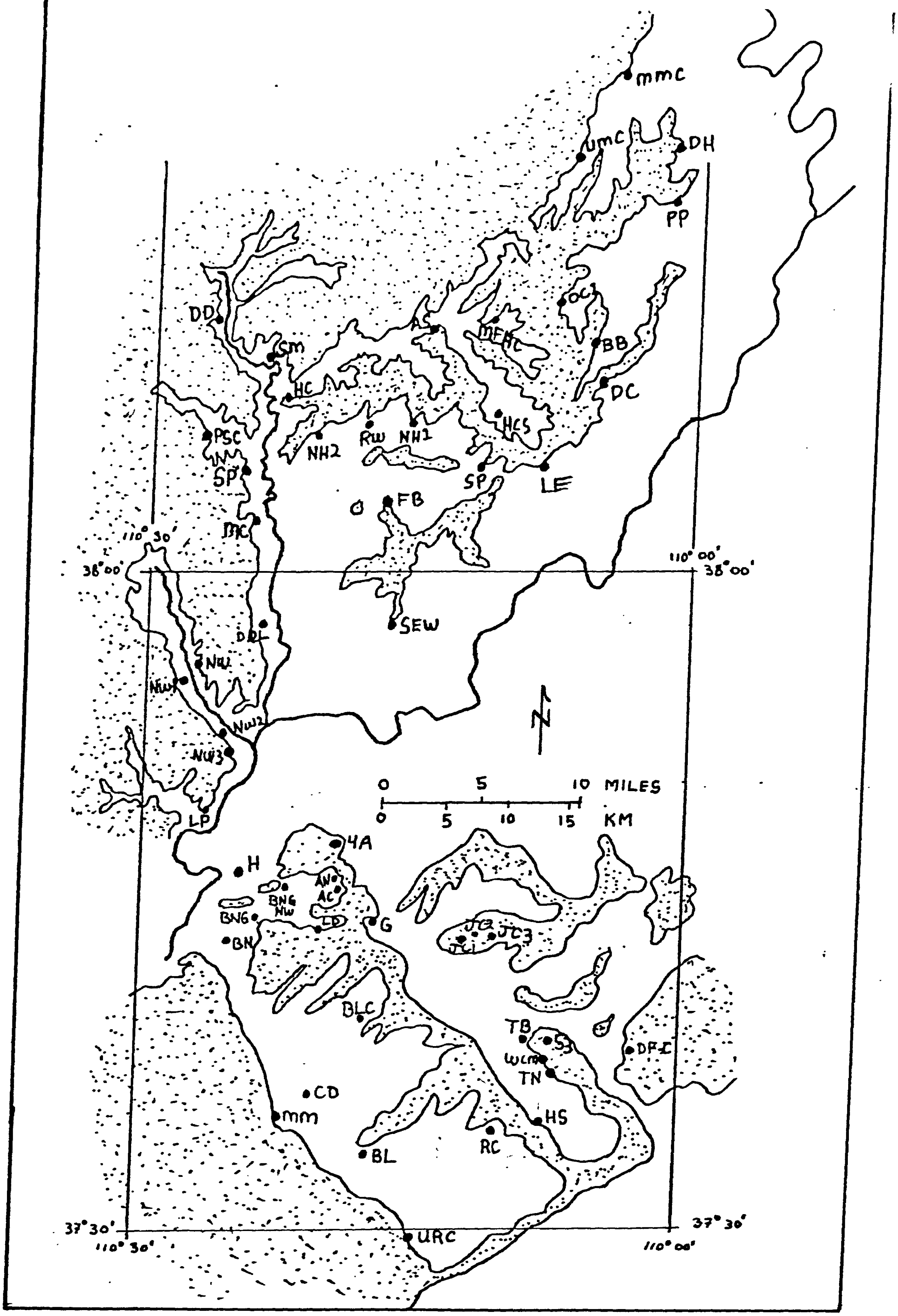

Figure 3.-- Index map showing location of measured sections.

Miller (1955). The lower unit is characterized by abundant large-scale trough crossbeds and minor tabular-planar crossbeds and horizontal laminations. Generally, this unit was deposited in large scours or channels eroded into the underlying Moenkopi Formation. These were recognized as paleo-drainage channels by Miller (1955). These valley-fill sandstones locally have conglomeratic bases, and generally comprise fining-upward sequences from very coarse- to fine-grained sand and show an upward decrease in the size of trough-crossbeds. Gray, carbonaceous, horizontally laminated clay "plugs" (Stewart and others, 1972a) are present in the sequence. Smaller channels have horizontally laminated siltstone with rare mudcracks at the base of the channel-fill and trough-crossbedded sandstone at the top. Carbonized twigs and sticks are locally abundant. Ripup clasts of Moenkopi sediment are incorporated in some basal lag deposits. Epsilon bedding is locally present.

These characteristics are typical of meandering stream systems with basal channel-lags, point bars, and channel cut-offs (Reineck & Singh, 1975; Harms & others, 1975), which in this case, fill paleo-drainages scoured into the underlying Moenkopi Fm. Red and gray mudstone, horizontally laminated siltstone, and very fine-grained sandstone laterally interfinger with and overlie Shinarump fluvial sandstone. These are interpreted as overbank and flood plain deposits that accumulated during flood-stage deposition lateral to the main fluvial channel systems. Several measured sections have black, organic-rich, thinly laminated mudstone between or overlying fluvial sandstone. These may represent channel-fill deposits of cut-off meanders or oxbow lakes. More commonly, the black mudstones are lateral to Shinarump fluvial sandstone, grade upward into other fine-grained deposits and are considered part of the Monitor Butte Member.

The upper unit of the Shinarump Member commonly extends beyond the lower unit and comprises laterally extensive tabular or sheet-like, very coarse- to coarse-grained, well-rounded, poorly sorted and pebbly quartzose sandstone. This lithofacies is interpreted as braided stream deposits because of the laterally extensive beds and the lack of fine-grained sediment. The upper unit represents a fluvial system that migrated laterally subsequent to infilling of the paleo-drainages by the lower unit. Locally the upper unit contains small, 1 cm in diameter vertical and horizontal branching burrows. The lack of fluvial bedding structures and the presence of burrowing organisms suggest a possible nearshore lacustrine depositional environment for these Shinarump beds.

MONITOR BUTTE MEMBER

Mudstone

The Monitor Butte Member is composed of several varied and complexly interfingered lithofacies. Associated with the Shinarump fluvial sandstones are black to gray or brown, horizontally and very thinly laminated organic-rich mudstones. Locally, these mudstones overlie and in turn, are overlain by typical Shinarump fluvial sandstone and are commonly included with the Shinarump Member. Where the black mudstones grade upward into other slope-forming units they are included with the Monitor Butte Member. Typically, the black, organic-rich mudstone is underlain by and grades laterally into a horizontally laminated, carbonaceous gray mudstone. Less commonly, the lateral facies change is into a structureless medium-brown mudstone. Black mudstones grade vertically into silty, bentonitic, and sometimes calcareous mudstones, or are overlain by poorly sorted, burrowed sandstones. Rarely, thin (6 in., 15 cm) beds of coal (Thaden and others, 1964, fig. 10), large (1 ft, 0.3 m) calcareous nodules and thin (6 in., 15 cm) beds of white natro-allunite $[(Na,K)Al_3(SiO_4)_2OH_6]$ and yellow-orange natro-jarosite $[NaFe_3(SO_4)_2(OH)_6]$ are present within the organic-rich mudstones. Conchostracan (order Conchostraca, class Branchiopoda, phylum Arthropoda) assemblages (R.M. Forester, written comm., 1982;) are common in the organic-rich mudstones. Conchostracans have been described from similar organic-rich mudstones from a Late Triassic Lake in the Monitor Butte Member in the Ft. Wingate area of New Mexico (Tasch, 1978). At section MM (fig. 3) and the Four Aces Mine, (fig. 3) the black, organic-rich mudstones alternate with calcareous dark-gray mudstones that contain ostracode (order Ostracoda, class Crustacea, phylum Arthropoda) assemblages (R.M. Forester, written comm., 1982). Ostracodes are also present in calcareous mudstone of the LP section (fig. 3).

Laterally extensive, very thinly laminated horizontal beds and the presence of conchostracans and ostracodes confirm the lacustrine origin of the black mudstone. The lack of evidence of benthic burrowing organisms and the presence of organic-carbon content up to 20 weight percent (M. Stanton, analysis and written comm., 1982) suggest deposition in lakes with high organic productivity and anoxic bottom conditions. Modern conchostracans are most common in marginal lacustrine settings. The non-calcified conchostracan carapace is usually not preserved unless the depositional environment has high sediment turbidity (R. M. Forester, written comm., 1982). Modern ostracodes similar to those found in these Monitor Butte beds prefer an oxygenated littoral or profundal environment (R. M. Forester, written comm., 1982). This combination of factors suggests that these black mudstones represent lacustrine-marsh deposits marginal to a large, freshwater lake. Johnson and Thordarson (1959) recognized the black mudstones east of Jacob's Chair as marsh deposits. These low-energy depositional environments existed adjacent to major fluvial systems. Organic mudstone accumulation as much as 30 ft (10 m) thick also indicates the existence of a continually high fresh water table subsequent to deposition to prevent oxidation of organic matter (Collinson, 1978).

Portions of the Monitor Butte Member (fig. 3, sections CD, JC3), and in places the entire member (fig. 3, sections URC, BL) are composed of green to gray and red, laterally extensive, horizontally bedded, bentonitic mudstone, silty mudstone, and micritic limestone. The gray and green mudstones are generally bentonitic, micaceous, and contain abundant carbonized plant and unidentifiable organic fragments. Red bentonitic mudstones commonly contain calcareous and dolomite-filled nodules that increase upward in abundance and in places coalesce into large calcareous masses. Red mudstones do not contain organic matter. Locally, the nodule-bearing red mudstones grade laterally into the Moss Back Member sandstone. Red bentonitic mudstones are sometimes bleached green 6 in. (15 cm) below sandstone beds. The red and green bentonitic mudstones in the North Wash area (fig. 2), where the red units locally contain limestone nodules, contain abundant, small (1 cm. diameter) horizontal and vertical burrows with a distinctive knobby texture. The thick Monitor Butte mudstone sections at URC, NW2, and RRC (fig. 3) also contain thin (1 cm), isolated horizontal beds of red chert with minor calcite. The section at URC contains at the basal contact with the Moenkopi, a discrete, lenticular unit of well-rounded, well-sorted quartz and chert pebbles surrounded by mudstone. Clifton (1973) noted that in shallow-water marine environments pebbles tend to aggregate in discrete lenses rather than be scattered as in fluvial sandstones.

Nodular micrite-mudstone which formed as fossil caliche has been described from the "carbonate zone" of the Moss Back Member (Gubitosa, 1981) near Moab and the correlative Dolores Formation (Blodgett, 1980) in Colorado. The calcareous nodules in red bentonitic mudstones and siltstones observed in this study probably formed as a result of similar processes. The grain size, lack of organic matter, and field observations of the red mudstones suggest deposition as overbank deposits on floodplains lateral to major fluvial systems. These mudstones were deposited at a time during which there was a deep water table (Collinson, 1978). The preservation of carbonaceous material in gray and green, bentonitic and silty mudstones indicates deposition under reducing conditions that prevented the oxidation of detrital organic matter. Reducing conditions may have existed in soils with a high water table, in anoxic bottom water of lakes or ponds (Peterson and Turner-Peterson, 1980), or in the reducing sediment and interstitial water of lakes with oxygenated water columns.

Sandstone

Sandstone comprises a small portion of the Monitor Butte Member within the study area. White, yellow-orange to brown and gray, fine- to coarse-grained, well-rounded quartzose sandstone occurs in widely scattered areas as lenticular units enclosed by bentonitic mudstones. They are generally characterized by abundant small scale trough-crossbeds and rare tabular-planar crossbeds and are interpreted as meadering stream deposits. Locally present in sandstone beds are conglomerate beds composed partly of well-rounded quartz and chert pebbles but primarily of calcareous, micaceous, ripple-laminated siltstone ripup-clasts, well-rounded iron concretions, and calcareous nodules derived from other units in the Monitor Butte Member. These intra-clast conglomerates have been reported from the "carbonate zone" of the Moss Back in the Moab area (Gubitosa, 1981). The intraclasts are clasts that were eroded by Monitor Butte streams from partially lithified Monitor Butte sediments and redeposited in coarse-grained meandering streams. The sections at TB, AN, and JC3 (fig. 3) exhibit local erosional contacts between units of lacustrine and deltaic character and may be the result of local regression of the lacustrine environment. During episodes of regression of the lake, Monitor Butte streams reworked exposed deposits and redeposited the clasts.

In several places (fig. 3, sections JC, SM, NH1, HC) Monitor Butte sandstones are composed of fine- to medium-grained, well-rounded quartz sandstone with abundant small-scale trough-crossbeds in vertically stacked sequences, 15 to 50 ft (4.5 to 15 m) thick. These sandstones occur lateral to green, micaceous, steeply dipping, interbedded siltstone and fine-grained sandstone. These sandstones are interpreted as distributary channel deposits that scoured into distributary mouth bars of a lobate, deltaic system (Coleman and Gagliano, 1965) (fig. 4).

Poorly Sorted Sandstones

The Monitor Butte Member contains a white to yellow-orange, fine-grained,

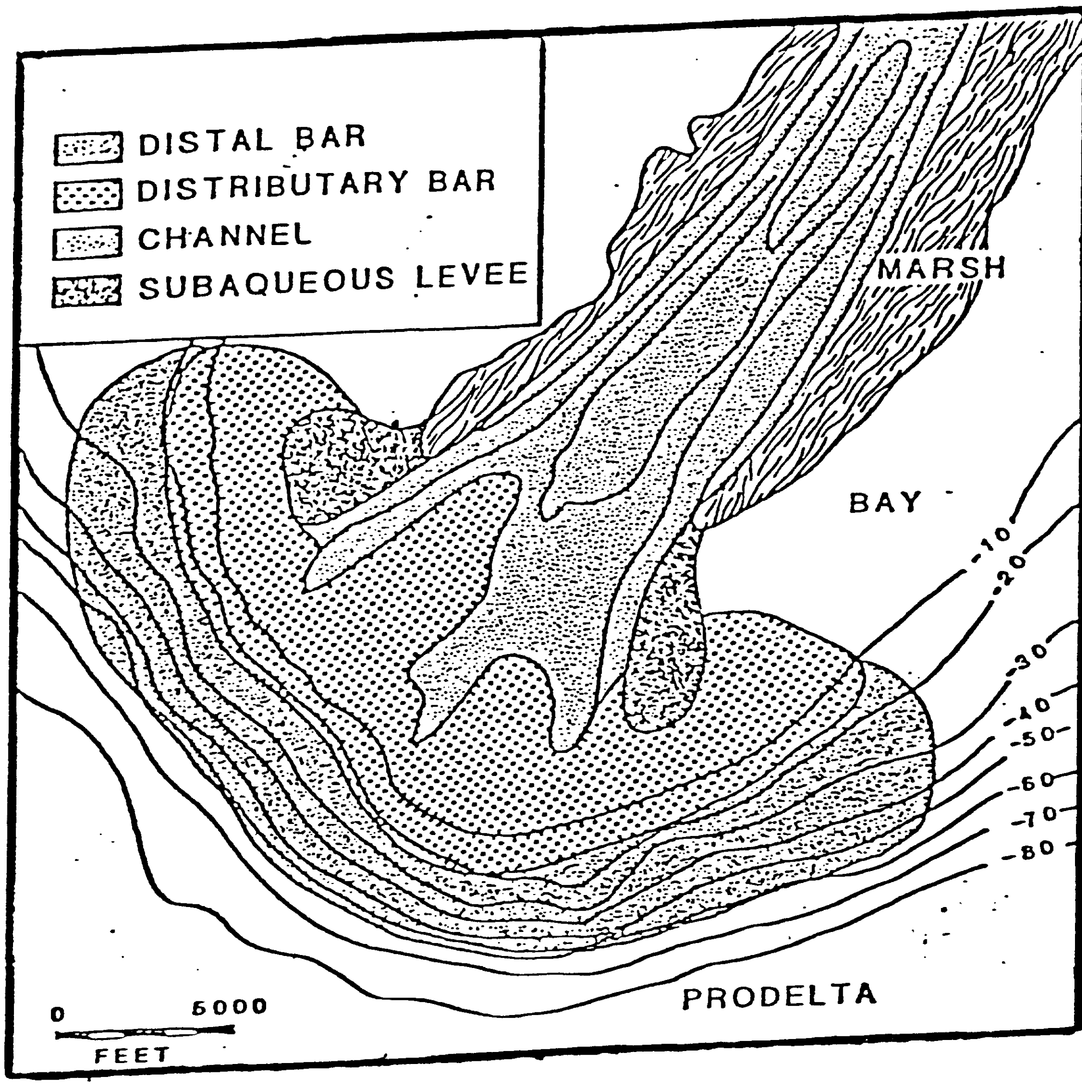

Figure 4.-- Delta-front environments in a lobate, river-dominated delta. Hydrographic contours in feet (modified from Coleman and Gagliano, 1965).

poorly sorted sandstone that contains scattered coarse, well-rounded quartz grains. This sandstone unit overlies black or gray, organic-rich mudstone at sections WCM, G, AC, HS, and JC3 (fig. 3). The unit is characterized by abundant large vertical burrows up to 4 in. (10 cm.) in diameter and up to 3 ft. (1 m) long. The sandstone unit and an underlying, carbonaceous siltstone unit are locally mottled white, yellow, and purple. While the well-rounded, coarse quartz grains suggest a fluvial source, their scattered distribution, the presence of burrows, and the lack of other sedimentary structures indicate the unit has been reworked. The poorly sorted, burrowed sandstones generally are present in sections that also contain an underlying Shinarump fluvial sandstone. Vos (1981) (fig. 5), Curtis (1970) (fig. 6), and Flores and Tur (1982) discuss facies relationships in destructional deltaic sequences. Their work suggests reworked sands are deposited offshore and alongshore from drowned fluvial systems under transgressive conditions. Abundant large burrowing organisms, a reworked sandstone texture, and the position of the burrowed unit between underlying organic-rich, lacustrine-marsh mudstone and overlying lacustrine mudstone and deltaic sediments (discussed in a following section) suggest that this poorly sorted sandstone unit is part of a transgressional sequence. It was deposited in response to the expansion of a body of water when the rate of subsidence in the basin (Rs) was much greater than the rate of deposition (Rd) or $Rd/Rs<1$ (fig. 6) (Curtis, 1970). The result was a drowning of fluvial systems, a reworking of fluvial sands, and the deposition of sheet-like sandstone units adjacent to areas of fluvial sand input.

Mottled Units

A distinctive purple, yellow, and white mottling is present in the Moenkopi Formation and members of the lower part of the Chinle Formation locally within the study area. The coloration is very similar to that found in the Temple Mountain Member of the Chinle Formation in the San Rafael Swell (Robeck, 1956; Hawley and others, 1968) and to mottled Chinle units described from other areas (Finch, 1954; Johnson and Thordarson, 1966; Stewart and others, 1972a).

The Moenkopi Formation is mottled at sections DDL, DC, URC and in North Wash (figs. 2 and 3). The intensity of mottling decreases downward to a depth 10 to 20 ft. (3 to 6 m) below the Moenkopi-Chinle contact and grades downward into typical red-brown Moenkopi siltstones. At section DDL and in North Wash the mottling stops abruptly at the Moenkopi-Chinle unconformity and does not extend into the overlying Monitor Butte Member bentonitic mudstones. At sections DC and URC, the mottling extends upward from the Moenkopi Formation into the basal few feet of the Monitor Butte mudstones and sandstones. Mottling also occurs in the poorly sorted, generally burrowed and bioturbated, sandstones of the Monitor Butte Member in the sections at JC1, WCM, HS, G, AN, AC, BNC-NW, and SEW (fig. 3).

The peculiar mottling in the Temple Mountain Member and other members of the Chinle Formation in southeastern Utah has been attributed to soil-forming processes (Stewart and others, 1972a; Johnson, 1957; Johnson, 1964; Lupe 1977 and to hydrothermal alteration (Abdel-Gawad and Kerr, 1963; Kerr and Abdel-Gawad, 1964). However, where the Moenkopi Formation is mottled, overlying Chinle sediments comprise fine-grained bentonitic mudstones interpreted as lacustrine deposits. Where the poorly sorted sandstones are mottled, they are

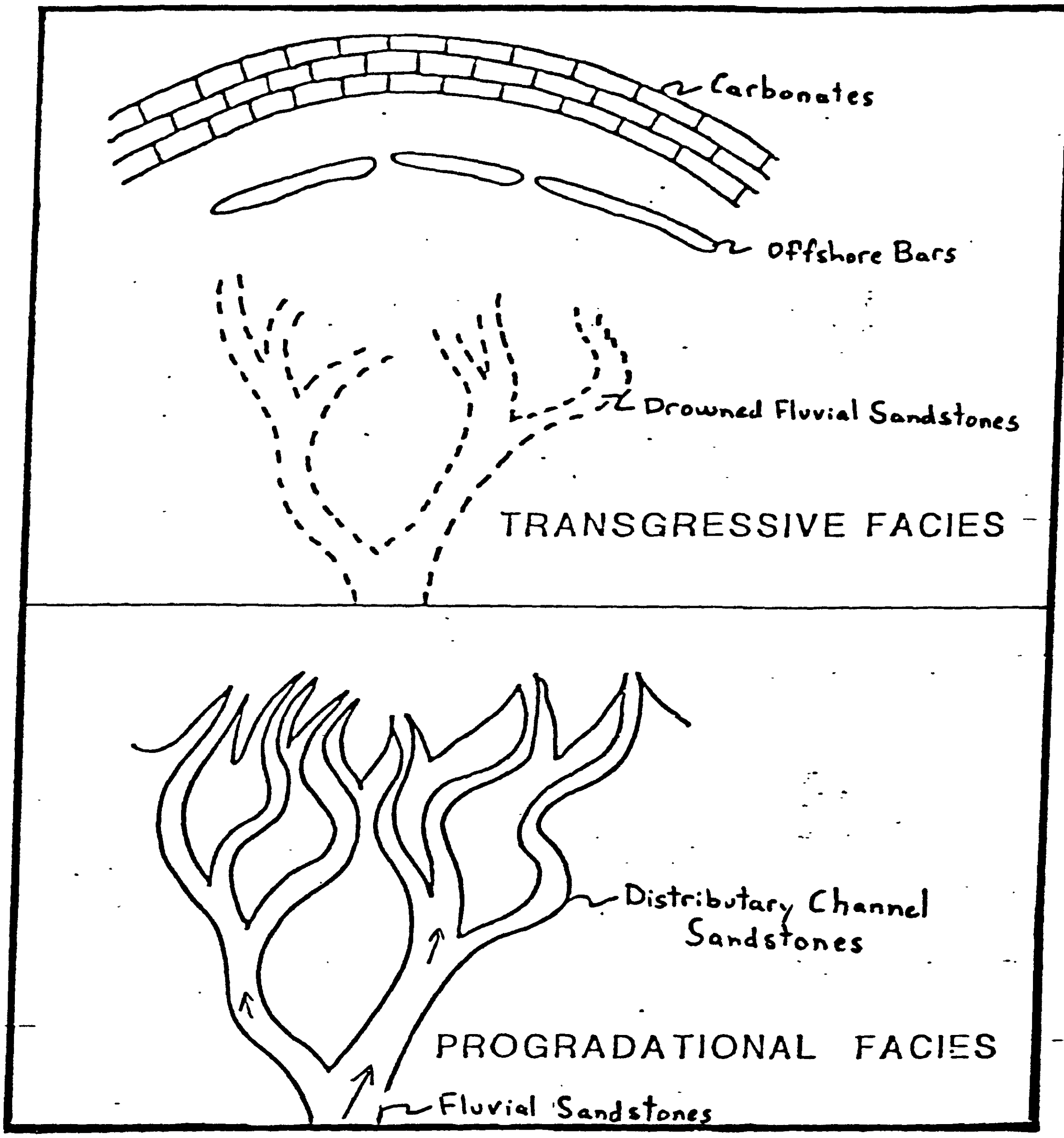

Figure 5.-- Diagrammatic plan view of facies present under progradational and transgressive conditions of fluvial flow into a standing body of water (modified from Vos, 1981).

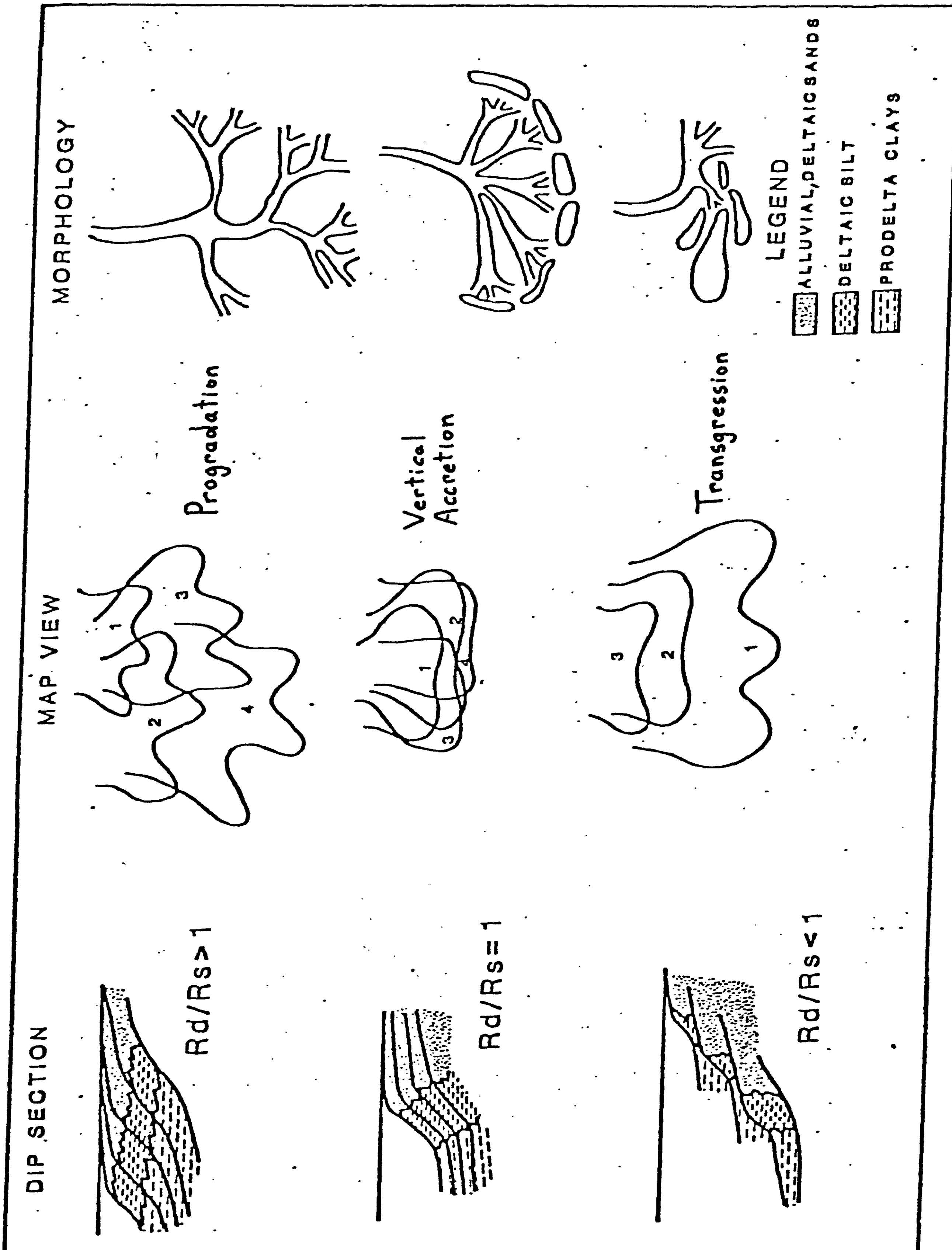

Figure 6.-- Conceptual diagrams of deltaic sedimentation under changing conditions of rate of deposition (Rd) and rate of subsidence (Rs) in a basin (modified from Curtis, 1970).

commonly burrowed and bioturbated. The poorly sorted sandstones also are overlain by cyclically bedded siltstones and sandstones, and bentonitic mudstones that are interpreted as deltaic lacustrine deposits. The association of mottled rocks in the Moenkopi and Chinle Formations with large burrows and lacustrine facies suggests a relationship between mottling and the lacustrine environment. The mottled units are interpreted as part of a transgressive lacustrine sequence and the mottling may be the result of extensive burrowing or the result of chemical reactions in response to transgression by anoxic lake waters.

Limestone

Scattered and isolated but laterally extensive beds of light-gray, dense, fine-grained limestone occur as small distinct ledges in predominantly bentonitic mudstone sections of the Monitor Butte Member at sections MM, H, LD, FB, and BLC. Beds are 1 to 4 ft (1 m) thick, and extend laterally for several hundred feet (tens of meters). Silty and sandy bentonitic mudstones are often calcareous.

Lacustrine limestones are reported from Tertiary sediments of the Upper Ruby River Basin in southwestern Montana (Monroe, 1981) and modern Lake Constance (Schottle and Muller, 1968). An extensive discussion of criteria for lacustrine limestones is given by Picard and High (1972). The association of limestone in a continental sequence with fine-grained and bentonitic mudstone, and facies associations with fluvial and deltaic units implies deposition by precipitation in a calcareous lacustrine basin, removed from any clastic sediment input.

Deltaic Deposits

Much of the remaining Monitor Butte Member is composed of gray to green, micaceous, carbonaceous, and calcareous siltstone and fine-grained sandstone in foreset beds tilted and contorted beds and cyclically bedded coarsening upward sequences. The foreset-bedded units (sections SR, H, SM, HC, LP fig. 3) are 15 to 70 ft (4.5 to 21 m) thick and are composed of alternating green, micaceous siltstone and fine-grained sandstone, which can be traced from horizontal beds into foreset-beds that dip from 15^{0} to 28^{0}. These units represent distal- and distributary-mouth bars of a prograding fluvial-lacustrine fan-delta system (fig. 4) (Coleman and Gagliano, 1965), and are identical to those reported from "carbonate zone" of the Moss Back (Goubitosa, 1981). The 70 ft (21 m) thick foresets at LP indicate, without accounting for compaction or diagensis, a lake that was at least 70 ft (21 m) deep.

At sections WCM, AN, AC, BLC, CD, G, and JC3 (fig. 3), green, cyclically bedded, micaceous mudstone, siltstone, and sandstone range from 10 to 120 ft (3 to 36 m) thick. The lower third of each sequence (fig. 7) is predominantly carbonaceous, fossil plant-bearing, horizontally laminated mudstone in beds 4 to 5 ft (1.5 m) thick. The middle portion consists of beds 2 to 3 ft (1 m) thick, with gray, carbonaceous fossil plant-bearing, horizontally laminated mudstone 4 to 6 inches (10 to 15 cm) thick at the base that coarsens upward into climbing-ripple laminated calcareous sandstone. The upper third of each cyclic sequence is composed of 2 to 3 ft (1 m) thick beds consisting of 2 to 3 inch (5 to 8 cm) thick gray, horizontally laminated mudstone that grades upward into foreset-bedded fine- to medium-grained sandstone. The entire

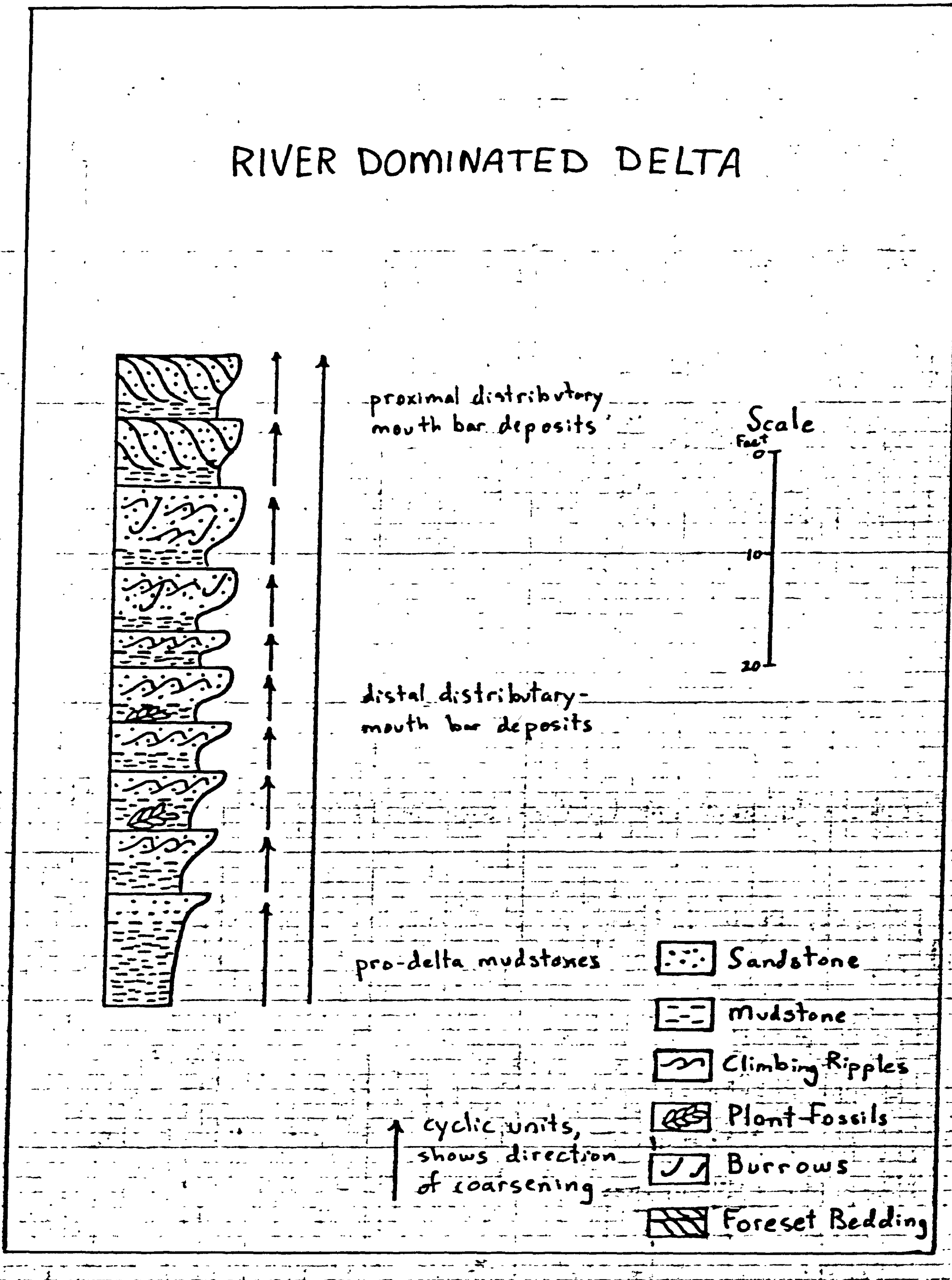

Figure 7.-- Schematic stratigraphic section of a river-dominated deltaic sequence (modified from Miall, 1979).

cyclic sequence coarsens upward. The mudstone base of each bed contains abundant carbonized fragments and whole specimens of Zamites powelli, Phlebopteris smithii, (S. R. Ash, written comm., 1981; Ash, 1978; Gottlesfeld, 1972) and other Late Triassic flora. The excellent preservation of carbonaceous whole-leaf structures in gray, horizontally laminated mudstone suggests quiet water deposition and rapid burial under anoxic conditions in the sediment that inhibited the oxidation of plant matter. The ripple cross-laminated sandstones locally contain abundant U- and J- shaped burrows 1 cm in diameter that deform ripple laminations downward along burrow walls.

The lower muddy third of the sequence represents slightly deeper, distal deposits overlain by successively shallower water and more proximal deposits of a prograding delta. Individual beds in the middle portion, which coarsen upward, represent minor local transgressions due to local subsidence and/or deltaic subsidence due to sediment loading that was followed by clastic deltaic deposition from an approaching fluvial source. Oscillation ripples in thin, 2 in (5 cm) thick reworked zones at the top of climbing ripple-laminated beds probably formed during periods of quiet standing water just after a minor local transgression and prior to mudstone deposition of the next clastic infilling cycle. The foreset-bedded upper third of the sequence represents clastic deltaic deposition as the fluvial source prograded into the locally subsiding basin. The schematic stratigraphic section of a river-dominated deltaic sequence (Miall, 1979) (fig. 7) is identical to the sequence at sections WCM, AN, AC, G, and JC3 (this paper and Dubiel, 1982a, 1982b). The cyclic sequences represent river-dominated clastic deltaic deposition into a fairly large, permanent lake in which the rate of clastic deposition (Rd) was equal to or slightly greater than the rate of subsidence (Rs) of the basin, or Rd/Rs = 1 (fig. 6; Curtis, 1970).

The sections at NH1 and SM (fig. 3) consist of 15 to 30 ft (4.5 to 9 m) thick sections of coarse-grained, well-rounded, well-sorted quartz sandstone in stacked, fluvial packages. At NH1 the sandstone bodies show a bi-convex shape attributed to bar-finger sands (Reineck and Singh, 1975) of distributary-fluvial sandstones of a Mississippi-type fluvial-dominated deltaic system. Adjacent to these bar-finger sands are green, steeply dipping, inter-bedded, micaceous siltstone and sandstone. The beds are in 5 to 6 ft (1.5 to 2 m) thick stacked sequences separated by low-angle listric faults. Individual beds are horizontally bedded adjacent to the fluvial sandstone and can be traced laterally into dipping beds. The beds dip away from the laterally equivalent fluvial sandstones at angles that vary from 20^{o} to 45^{o}. Movement on these faults would have rotated sediments to decrease dips. Compaction would also decrease dips. The anomalously high dip of the beds may have been steepened after deposition by the loading of successive fluvial sandstone packages. The loading and sinking of sandstones into muds and silts could have pushed sediment away from the locus of loading. The siltstones and sandstones represent distal distributary-mouth bars and distributary channel sands (fig. 3) and the fluvial sandstones represent bar-finger sands (Coleman and Gagliano, 1965) of an elongate distributary deltaic system. Convoluted and tilted beds of similar lithology represent delta fore-slope slumps, resulting from oversteepening by rapid deposition (fig. 8; Elliot, 1978; Miall, 1979).

The preponderance of cyclically bedded, coarsening upward sequences of river-dominated and lobate deltaic deposits indicates prograding fluvial-

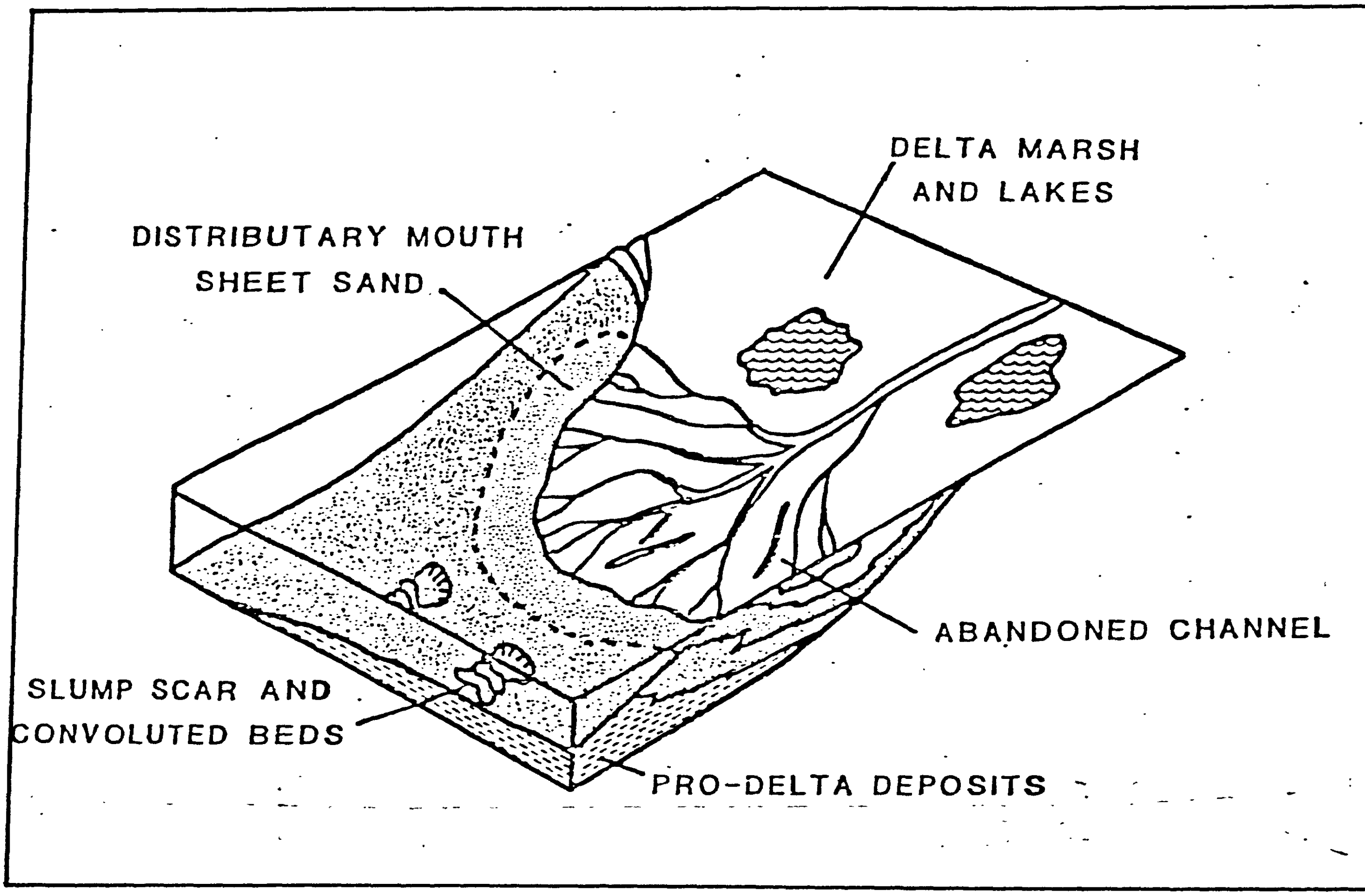

Figure 8.-- Block diagram of a lobate, river-dominated delta exhibiting slump scars and convoluted beds on the delta fore-slope (modified from Miall,1979).

deltaic infilling of a large lacustrine system in which the rate of subsidence was slightly less than the rate of deposition. While clastic deltaic deposition and local regression of the lacustrine system proceeded at sections WCM, JC3, G, AN, AC, SR, SM, HC, NH1, simultaneous local transgression in the inter-delta areas deposited sandy and silty bentonitic, reworked lacustrine mudstone at sections LD, JC1, JC2, BNG-NW, HCS, and AS (fig. 3).

Moss Back Member

The Moss Back Member comprises brown to yellow-orange, fine- to medium-grained, conglomeratic sandstone; minor siltstone; and gray-green mudstone. It generally occurs as a laterally extensive cliff-forming unit ranging from 10 to 120 ft (3 to 36 m) thick, which is characterized by medium- to small-scale trough-cross beds, overturned crossbeds, tabular-planar crossbeds, and abundant horizontal laminations. The tabular-planar crossbeds are inferred to be the product of migrating transverse bars (Smith, 1970). Abundant tabular-planar crossbeds, a general lack of fining-upward sequences or fine-grained organic-rich abandoned channel-fill sediments, and laterally extensive tabular beds suggests deposition by braided streams (Reineck and Singh, 1975; Smith, 1970).

Locally present, but increasing in abundance to the north, are beds of intraclast conglomerate composed of calcareous, micaceous, ripple-laminated siltstone ripup-clasts and limestone nodules from the underlying Monitor Butte Member. The Monitor Butte Member locally exhibits similar fluvial beds that contain calcareous intraclast conglomerate. In both instances, these beds are interpreted as representing deposition of locally eroded and reworked Monitor Butte sediments by fluvial systems. These units probably represent deposits of coarse-grained meander-belt streams similar to those described by Smith (1970).

Isolated lenses of gray to green bentonitic mudstone enclosed within Moss Back fluvial sandstone probably represent quiet-water lacustrine deposition in abandoned channels. Locally, the Moss Back channel sandstones grade laterally into overbank and flood plain deposits of green micaceous sandstone and siltstone of the Monitor Butte Member. More commonly, the Moss Back grades laterally into calcareous nodule-bearing red mudstone. The presence of calcareous nodules indicates low water tables on the floodplain (Collinson, 1978).

Isolated, steeply dipping beds are locally present within the Moss Back Member. These units probably represent clastic deltaic infillings of small ponds that occupied abandoned channels of the Moss Back fluvial system.

Measurements of dips of cross-strata and current lineation directions; the distribution of the Moss Back Member from isopach data; field observations of lateral facies changes of the member; and previous investigations (Stewart and others, 1972a; Gubitosa, 1981) all indicate that the flow of Moss Back streams was to the north and northwest through the study area.

Progradation of the fluvial Moss Back braided stream system over deltaic, nearshore, and offshore lacustrine deposits represents the clastic infilling of the lake basin when the rate of deposition (Rd) was much greater than the rate of subsidence (Rs) in the basin, or Rd/Rs>1 (fig. 5) (Curtis, 1970).

PALEOTECTONICS

The continental beds of the lower part of the Chinle Formation in the White Canyon area were deposited in a complex fluvial-deltaic-lacustrine system (Dubiel, 1982a, 1982b). Stratigraphic sections across the north wall of Blue Notch Canyon (fig. 9), across White Canyon between the Gonaway Mine and Jacob's Chair (fig. 10), and across the eastern end of White and Red Canyons (fig. 11) (Dubiel, 1982a; 1982b) all exhibit similar stratigraphic and facies relationships. Generally, fluvial sandstones and finer-grained deposits associated with Shinarump stream systems unconformably overlie the Moenkopi Formation and are conformably overlain by fluvial, deltaic, and lacustrine deposits of the Monitor Butte Member. The fluvial sandstones of the Moss Back Member conformably overlie but locally scour into deposits of the Monitor Butte Member.

Isopach maps of members and of various genetic units within members, constructed from thicknesses of units at measured sections, illustrate the distribution of specific facies and their interrelationship with other facies. The coincidence and recurrence of isopach thicks and thins of several units within the same geographic area suggest that large- and small-scale structural features influenced sedimentation. Facies changes coincide with or parallel isopach thicks in subsequent members. This suggests that changes in depositional environments occurred on the edge of developing basins. The subsidence and growth of small basins during Chinle time resulted in anomolously thick accumulations of some sediments as shown on isopach maps (figs. 13, 14, 15, 16, 17, 18, 19, 20). Additionally, the isopach thicks in several units coincide with the traces of modern structural synclines (Hackman and Wyant, 1973; Williams and Hackman, 1971) (fig. 12) suggesting that these features were active during the Late Triassic. The development and growth of small basins on a local scale may account for the change in sedimentary regime and distribution of various facies; for example, the localization of relatively high-energy fluvial systems of the Shinarump and Moss Back Members and low-energy deltaic-lacustrine sedimentation in the Monitor Butte Member. Facies changes in response to sedimentary regime may also reflect changing gradient in response to the growth of the larger Henry Mtn. basinal system to the west of the study area.

The isopach map of the entire lower three members of the Chinle Formation (fig. 13) shows a distinct increase in thickness from the north, where only Moss Back is present, to the south, where Shinarump, Monitor Butte, and Moss Back are present. Several areas exhibit isopach thicks in the south which correspond to modern structural synclines (fig. 12). Movement on these synclines to form locally subsiding basins during the Late Triassic may have enabled anomalous thicknesses of lower Chinle sediments to accumulate.

The distribution of Shinarump fluvial sandstone (fig. 14) is restricted to the southern portion of the study area. The isopach map shows thick accumulations of fluvial sandstone in paleo-stream channels that were scoured into the Moenkopi Formation with the deposition of sandstone thinning lateral to main channel systems. Shinarump deposition may have been controlled by a pre-existing topography developed on the underlying Moenkopi Fm. However, several of the Shinarump isopach thicks coincide with the traces of modern structural synclines (fig. 12), which suggests a structural control on deposition in these areas.

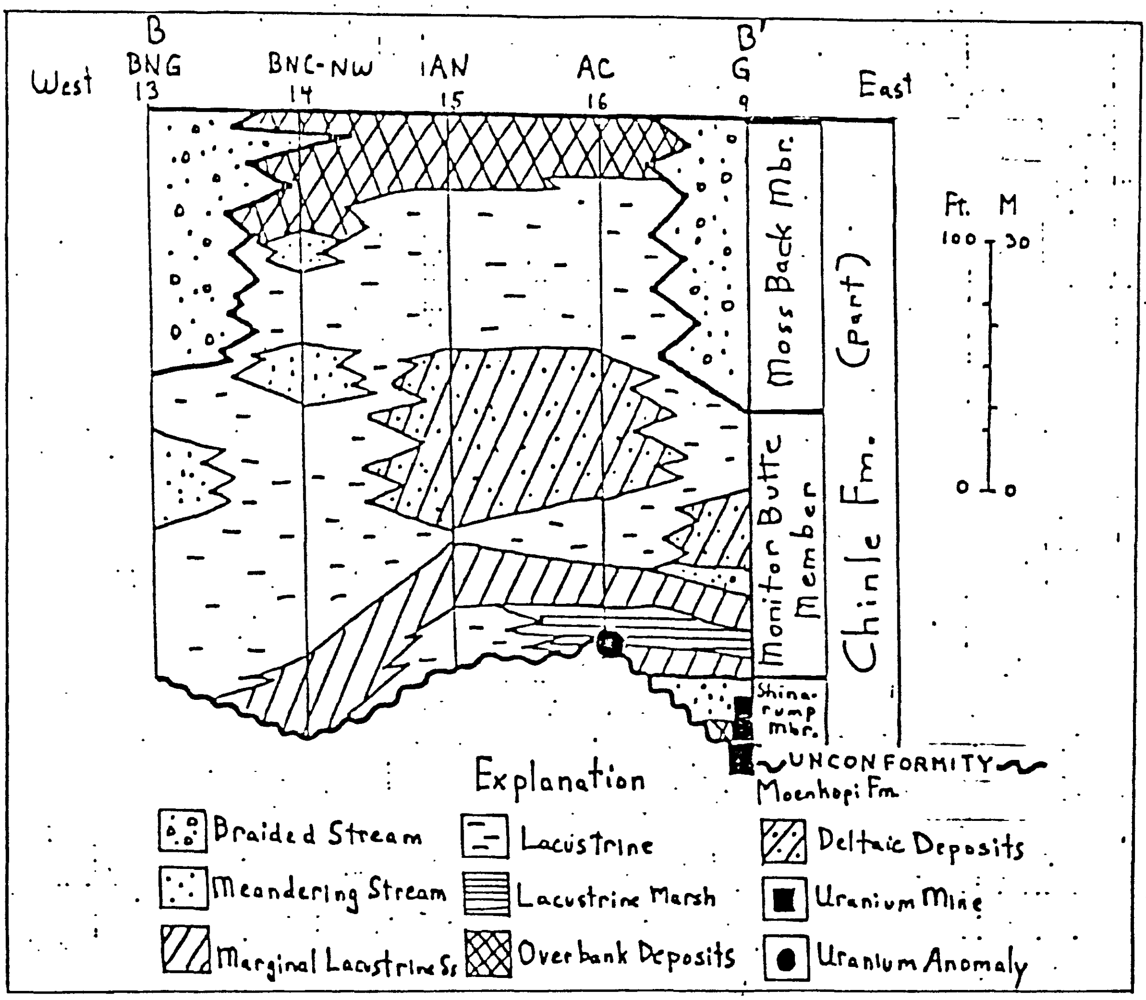

Figure 9.-- Stratigraphic cross section along the north wall of Blue Notch Canyon (from Dubiel, 1983); see Fig. 3 for location of sections.

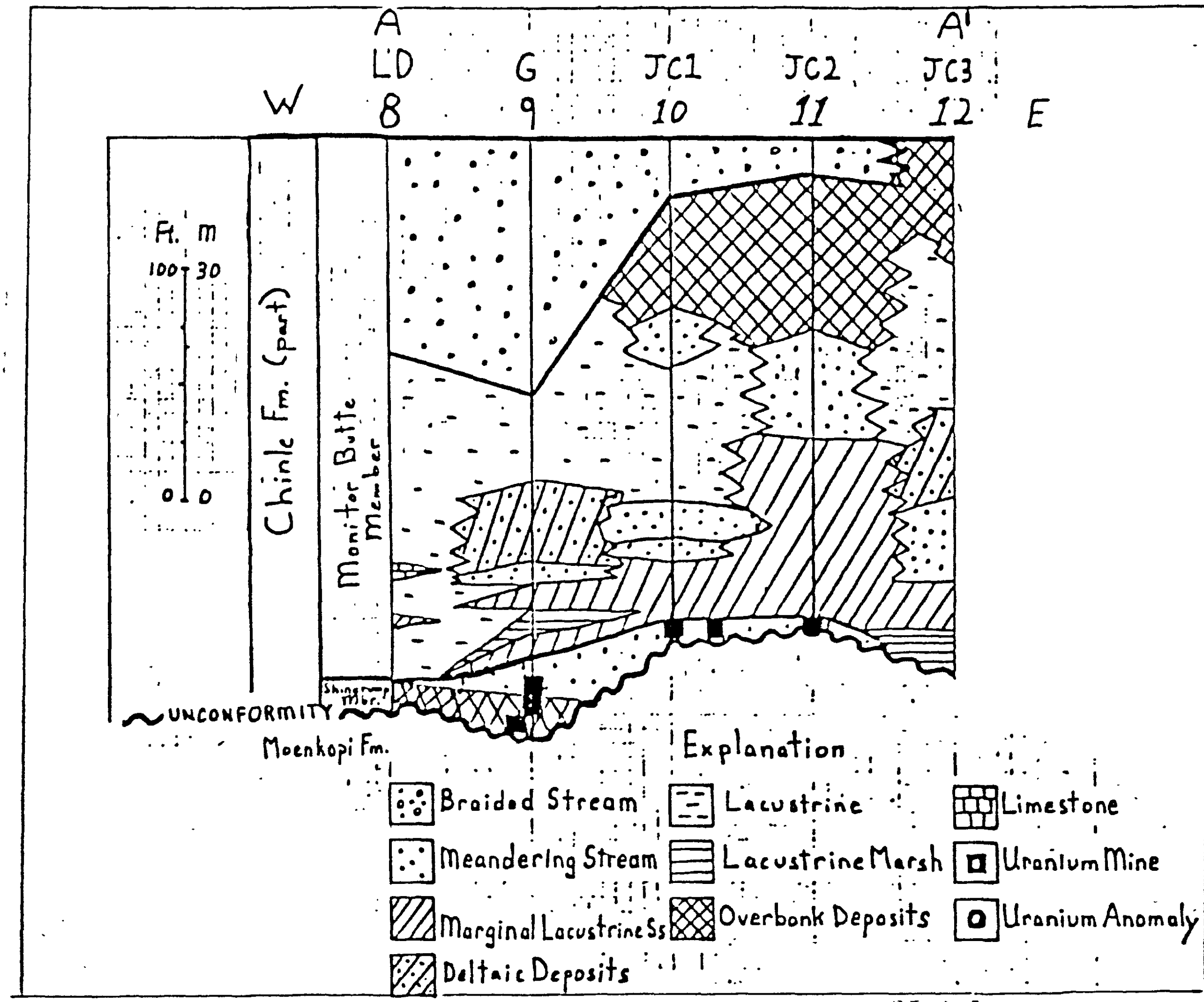

Figure 10.-- Stratigraphic cross section across north end of White Canyon (from Dubiel, 1983); see Fig. 3 for location of sections.

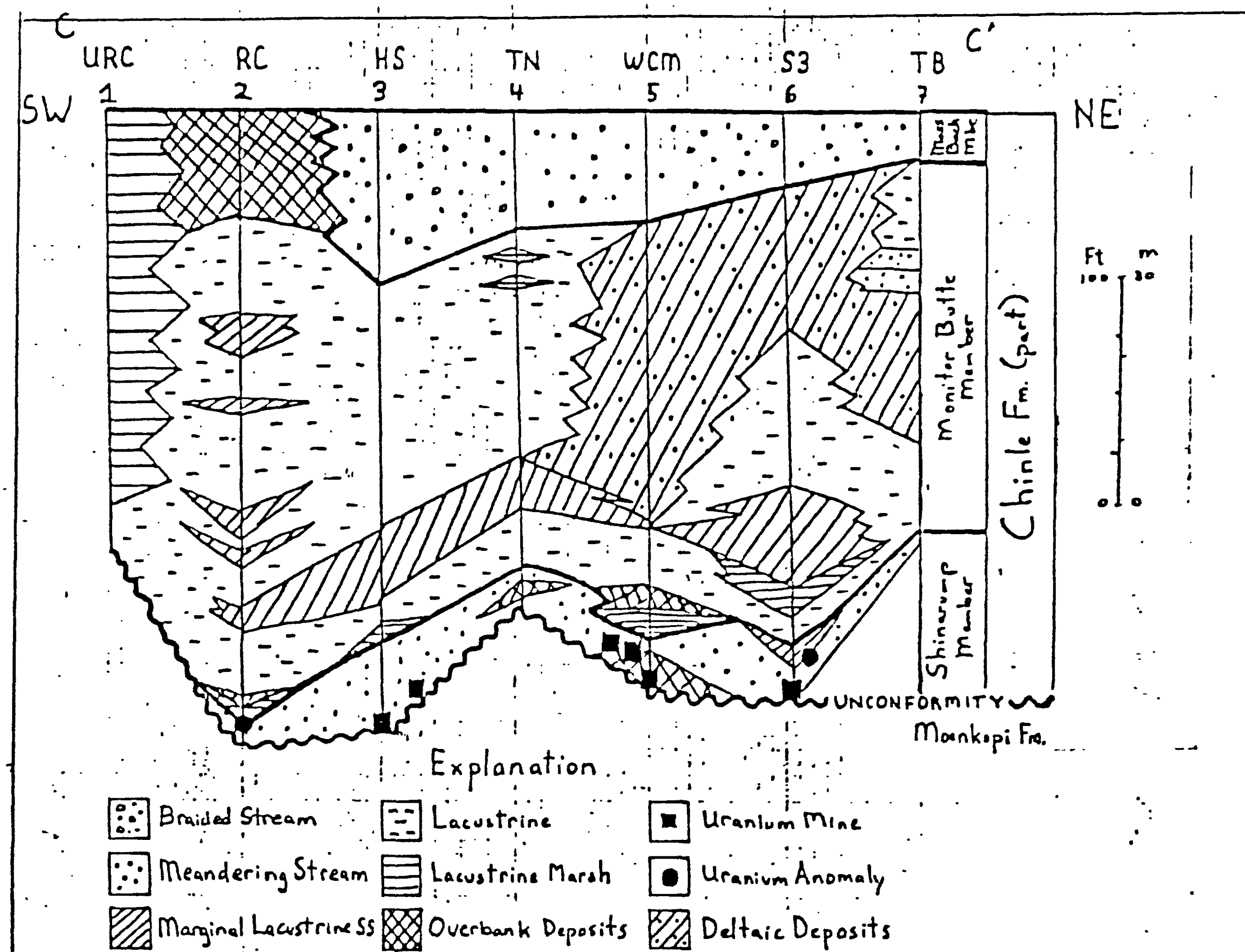

Figure 11.-- Stratigraphic cross section across east end of White and Red Canyons (from Dubiel, 1982); see Fig. 3 for location of sections.

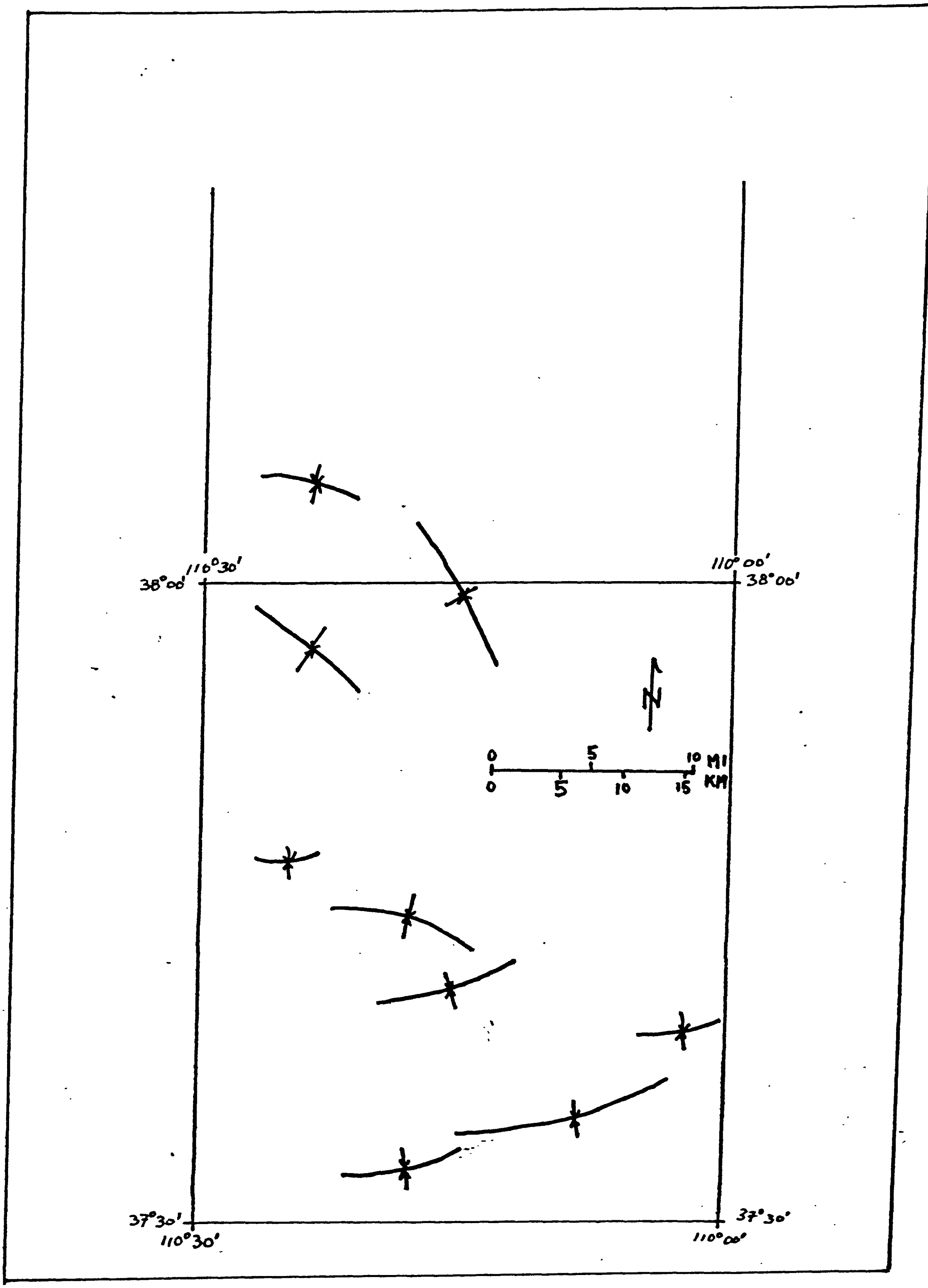

Figure 12.-- Traces of axes of structural synclines in the study area. Dots represent location of measured sections.

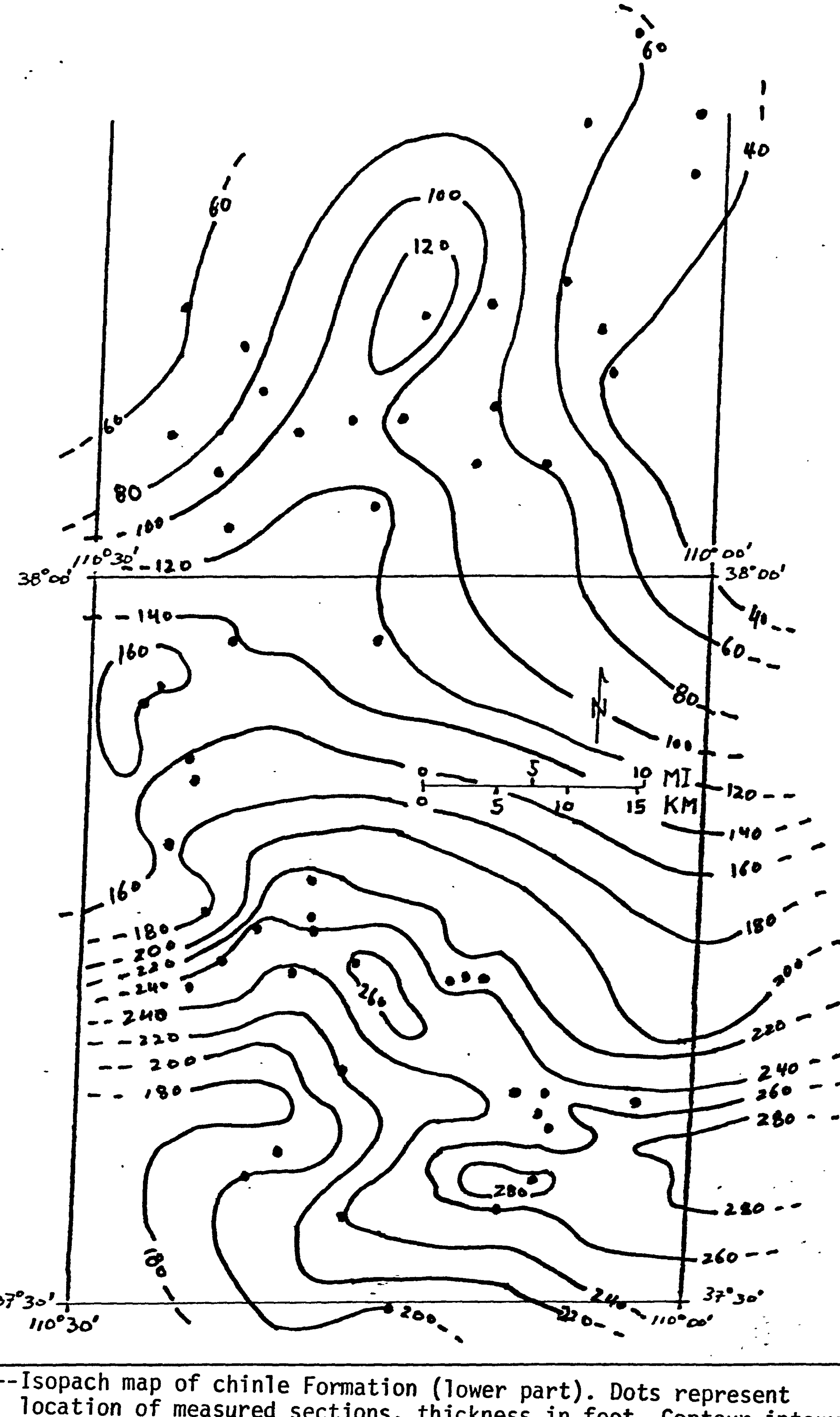

Figure 13.--Isopach map of chinle Formation (lower part). Dots represent location of measured sections, thickness in feet. Contour interval 2o feet;isopach dashed where inferred. No data for unnumberedsections due to difficulty in picking member contacts.

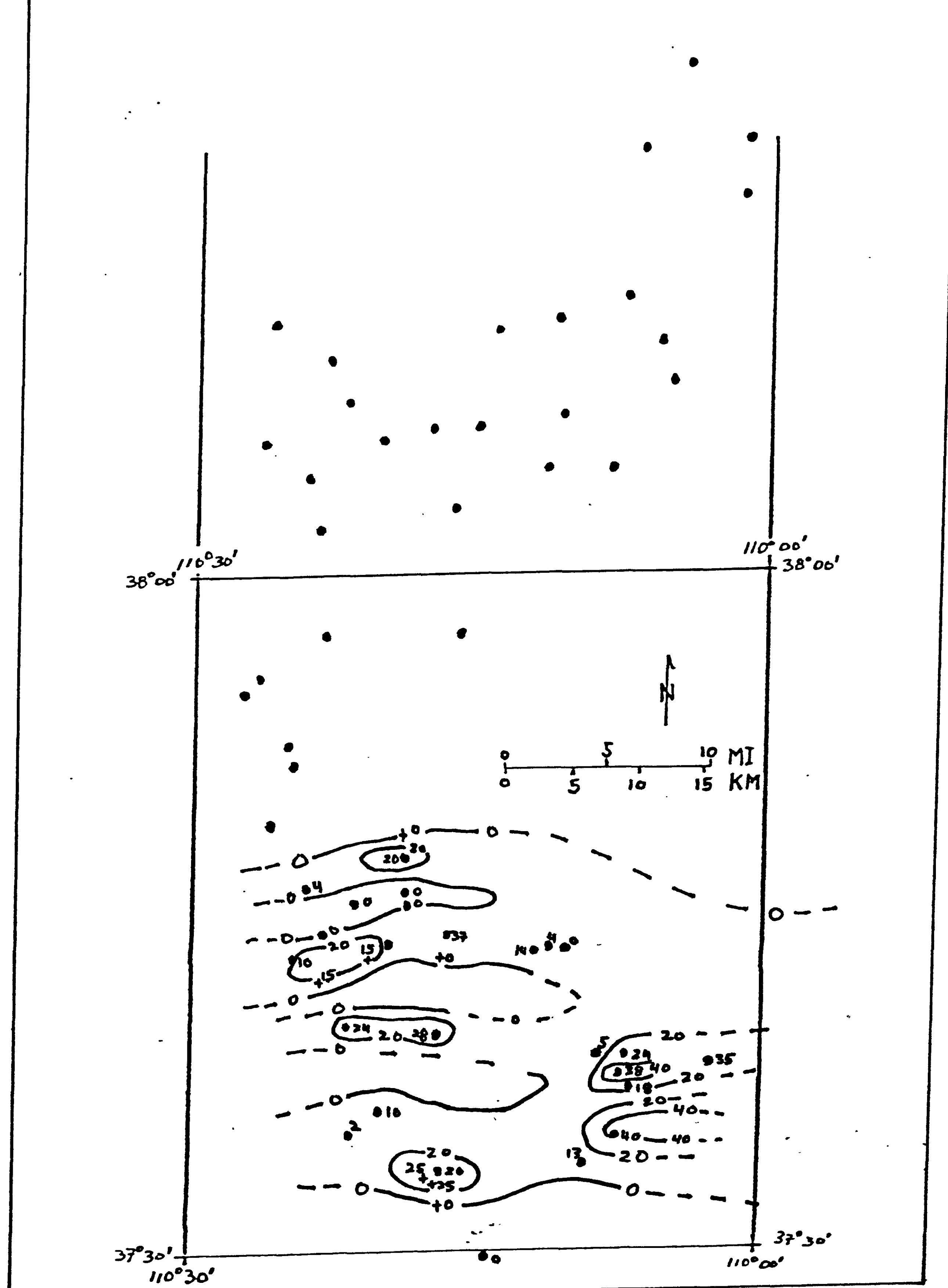

Figure 14.--Isopach map of Shinarump Member. Dots represent location of measured sections, crosses represent observed sections; thickness in feet. Member not present where no data is recorded. Contour interval 10 feet; isopach dashed where inferred.

The isopach map of black, organic-rich, lacustrine-marsh mudstones (fig. 15) shows the distribution of lacustrine deposits that stratigraphically overlie Shinarump fluvial sandstone. Generally, thick lacustrine-marsh deposits lie along the trends of Shinarump fluvial systems (fig. 14) and correspond with structual synclines. The association of low-energy lacustrine-marsh deposits with thicker parts of the Chinle (part) section again suggests active subsiding synclines during Chinle time.

The three sections located just north of the 38^0 latitude line (fig. 15) contain light gray laminated mudstone that underlies lacustrine-marsh mudstone in other areas. These and the two 2 ft (0.6 m) thick lacustrine deposits along the 110^0 longitude line were noted from both drill core and outcrop observation and are included to support a later discussion of uranium occurrences in the area.

The isopach map of the entire Monitor Butte Member (fig. 16) shows the gradual thinning and pinchout of the member to the northeast and anomalously thick areas that coincide with isopach thicks of Monitor Butte fluvial sandstone (fig. 17) and deltaic sandstone (fig. 18). These geographic areas of recurring isopach thicks in Monitor Butte facies correspond to the traces of structural synclines (fig. 11), as do isopach thicks of Monitor Butte limestone (fig. 19). This coincidence of isopach thicks with structural synclines indicates that Monitor Butte sedimentation was locally controlled by subsiding basins and that facies distribution in the fluvial-deltaic-lacustrine system was influenced by these small, active structural synclines.

The isopach map of mottled units (fig. 20) shows the distribution of mottled Moenkopi Fm., mottled Monitor Butte Member units, and the large burrows present in poorly sorted sandstone. The mottling and burrows are inferred to be a result of the depositional history and are discussed in a following section.

The isopach map of the Moss Back Member (fig. 21) shows the widespread and extensive distribution of this fluvial sandstone. In the area of WCM and BNG (fig. 3) the unit is from 60 to 100 ft (18 to 30 m) thick; in other areas the Moss Back varies from 0 to 60 ft (0 to 18 m) thick. To the west of WCM and in the vicinity of NH2 (fig. 3) the Moss Back fluvial sandstone thins and grades laterally into floodplain deposits composed of micaceous siltstone and sandstone that are technically referred to the Monitor Butte Member. Thus, the Moss Back Member is conspicuously absent (fig. 21). These areas of non-deposition of fluvial sandstone correspond to isopach thicks that were persistent throughout Monitor Butte deposition. This coincidence may reflect either a cessation of local subsidence that influenced Monitor Butte lacustrine deposition in small basins or a localization of the Moss Back fluvial system by subsequent subsidence. The progradation of the Moss Back braided stream system may, in fact, represent the expected evolution and infilling of a lacustrine basin. Moss Back braided fluvial systems prograded through the area subsequent to clastic infilling of small basins that underwent continual development in Monitor Butte time. Subsidence may have persisted enough to localize flow of the Moss Back braided streams.

The recurrence of isopach thicks in the same geographic position in Shinarump and Monitor Butte time, the association of facies changes parallel to or coincident with the edges of isopach thicks and the correspondence of

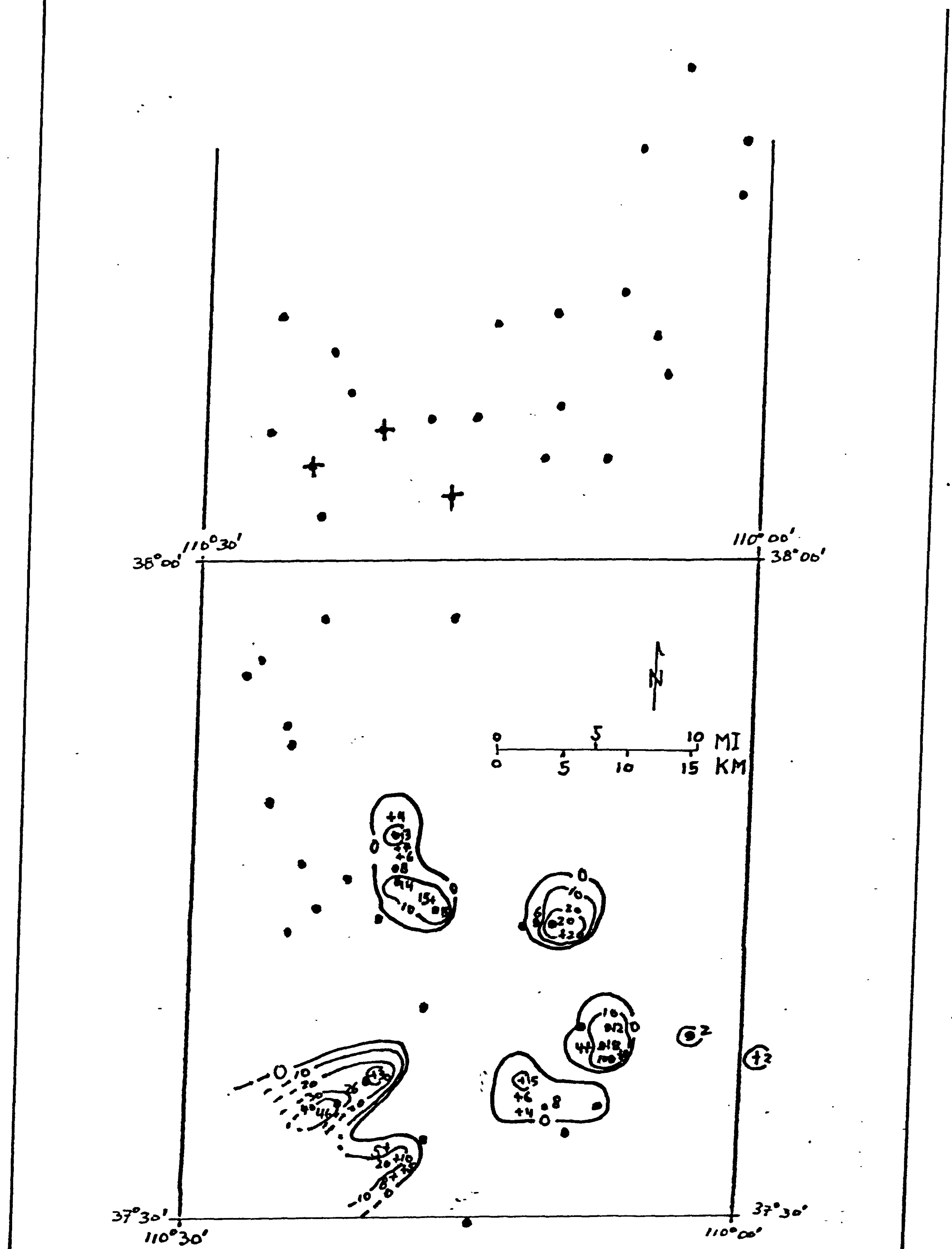

Figure 15.-- Isopach map of organic-rich mudstones. Dots represent location of measured sections, crosses represent location of observed sections; thickness in feet. Dots with cross represent location of gray mudstone. Contour interval 10 feet, dashed where inferred.

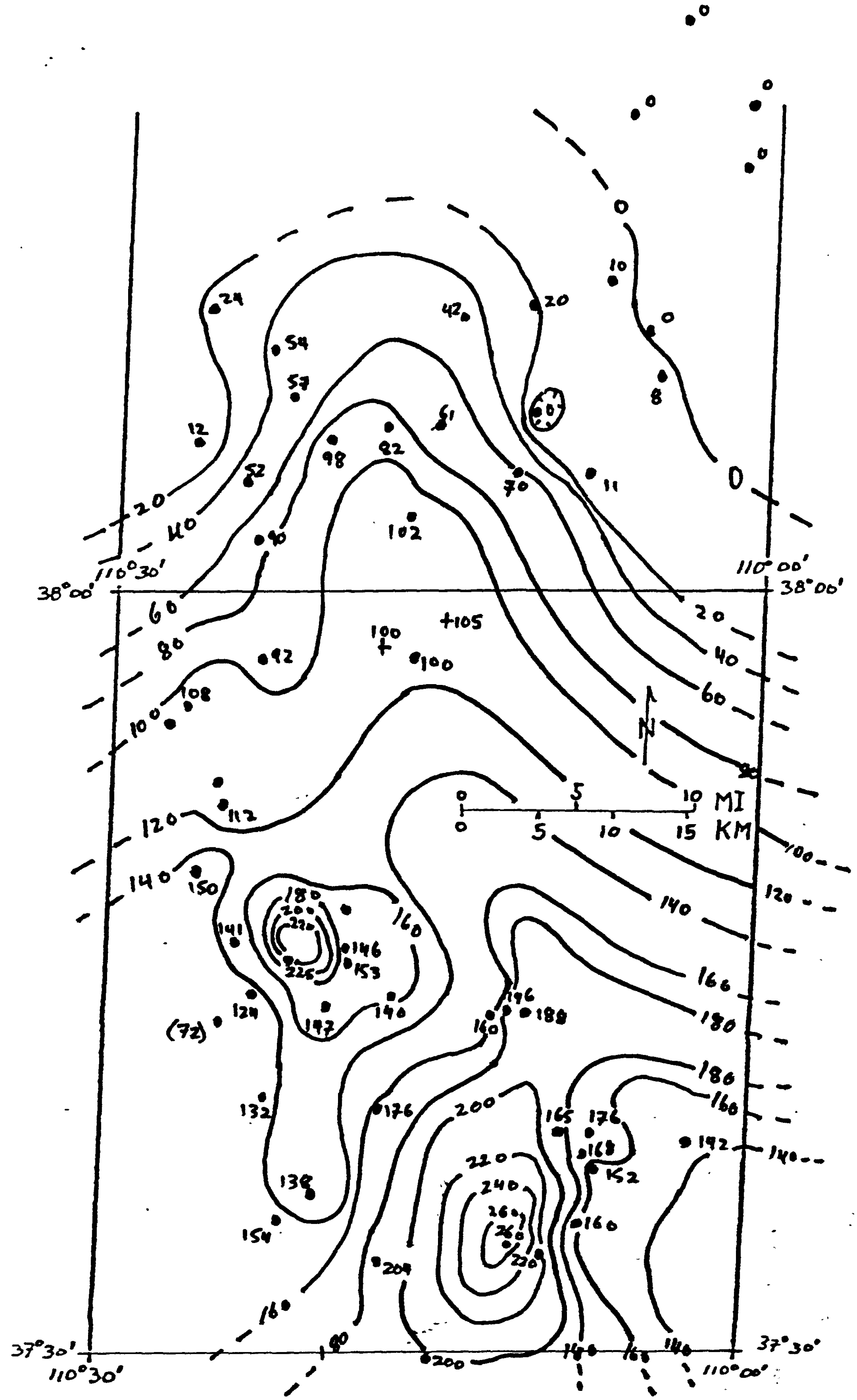

Figure 16.-- Isopach map of Monitor Butte Member. Dots represent location of measured sections, crosses represent observed section; thickness in feet . Contour interval 20 feet, dashed where inferred. The thickness in parentheses is minimum thickness as upper part of section is missing.

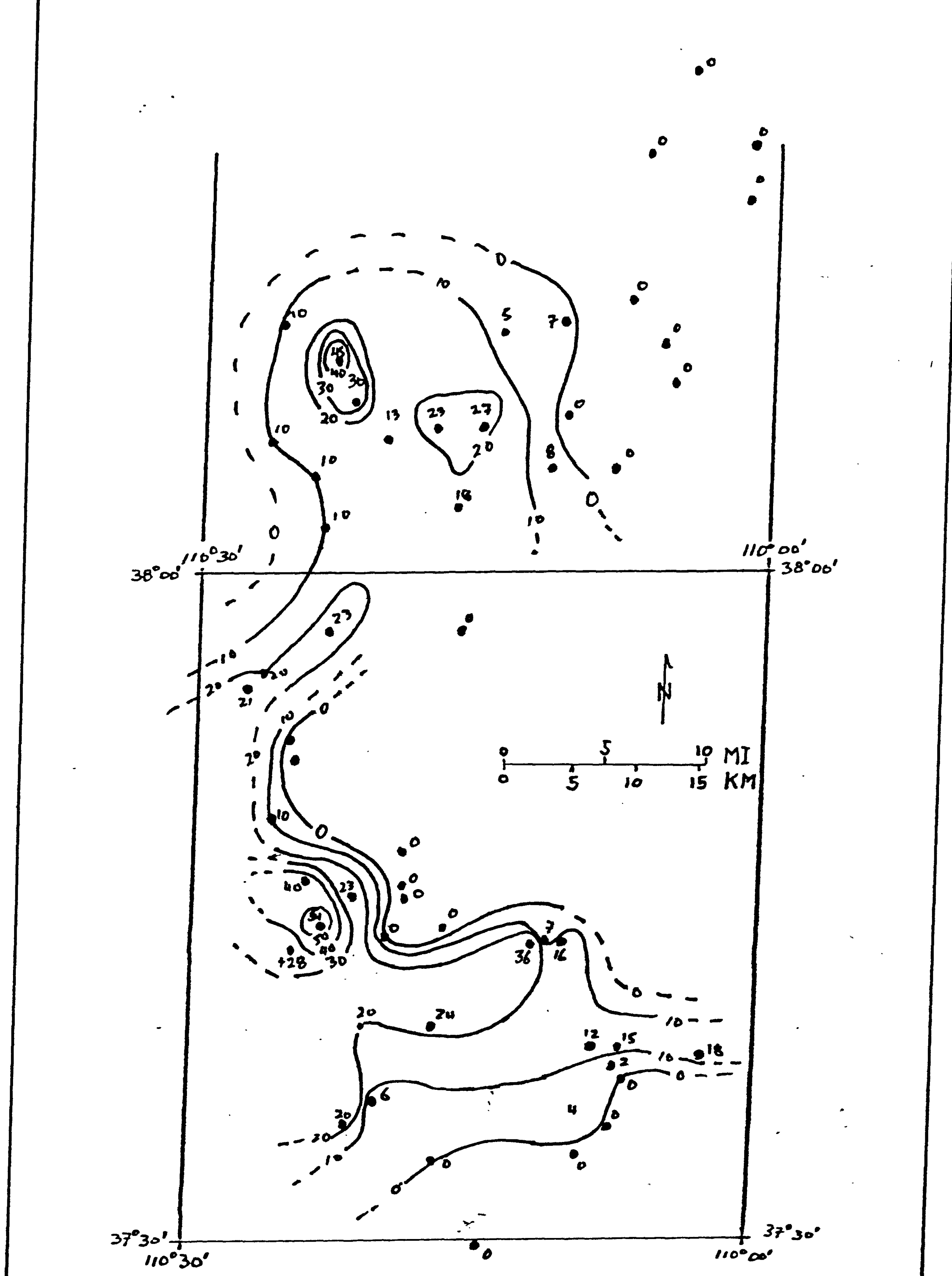

Figure 17.-- Isopach map of Monitor Butte Member fluvial sandstones. Dots represent location of measured sections, thickness in feet. Contour interval 10 feet, dashed where inferred.

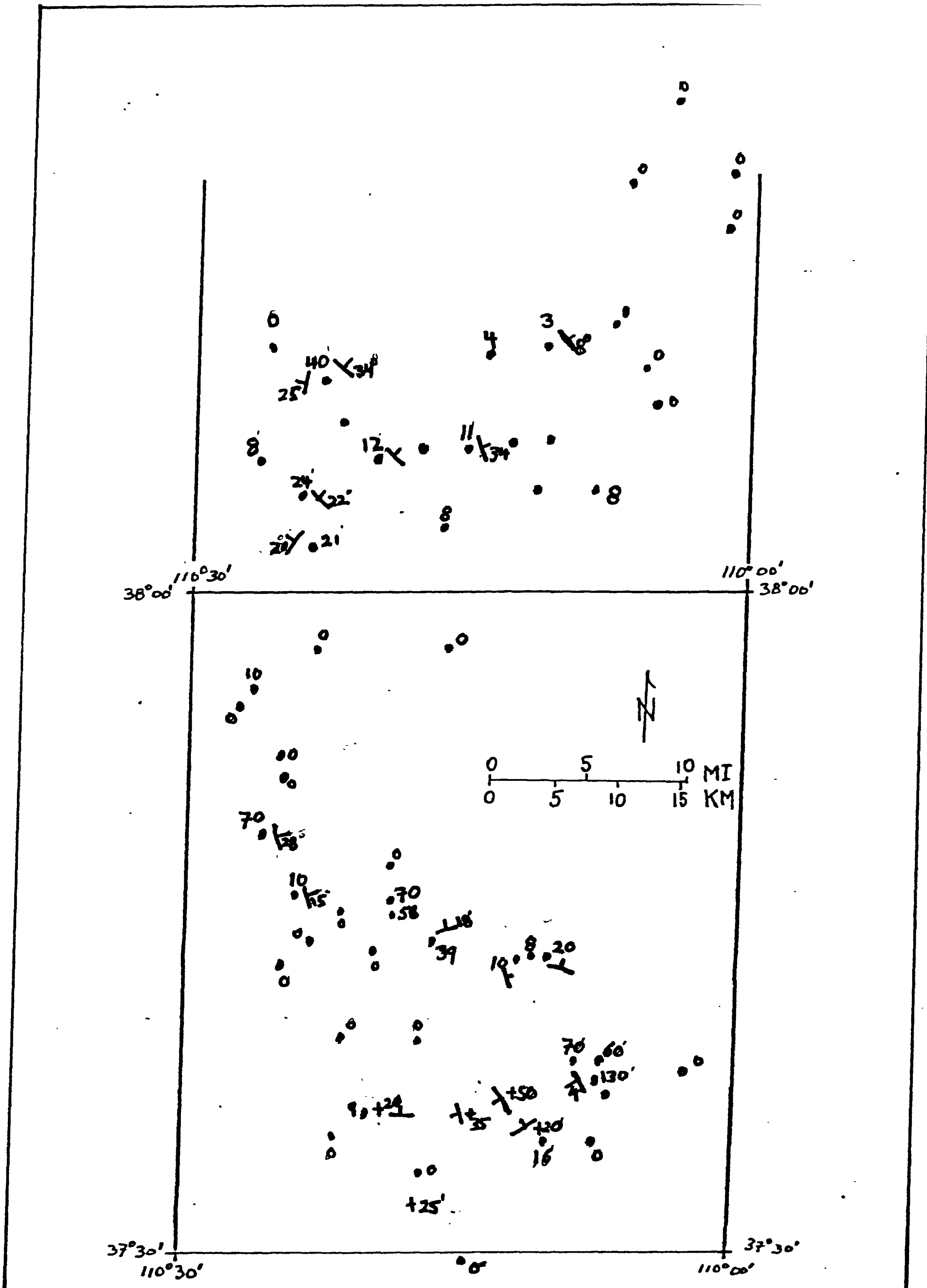

Figure 18.-- Isopach map of Monitor Butte Member deltaic sandstones. Dots represent location of measured sections, crosses represent observed sections; thickness in feet. Strike and dip of foresets as shown. Contours not shown due to discontinuous nature of delta lobes in outcrop.

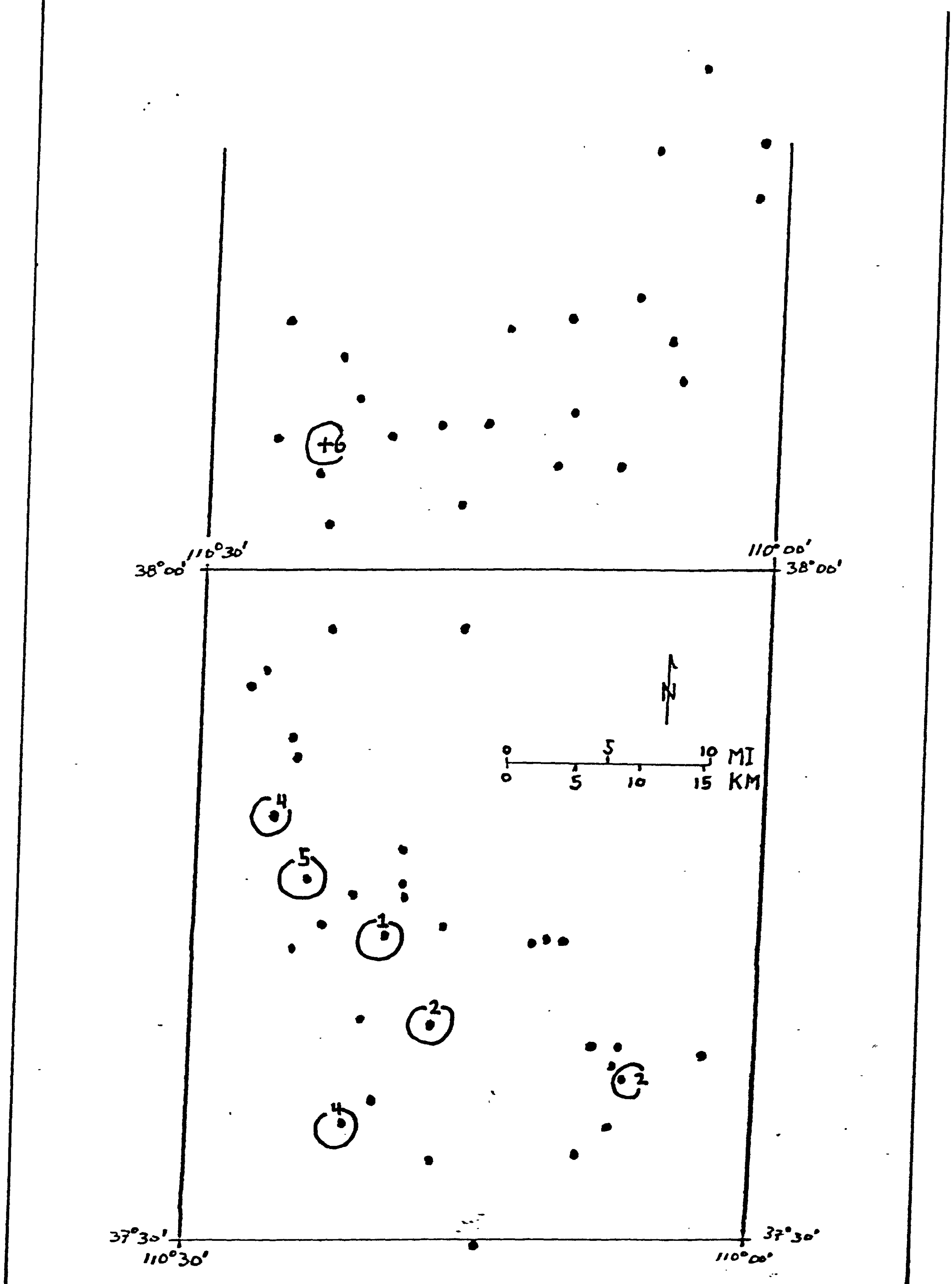

Figure 19.-- Isopach map of Monitor Butte Member limestones. Dots represent location of measured sections, crosses represent observed sections; thickness in feet. Contour line is schematic.

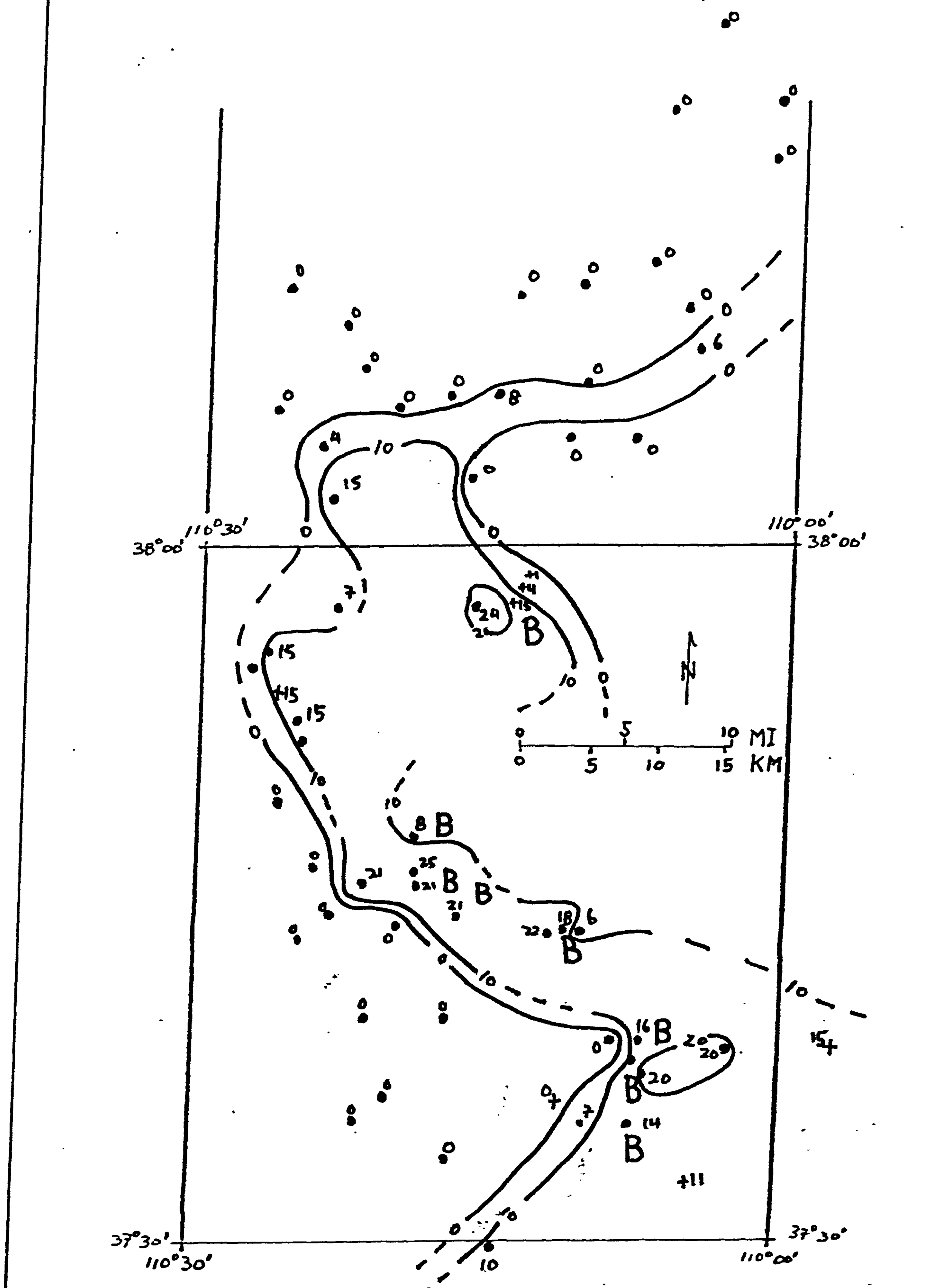

Figure 20.-- Isopach map of mottled units. Dots represent location of measured sections, crosses represent observed sections; thickness in feet. B shows location of large burrows described in text. Contour interval 10 feet.

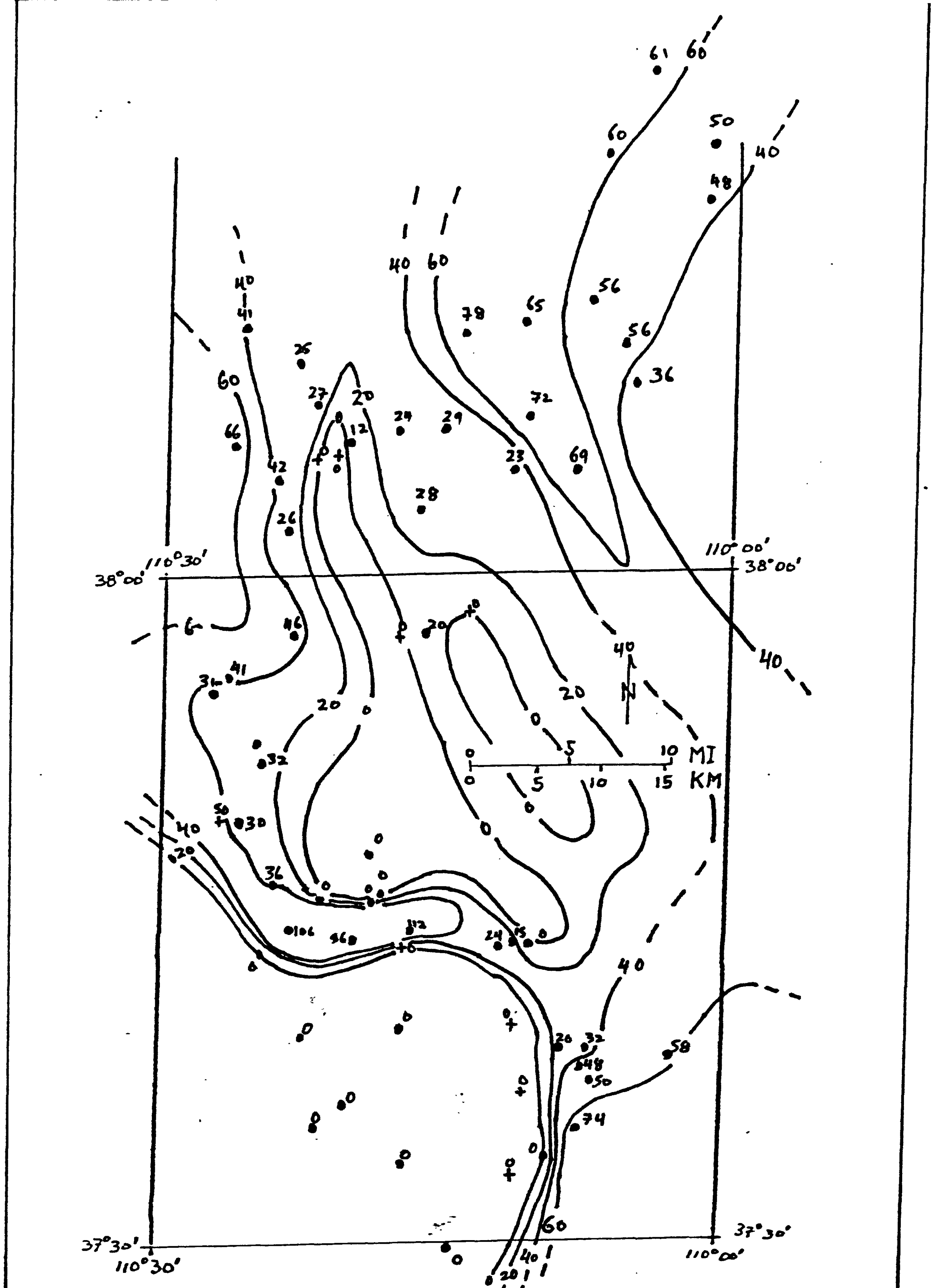

Figure 21.-- Isopach map of Moss Back Member. Dots represent location of measured sections, crosses represent observed sections; thickness in feet. Contour interval 20 feet.

these isopach thicks with the traces of modern structural synclines all indicate that Chinle sedimentation patterns in the three lower members were controlled by the growth of regionally downwarping basins, and that facies distribution within these basins was affected by the growth of smaller, active synclinal features.

DEPOSITIONAL HISTORY

A model for the depositional history of the lower part of the Chinle Formation in the White Canyon area must account for the varied lithologies and facies relationships of the units present as parts of fluvial-deltaic-lacustrine systems. Additionally, it must consider paleo-tectonics and also explain small-scale features present in the rocks, such as: forset-, cyclic-, and convoluted- bedding in deltaic deposits; the abundance of organic-rich lacustrine-marsh mudstone, which indicates a continually high water table; and poorly sorted, bioturbated sandstone, which indicates an environment conducive to large burrowing organisms. A five-stage model is presented to account for the regional distribution of sediment types and facies relationships.

The unconformity that is developed on fine-grained Moenkopi mudflat deposits suggests that a relative drop in sea level lowered the regional base level prior to Shinarump deposition. In response to lowered base level and steepened gradients, degrading streams eroded Moenkopi sediments and developed a topography with incised valleys. These stream courses may have been localized by small, developing synclines. The streams flowed into a basin to the west. Local base level rose along with lake level, producing a decrease in stream gradients, and causing aggrading Shinarump streams to deposit coarse-grained valley-fill on the Moenkopi topography (fig. 22). As streams continually supplied water to the lake basin to the west, lake level rose and transgressed to the east. Low areas in the valleys were filled with sediment, stream gradients continued to decrease and the streams deposited the upper unit of Shinarump sheet sands. During this initial stage, the rate of deposition (Rd) was less than the rate of subsidence (Rs)in the basin, or Rd/Rs <1.

There was a gradual transition to the next stage of development as continued sediment accumulation produced a low gradient floodplain. By the time of initial Monitor Butte deposition stream gradient had decreased to the point where meandering streams flowed on the floodplain. Rising and continually high water tables provided an anoxic environment that preserved thick accumulations of organic matter in marshes that developed adjacent to and overlying fluvial systems (fig. 23). Conchostracans flourished in the turbid marshes; their association with ostracodes in the Red Canyon sections indicates that the marsh environment graded to the west to an open, fresh water lake. The location of lakes and marshes was controlled by the active development of small, growing synclines. The large lake basin to the west continued to fill with water, transgressed to the east, and drowned the fluvial systems (fig.24). The drowned, coarse-grained fluvial sediment provided a stable substrate for large, burrowing organisms. The burrowing destroyed sedimentary structures and, with the transgression of lake water, produced mottling in the units. Limestone developed in clear, open lake water to the west that was removed from clastic input. During this stage, the rate of deposition (Rd) was much less than the rate of subsidence in the bain (Rs), or Rd/Rs<1. At least one major regression of the large lake is evidenced by

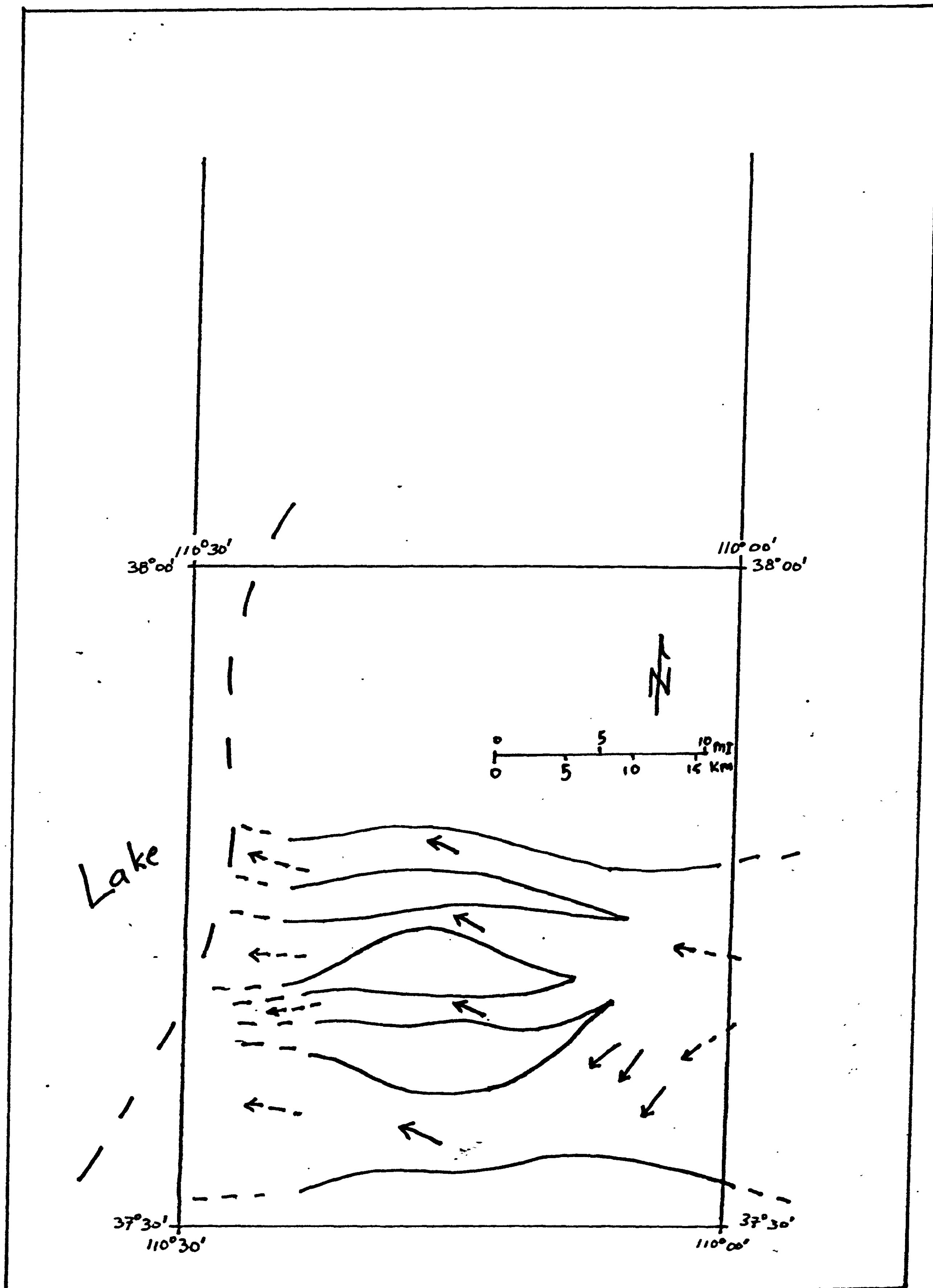

Figure 22.-- Depositional model, Shinarump time, showing fluvial system flowing in incised valleys toward large lake basin to the west. Paleocurrent measurements shown by arrw, dashed where inferred.

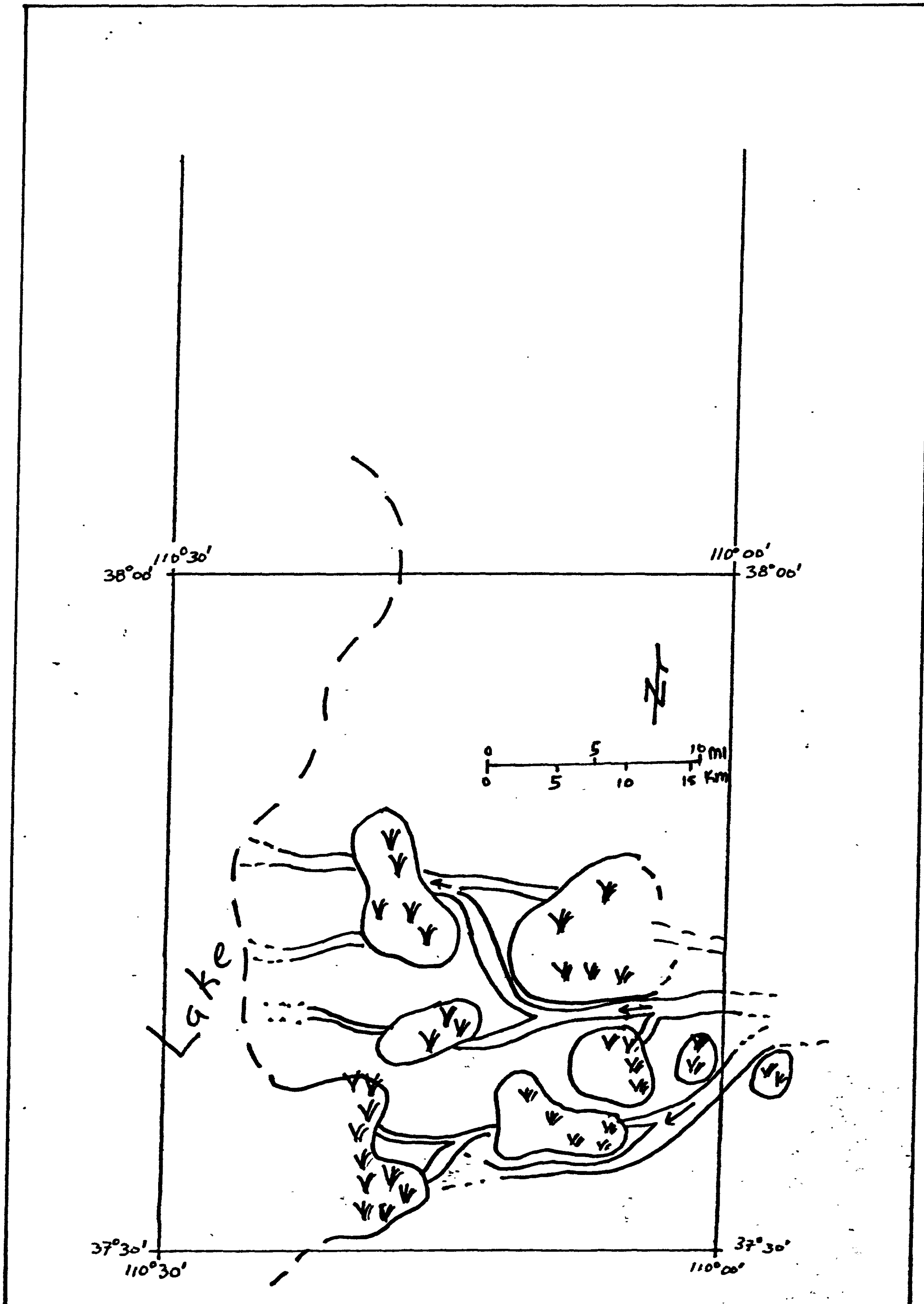

Figure 23.-- Depositional model, early Monitor Butte time, showing large lake that has transgressed east, meandering stream system, and lacustrine marshes.

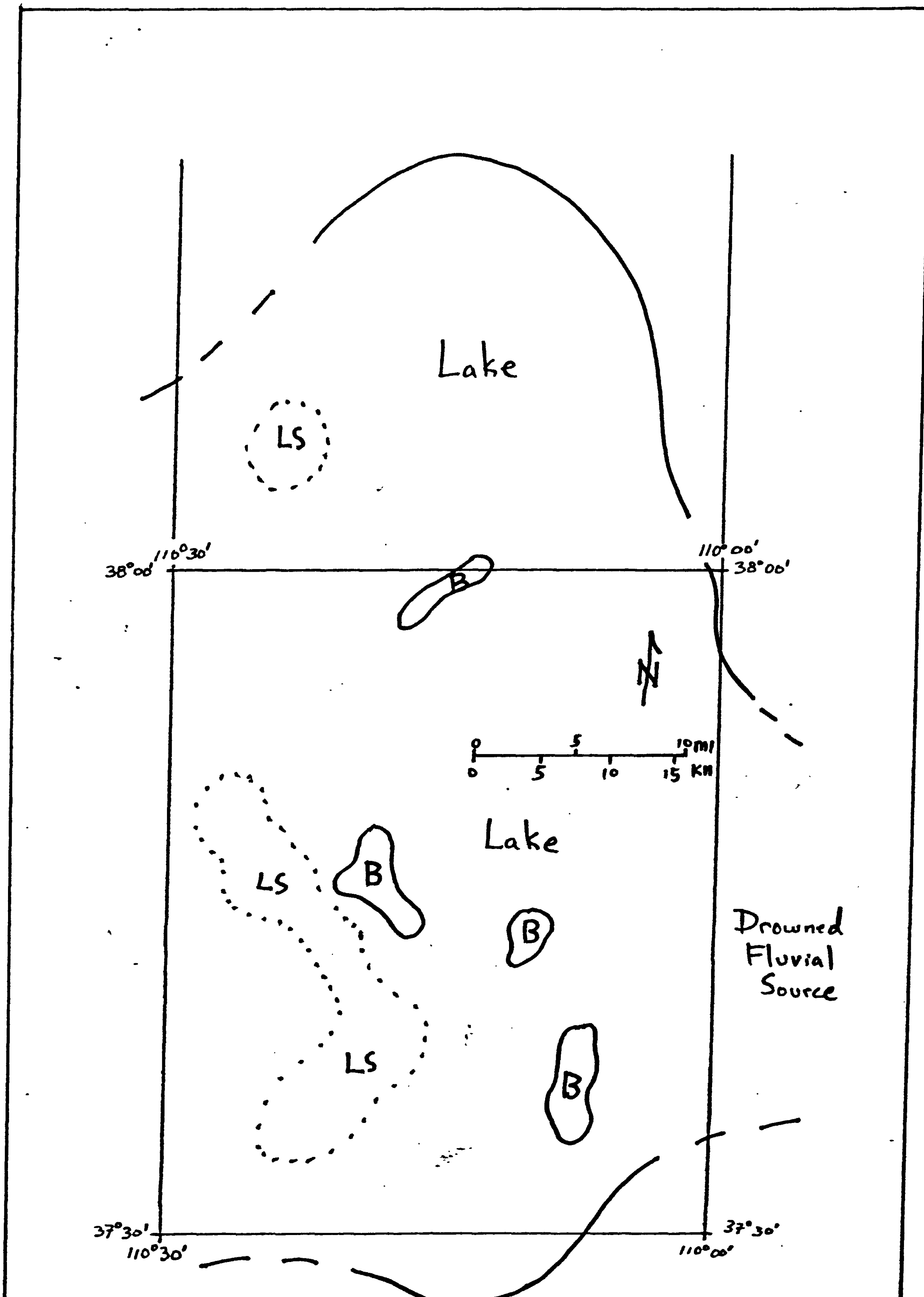

Figure 24.-- Depositional model, middle Monitoe Butte time, showing large lake that has transgressed east, drowning fluvial systems. LS represents limestone, B represents large burrows.

local diastems in the Monitor Butte, by deltaic deposits erosively overlying fine-grained, offshore mudstones, and by the presence of intraclast conglomerate lag deposits in Monitor Butte streams.

In the third stage of Monitor Butte deposition, the relative rate of deposition (Rd) increased to a point where it was roughly equal to, and slightly greater than the rate of subsidence (Rs), or Rd/Rs=1 (Curtis, 1970). River-dominated, cyclically-bedded, lobate deltas prograded out to the west at WCM, Jacob's Chair, Gonaway, and Apollo areas, their positions locally controlled by small growing synclines (fig. 25). Deltaic deposition was rapid, incorporating abundant detrital plant leaves and numerous organic fragments. The decay of organic matter, which was removed from oxygenated lake water, produced a large, reducing environment that preserved included flora. Rapid deposition, and oversteepening on delta fronts caused slumps, which produced contorted and convoluted Monitor Butte strata. Sediments that formed bentonitic, sandy mudstone were deposited in inter-deltaic bays and on mudflats removed from active deltaic sedimentation. Delta-plain meandering streams then cut into and eroded delta and delta-plain sediments producing local unconformities and diastems, and depositing intra-clast gravels. Deltaic sedimentation proceeded to the west and to the north. Foreset-bedded fan deltas built out at SR, HC, LP, SM, and NH1(fig. 3) in an elongate river-dominated delta.

In the last stage, the rate of subsidence in the basin (Rs) was much less than the rate of deposition (Rd) or Rd/Rs > 1 (Curtis, 1970). Cessation of basin subsidence allowed the braided Moss Back fluvial system (fig. 26) to advance and prograde northwest through the area subsequent to clastic infilling of the small basins. However, portions of the Moss Back fluvial system were apparently localized by active synclines. Clastic fluvial deposition and local erosion and reworking of Monitor Butte delta-plain sediments resulted in the braided stream fluvial deposits and intra-clast conglomerates now observed in the Moss Back. The regional water table dropped and caliche developed on subaerially exposed, oxidizing floodplains adjacent to the Moss Back fluvial system.

The overlying Petrified Forest Member comprises fine-grained calcareous sandstone, bentonitic mudstone, and limestone suggestive of another lacustrine expansion cycle that occurred in response to local basinal subsidence or expansion of a larger lacustrine system lying to the west of the study area. This sequence of events would correlate with that proposed by Gubitosa (1982) for the upper portion of the Chinle Formation to the northeast in the Moab area. Gubitosa proposed for the Petrified Forest, Owl Rock, and Church Rock Members, a sequence of events in which Moss Back fluvial systems flowing to the northwest were overlain by a lacustrine-deltaic depositional package, and then a progradational fluvial sequence. This sequence of events suggests that Chinle sedimentation in the Moab-White Canyon area could have formed in response to cyclic expansions of a large lacustrine system lying to the west in the Henry Basin.

URANIUM

Uranium ore deposits of the White Canyon district are generally restricted to basal Shinarump fluvial channel sandstones and are most often found in deeper channel scours associated with "carbon trash" pockets (Thaden

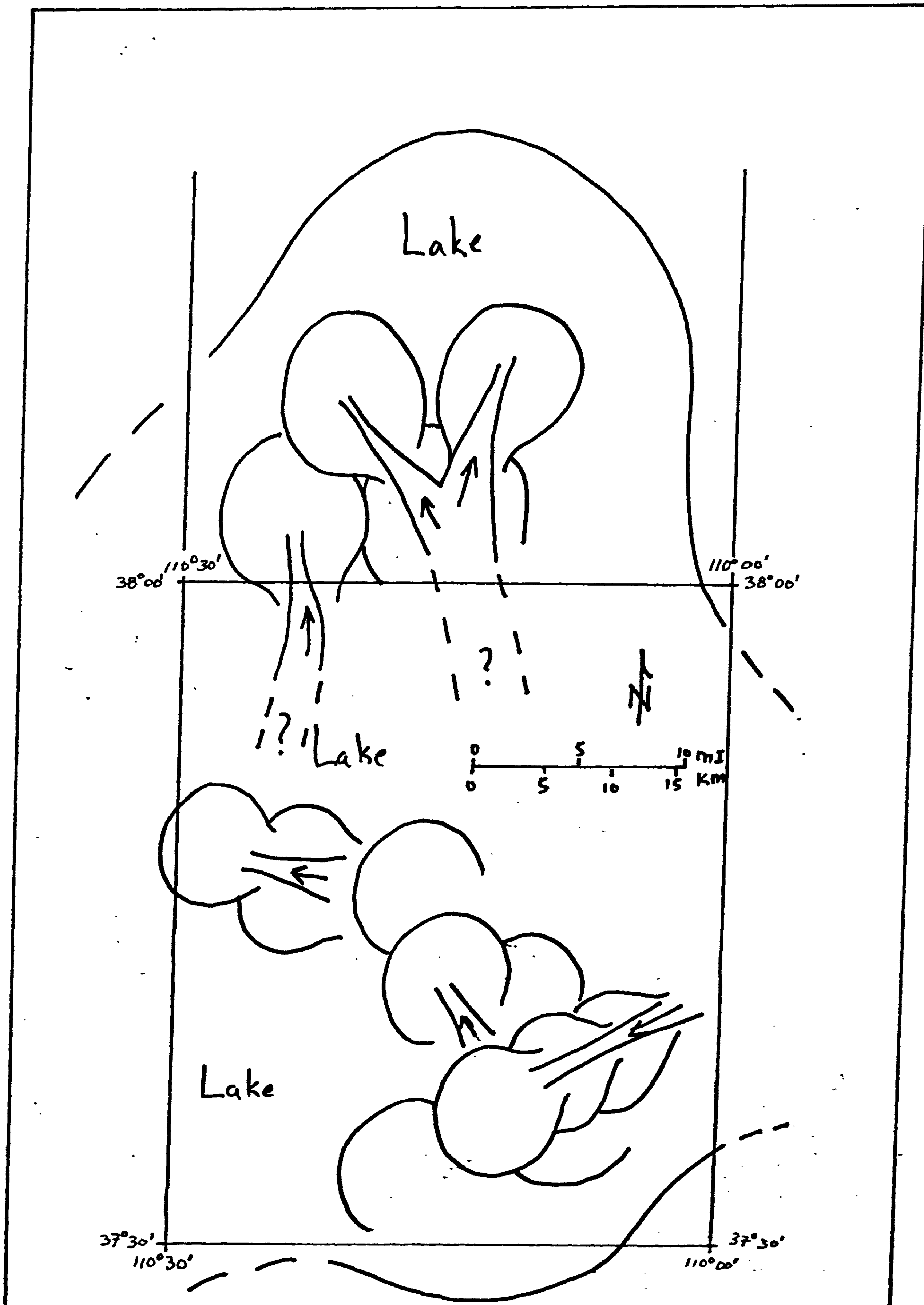

Figure 25.-- Depositional model, late Monitor Butte time, showing the large lake and delta distributary system with delta lobes. Progradation proceeded from east to west and from south to north.

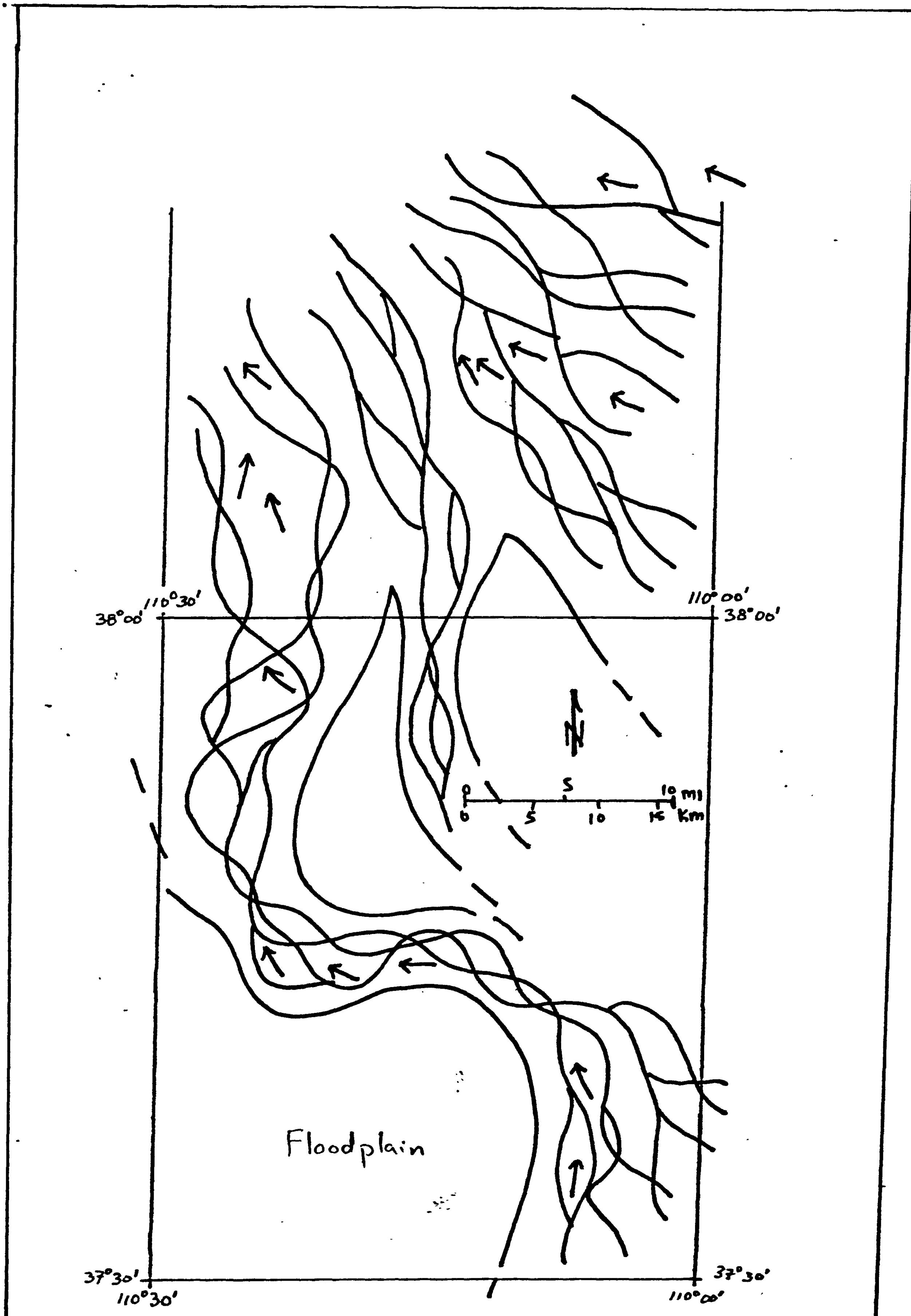

Figure 26.-- Depositional model, Moss Back time, showing braided fluvial system and exposed mudflats. Paleocurrent measurements shown by arrows.

and others, 1964). Uranium deposits in the Monument Valley district, which is directly south of the White Canyon district, occur in a similar association with Shinarump fluvial sandstones (Witkind & Thaden, 1963). In the Elk Ridge and Deer Flat areas (fig. 2), uranium deposits are also found in basal fluvial channel sandstones of the Monitor Butte Member where they lie in contact with the Moenkopi Formation (Lewis & Campbell, 1965).

Uranium occurrences examined in this study (fig. 27) occur in close spatial association with black, organic-rich, lacustrine-marsh mudstones (fig. 15). A comparison of the distribution of marsh-mudstone (fig. 15) and uranium occurrences (fig. 27) demonstrates that the marsh sediments overlie uranium deposits in host fluvial sandstones at every occurrence examined except at Jacob's Chair and the three occurrences north of the Colorado River. Black, organic-rich, lacustrine-marsh mudstones do occur only a few hundred feet (tens of meters) northeast of mineralized ground at Jacob's Chair; the three occurrences north of the Colorado River are associated with gray lacustrine mudstone that is commonly found lateral to or underlies the organic-rich mudstone in other areas. Deltaic deposits of the Monitor Butte Member (fig. 18) overlie the marsh mudstone at each uranium occurrence investigated. Uranium occurrences, then, are associated with black lacustrine-marsh mudstone where highly reducing conditions existed and also with deltaic deposits where rapid, clastic deposition covered abundant whole leaf specimens and organic plant fragments in a subaqueous quiet water environment. Rapid burial removed the organic matter from contact with oxygenated lake and river water and preserved the organic matter in an oxygen deficient environment. These anoxic environment facies are restricted to areas that appear to have been active, locally subsiding basins during Chinle deposition. The anoxic environment was not maintained everywhere as evidenced by red, calcareous and nodular-limestone mudstones that contain no leaf specimens and no fragmented organic matter. This suggests that sediments that formed the red mudstones were deposited under oxygenated conditions in which detrital organic matter was oxidized. Because a reducing environment was not preserved in the red sediments, these sediments were not conducive to localizing uranium.

Similar associations between reducing lake muds and uranium occurrences have been reported from other areas. Peterson (1980) demonstrates a relationship between uranium deposits in fluvial sandstone and gray carbonaceous lacustrine mudstone in the Salt Wash Member of the Morrison Formation (Upper Jurassic) in the Henry Basin of southern Utah. Turner-Peterson (1980) suggests an identical relationship in the Stockton and Lockatong Formations (Triassic) in the Newark Basin of Pennsylvania and New Jersey. In the Henry Basin, the mudstones tend to occur in depositional environments dominated by low-energy fluvial processes. Lupe (1977) also noted the relationship in the Chinle Formation between uranium occurrences and low-energy depositional environments lateral to Moss Back streams in the San Rafael Swell area, Utah.

Uranium occurrences in the White Canyon district are related to lacustrine environments associated with low-energy, fluvial and lacustrine depositional regimes in small subsiding basins. The accumulation of organic-rich lacustrine-marsh mudstone in small areas that had high watertables and were removed from clastic input provided a strongly reducing environment that protected organic matter from oxidation and may have controlled localization of uranium in underlying host fluvial sandstones. Additionally, deltaic

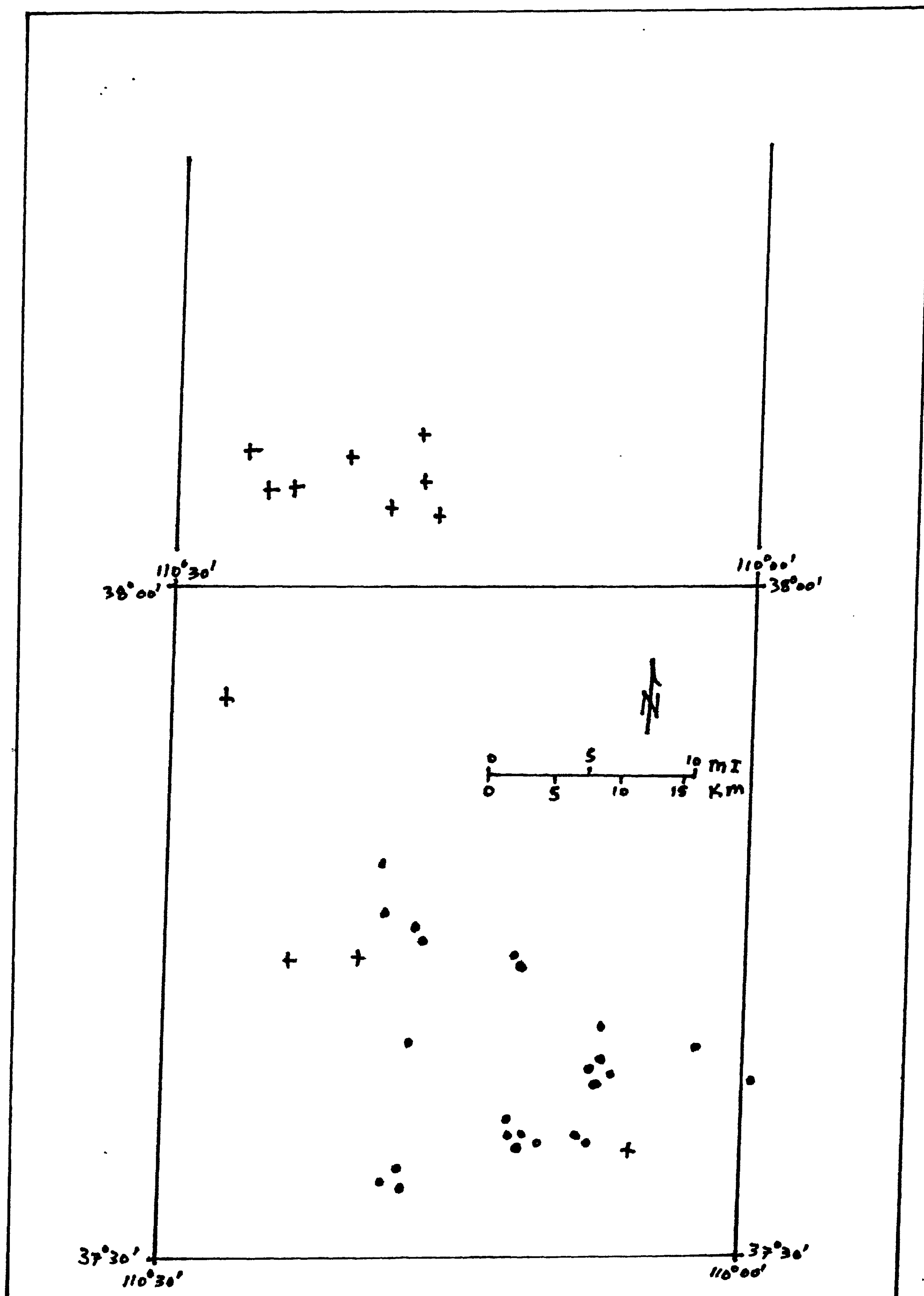

Figure 27.-- Location of uranium occurrences examined in the study area. Dots represent mines, crosses represent prospects and minor occurrences.

progradation over these areas during Monitor Butte time resulted in rapid clastic burial with the inclusion of abundant organic matter in the form of whole leaves and plant fragments that were effectively removed from interaction with aerated meteoric water and the effects of subsequent oxidation. The interstitial water in these marsh and delta enviroments developed reducing conditions when organic matter subaqueously decomposed. The resulting large reducing envelope, which encompasses the organic-rich mudstones and all of the uranium occurrences examined in the White Canyon district, may have provided the reducing environment necessary for uranium precipitation, as well as providing a reducing environment that protected organic-rich mudstones, carbon trash in sandstones, and uranium from possible regional oxidation at a later time. Peterson and Turner-Peterson (1980) proposed a model in which humic acids are squeezed from carbonaceous lacustrine mudstones under compaction into adjacent fluvial sandstones to provide the reducing environment necessary to precipitate and localize uranium. While this study demonstrates a similar facies relationship with associated uranium, the mere presence of a reducing environment in interstitial water of organic-rich lacustrine-marsh and deltaic sediments may have provided or helped to maintain the reducing environment necessary to localize uranium in underlying, porous, carbon trash-bearing fluvial host sandstones.

CONCLUSIONS

The lower part of the Chinle Formation in and around the White Canyon area of southeastern Utah comprises a succession of continental beds deposited in an essentially continuous depositional sequence. The coarse-grained sandstone and gray, carbonaceous mudstone of the Shinarump Member represent deposits of a valley-fill sequence deposited by streams that flowed into a large basin to the west and southwest. Paleostream directions were controlled by small structural synclines. Local downwarping caused a decrease in stream gradients, an expansion and transgression of the low-energy lacustrine environment, and a resulting eastward retreat of areas of fluvia sediment input. Subsequent progradation of Monitor Butte deltas filled in the basins and Moss Back braided streams advanced to the north and northwest over the area.

Localization of uranium in basal fluvial sandstones appears to be related to specific low-energy depositional environments. Ore-bearing sandstones are overlain by black, organic-rich mudstones deposited in lacustrine marshes with anoxic bottom conditions. These mudstones are overlain by green, carbonaceous deltaic deposits. Rapid deltaic sedimentation buried organic-rich delta sediments, interstitial water, and underlying units and effectively removed them from aerated meteoric water. This rapid burial inhibited the oxidation of organic matter. Thus, a reducing environment was preserved to localize subsequent uranium mineralization.

Complex interfingering of units in the Chinle Formation and rapid lateral facies changes over small distances necessitates closely spaced measured sections and detailed small-scale stratigraphic investigations to delineate and interpret depositional environments and their relationship to mineralization. Vertical and lateral lithofacies relationships permit an interpretation of depositional environments consistent with outcrop observation. The fact that uranium consistently occurs in the same stratigraphic setting supports the conclusion that specific depositional environments can control ore localization, deposition, and preservation. However, the complexity of the depositional system in the study area precludes an extension of the model into other areas without a similar detailed study.

ACKNOWLEDGMENTS

The author would like to express his gratitude to Allan Kirk, James Otton, and Jennie Ridgley for reviewing early drafts of this manuscript.

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