DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

Stratigraphic and Sedimentologic Studies of the Twowells Tongue of the Dakota Sandstone, Southern San Juan Basin, New Mexico

by

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INTRODUCTION

The Dakota Sandstone is a time transgressive, lithologically heterogenous formation which was deposited in and adjacent to the Cretaceous seaway of the Western Interior throughout the present-day Colorado Plateau, Rocky Mountain, and Great Plains regions. In the San Juan Basin, the Dakota is of Cenomanian age and it crops out discontinuously around the margins of the basin (fig. 1). The Twowells Tongue, the uppermost of five members of the Dakota Sandstone, is composed of fine to medium-grained sandstone, silty sandstone, and minor conglomeratic sandstone, and it contains sedimentary structures and ichnofossils characteristic of deposition on a shallow epicontinental shelf. This tongue is well exposed along the southern, eastern, and western margins of the San Juan Basin.

PURPOSE AND METHODS

This study was conducted to determine the depositional history of the Twowells Tongue in the southern part of the San Juan Basin. This report presents the data as columnar measured stratigraphic sections, and includes the results of field research during the summers of 1987 and 1988. Brief interpretations are offered at the conclusion of this report; comprehensive interpretations will be included in a future report.

Sections were measured and described between the top of the Oak Canyon Member of the Dakota Sandstone or the top of the main body of the Dakota Sandstone (depending on the locality of the measured section) and the top of the Twowells Tongue at 11 localities within and 2 localities outside the study area (figs. 2 and 3). Only the Twowells Tongue of the Dakota Sandstone and the Whitewater Arroyo Tongue of the Mancos Shale are shown in the columnar measured sections of figures 6 through 18. Distances between measured sections within the study area range from 3 to 30 miles (5-48 km). Sections were measured with a Jacob Staff, an Abney level, and a tape.

GEOLOGIC SETTING

During early Late Cretaceous (Cenomanian) time, the Dakota Sandstone and Mancos Shale were deposited in the Western Interior seaway. This epeiric seaway bisected North America and, at maximum development, extended from Arctic Canada to the Gulf of Mexico (Kauffman, 1977). The Dakota Sandstone and lower part of the Mancos Shale record the first of a number of major transgressive-regressive cycles that occurred during Late Cretaceous time throughout the southern Colorado plateau and adjacent areas (Molenaar, 1983). The present structure of the San Juan Basin was subsequently formed by Laramide tectonic activity during Late Cretaceous and early Tertiary time (Molenaar, 1983). The original extent of Tertiary deposits in the area is unknown since nearly all of these strata have been removed by erosion.

PREVIOUS WORK

Many reports and maps have been published concerning the Dakota Sandstone in the San Juan basin, but few of them pertain to the Twowells Tongue. Landis, Dane, and Cobban (1973) formally named and described the intertonguing members of the Dakota Sandstone and Mancos Shale that form the basal Cretaceous sequence in the southern part of the San Juan Basin. Dane (1960) correlated the Dakota Sandstone and Mancos Shale of the northeastern part of the San Juan Basin with equivalent beds in the southern part of the basin. McPeek (1965) also described the stratigraphy of the Dakota in the northeast part of the basin. Owen (1966, 1973) and Owen and Seimers (1977) further refined the stratigraphy of the Dakota Sandstone in the eastern part of the basin. Cobban (1977) and Hook and Cobban (1977) described fossil mollusks found in each tongue of the Dakota-Mancos interval in the San Juan Basin. Cobban and Hook (1984) biostratigraphically interpreted the paleogeography of the Four Corners area during deposition of the Dakota and Mancos.

Several unpublished masters' theses have dealt more specifically with environmental interpretations of the Twowells Tongue of the Dakota Sandstone. Wolter (1987) interpreted the depositional history of the Twowells Tongue regionally. Noon (1980) interpreted the depositional environments of the Twowells Tongue on the eastern side of the San Juan Basin, and West (1984) proposed some preliminary interpretations on the western side of the basin.

STRATIGRAPHY

In the southern, eastern, and western parts of the San Juan Basin, the Dakota Sandstone unconformably overlies the Jurassic Morrison Formation. In the northern part of the basin, the Dakota Sandstone overlies the Lower Cretaceous Burro Canyon Formation. Throughout the basin, the Dakota intertongues with the overlying Mancos Shale.

In the study area, the Dakota Sandstone is divided into five formal members or tongues separated by two tongues of the lower Mancos Shale. In ascending order, the members of both formations are the Encinal Canyon Member (Aubrey, 1988), the Oak Canyon Member, and the Cubero Tongue of the Dakota Sandstone; the Clay Mesa Tongue of the Mancos Shale; the Paguate Tongue of the Dakota Sandstone; the Whitewater Arroyo Tongue of the Mancos Shale; and the Twowells Tongue of the Dakota Sandstone (Landis and others, 1973) (fig. 3). The term "main body" of the Dakota Sandstone is informally used in this report to indicate the lower part of the Dakota Sandstone in the western half of the study area where the Oak Canyon Member, the Cubero Tongue, and the Paguate Tongue are not distinguishable (fig. 3).

Thickness of the Dakota-Mancos interval in the study area ranges from 410 ft (125 m) near Laguna, where all tongues are present and well developed, to approximately 220 ft (67 m) near Gallup, where only the main body of the Dakota Sandstone, the Whitewater Arroyo Tongue of the Mancos Shale, and the Twowells Tongue of the Dakota Sandstone are present.

Marine fossils from the southeast part of the San Juan Basin indicate an early Cenomanian (earliest Late Cretaceous) age for the lowest part of the Dakota Sandstone (Molenaar, 1977). Ammonites, gastropods, and bivalves indicate a middle Cenomanian age for the Cubero, Clay Mesa, and Paguate Tongues (Cobban, 1977). Ammonites, gastropods, and bivalves indicate a late Cenomanian age for the Whitewater Arroyo Tongue and the Twowells Tongue (Cobban, 1977).

The Encinal Canyon Member of the Dakota Sandstone is a fine- to medium-grained, cross-stratified sandstone, commonly conglomeratic at the base, that is present locally within the study area (Aubrey, 1988). It is generally trough crossbedded and was deposited in a fluvial environment (Aubrey, 1988). Thickness of the Encinal Canyon in the southern part of the San Juan Basin ranges from 0-70 ft (0-21 m)(Aubrey, 1988).

The Oak Canyon Member of the Dakota Sandstone is informally divided into upper and lower units by Landis and others (1973). The lower unit consists of very fine grained to coarse-grained sandstone and carbonaceous shale. Landis and others (1973) interpret the depositional environment of the lower unit as fluviatile to paralic. The upper unit of the Oak Canyon Member consists mostly of shale and siltstone, which accumulated mainly in an open-marine environment (Landis and others, 1973). The Oak Canyon Member joins the Cubero Tongue to form the main body of the Dakota Sandstone a few miles west of Grants along a line trending roughly northeast (Landis and others, 1973) (fig. 3). Thickness of the Oak Canyon in the study area ranges from 72-92 ft (22-28 m) (Landis and others, 1973).

The Cubero Tongue of the Dakota Sandstone consists of mostly very fine to fine-grained sandstone; carbonaceous siltstone and shale locally comprise about 25 percent of the tongue (Landis and others, 1973). The Cubero Tongue, which has a gradational base and a sharp unconformable top, is interpreted to be a shoreline-connected, shallow-marine, shelf sandstone. It reflects deposition of coarsening-upward sediments in a shallowing sea (Landis and others, 1973). Thickness of the Cubero Tongue in the study area increases from 50 ft (15 m) in the Laguna area to about 60 ft (18 m) in the Grants area before merging into the main body to the west (Landis and others, 1973).

The lithologies of the Paguate and Cubero Tongues of the Dakota Sandstone are similar. The Paguate consists of very fine to fine-grained and minor medium-grained sandstone, and minor interbedded siltstone. Brown calcareous concretions are common (Landis and others, 1973). This tongue has a gradational base and a relatively sharp upper contact that possibly is a disconformity (Landis and others, 1973). The Paguate Tongue is also shoreline-connected and reflects an overall regressional marine sequence that is coarsening upward (Landis and others, 1973). Thickness of the Paguate Tongue in the study area is approximately 60 ft (18 m). It presumaby thickens slightly to the west and merges into the main body of the Dakota Sandstone about 12 miles west of Grants (Landis and others, 1973).

The Clay Mesa Tongue of the Mancos Shale overlies the Cubero Tongue of the Dakota Sandstone, and the Whitewater Arroyo Tongue of the Mancos Shale overlies the Paguate Tongue of the Dakota Sandstone (fig. 3). These tongues of the Mancos are lithologically very similar and are therefore described together. Both consist of dark-gray shale, local bentonite beds, and calcareous concretions. The composition of each tongue becomes siltier and sandier upward, reflecting a shallowing of the sea and/or a prograding shoreline. Both reflect deposition in a quiet, shallow-water, marine-shelf environment (Landis and others, 1973; Owens and Seimer, 1977). Thickness of the Clay Mesa Tongue increases from about 50 ft (15 m) near Grants to 70 ft (21 m) near Laguna. Thickness of the Whitewater Arroyo Tongue ranges from 30 ft to 117 ft (9 m to 36 m) (fig. 4).

The Twowells Tongue of the Dakota Sandstone consists predominantly of very fine to medium-grained sandstone, very silty sandstone, and minor conglomeratic sandstone. It commonly contains a few scattered pebbles. Detailed columnar measured sections of the Twowells Tongue are presented in figures 5-18. The Twowells Tongue differs from the Paguate and Cubero Tongues in that it is more extensive and not shoreline-connected in the study area; it is also more glauconitic, generally coarser grained, and commonly contains crossbedding. The Twowells Tongue generally grades into the underlying Whitewater Arroyo Tongue of the Mancos Shale and is sharply overlain by the Graneros Shale Member of the Mancos Shale.

The Twowells Tongue is fossiliferous at many locations. Collections of the U.S. Geological Survey include 21 species of bivalves, 2 species of gastropods, and 5 species of ammonites (Cobban, 1977). The most common bivalve is Pycnodonte aff. P. kellumi (Jones), known previously by Landis and others (1973) as "Gryphaea newberryi".

Another biostratigraphically important, slightly younger, bivalve is Pcynodonte newberryi, which occurs only at the top of the Twowells Tongue and extends into the lower part of the Mancos Shale (Hook and Cobban, 1977). Other fossils commonly found in the Twowells are documented by Cobban (1977).

The Twowells Tongue in the study area ranges in thickness from less than 15 ft (5 m) several miles east of the Casamero Lake section to 98 ft (30 m) at the McCartys RR section (fig. 4).

On the eastern flank of the San Juan Basin, outside the study area, the Twowells Tongue thins rapidly to the north from the L-Bar Mine section, becomes discontinuous, and is absent about 5-10 miles (8-16 km) southeast of La Ventana (Owen and Seimers, 1977; Noon, 1980). The Twowells Tongue extends southward from Laguna to at least the Alamo Day School section (sec. 13, T. 3 N., R. 7 W., fig. 1) (Landis and others, 1973) near the Rio Salado River. On the southwest side of the basin, the Twowells extends at least as far south as the Atarque section (sec. 6, 7, and 18, T. 6 N., R. 17 W., fig. 1) (West, 1984), where about 5 ft (2 m) of Twowells Tongue was measured. Landis and others (1973) and Molenaar (1977) reported that the Twowells Tongue merges with the main body of the Dakota Sandstone near Window Rock, Arizona, which is west of the western edge of the basin. This is consistent with the findings of this study.

SEDIMENTOLOGY

The Twowells Tongue of the Dakota Sandstone is predominantly yellowish-gray to yellowish-orange, partly silty, very fine to medium-grained to minor coarse-grained sandstone that may contain scattered pebbles and minor conglomerate. In the study area, it ranges in thickness from less than 15 ft to 98 ft (5-30 m). Columnar stratigraphic sections measured for this study are shown in figures 6 through 18; figure 5 is an explanation of the symbols used in these figures.

Four different lithofacies of the Twowells have been identified on the basis of lithology, sedimentary structures, and biogenic structures. They are:

1) very silty sandstone facies
2) horizontal-bedded sandstone facies
3) bioturbated structureless sandstone facies
4) crossbedded sandstone facies

The very silty sandstone facies consists of very fine to fine-grained sandstone with large amounts of silt and clay intermixed. Grains are well-rounded to subrounded. Locally, minor siltstone laminae and less silty sandstone layers are interbedded with the very silty sandstone. The facies is bioturbated throughout and curved clay blebs occur where the sediment has been churned. If bedding is visible, it is slightly undulatory or rippled. Veins and coatings of gypsum are common, and some cleaner sandstone layers are tightly cemented by calcite. Concretions 1-2 ft (0.3-0.6 m) in diameter are locally present as are clay pebbles. Layers of shell lag and fragments of the bivalve Pinna petrina are in the cleaner sandstone layers; small white bivalves approximately one centimeter in diameter occur in the very silty beds of this facies.

The very silty sandstone facies was deposited by suspended sediment flows on a low-energy shelf. Infrequent, distal, storm currents probably transported sediment which was then churned by sediment-feeding organisms (Wolter, 1987). The cleaner sandstone layers in this facies represent an environment of slightly higher energy than that of the enclosing silty sandstone. This interpretation is supported by the evidence of transported shell deposits.

The horizontal-bedded sandstone facies, commonly overlying the very silty sandstone facies, is dominantly very fine to fine-grained sandstone. The constituent grains are well rounded to subangular and well sorted, and they include minor medium grains. The sandstone ranges from silty to very clean. This facies is mostly laminaed to thick bedded, as much as 3 ft (1 m) thick, and includes low-angle or hummocky crossbedding. Scour surfaces, soft sediment deformation (fig. 9), and sand rolls (fig. 12) have also been observed in this facies. Ophiomorpha are common; these and other burrows are vertical, horizontal, oblique, and curving and have hardened iron-stained edges. Bedding surfaces typically display abundant horizontal burrows. Sparse curved blebs of clay in these rocks indicate a type of bioturbation that is most common in the very silty sandstone facies. Calcareous concretions and layers were found in several outcrops. The sandstone in this facies tends to be more calcareous than the sandstone in the very silty sandstone facies. Fossils in this facies include fragments of Pinna petrina and the bivalve Pycnodonte sp. which occur individually or in lag deposits.

The horizontal-bedded facies was deposited probably by decelerating storm currents. It contains larger grains and less silt and clay than the very silty sandstone facies, indicating stronger currents and higher rates of sedimentation. The laminae are less burrowed than the thick beds. Hummocky crossbedding in this facies indicates a depositional setting similar to lower shoreface environments. The sand rolls probably develop when massive, structureless bodies of sand liquify beneath thinly laminated, rapidly deposited sand. The laminated sand then sinks and forms sand rolls.

The bioturbated, structureless facies consists of very fine to fine-grained, fairly clean and moderately well-sorted, structureless sandstone and minor layers of very hard, calcareous sandstone. The sand grains are well rounded to subrounded. Whether the layers of hard, calcareous sandstone are primary bedding features or tightly cemented zones was not determined. Burrows are most abundant in this facies and all traces of bedding are obliterated. Burrows occur at all attitudes, but most of the facies is completely bioturbated. Rare star-shaped ichnofossils were observed but not identified. Fossil bivalves occur in the sandstone both individually and in shell lag layers. Sand rolls are found at the top of this facies, and mud chips were observed in this unit at the Fallen Timber Ridge section (fig. 9).

The bioturbated structureless facies could have been deposited in an environment similar to that of the horizontal-bedded facies, but the bioturbation that accompanied either infrequent rapid deposition or continuous, slow deposition eliminated all stratification.

The crossbedded sandstone facies is characteristically composed of fine to medium- or even coarse-grained, clean, quartzose sandstone that is well sorted. Basal scours are common in these rocks. Bedding types, in order of decreasing frequency, include low- to high-angle opposing tabular tangential crossbeds, low- to high-angle unidirectional tabular tangential crossbeds, tabular planar crossbeds, thin to thick bioturbated layers without internal bedding, small- to large-scale single trough crossbeds, small- to large-scale rippled beds, herringbone or chevron beds, overturned crossbeds, and mud drapes that usually overlie rippled surfaces. Rare interbeds of pebble-conglomerate are horizontal bedded or tangential crossbedded; isolated pebbles commonly occur in fine- to medium-grained, crossbedded sandstone. Layers of shell are rare and burrows of every orientation are sparse to abundant. Common trace fossils include <u>Ophiomorpha</u>, <u>Thalassinoides</u>, and <u>Planolites</u>.

The crossbedded facies is most common in the eastern half of the study area. It was deposited probably by storm currents flowing from the north (Wolter, 1987). The overturned crossbeds developed when rapidly deposited crossbedded sand was sheared by subsequent, high-velocity, storm currents (Wolter, 1987). Certain outcrops, such as the McCartys RR section (fig. 13), contain mud drapes and herringbone crossbedding and apparently were affected by tides (Wolter, 1987).

CONCLUSION

The four defined lithofacies of the Twowells Tongue formed under a wide range of energy conditions. The areal distribution of these facies suggests that the depositional environments varied significantly from west to east. Wolter (1987) believes that the Twowells Tongue west of Grants is a "blanket sandstone," inferred to be a storm-dominated, continuous shoreface deposit; and that the blanket sandstone east of Grants (similar to the Laguna section, fig. 15) was deposited as plume sands by coastal currents flowing southward from a headland or delta complex located in the Four Corners area. Tidal currents that produced beds similar to those in the McCartys RR section (fig. 13) probably created a sand ridge that was protected from currents of the open shelf by the Four Corners Headland (Wolter, 1987). The author believes that Wolter's theories are applicable but need confirmation. It can be stated with certainty that the lithofacies of the Twowells are similar to deposits of both shoreface and offshore-marine environments and indicate a complex depositional history.

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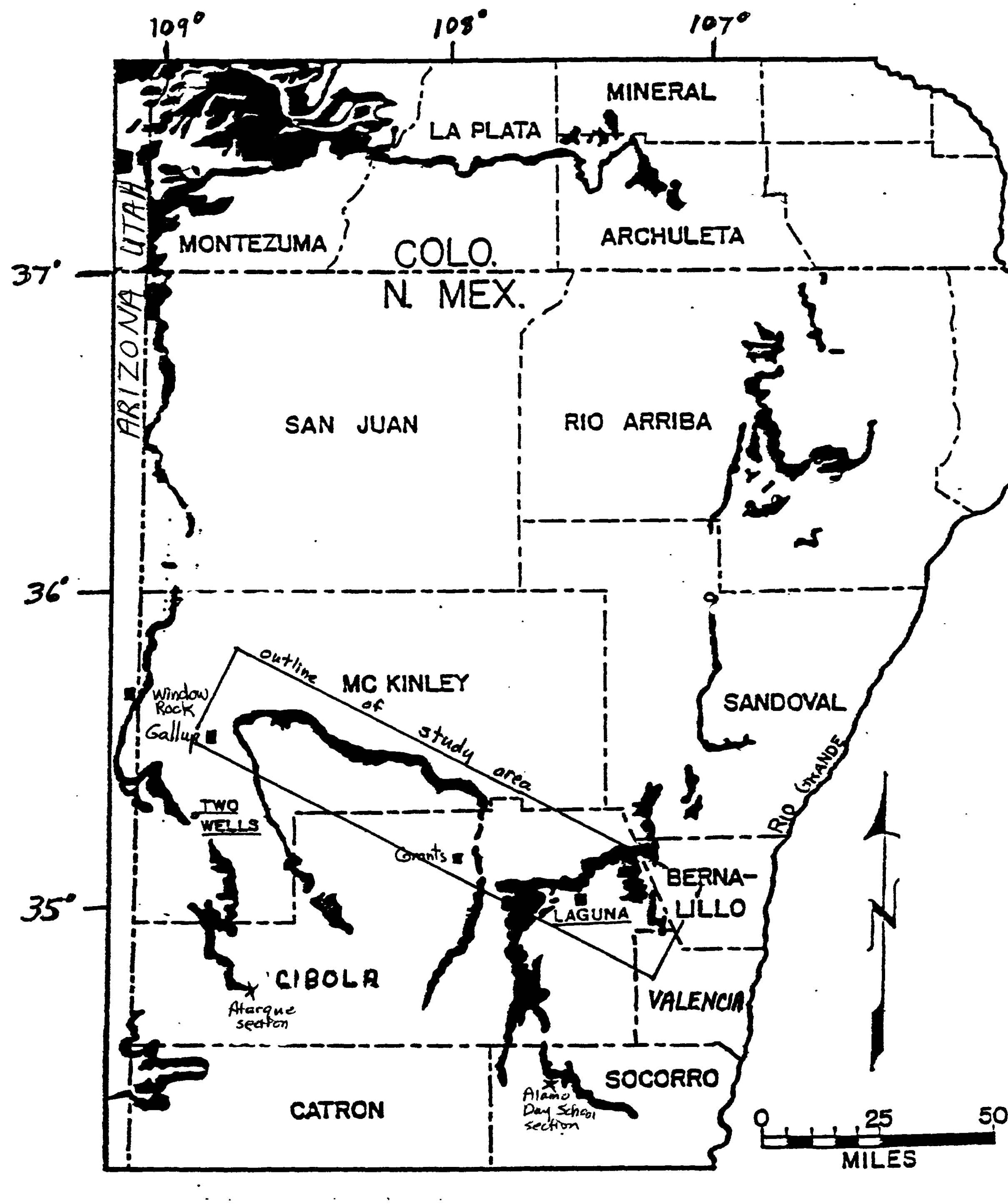


Figure 1 - Map of the San Juan Basin showing outcrops (black) of the Dakota Sandstone and an outline of the study area (modified from Owen, 1966).

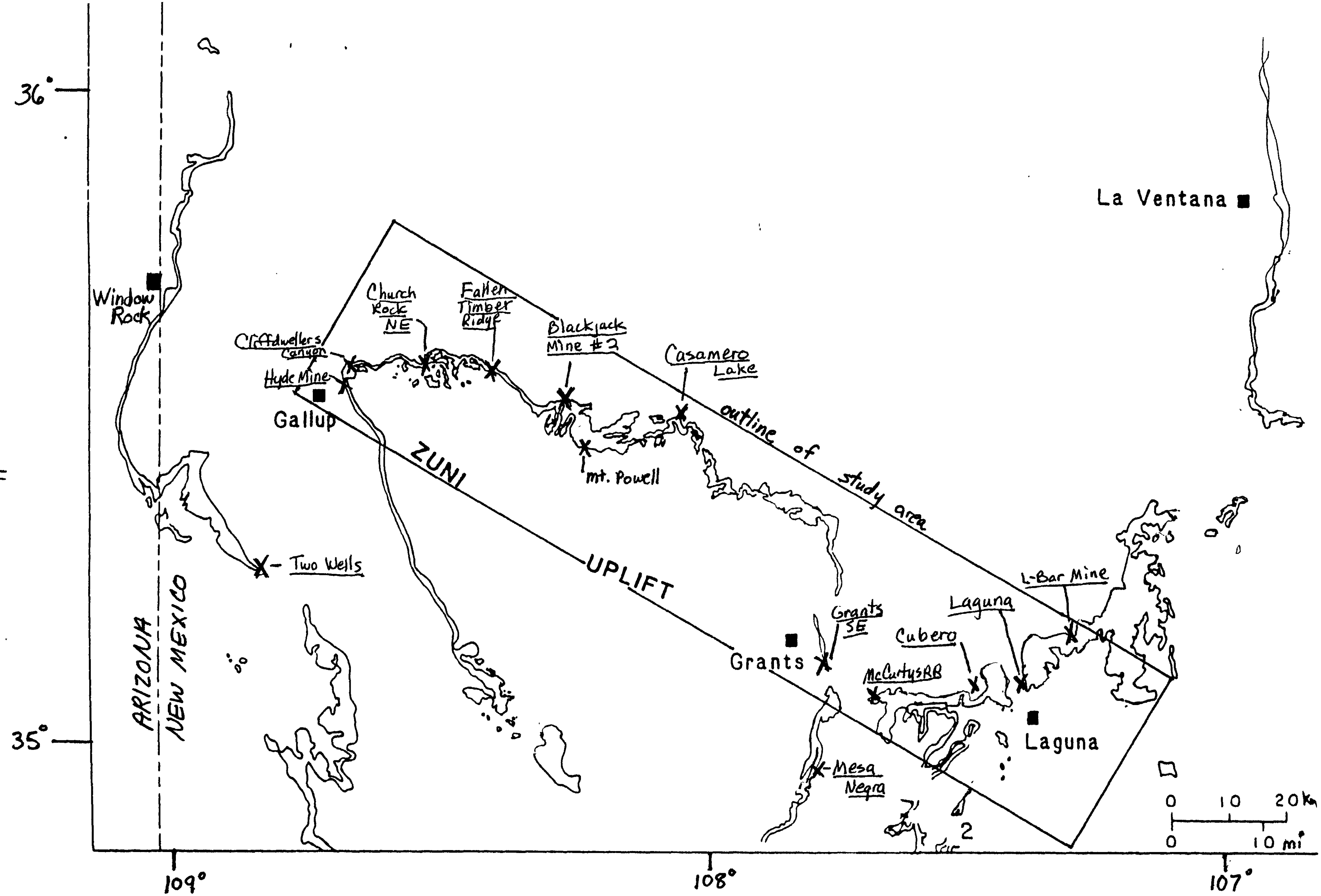


Figure 2 - Map showing outcrops of the Dakota Sandstone and the study area in the southern part of the San Juan Basin, New Mexico (modified from Aubrey, 1988). Underlined names and x's indicate sections measured by author.

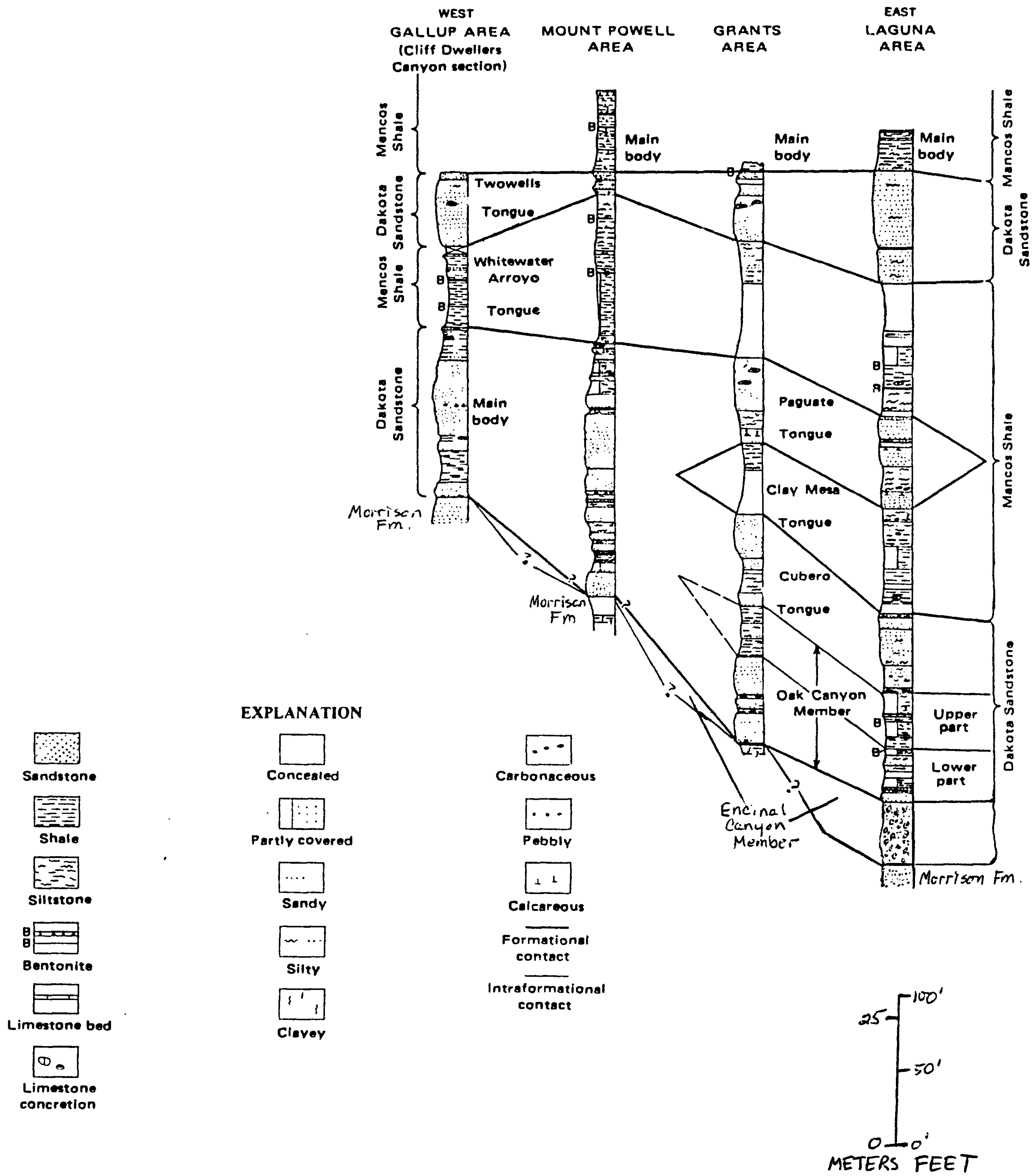


Figure 3 - East-west diagrammatic cross section showing members and tongues in Dakota-Mancos interval in study area (modified from Landis and others, 1973). Localities shown on Figure 2.

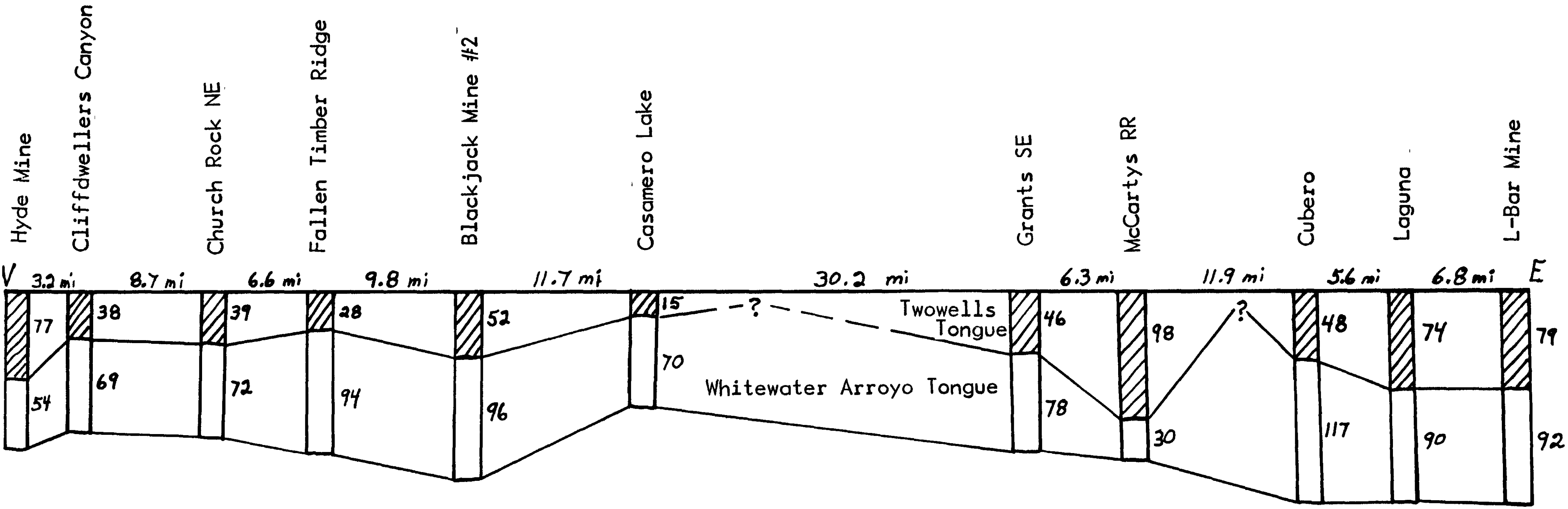


Figure 4 - Diagrammatic cross section of Twowells Tongue (lined pattern) and underlying Whitewater Arroyo Tongue showing thicknesses (ft) from measured sections in study area. Localities shown on Figure 2. Distances between sections shown in miles.

Symbols used in measured sections

Lithology

- basalt cap
- sandstone
- silty sandstone
- sandy siltstone
- hard calcareous sandstone lenses
- shale
- coarse-grained conglomeratic sandstone
- pebbles
- mudchips
- large concretions(?)

Primary physical structures

- massive structureless bioturbated sandstone
- trough crossbeds
- planar tangential crossbeds
- planar tabular crossbeds
- hummocky crossbeds
- horizontal laminations
- waveform bedding
- rippled surfaces
- overturned crossbeds
- sand rolls
- slumped bedding

Biogenic structures

- horizontal burrows
- vertical burrows
- oblique burrows
- shale traces indicative of bioturbation
- Ophiomorpha sp
- Thalassinoides sp.
- horizontal smooth-walled burrows of varying widths
- vertical smooth-walled burrows of varying widths
- snail trails
- bioturbation structures of uncertain origin

Other

- shell fragments
- gastropods
- small cm-sized bivalves
- Pinna sp.
- Pycnodonte sp.
- ammonite
- septarian nodule

Note: The Whitewater Arroyo Tongue of the Mancos Shale depicted at the base of each measured section is shown as a shale lithology even though it often includes siltstone and sandstone in its lithology. Also, the gradational zone from Whitewater Arroyo Tongue to Twowells Tongue is included in the Whitewater Arroyo Tongue where exposure allowed measurement.

Figure 5

Hyde Mine section
T. 15 N., R. 18 W.
section 12, NE NW
measured by J. Dillinger

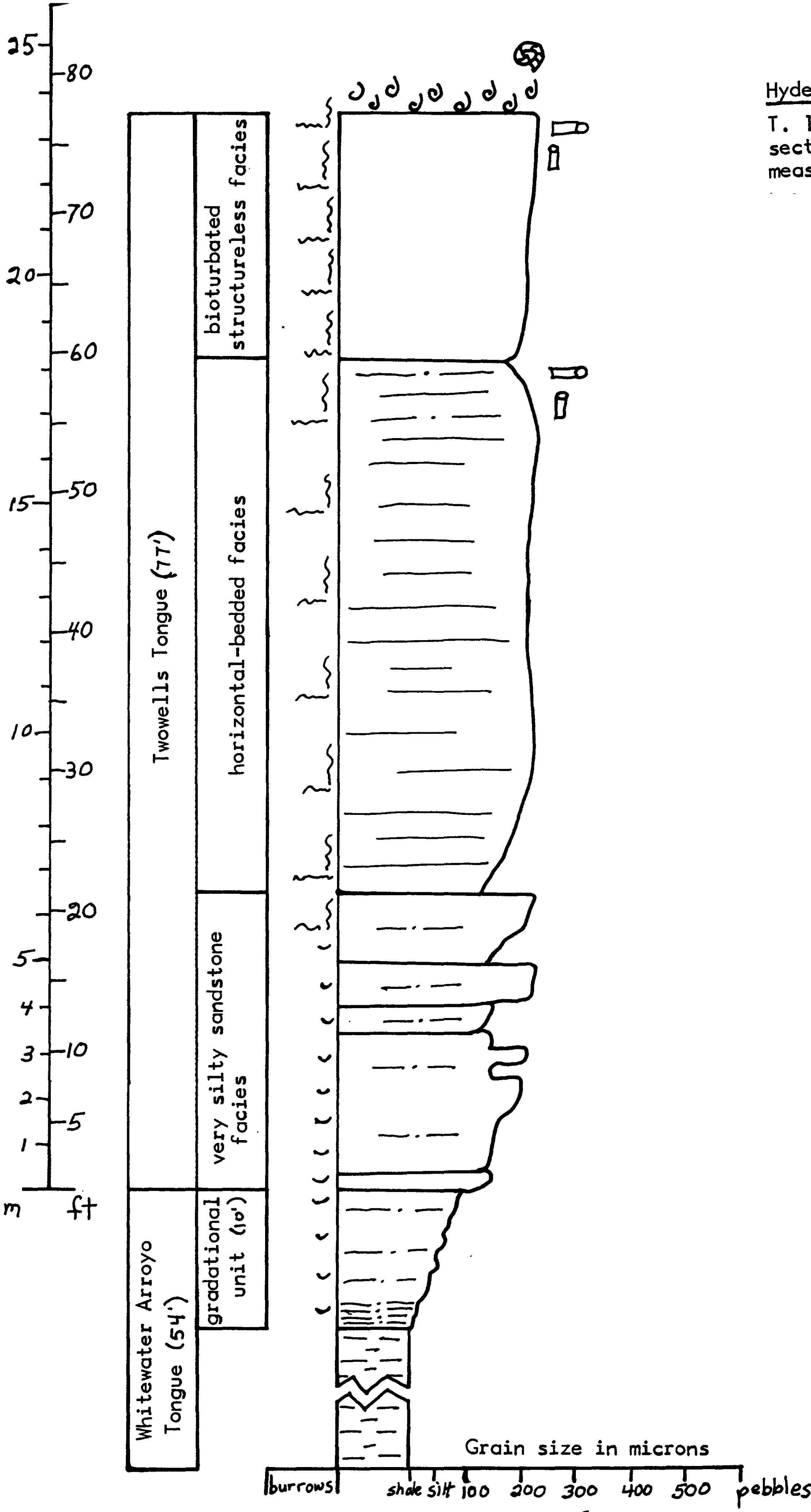


Figure 6

Cliffdwellers Canyon section

T. 16 N., R. 17 W.
section 30, NW NW
measured by J. Dillinger

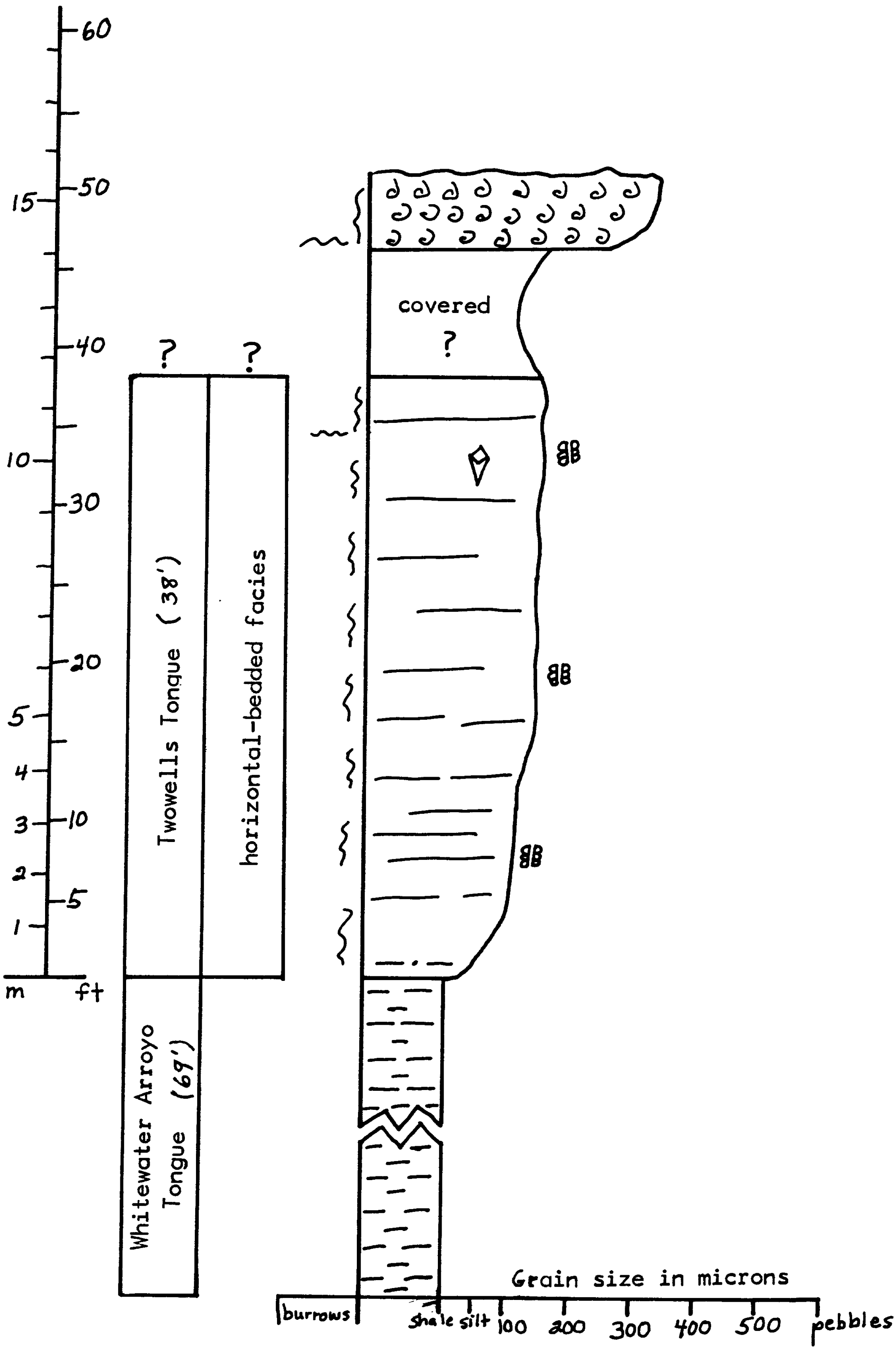


Figure 7

Church Rock NE section

T. 16 N., R. 16 W.
section 28, NE NE
measured by J. Dillinger

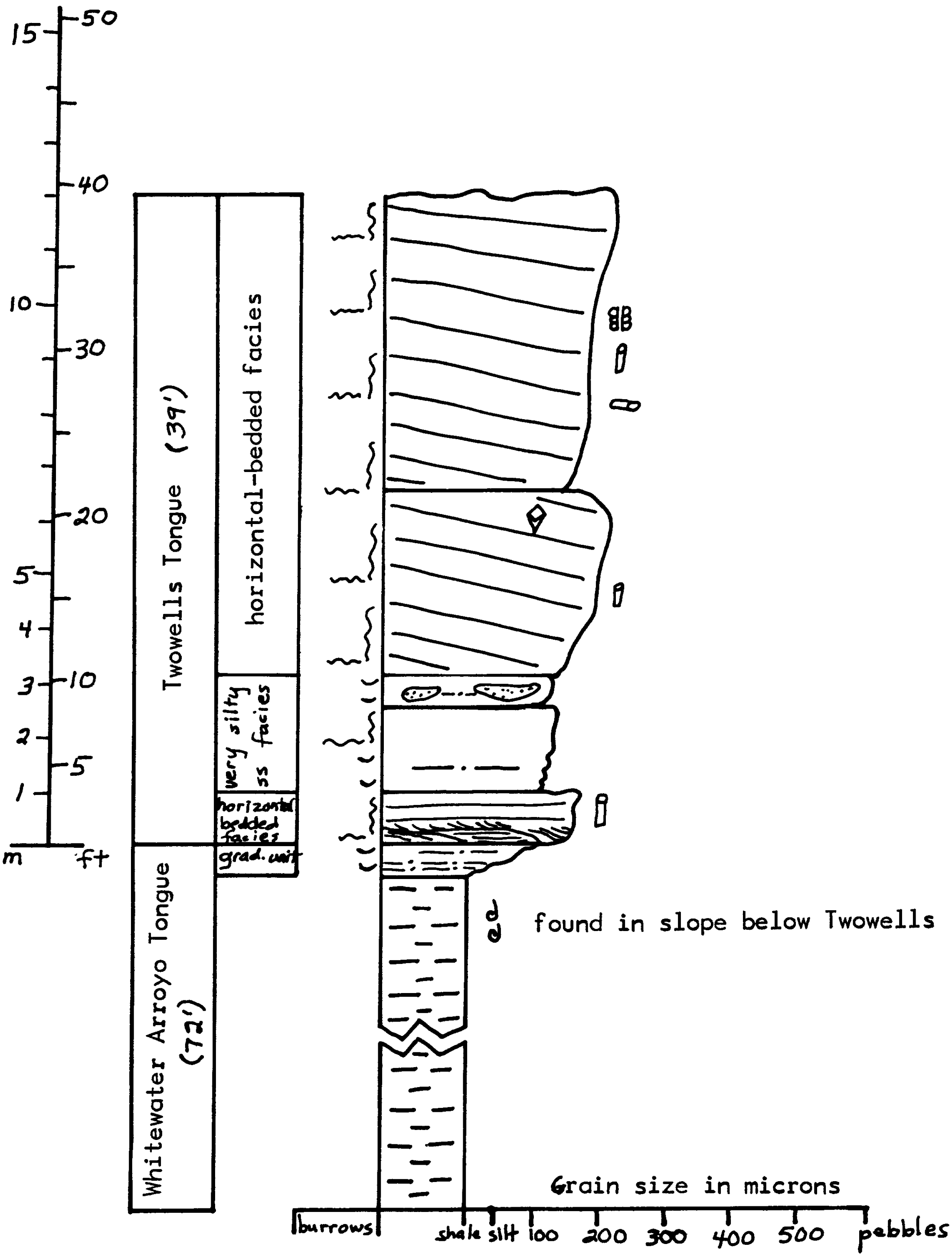


Figure 8

Fallen Timber Ridge section

T. 16 N., R. 15 W.
section 27, SE SW
measured by J. Dillinger

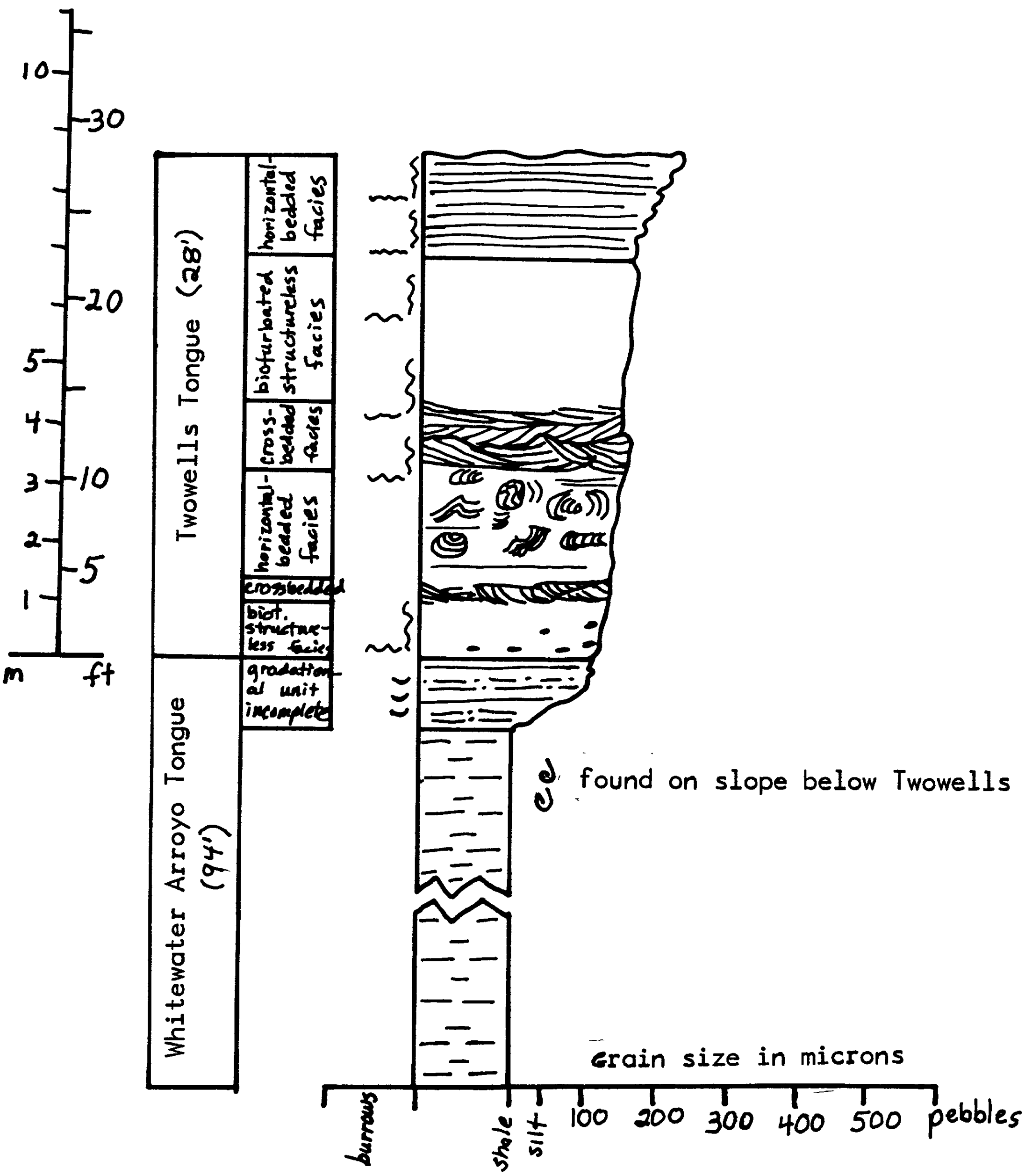
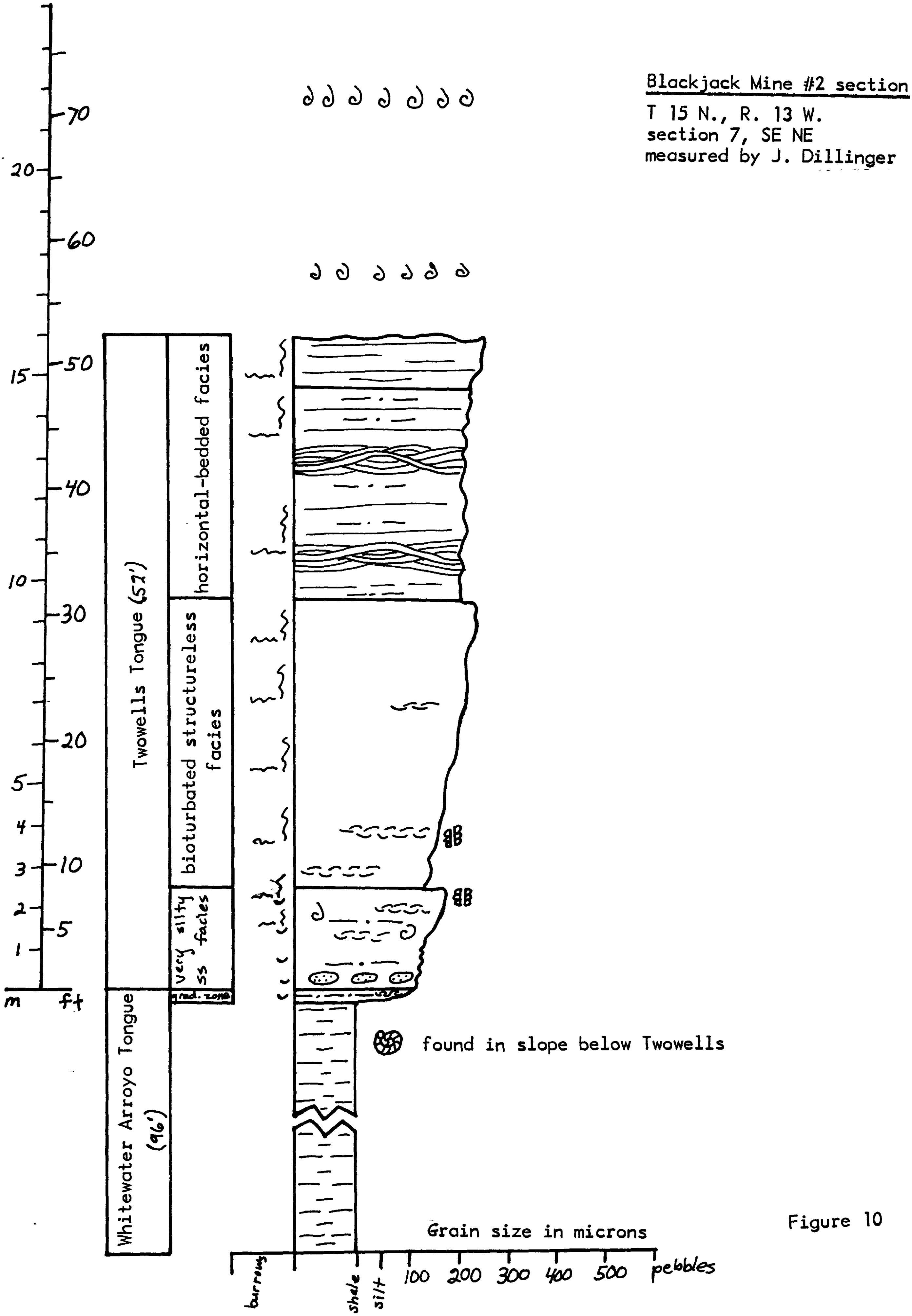


Figure 9



Blackjack Mine #2 section
T 15 N., R. 13 W.
section 7, SE NE
measured by J. Dillinger
m
ft
70
60
50
40
30
20
10
5
20
15
10
5
4
3
2
1
Twowells Tongue (52')
horizontal-bedded facies
bioturbated structureless facies
very silty ss facies
grad. zone
Whitewater Arroyo Tongue (96')
found in slope below Twowells
Grain size in microns
burrows
shale
silt
100
200
300
400
500
pebbles

Figure 10

Casamero Lake section

T. 15 N., R. 11 W.
section 30, NE NW
measured by J. Dillinger

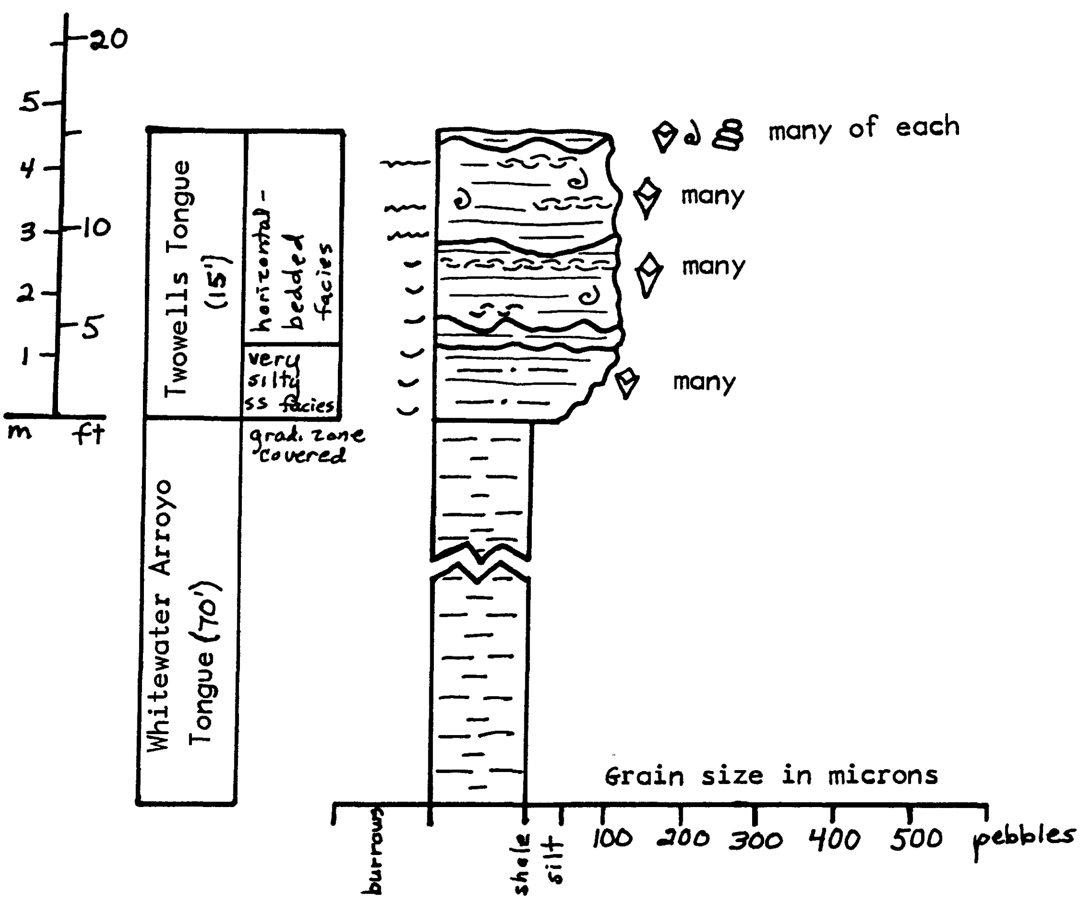


Figure 11

Grants SE section

T. 10 N., R. 9 W.
section 4, SE SE
measured by J. Dillinger

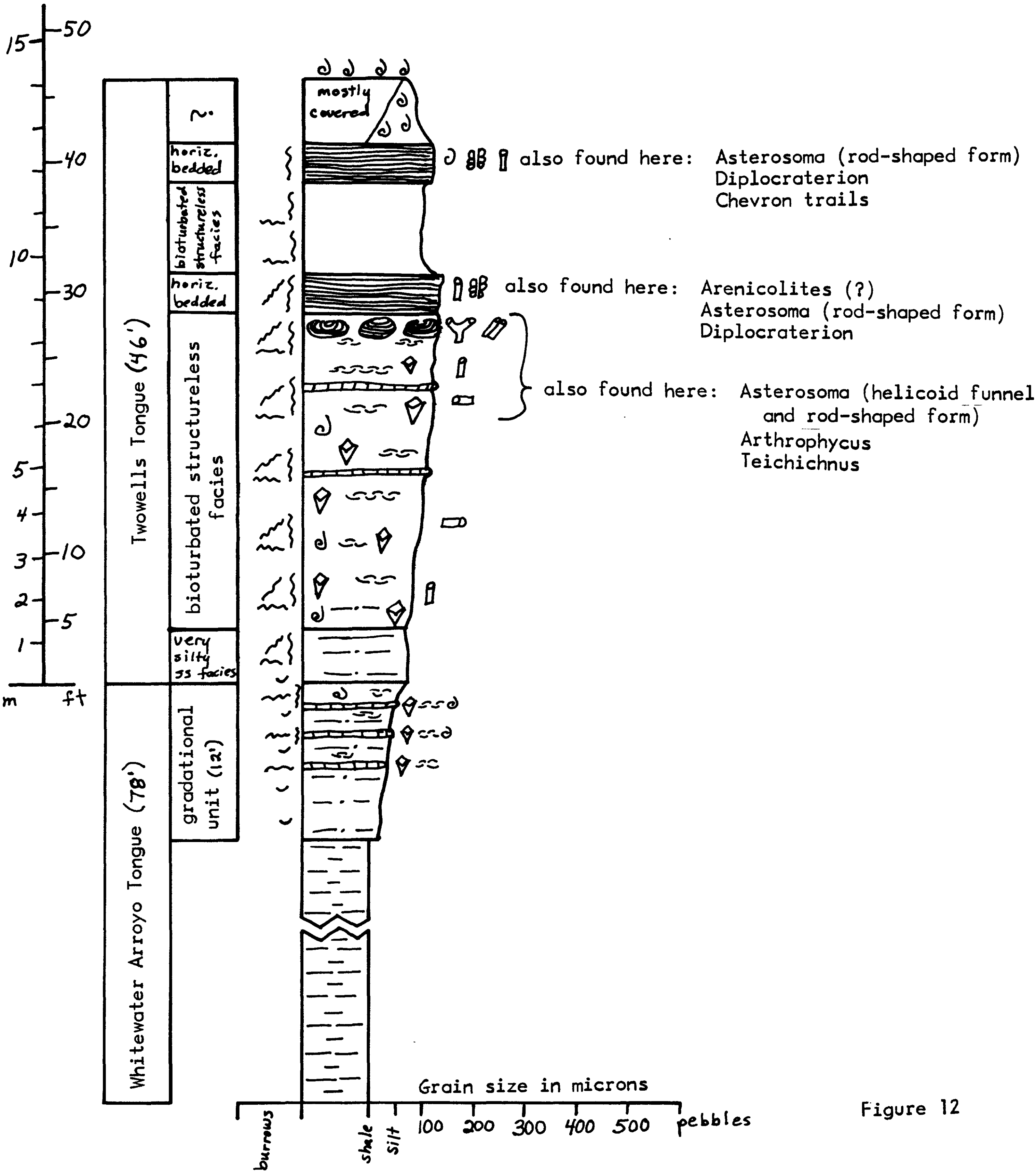
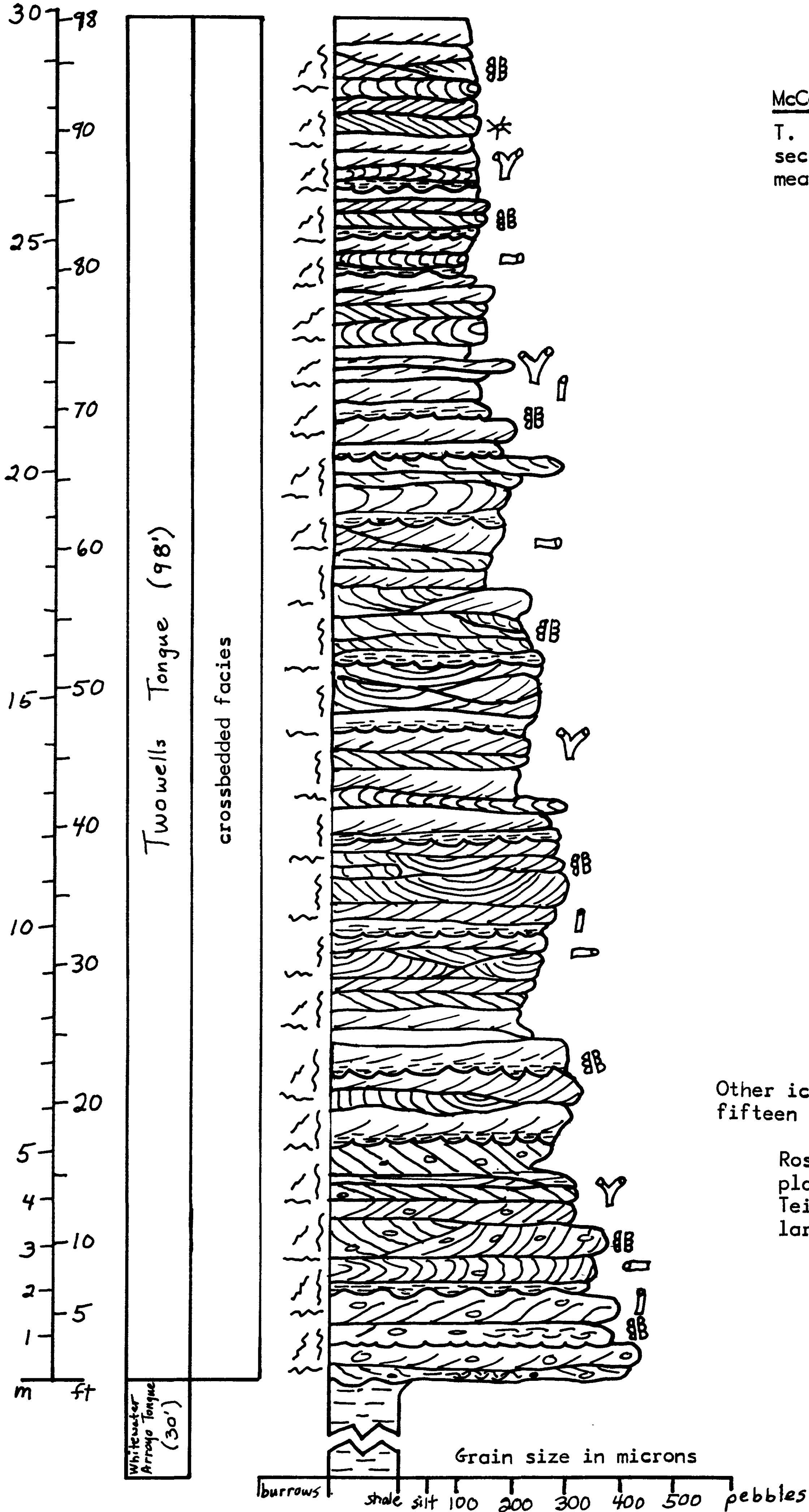


Figure 12



McCartys RR section

T. 10 N., R. 8 W.
section 28, NW SE
measured by J. Dillinger

Other ichnofossils seen in lower fifteen feet include:

Rosselia
planar curving tubes
Teichichnus
large escape structure (1 ft. long, 5 in. wide)

Figure 13

Cubero section

T. 10 N., R. 6 W.
section 21, SW SE
measured by J. Dillinger
and M.A. Carey

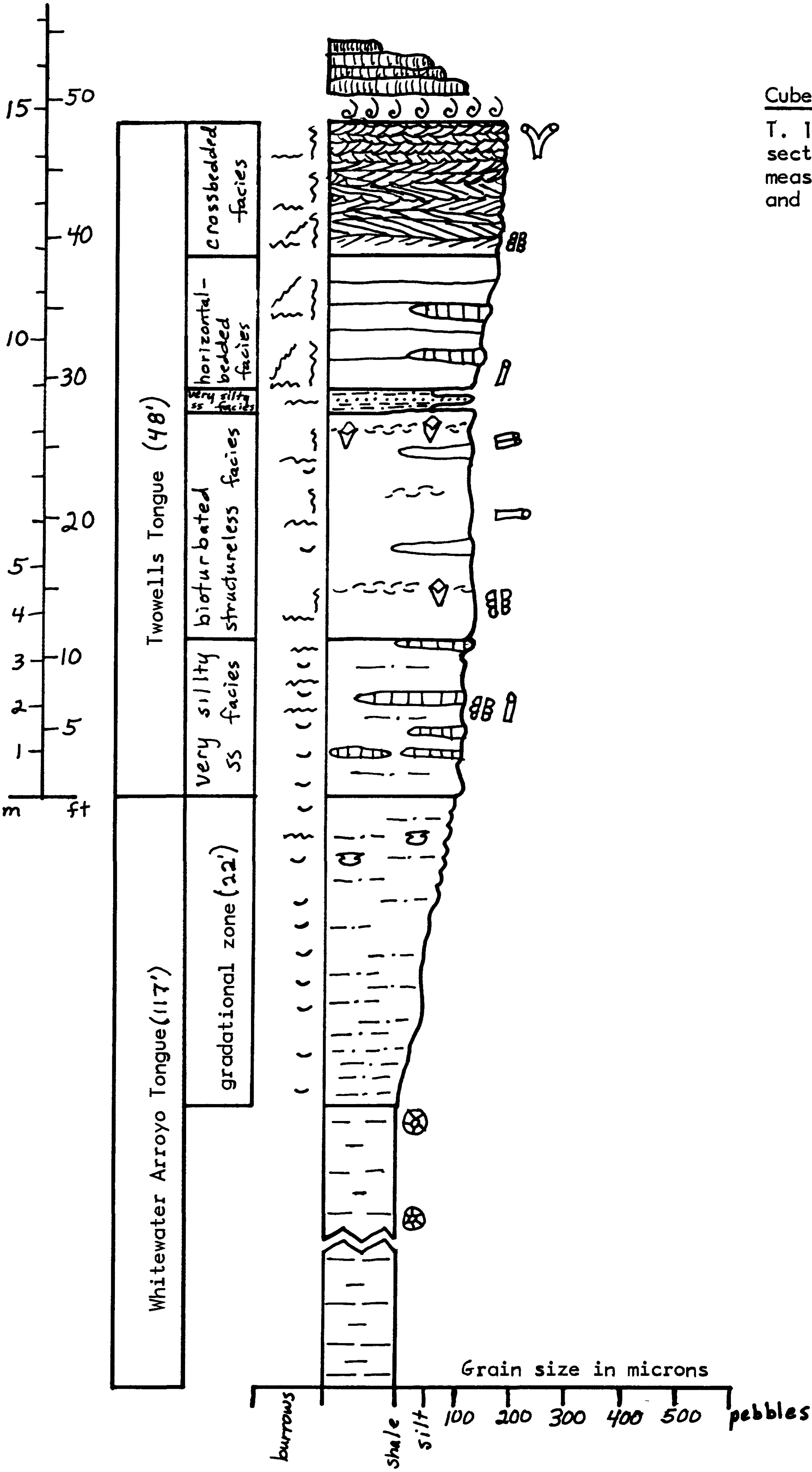


Figure 14

Laguna section

T. 10 N., R. 5 W.
section 21, SW NW
measured by J. Dillinger

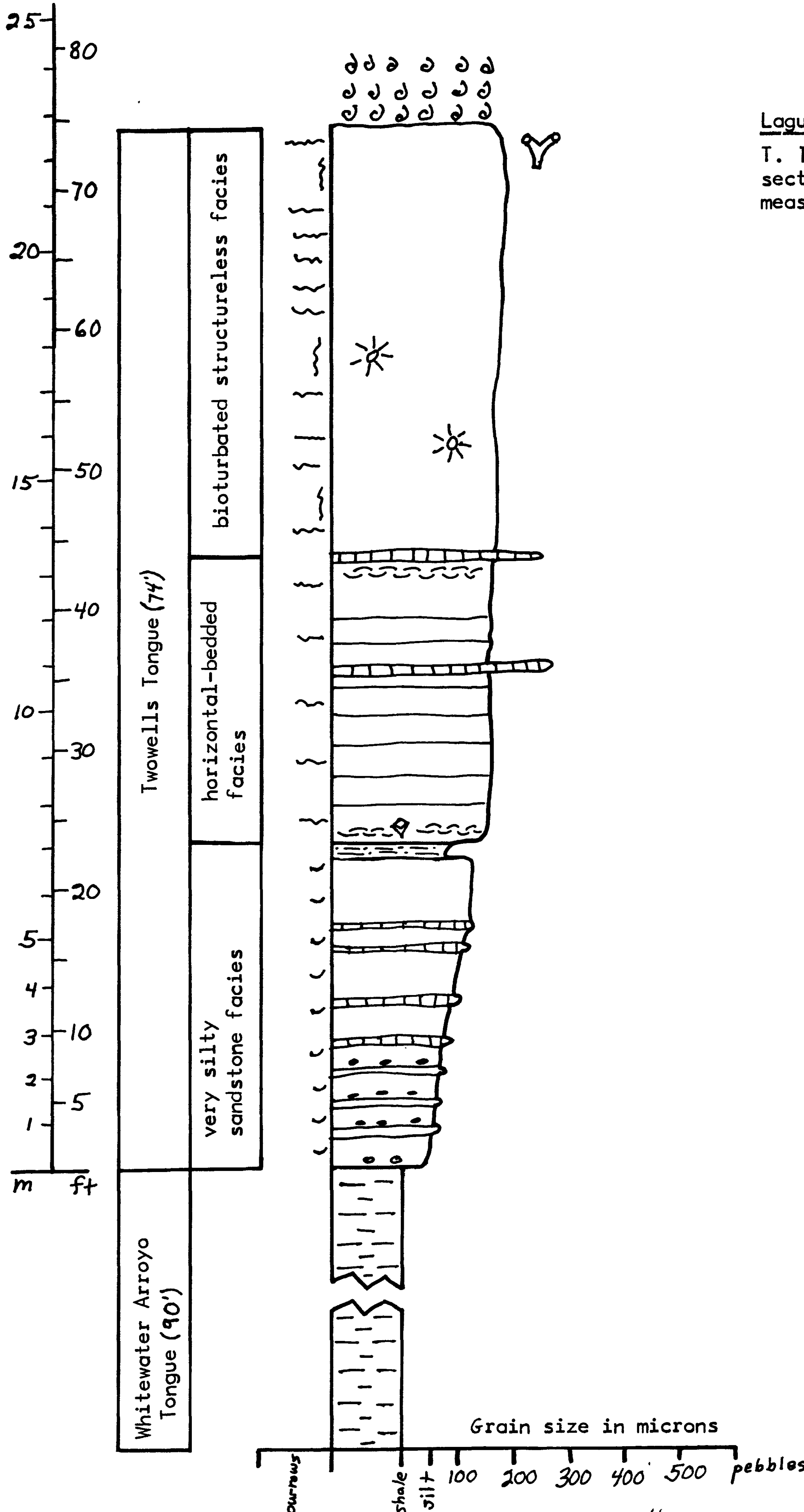
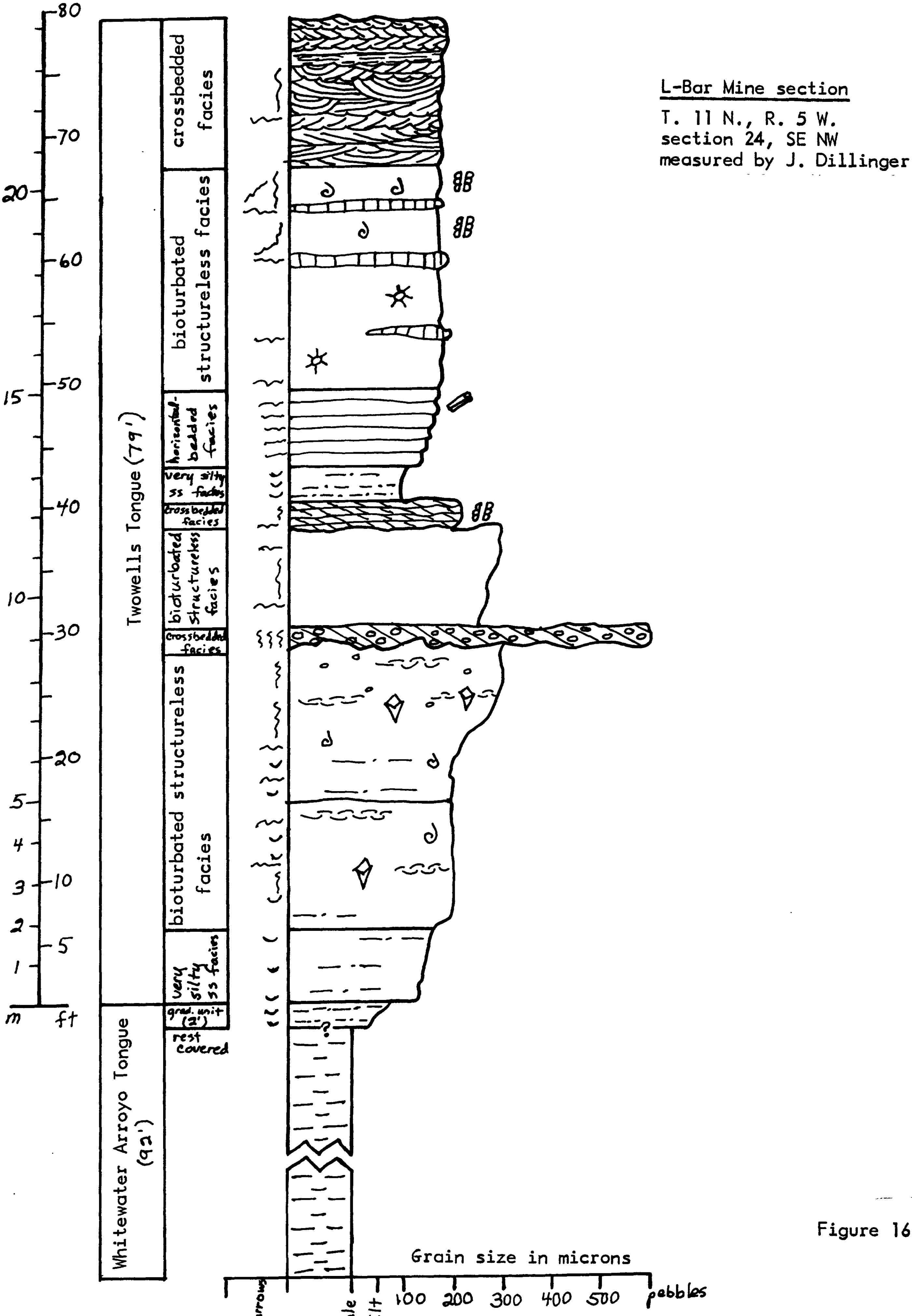


Figure 15



L-Bar Mine section
T. 11 N., R. 5 W.
section 24, SE NW
measured by J. Dillinger
m
ft
80
70
60
50
40
30
20
10
5
20
15
10
5
4
3
2
1
Twowells Tongue (79')
Whitewater Arroyo Tongue (92')
crossbedded facies
bioturbated structureless facies
horizontal-bedded facies
very silty ss facies
crossbedded facies
bioturbated structureless facies
crossbedded facies
bioturbated structureless facies
very silty ss facies
grad. unit (2')
rest covered
Grain size in microns
burrows
shale
silt
100
200
300
400
500
pebbles

Figure 16

Mesa Negra section

T. 8 N., R 9 W.
section 4, NE
measured by J. Dillinger

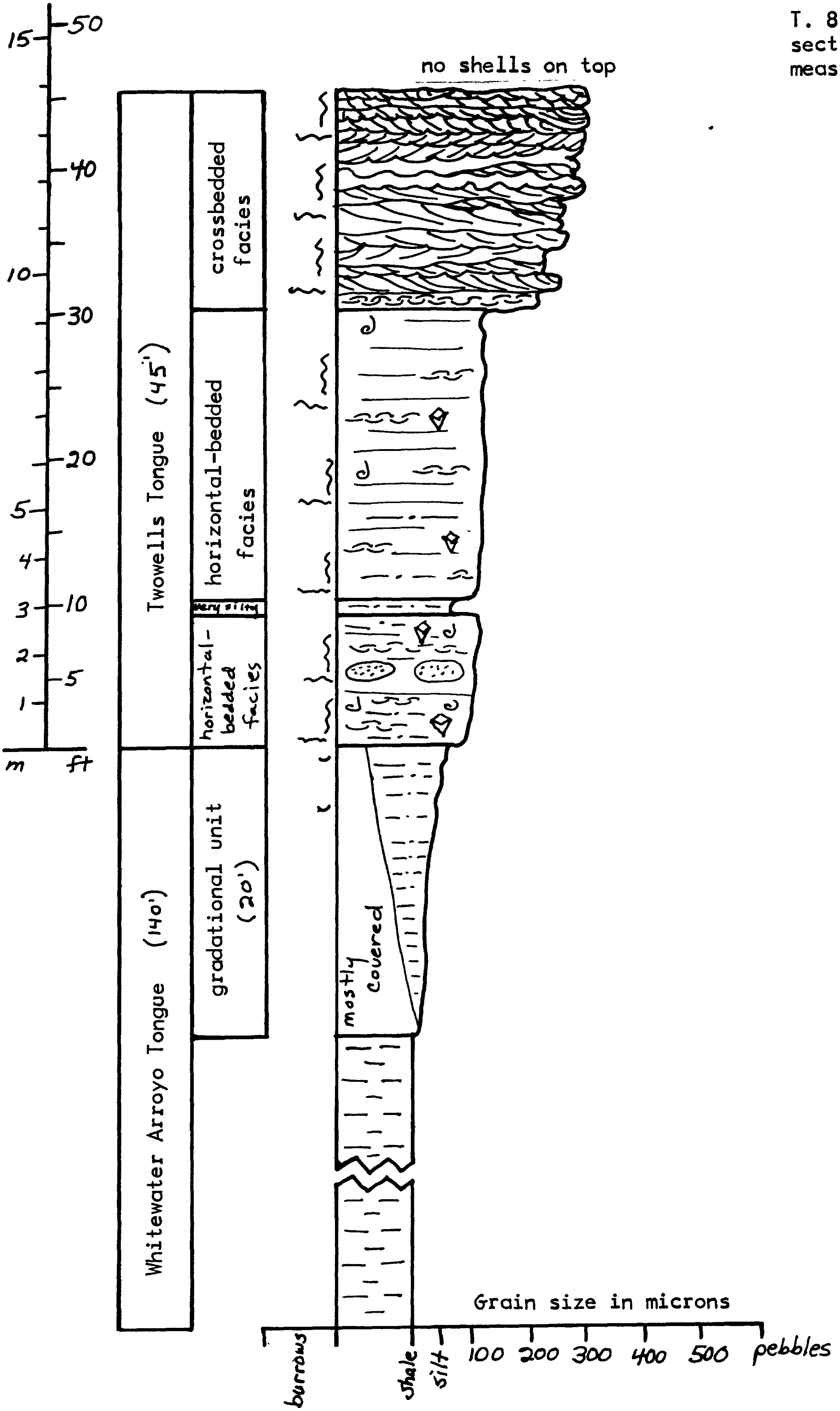


Figure 17

Two Wells section

T. 12 N., R. 19 W.
section 17, NE NW
measured by J. Dillinger

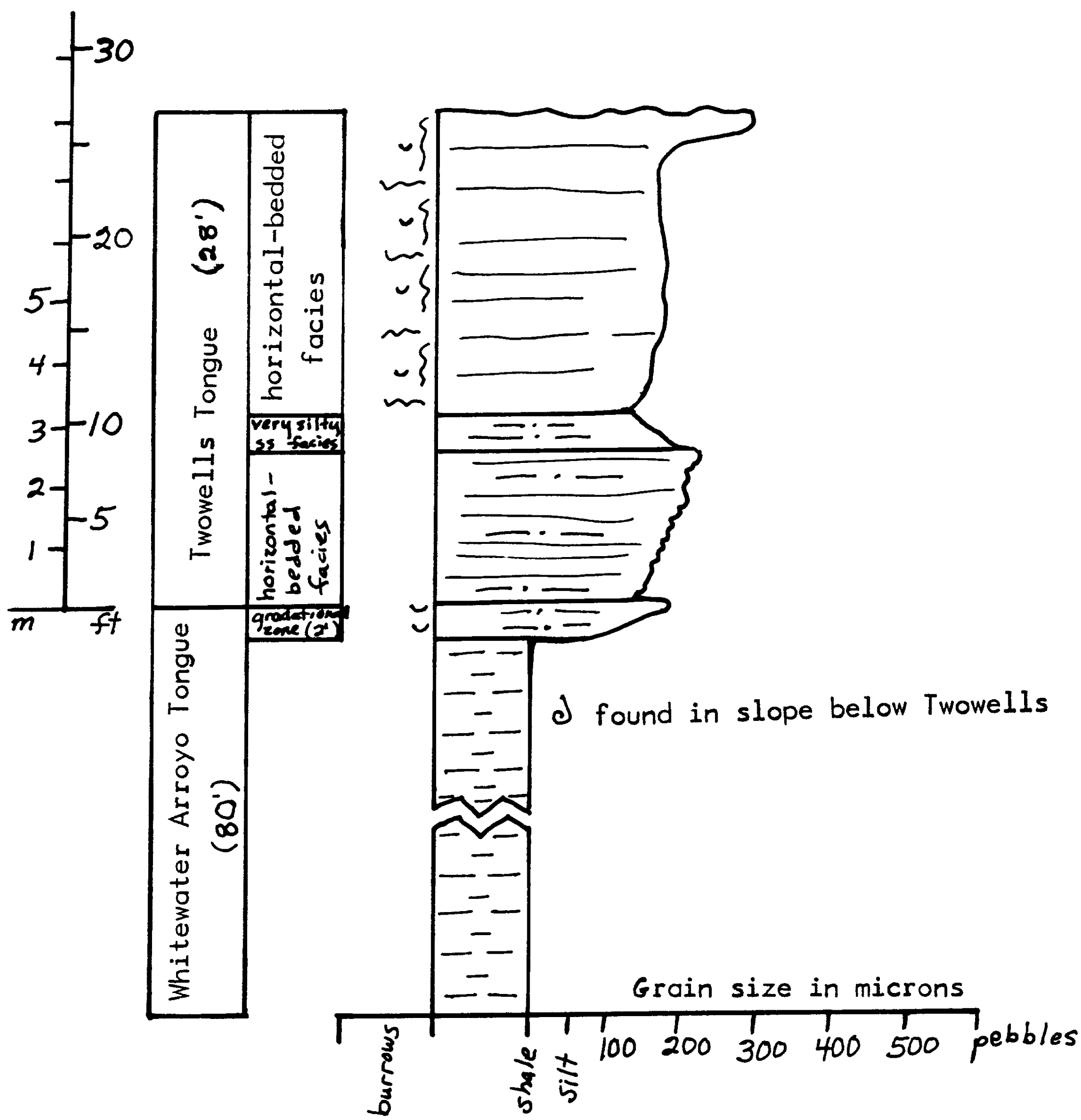


Figure 18