U.S. DEPARTMENT OF INTERIOR

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# FIELD TRIP GUIDE: QUATERNARY-HOLOCENE LACUSTRINE SEDIMENTS OF LAKE LAHONTAN, TRUCKEE RIVER CANYON NORTH OF WADSWORTH, NEVADA

by

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## INTRODUCTION

This field trip focuses on the classic outcrops of lacustrine and fluvial strata exposed in the canyon cut by the Truckee River north of the town of Wadsworth (fig.1). The stratigraphic sections along the Truckee River canyon have been described by Russell (1885), Antevs (1925), Morrison (1965), Morrison and others (1965), and Morrison and Davis (1984). This study is an attempt to characterize the sedimentary processes responsible for the deposition of these sediments and to correlate the deposits in the canyon with outcrops and core around Pyramid Lake. This type of study will allow us to reconstruct the three-dimensional system of lake size fluctuations. This volumetric data can be applied to precipitation-evaporation budgets that are used in climatic reconstructions (Hostetler and Benson, 1990). This study is ongoing, so hypotheses presented here are still subject to verification. There is enough existing information, however, to illustrate some important principles concerning the nature of sedimentation and the geometry of sedimentary deposits in this setting. Although the sedimentary succession is probably unique to this setting, the principles should be applicable to other areas and may be useful in formulating interpretation of past climatic change.

The stratigraphic descriptions used in this study emphasize sedimentary structures produced by mechanical, biological, and chemical processes. As a result, the boundaries of some units differ from those of previous workers who emphasized grain size and color. In order to help you understand my reasoning for placement of boundaries, I will briefly discuss some of the sedimentary processes and resultant structures.

1) **Lacustrine clay and muddy silt deposits.** The deposition of thick sequences of clay and muddy silt requires water that is effectively free of turbulence over extended periods of time in order for the small grain sizes to settle to the bottom. This condition is most easily met in deep lakes, although the absolute depth depends upon a number of factors including the uninterrupted surface area for wind stress (fetch), the rate of sediment introduction, and the magnitude and duration of wind stress events (storms). Sedimentary structures within the fine-grained sediment provide clues to the relative depths of deposition, although the absolute depths of deposition may vary through time.

In lakes with large depth/surface area ratios, surface turbulence is less effective in mixing the water mass. In these conditions, the water column may be stratified by temperature or salinity over prolonged periods of time and the lower dense water mass may become anoxic enough to deter bottom organisms (see Anderson and Dean, 1988). The effectiveness of this stratification depends upon a variety of factors, including salinity difference, seasonal temperature fluctuations, and organic productivity. Suspended sediment and plankton settle-out through the water column producing thin, continuous, flat laminae (fig. 2a). The anoxic conditions insure the preservation of the laminae by eliminating burrowing organisms that would disturb the sediment. Seasonal mixing of the water column must also be ineffective in oxidizing the bottom waters in order to deter bioturbation. The surface area-to-depth constraints are lower when the density contrast is higher, such as in lakes with hypersaline bottom waters, because more turbulence is needed to extend across the density boundary and the high salinity can eliminate burrowing organisms. There is no evidence for hypersaline brines having ever been present in Pyramid Lake.

Shallower lakes are more prone to complete oxidation of bottom water by wave mixing. If the bottom waters are mostly anoxic, the burrowing may be restricted to bedding planes and laminae may be partially preserved (fig. 2b).

If the bottom waters are mostly oxidized, the burrowing will randomly penetrate the sediment (fig. 2c) and laminae will be destroyed unless the sedimentation rate is rapid. If there is a constant flux of suspended sediment, such as in a prodelta setting, the sediment may lack bedding and will be poorly sorted. In this environment long vertical burrows (escape burrows) and dewatering features may be common. Frequent sedimentation events, such as bottom density flows (turbidites) and storm wave disturbances, may produce laminated deposits despite of the presence of burrowing organisms. Turbidity flow deposits are characterized by internal grain-size grading, irregular thickness of the lower coarsest part (commonly over scours), and internal stratification including flat lamination and ripple cross lamination (see delta discussion) (fig. 2d). Storm wave disturbances commonly overlie flat to scalloped erosional bases and consist of well-sorted coarse silt to sand forming lenses or layers that thicken and thin rhythmically (fig. 2e). Storm waves also produce laminae by winnowing fine-grained sediment and leaving a lag of coarser material. These sand or silt laminae commonly consist only of skeletal material that is scattered in the surrounding fine-grained sediment. The skeletal material in the laminae show little or no evidence of transport or sorting. A stratigraphic transition from sediment with no evidence of wave activity to sediment with abundant evidence of wave activity may be interpreted as an indication of shallowing conditions.

Deep-water laminae were not observed in any of the measured sections along the Truckee River canyon, although laminae of this type are found in sections and core around the margin of Pyramid Lake. Clay with horizontal burrows and partial preservation of laminae comprise just a few thin layers. Random burrows (commonly associated with abundant ostracodes), turbidites, and wave-formed structures are the most common types of sedimentary structures observed in the clays and muddy silts. These features are difficult to recognize in outcrop, so samples spanning each clay and muddy silt layer are collected, carefully cleaned, then examined under a binocular microscope. This work is ongoing, so the mud and muddy silt associations shown in figures 4, 7, and 9 are only approximations.

**2) Deltaic deposits.** Deltaic deposits occur where a river intersects a standing body of water. There are several varieties of deltas, but Gilbert-type deltas, which have smooth, steep delta fronts that produce tabular foresets, dominate the Truckee River canyon section. Deposition of Gilbert-type deltas occurs as fluvial sediment spills over the delta front. On the steepest slopes of the upper delta foreset, sediment is deposited as grain flows producing flat tabular foresets. On the gentler slopes of the lower foreset and toeset, deposition is by turbidity flows. The turbidity flow deposits are characterized by planar lamination and climbing ripple cross-lamination (fig. 3). On steeper slopes, turbidity flow deposits are characterized by planar lamination grading upward into low-angle climbing-ripples. On lower slopes, the turbidity sequence consists of low-angle climbing ripples grading upward into high-angle climbing-ripples. At the delta toe, turbidite sequences consist of high-angle climbing ripples with a planar silt drape. The lateral transition of these depositional styles across the delta front produce vertical successions as the delta builds out into the lake.

**3) Wave deposits.** There are several types of wave deposits present in the Truckee River canyon. Wave deposits are characteristically well sorted by grain size and shape. Beach bar deposits in the Truckee River canyon consist of tabular foresets, 10-40 cm thick, whose layers show alternations of well-sorted grain sizes and shapes. These are often interbedded or associated with sandy deposits having oscillatory ripples. Oscillatory ripples are characterized by rounded crests, high sorting within layers, commonly opposing orientations of internal cross laminae, and flat to scalloped bases (Raaf and others, 1977). In water less than 3m deep, oscillatory rippled sand commonly forms layers that alternate with beds of silt or silty mud. In places where waves erode into older coarse-grained deposits, the largest clasts are not moved but are left as lags on erosional surfaces. The surrounding finer-grained sediment is sorted, but this sorting is patchy due to wave refraction around the larger clasts. The resultant deposit is poorly sorted and often unbedded.

4) **Fluvial deposits.** There are two types of fluvial deposits found in outcrops along the Truckee River canyon. The fluvial deposits change thickness over short lateral distances reflecting the erosional channels in which they were deposited. The most common type of fluvial deposit consists of poorly sorted pebbly sand and conglomerates. This deposit reflects shallow, flash-flooding streams that produce imbricated clast deposits, and debris flows that produce matrix-supported deposits. This type of fluvial deposit is commonly disrupted by root structures that obscure depositional structures. The second type of fluvial deposit is better sorted and dominated by decimeter-scale, trough cross-bedding and intercalated tabular cross-bedding. The assemblage of sedimentary strucutres reflect braided streams that are larger and deeper than the present Truckee River. Mud layers are generally thin and disrupted by cracks and roots, consistent with the braided stream model.

5) **Subaerial deposits.** There are several horizons within the Truckee River canyon section that show evidence of prolonged subaerial exposure. Horizons with abundant root structures, eluviated clay, desiccation cracks, red color, and carbonate-filled cavities are commonly associated with the fluvial deposits. These features are interpreted as soils. Eolian sand layers are associated with some of these soil horizons. Root structures and prismatic cracks are superimposed on lacustrine silts and clays in places indicating periods of subaerial exposure. Gypsum crystals that are associated with some of these deposits are interpreted as products of the oxidation of sulfides within the lacustrine clays rather than deposits of saline groundwater. Desiccation features superimposed on the outcrops are difficult to distinguish from those formed syndepositionally and verification requires trenching deep into the outcrop face.

## STOP 1: Wadsworth Amphitheater

Most of the morning will be spent at this locality. The stratigraphic section enclosed (fig. 4) is essentially identical to that of Morrison and others (1965), but the emphasis is on sedimentary structures which makes it look a little different from their section. The general succession which Morrison and others (1965) assigned to the Eetza (lower gray), Wymaha (red), and Seehoo (upper gray) formations are exposed along the bluffs at this locality. They called the dark layer exposed on the south side of the amphitheater the Paiute formation, which they interpreted as a Pleistocene unit below the lacustrine sequence.

The clay and silt at the base of this section (unit 1 of fig. 4) are the oldest fine-grained lacustrine deposits in the canyon. On the west side of the river, the silt and clay sequence overlies about 95 cm of deltaic sand which unconformably overlies red fluvial sand and mud which will be discussed later on in the trip. The clay units within this lower sequence were in part deposited below wave base which, depending upon the regional wind directions, probably required at least a couple of tens of meters of lake water. The clay sequence is overlain by silt grading upward to sand which represents a deltaic deposit. Note the vertical succession from high-angle climbing ripples with silt drapes to low-angle climbing ripples capped by high-angle climbing ripples, and finally poorly exposed tabular foresets. The transition from steep foresets to flatter foresets is visible in a few places. The top of the deltaic sequence is a trough cross-bedded fluvial sand. One may be tempted to estimate the lake depth of the clays by measuring the thickness of the deltaic sequence, which is less than 5 m. I walked out this unit and found a fair amount of variability in thickness which is inconsistent with that hypothesis. The thickness of the deltaic deposit is actually reflecting the rate of sediment accumulation as lake depth decreases. Notice the abundance of gray mud and silt intraclasts in the delta foreset sand and in the fluvial sand. As lake level dropped, the fluvial system eroded the exposed delta and deposited the eroded sediments at the delta front. The deltaic sands overlying clay unit 3 (fig. 4) form an upward-coarsening sedimentary succession composed of at least two steep foresets separated by flat rippled silts (there are actually three foreset sequences). The stacking of delta foresets results from lake level rising and falling as the delta prograded (fig. 5). I call the upward-coarsening sequence composed of these delta foresets a "stacked Gilbert delta". I've observed this type of delta deposit at Mono Lake and Walker Lake and in photos of Lake Hazar, Turkey (Dunne and Hempton, 1984). I have also found this type of deltaic deposit in Triassic and Jurassic rocks of the Newark Supergroup in the eastern U.S. (Smoot, 1991). The implication of this delta style is that lake level fluctuated radically through time, as is common in closed basins.

The fluvial sands that cap the upward-coarsening sequence above clay unit 1 (fig. 4) are overlain by coarse sand with tabular foresets. These are wave-formed bar deposits separated by sand with oscillatory ripples. This coarse sequence is overlain by a thin, laminated clay (unit 2 on fig. 4) which is traceable over most of the canyon. I interpret this succession as a transgressive sequence capped by a deep-water clay. The wave deposits overlie an erosional surface and cut into the underlying regressive sequence. The asymmetry of the transgressive (thin) versus regressive (thick) sequences is obvious throughout this section. Such asymmetry in the marine record has been attributed to rapid sea-level rise and slower sea-level fall. I believe the asymmetry of the deposits here (and possibly in the marine record) is due to the availability of sediment. During periods of lake level rise, the lake invades the surrounding drainages. The standing lake water decreases the amount of drainage area available for sediment transport and baffles the fluvial sediment, trapping it near the new shoreline. However, when lake level falls, the sediment trapped at higher elevations (filling channels and forming delta foresets) is out of equilibrium with the drainages and is rapidly eroded and redeposited into the falling lake. This sedimentary asymmetry is also present in the cored sequence from the north end of the lake where there was no delta. The implication of this concept is that climatic models based on rates of sediment accumulation must consider the possibility that lower rates accompany wetter periods (transgression) and the higher rates occur during drier periods (regression).

With respect to the contact just below clay unit 4 (fig. 4), a layer of cobbles in the deltaic sand are topset deposits that were reworked by waves and left as a lag deposit. The orange silt layer with soft-sediment deformation that immediately overlies the sand was believed to be a tephra, but Andrei Sarna-Wojcicki (pers. comm.) identified it as reworked Tertiary volcanics. The thickness of the layer and unusual provenance suggest a catastrophic deposition, perhaps a flood. The orange silt and the overlying clay with oscillatory ripple lenses are disrupted by sand-filled fractures. The soft sediment deformation may reflect fluidization of water-saturated silt on the delta topset, but may also represent fluidization in response to earthquake shaking (as in Sims, 1975). Similar soft-sediment deformation structures occur at nearly all of the contacts between deltaic deposits and lacustrine silts and clays. This suggests the process may be related to resaturation of the deltaic sands during lake transgressions rather than to earthquakes (see Obermeier and others, 1990, p. 35-38).

Clay unit 4 is characterized by numerous silt layers, varying from 1-20 cm thick, that are traceable over the entire length of the canyon. Each layer gradually thins to the north, the direction of net transport. The silt layers are each formed by turbidity flows. These differ from the deltaic deposits in their continuity and lack of lateral gradation into foreset beds. This type of turbidite requires that a large amount of sediment was transported along the lake floor. Turbidite underflows along nearly flat lake bottoms are produced by flooding streams with high sediment concentrations (see Middleton, 1970; Sturm and Matter, 1978). Within the turbidite interval of unit 4, there is a thin orange-weathering silt that is not graded. This is the Wadsworth tephra of Davis (1978). This unit is a useful marker bed because it is easily recognized within the distincitve succession of turbidites.

The flat surface of muddy sediment with the steep front that occurs in the bowl of the amphitheater just to the south, is the upper Sehoo alluvium of Morrison and Davis (1984) Although patches of internal stratification are found, the deposit is mostly disturbed by roots and desiccation cracks. Similar terrace wedges have upper flat surfaces at roughly the same elevation (about 1,230 m) at the mouths of most of the side canyons. Furthermore, these wedges are characteristically asymmetric to the north of the canyon mouth. A particularly good cross-section of the large flat at the mouth of Gardella Canyon (almost directly west across the river from here) shows internal delta-like foresets inclined away from the canyon mouth and toward the north. This indicates that the flat muddy terraces are deltas formed into a sluggish Truckee River by streams in side channel canyons. Contrary to the interpretation of Morrison and others (1965), I believe that the dark unit in this locality (which they call the Pauite Formation) is another terrace that predates the lower one. Red, poorly sorted, muddy sand occurs at the base of some of the deeper gullies could be deposits that predate the lacustrine sequence, but most the muddy sand and conglomerate is a younger terrace. My reasoning is based on the following observations: 1) In some of the erosional rills through this deposit, I observed intraclasts of lacustrine muddy silt and clay similar to the presumably overlying beds, 2) The conglomerate at the top of the dark bed has been reworked by waves, and a zone of these dark cobbles can be observed at the same elevation (just below 1,240 m) throughout the canyon, 3) The dark bed cuts across the boundaries of the other stratigraphic units and the conglomerate is commonly just a veneer (notice the scattered cobbles around here that stop just below 1,240 m), and 4) At the same elevation in Gardella Canyon, there is a set of delta-like foresets with the wave reworked conglomerate on top. I interpret these terraces, therefore, as indicating a lake that rose into the canyon and formed the wave terrace (just below 1,240 m) with some deltas produced by side canyons, followed by a fall in lake level during which river flow was sluggish and side canyon streams produced the lower terraces (about 1,230 m). Both terraces are younger than tufas that have been dated 12,900±100 using $C^{14}$ (Benson, oral comm.). The Tsoyawata tephra (about 7,000 BP) crops out next to the terraces in the Wadsworth Amphitheater

(Davis, 1978), but has not been found in any of the gullies in these terraces. This suggests that the terraces predate the Tsoyawata.

Back to the measured section, clay unit 4 (fig. 4) is overlain by upward-coarsening, stacked Gilbert delta deposits representing the fall of the lake. The deltaic deposits are overlain by the reddish unit Morrison and others (1965) called the Wymaha formation (W on (fig. 4). The Wymaha at this locality is an extremely complicated deposit. We could spend all day (or a week as I did) walking out this unit in the Wadsworth Amphitheater and observe the tremendous amount of lateral variability. The location we will see is not typical of the Wymaha, (in fact it is pretty atypical), but it is convenient to reach. I will condense some of the relationships which we, unfortunately, will not be able to view. Notice the orientation of the silt beds as we approach the Wymaha. Typically the sediments underlying the Wymaha have been fluidized to various degrees with soft-sediment folds and diapiric intrusions all of which are truncated by the Wymaha sands. The Wymaha sand at this locality consists of a lower unit with steeply inclined bedding. This inclined bedding is not foresets, but is actually wave-sorted sand that was originally deposited horizontally and then was rotated. The horizontal dark unbedded surface on top of the rotated unit contains numerous root casts (many of which are carbonate filled) and is very clay rich. I've interpreted this as a soil. The soil is overlain by more sand which includes a thin bed that may be eolian, but most of it is wave deposited. Walking southward along the rim of the amphitheater, the wave-deposited unit is replaced by a trough crossbedded fluvial deposit which is not rotated (the contact appears to be erosional). The crossbeds indicate a paleocurrent parallel to that of the present canyon. The thickest trough crossbedded deposits overlie a series of slump blocks in which the underlying deltaic silt and clay deposits and minor wave-sorted reddish sand are rotated. The crossbedded units thicken over the downsides and thin on the upsides of slumps and are not rotated, indicating that they postdate the slumps. These fluvial deposits are capped by a soil, which is typically overlain by wave deposits. There are two side drainages entering the Truckee River at the Wadsworth Amphitheater. At both of these drainages the thickness of the Wymaha reddish unit increases dramatically and is dominated by a poorly sorted, coarse conglomerate. The coarse conglomerates appear to have sources in the canyon drainage and shadow fabrics (Dal Cin, 1968) indicate flow was into the canyon. Also, the poorly sorted conglomerates appear to truncate the trough crossbedded fluvial deposits, but are capped by wave sorted sand.

My interpretation of the Wymaha depends in part upon some observations we will make in later stops. Figure 6 illustrates my understanding of the origin of the Wymaha that best explains these observations. (1) Following a long period of high lake level (unit 4 of fig. 4), lake level dropped and deltas were deposited. Intermittent lake level rises produced stacked Gilbert deltas and periods of wave erosion and deposition. (2) In the early stages of fluvial entrenchment, deposits on the channel bluffs were intermittently resaturated by rising lake levels. The water-saturated sediments flowed into lows or produced mudlumps where channels built out over them. (3) Continued downcutting of the channel left steep walls that slumped into the paleocanyon. The slumped deposits were then in part buried by fluvial deposits. (4) Older fluvial and wave deposits were abandoned on terraces where they were overprinted by soils as the river continued to cut down into the canyon. Side canyons incised into the older deposits as they drained into the new Truckee River canyon. (5) Lake level rise was accompanied by wave erosion that removed all evidence of soils on high areas and partially reworked deposits in the lower areas. Deep water clays draped the resultant topography (clay unit 5 of fig. 4).

The Wymaha probably represents the first development of the Truckee River canyon as we see it today. There was some canyon cutting associated with the fluvial episode following unit 1, but either the scale of cutting was smaller or the locus of canyon cutting was elsewhere because the underlying deposits are undeformed and the distribution of units is sheetlike. The distribution of lacustrine units overlying the Wymaha, particularly deltaic deposits, are much more locally controlled and in many places lake regression leads to desiccation of lake clays rather than burial by deltas. This observation is interpreted as indicating that the Truckee River canyon was present, and that only high lake stand deposits accumulated on the present flats and deposits of the falling lake accumulated inside the canyon.

We won't examine the lake deposits overlying the Wymaha here, but I would like to point out a couple of features on the section. Clay unit 5 (fig. 4) is a distinctive tan clay with abundant ostracodes and clay unit 6 (fig. 4) is a silty clay with two three orange silt bands that are bioturbated turbidites overlain by a thick silt with orange tube-fillings. Although the sandy material between these units varies in thickness or may be missing, the two clays are very distinctive and traceable northward over a distance of several miles. The coarse sand labeled PW in figure 4 (post-Wymaha) is important and will be discussed later.

**STOP 2: 0.9 Miles north of Wadsworth Amphitheater**

This is a quick stop at the second measured section (fig. 7). If you look down the steep bluff below the road, you will see coarse sand overlain by silt and clay. A thin distinctive clay overlying the sand is equivalent to clay unit 2 of the Wadsworth Amphitheater. The sand consists of fluvial deposits overlain by wave deposits equivalent to the upper part of the regressive sequence above clay unit 1 in the Wadsworth Amphitheater section (fig. 4). The fluvial unit in this section is almost 3 m thick (as opposed to less than a meter thick at the Wadsworth Amphitheater section) and has large-scale trough cross bedding. I attribute this to channel cutting during the drop in lake level, but at a much smaller scale than occured during Wymaha time.

The road is cut into stacked Gilbert delta deposits whose upper part is exposed in the bluffs along the road. The banded clay unit overlying the loose sand includes the turbidite-bearing portion of clay unit 4 (fig. 7) that contains the Wadsworth tephra. Every turbidite bed exactly matches those of the Wadsworth Amphitheater (fig. 4). Notice the thin orange sand overlying the clay deposits. That sand is composed entirely of wave deposits and is overlain by the tan ostracode-rich clay of unit 5 (fig. 7) and clay unit 6 with the thin orange silt layers. I confirmed these relationships by walking out the contacts, and the thin sand is equivalent to the Wymaha in the Wadsworth Amphitheater. There is about 5 m of section missing below the Wymaha at this locality (fig. 7) relative to the Wadsworth Amphitheater section (fig. 4). I originally interpreted this loss of section as an indication of a lakeward-sloping wave-cut surface produced by the transgression. The wave-cut surface part was right, but there is an important component of section lost canyonward. I interpret this loss as evidence of the canyon-cutting model I presented earlier.

Notice that the lacustrine section overlying PW in figure 7 is considerably thicker than at the Wadsworth Amphitheater section (fig. 4) and is capped by a tufa-bearing unit. The thicker lacustrine section overlying PW and the tufa are exposed on the south side of the Wadsworth Amphitheater, but there is no sign of tufa fragments in the intervening area. Considering the density of tufa fragments over the slopes where the tufa is found, I interpret there total absence as evidence that the tufa was not deposited over most of the Wadsworth Amphitheater area. I also believe that most of the fine-grained sediment overlying PW was eroded away by waves or wind. I'll discuss this more later.

**STOP 3: 1.7 Miles north of Wadsworth Amphitheater**

At this locality, the Wymaha is resting directly on the the highly deformed beds of the turbidite portion of clay unit 4 (fig. 8). Therefore, an additional 2.5 m of section is missing relative to the last stop (fig. 7). The Wymaha is entirely a wave deposit and there is no soil. This is the northernmost occurrence of Wymaha reddish sand on the eastern side of the canyon. The Wymaha here is actually thicker than at STOP 2. It appears to be filling a slump depression and it is also rotated. North of slumped deposits, the turbidite-rich portion of unit 4 is about 3 m lower and it grades upward into a deltaic sequence that is partly rotated. These deposits are all truncated by a wave-rippled sand overlain by clay unit 5 (fig. 8) and the rest of the fine-grained sequence capped by tufa (as in (fig. 7).

We will drive north for another mile and turn around. Notice the absence of the Wymaha red unit and, in a short distance, the absence of steep silt clay bluffs overlying loose gray sand. This is not a weathering artifact! In this area, the lacustrine deposits of clay unit 3 and above do not have regressive sequences capped by steep delta front sands. The numbered clay units are still identifieable, but there appear to be some desiccation overprints on them. I haven't measured a section up here yet to verify the exact relationships. Also, note the dark horizon that appears near the base. This is a veneer of rounded cobbles and pebbles extending down from a small bench cut into the sedimentary sequence at an elevation just below 1,240 m. I correlate this to the terrace at the Wadsworth Amphitheater which Morrison and others (1965) called the Paiute Formation.

**STOP 4: 1.9 Miles north of S-S Ranch on west side of Truckee River**

We aren't going to climb over the section at this stop because the walls are too steep and dangerous for a large group. The stratigraphic section for this locality (fig. 9) is actually a composite from exposures spanning an eighth of a mile to the north. The stratigraphic relationships were verified by walking out the overlapping intervals. Looking over the edge of the canyon, you can see two gray silt-clay units separated by a reddish sand. The temptation is to call the reddish sand the Wymaha and the gray units the Eetza and Seehoo. Actually, this entire section is younger than the Wymaha that is exposed in the Wadsworth Amphitheater. The thick, reddish fluvial sand here is equivalent to the thin wave-deposited sand of the post-Wymaha (PW in fig. 4) at the Wadsworth Amphitheater. The only equivalent strata to the Wymaha reddish sands on the west side of the Truckee River canyon are poorly sorted conglomerates at the mouths of side canyons similar to those in the Wadsworth Amphitheater.

Near the top of the exposure is a yellow sand rich in shell fragments in which small tufa heads occur. These tufa heads are equivalent to the tufas at the top of STOP 2. The sediments between the tufa and the unit PW are also identical to the sequence at STOP 2. I've interpreted the two blocky white silt beds as predominately turbidites, but they may actually represent more settle-out type sedimentation. The clay just below the tufa has prismatic cracks and is interpeted as a deep lake deposit with a desiccation surface superimposed.

The clays below the reddish sand include a tan ostracode rich clay (unit 5) and a silty clay with three orange silts (unit 6). Elsewhere along this canyon wall the PW sands thin and clay units 7 and 8 can be identified. The deltaic deposits below the lowest clays visible here are similar to those found at STOP 3 where the Wymaha pinches out.

**STOP 5: 0.9 Miles north of S-S ranch on west side of Truckee River**

At this stop we are going to take a look at more erosional features that are due to canyon cutting during low lake stands. As we walk toward the overlook, notice the abundant fragments of tufa on the surface. This is the same tufa we saw at the top of the section at STOP 4. The tufa is found along the edges of the canyon north of here and on the east side at the same elevation (about 1,260 m). The tufa disappears away from the present canyon rim whereever the elevation exceeds 1,261.5 m suggesting that the tufa grew where lake water lapped over the canyon edge forming a broad shallow pool. Since the youngest sediments of the Wadsworth Amphitheater section crop out at 1,270 m, the tufa-precipitating lake waters never reached that elevation. This brings up an important point. Deep-water deposits may overlie surfaces at different elevations but the distribution of shallow-water deposits is elevation sensitive. This is illustrated by looking at the distribution of different units as a function of elevation. The "pipeline" road that we took to this locality crosses an old railroad line about 1.5 miles west of the canyon. The bluff there exposes deposits over elevations from about 1,250 to 1,266 m (fig. 10A). The turbidite-bearing portion of clay unit 4 (fig. 4) crops out at base roughly at the same elevation it is found at the Wadsworth Amphitheater. Clay unit 4 is overlain by a regressive deltaic sequence, then reddish poorly sorted conglomerate of the Wymaha (W), followed by a thin deltaic sand, a thin wave sorted sand, and tan clay that is recognizable as clay unit 5 (fig. 4) at an elevation of 1,262 m. The elevation of clay unit 5 here is nearly 10 m higher than its elevation at STOP 4, whereas clay unit 4 is only 3 m higher. The lower elevation for clay unit 5 at STOP 4 and the apparent loss of section are attributed to wave erosion and slumping during Wymaha time (fig. 10C).

We are walking southward to an overlook of a steep gully just north of Gardella Canyon. Note the steeply inclined beds dipping westward that are overlain by flat-lying strata (fig. 10B). The youngest of the steeply dipping beds are clay unit 4 including the turbidite-bearing interval and the Wadsworth tephra. The flat-lying beds on top start with a wave-sorted sand that is capped by a tan ostracode-rich clay that is identifiable as unit 5, followed by the characteristic sequence underlying the tufa layer. Notice the soft-sediment folding of the rotated beds. I interpret this as a slump deposit formed during Wymaha time. Notice that the sense of rotation is toward the present canyon. The slump features I mentioned at the Wadsworth Amphitheater have the opposite sense of rotation which is consistent with slumping into the present canyon configuration. The drop in the elevation of deposits following clay unit 5 at STOP 4, that I described above, is consistent with large-scale slumping and/or erosion during Wymaha time and before lake transgression of unit 5.

**STOP 6: Railroad cut 2.4 miles north of turnoff for Numana Fishery**

At this stop we can observe a more proximal occurrence of the tufas that line the canyon to the south. Most of the railroad cut is comprised of a coarse gravel bar with foresets dipping southward and to the east (fig. 11). A thin sequence of silts and sand drape the bar, becoming thicker over the thinner part of the bar. The silts are overlain by tufa which also thins over the highest part of the bar. This whole succession overlies clay units 7 and 8 which are exposed on the bluffs below us. The wave formed bar deposits in the railroad cut are interpreted to be in part coeval with the soil forming episode on unit 10 (as in fig. 9). The silt drape is equivalent to the transgressive sand just below the tufa elsewhere. The succession described here and in the bluffs below is consistent with the stratigraphy I've described elsewhere including the turbidite-bearing portion of unit 4 and my Wadsworth tephra.

**SUMMARY**

The sedimentary record of the Truckee River includes a complex mix of fluvial, deltaic, and lacustrine environments. There are at least 10 mappable units of lacustrine clay and silty clay that represent periods of deep lake deposition exposed in the canyon. The thickest sequence of lacustrine silt and clay (unit 4) includes the Wadsworth tephra whose age is estimated at 201,000 ±45 BP using thermoluminescence (Berger, 1991) and is estimated at 160,000±25 BP by chemical comparison to ashes from other basins (Sarna-Wojcicki and Davis, 1991). Sediments that predate the Wymaha formation of Morrison and others (1965) at the Wadsworth Amphitheater characteristically consist of deep lake clays grading upward into stacked Gilbert deltas that are cut be transgressive wave deposits then sharply capped by deep lake clays. These successions illustrate the drowning of drainages by transgressing lakes, then higher sedimentation rates during regressing lakes as high stand deposits are eroded. Sedimentary deposits above the Wadsworth Amphitheater Wymaha have more complicated lateral relationships and in many cases have little or no regressive deltaic deposits. This is interpreted as evidence of a Truckee River canyon cut during Wymaha time. Slump deposits that underlie the Wadsworth Amphitheater Wymaha are present on both sides of the canyon with rotation that is consistent with the present canyon configuration. The mapping of the Wadsworth Amphitheater Wymaha is complicated by the fact that it is largely not represented by coarse sand and a soil on the west side of the Truckee River, and because a younger fluvial sand (PW) is similar in appearance. Tufa deposits rim the present canyon and are restricted to an elevation of 1,260-1,261.5 m. The tufas at STOP 4 were dated at 12,900±100 using $C^{14}$ (Benson, oral comm.). The tufas were formed during a transgressive event that deposited clays which were subsequently deflated away during subaerial exposure. Two terraces within the present Truckee River canyon are an older wave cut surface veneered by a cobble lag (just below 1,240 m) and younger delta-like muddy deposits that built downflow from side canyon drainages (about 1,230 m). These terraces postdate the tufa deposits and apparently predate the Tsoyawata tephra (about 7,000 BP; Sarna-Wojcicki and Davis, 1991).

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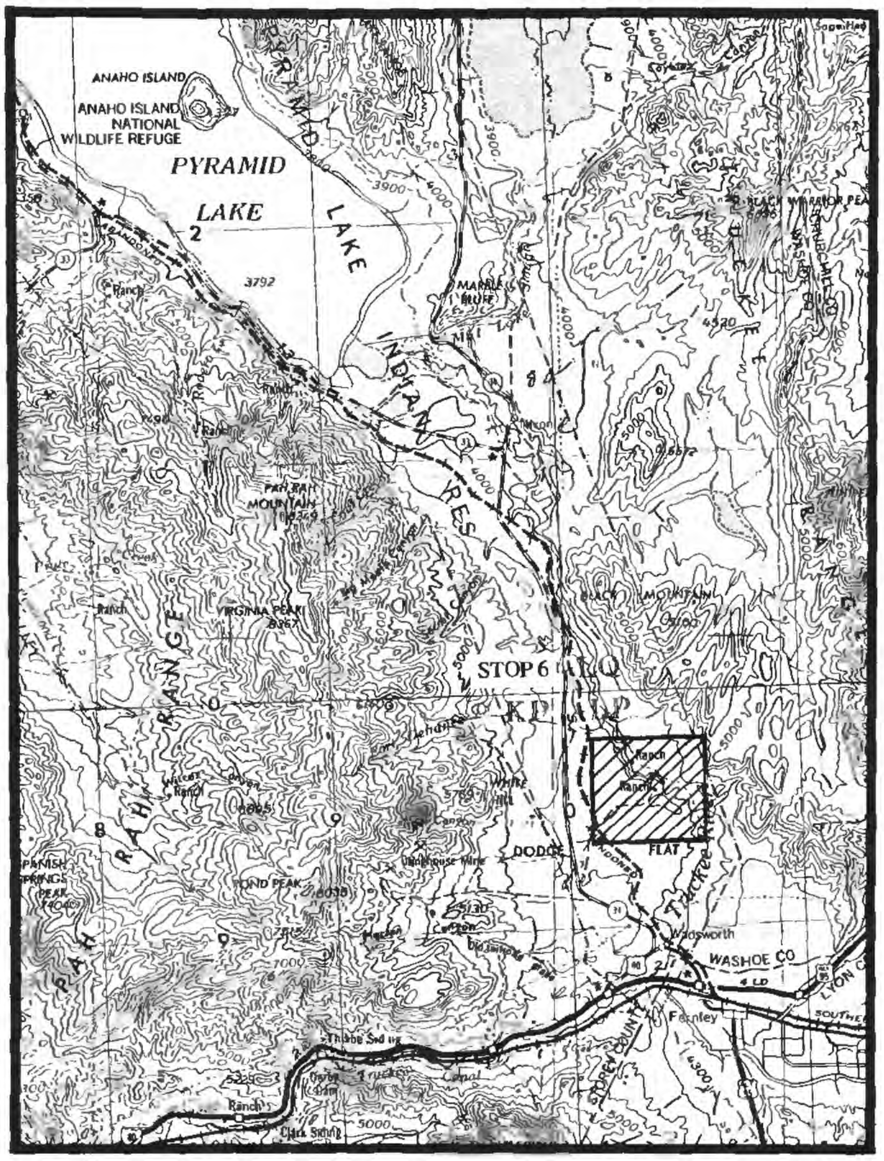
Figure 1. Location map of field trip in Truckee River canyon north of Wadsworth (A). Box shows location of area shown in (B).


ANAHO ISLAND
ANAHO ISLAND NATIONAL WILDLIFE REFUGE
PYRAMID LAKE
PYRAMID LAKE
3792
INDIAN RES
PAH RAH MOUNTAIN
VIRGINIA PEAK
BLACK MOUNTAIN
STOP 6
PAH RAH RANGE
DODGE
FLAT
POND PEAK
Wadsworth
WASHOE CO
Fernley

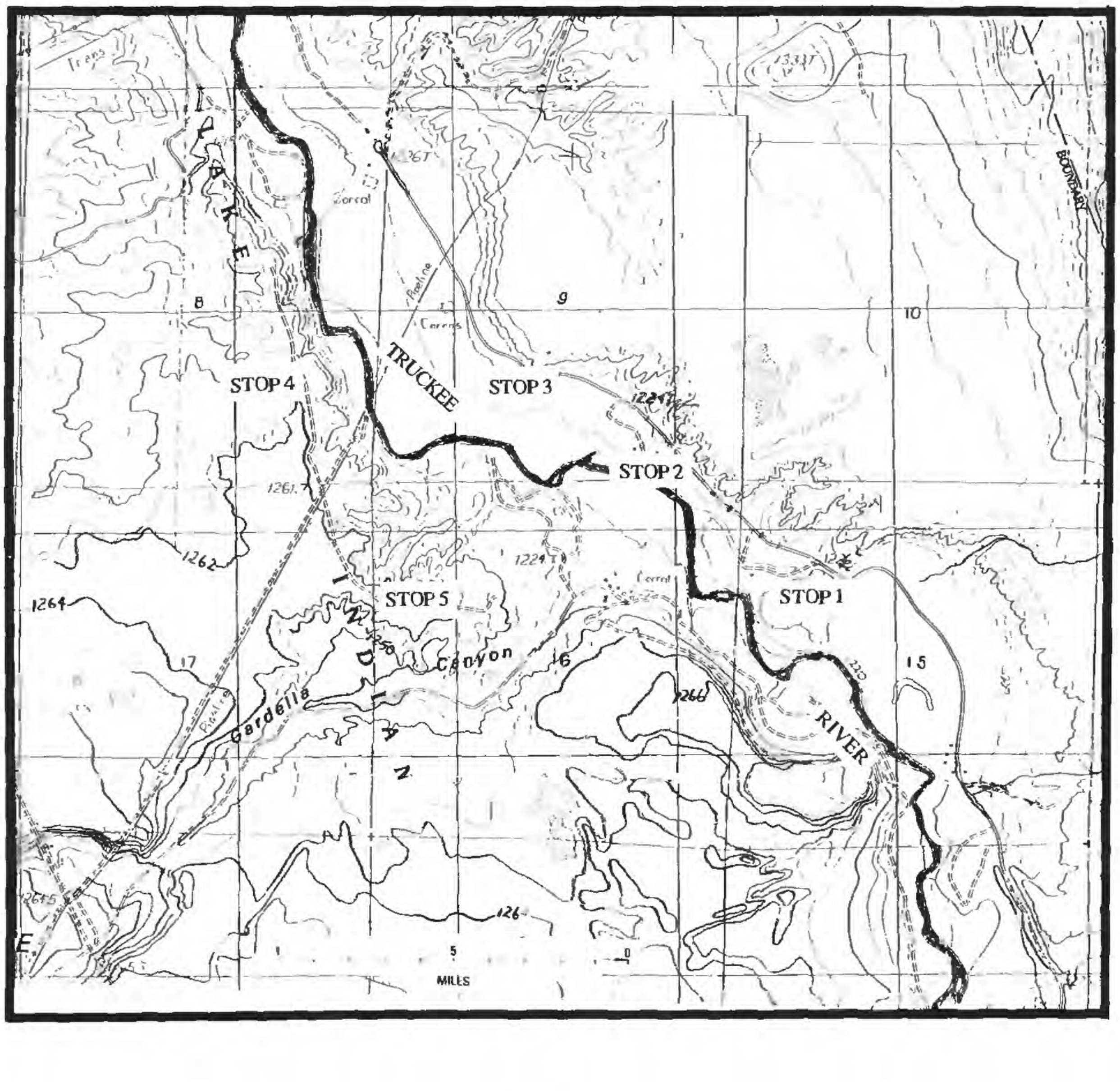

LAKE
TRUCKEE
RIVER
STOP 1
STOP 2
STOP 3
STOP 4
STOP 5
INDIAN
Gardella
Canyon
BOUNDARY
MILES

Figure 2. Depositional processes in lacustrine clay. (A) Flat laminae formed in an anoxic lake bottom. (B) Vague layering with horizontal burrows formed at the surface of anoxic lake bottom sediment. (C) Random burrows and vague layering formed in oxidized lake bottom sediment. (D) Turbidity-flow deposit formed in an environment typically dominated by settle-out deposition. (E) Oscillatory ripples formed by storms in an environment typically dominated by settle-out deposition.

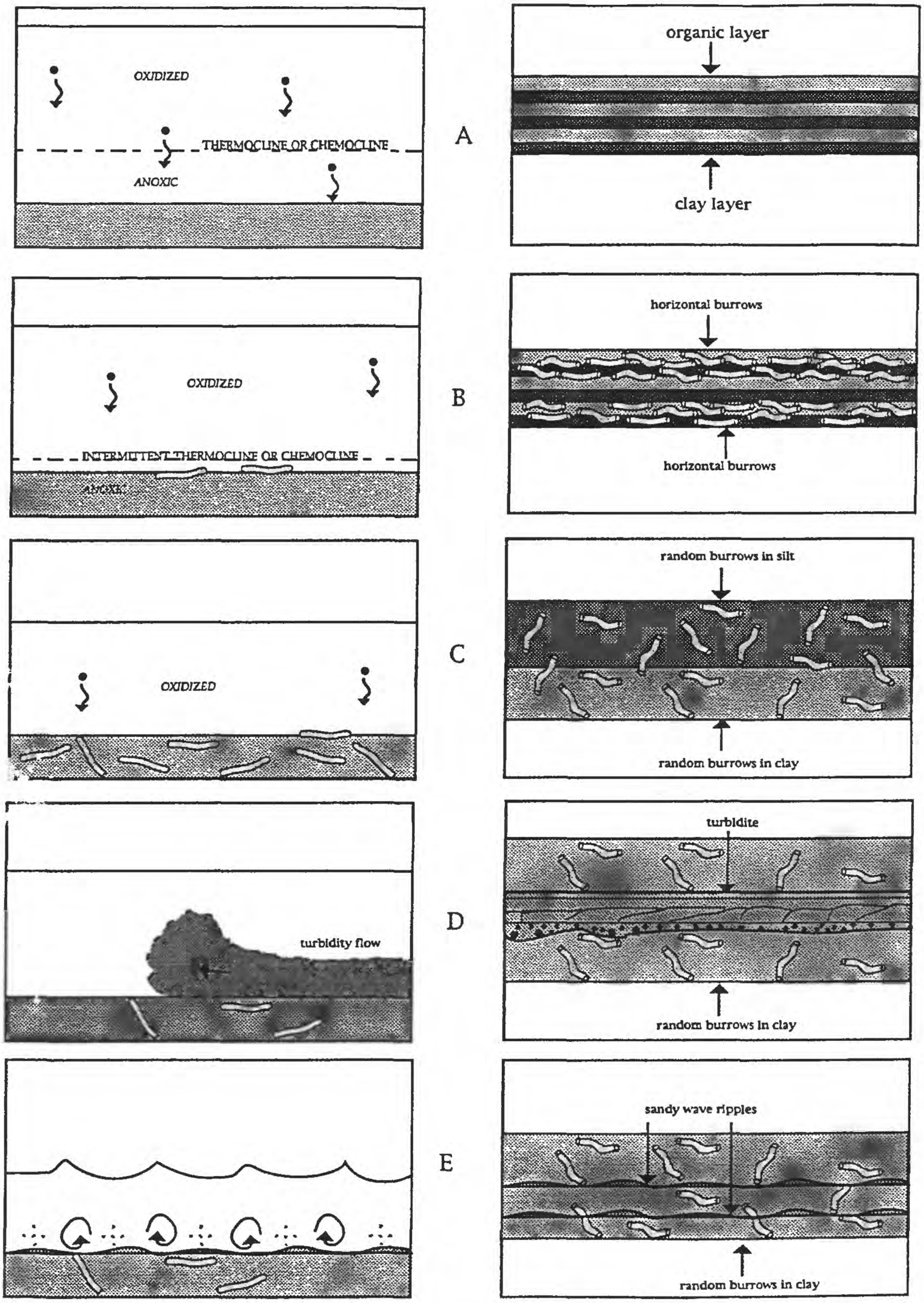
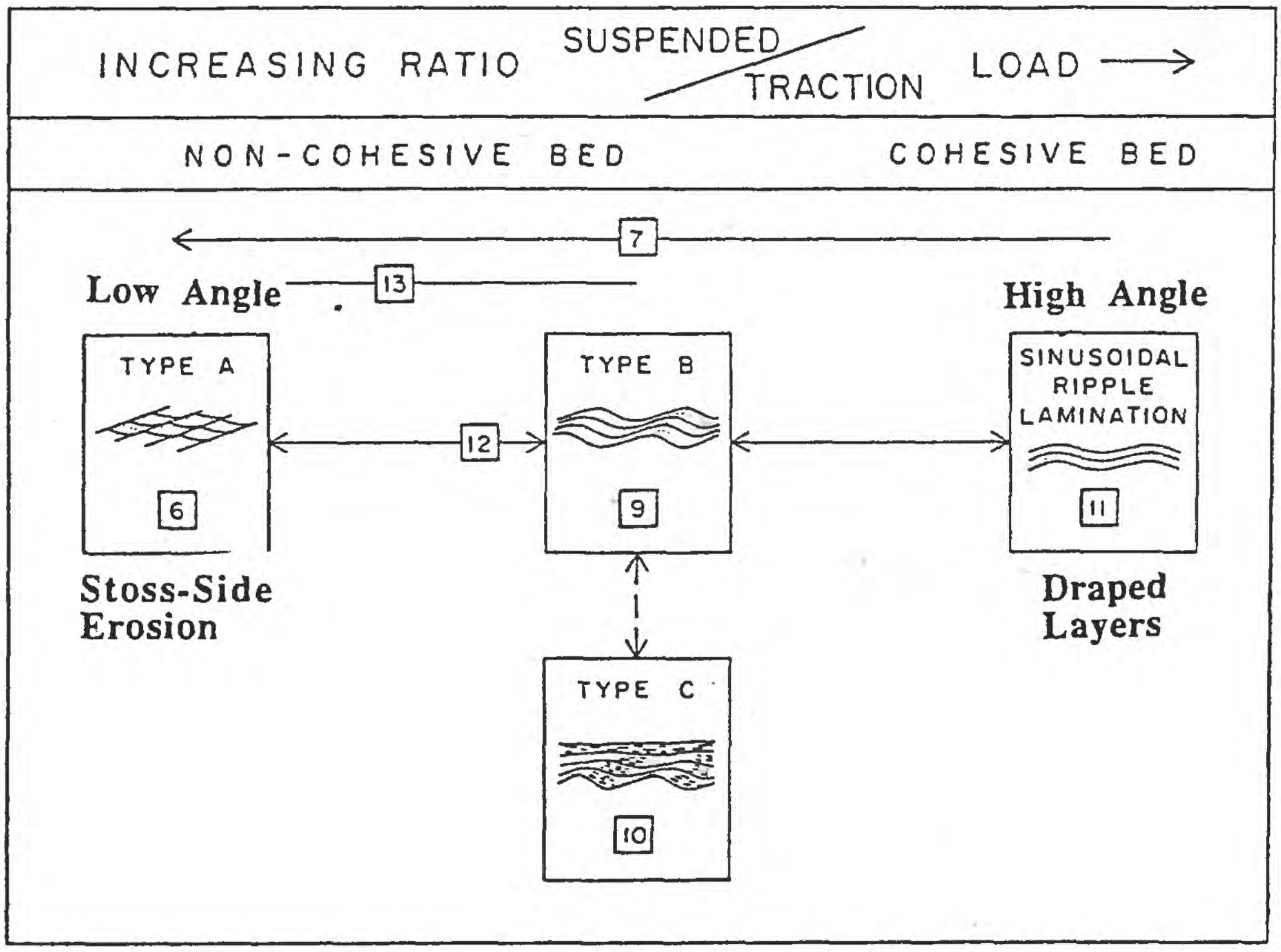
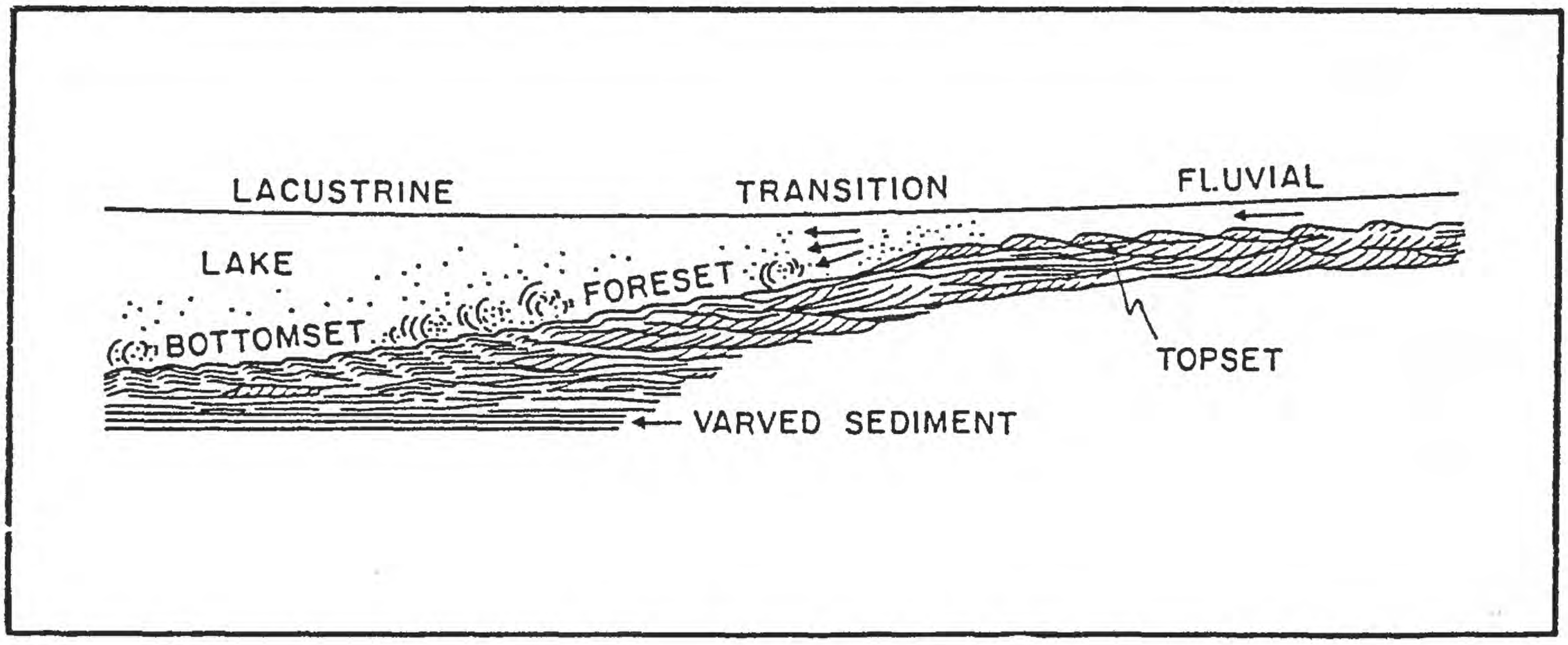

OXIDIZED
THERMOCLINE OR CHEMOCLINE
ANOXIC
organic layer
clay layer
A
OXIDIZED
INTERMITTENT THERMOCLINE OR CHEMOCLINE
horizontal burrows
horizontal burrows
B
OXIDIZED
random burrows in silt
random burrows in clay
C
turbidity flow
turbidite
random burrows in clay
D
sandy wave ripples
random burrows in clay
E

Figure 3. The formation of ripple cross-lamination on delta fronts. (A) Relation between flow velocity and sediment concentration on type of climbing ripple cross-lamination. Higher velocity to left (steeper slope) and higher suspended load to right. (B) Distribution of climbing ripple cross-lamination on a low-slope delta. From Jopling and Walker, 1968.

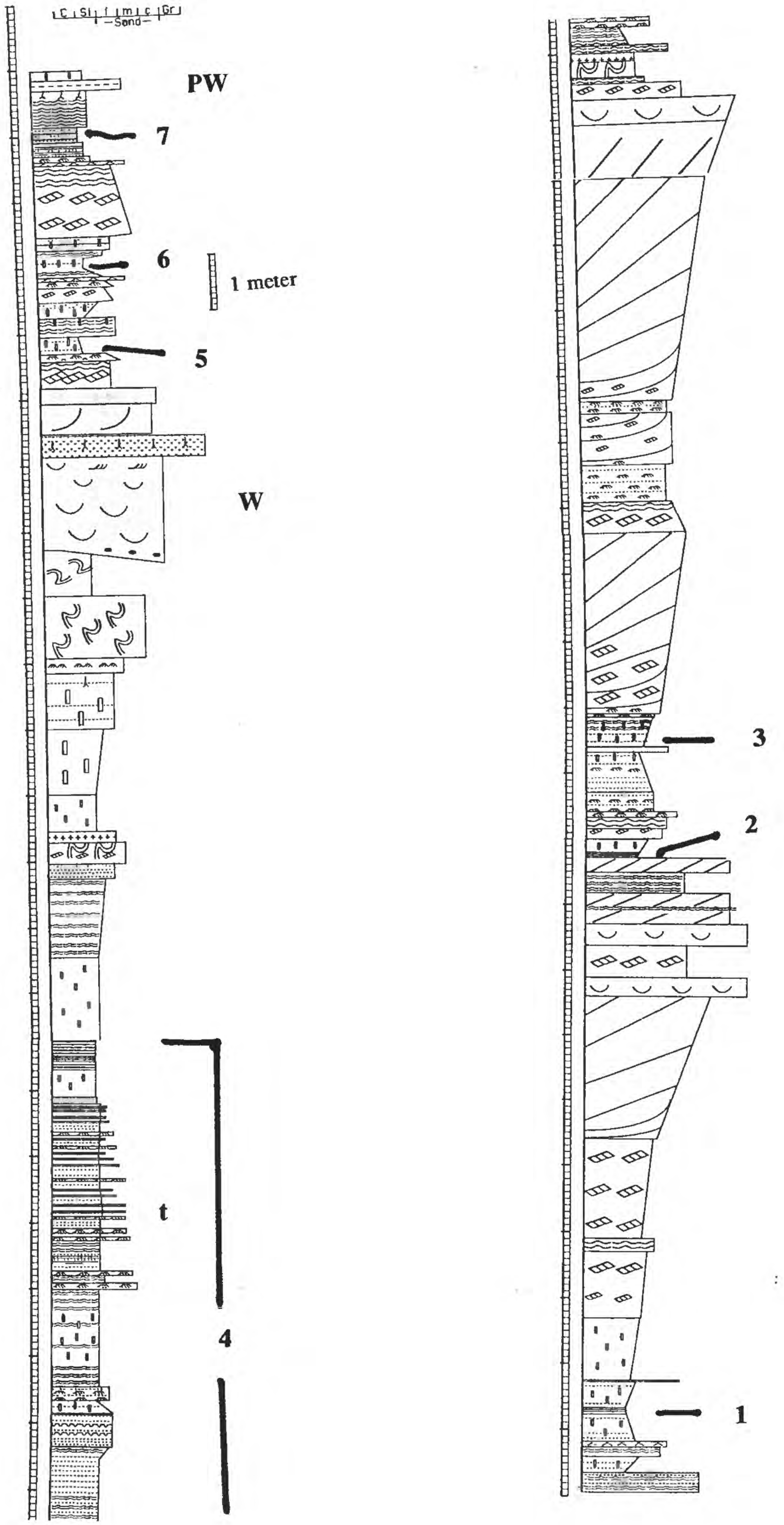

INCREASING RATIO SUSPENDED / TRACTION LOAD
NON-COHESIVE BED
COHESIVE BED
7
Low Angle
13
High Angle
TYPE A
6
Stoss-Side Erosion
12
TYPE B
9
SINUSOIDAL RIPPLE LAMINATION
11
Draped Layers
TYPE C
10

A


LACUSTRINE
TRANSITION
FLUVIAL
LAKE
FORESET
BOTTOMSET
TOPSET
VARVED SEDIMENT

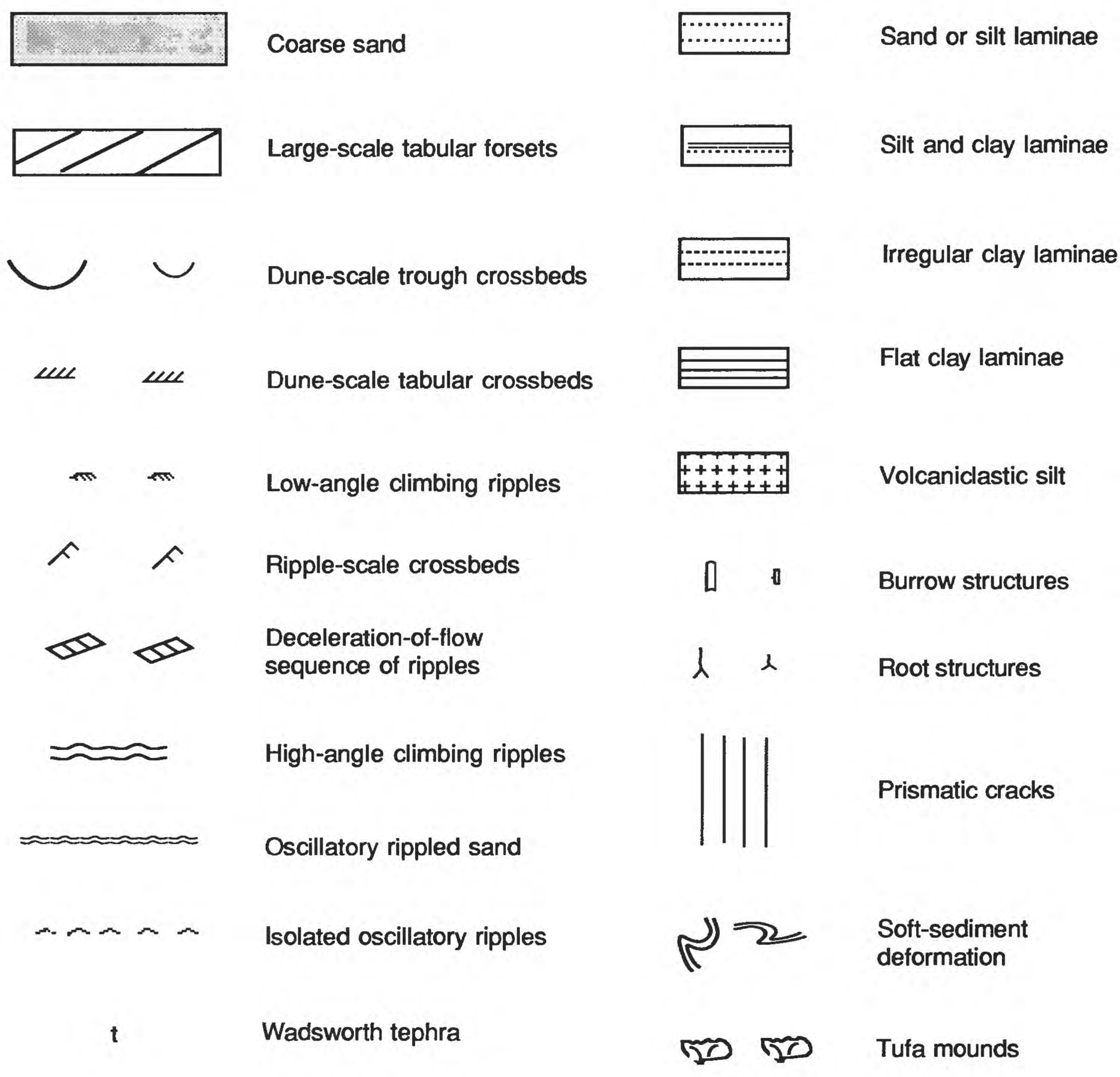
B

Figure 4. (A) Stratigraphic section at STOP 1. Numbers refer to correlative clay units. "W" is the Wymaha bed of Morrison and others (1965) and PW is the younger sandy unit that resembles the Wymaha. (B) Legend of symbols used in the stratigraphic sections.


C Si f m c Gr
Sand
PW
7
6
1 meter
5
W
t
4
3
2
1

# B

# LEGEND



Coarse sand
Large-scale tabular forsets
Dune-scale trough crossbeds
Dune-scale tabular crossbeds
Low-angle climbing ripples
Ripple-scale crossbeds
Deceleration-of-flow sequence of ripples
High-angle climbing ripples
Oscillatory rippled sand
Isolated oscillatory ripples
t
Wadsworth tephra
Sand or silt laminae
Silt and clay laminae
Irregular clay laminae
Flat clay laminae
Volcaniclastic silt
Burrow structures
Root structures
Prismatic cracks
Soft-sediment deformation
Tufa mounds

Figure 5. (A) Typical lateral relationships of medium to coarse sand (light), fine sand and silt with climbing ripple cross-lamination (medium) and silty clay (dark) in stacked Gilbert-type delta deposits. (B) How lake level fall produces thin upward-coarsening delta deposits.

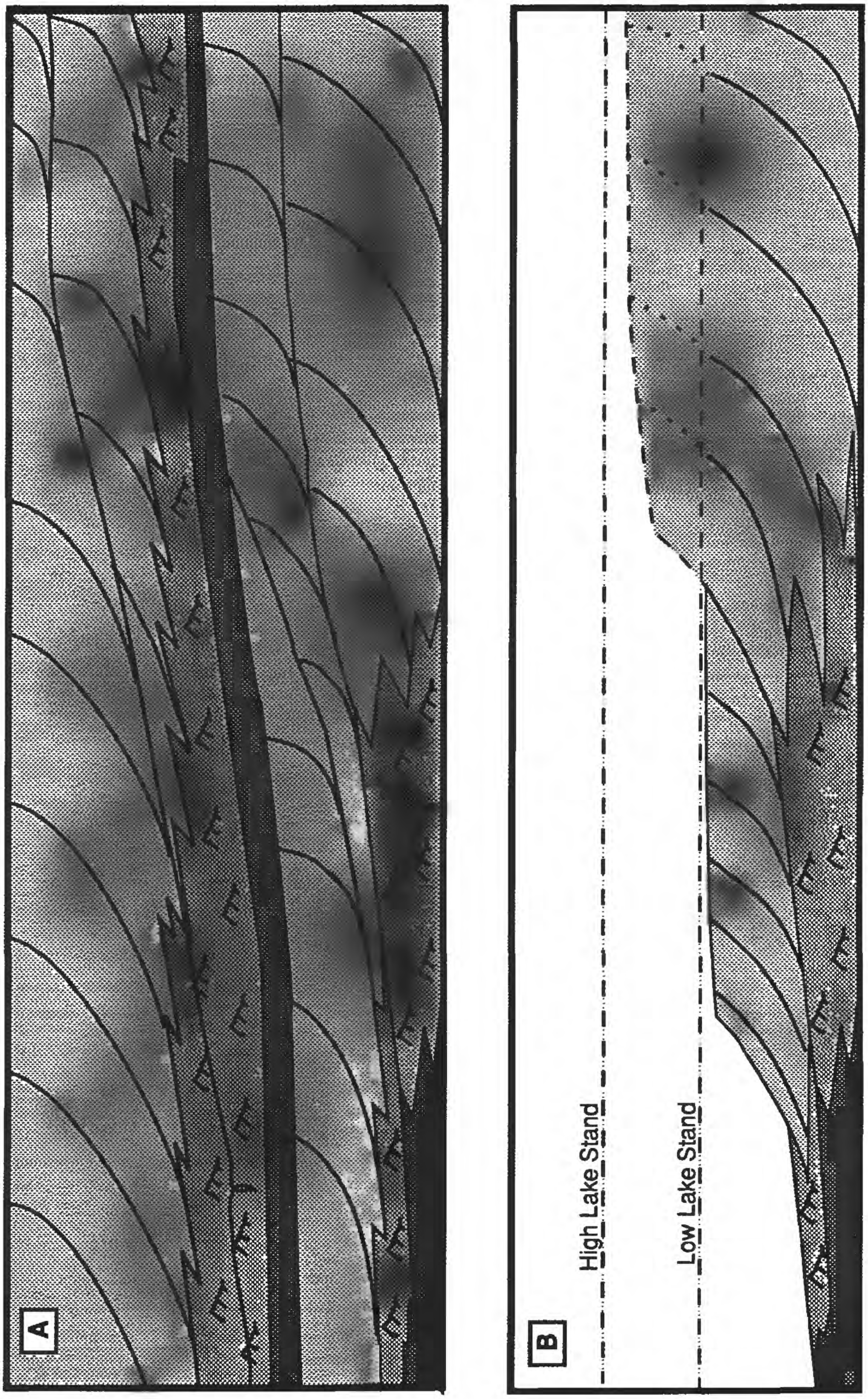
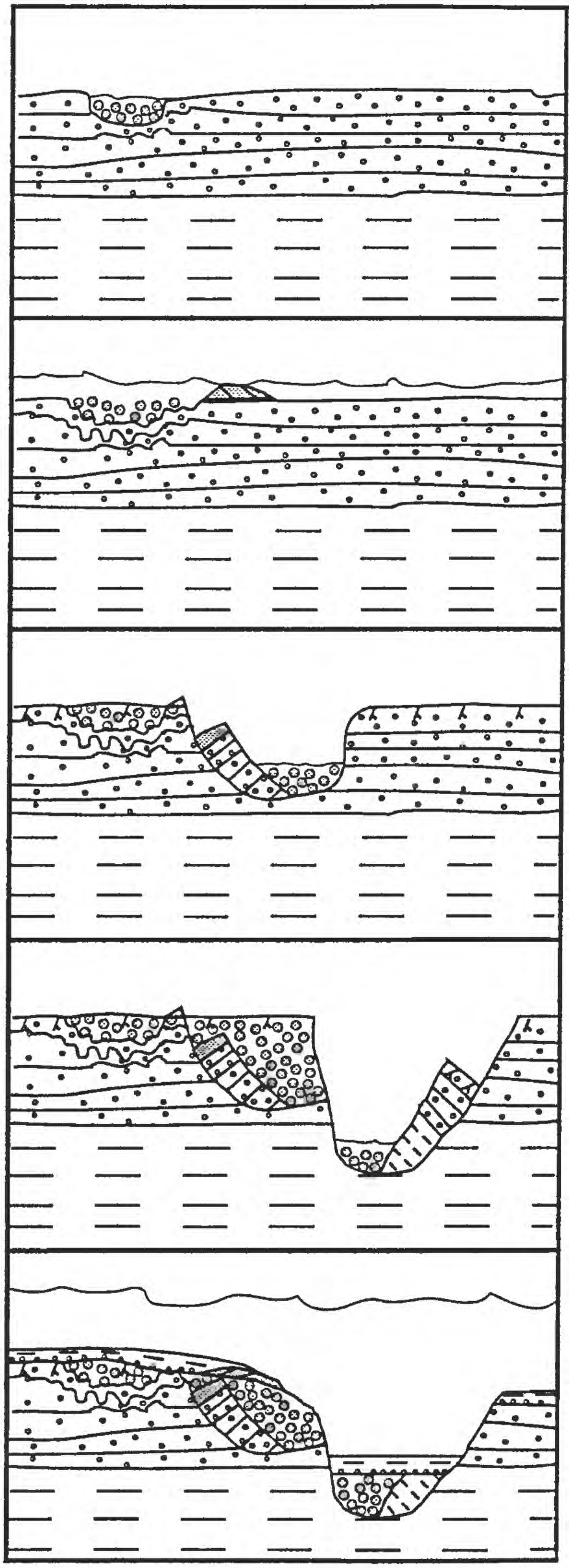

A
B
High Lake Stand
Low Lake Stand

Figure 6. Schematic showing the development of complex sedimentary relationships of the Wymaha bed in the Truckee River canyon. Large dots are coarse sand. Small dots are fine sand. Dashes are silt and clay. Wave-sorted sand is depicted by patterned area with crossbeds. Roots are represented by the lambda shape.



1. Channel entrenched into regressive delta overlying clay unit 4.

2. Minor transgression of lake causes fluidization of sand and deposition of wave deposits near channel

3. During major regression channel entrenchment causes slumps. Soils form on higher surfaces.

4. Further entrenchment of channel allows larger slumps to form.

5. Lake transgression leads to wave erosion of all surfaces leaving only remnants of soils. Lake clay drapes everything.

Figure 7. Stratigraphic section at STOP 2. See Figure 4B for explanation of symbols.

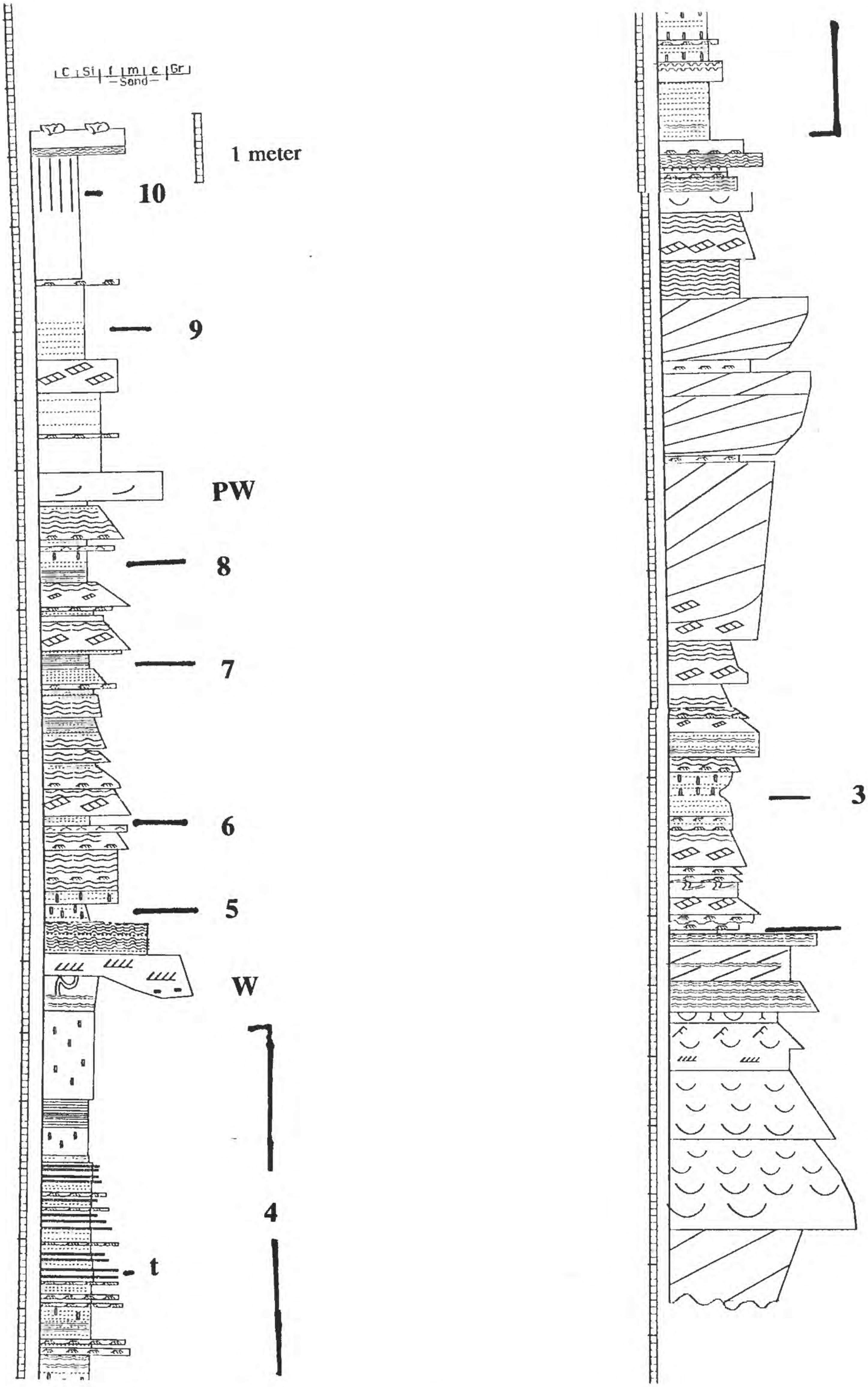

C Si f m c Gr
Sand
1 meter
10
9
PW
8
7
6
5
W
4
t
3
2

Figure 8. Sedimentary relationships at STOP 3 where the Wymaha bed (W) pinches out. Unit 4 and unit 5 refer to correlable clay beds in figures 4, 7, and 9. Inclined beds to the left of the Wymaha are deltaic foresets with climbing ripple cross-lamination at the base. Chevron shapes indicate wave-formed deposits. Vertical thickness shown is about 4 m.

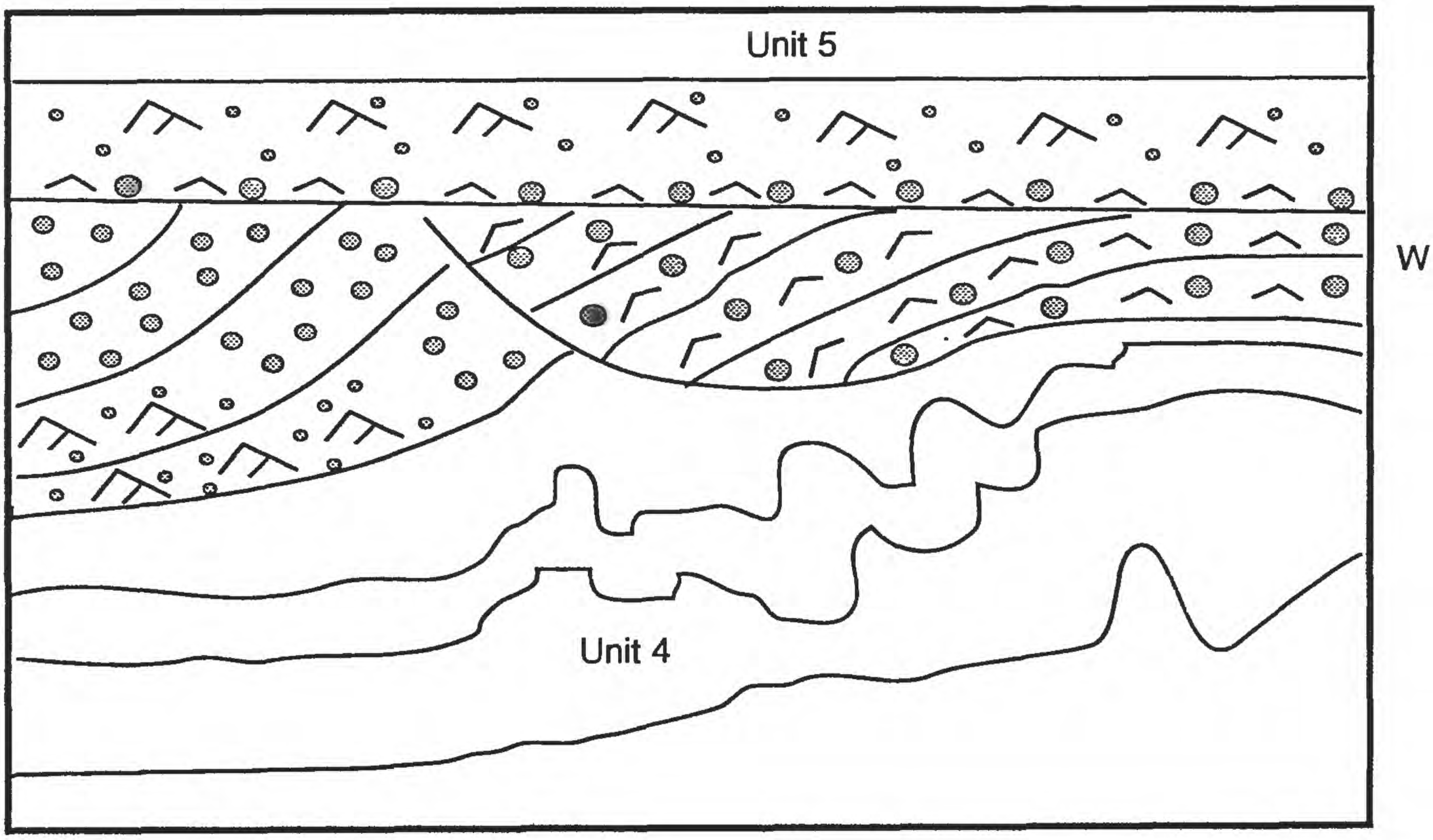
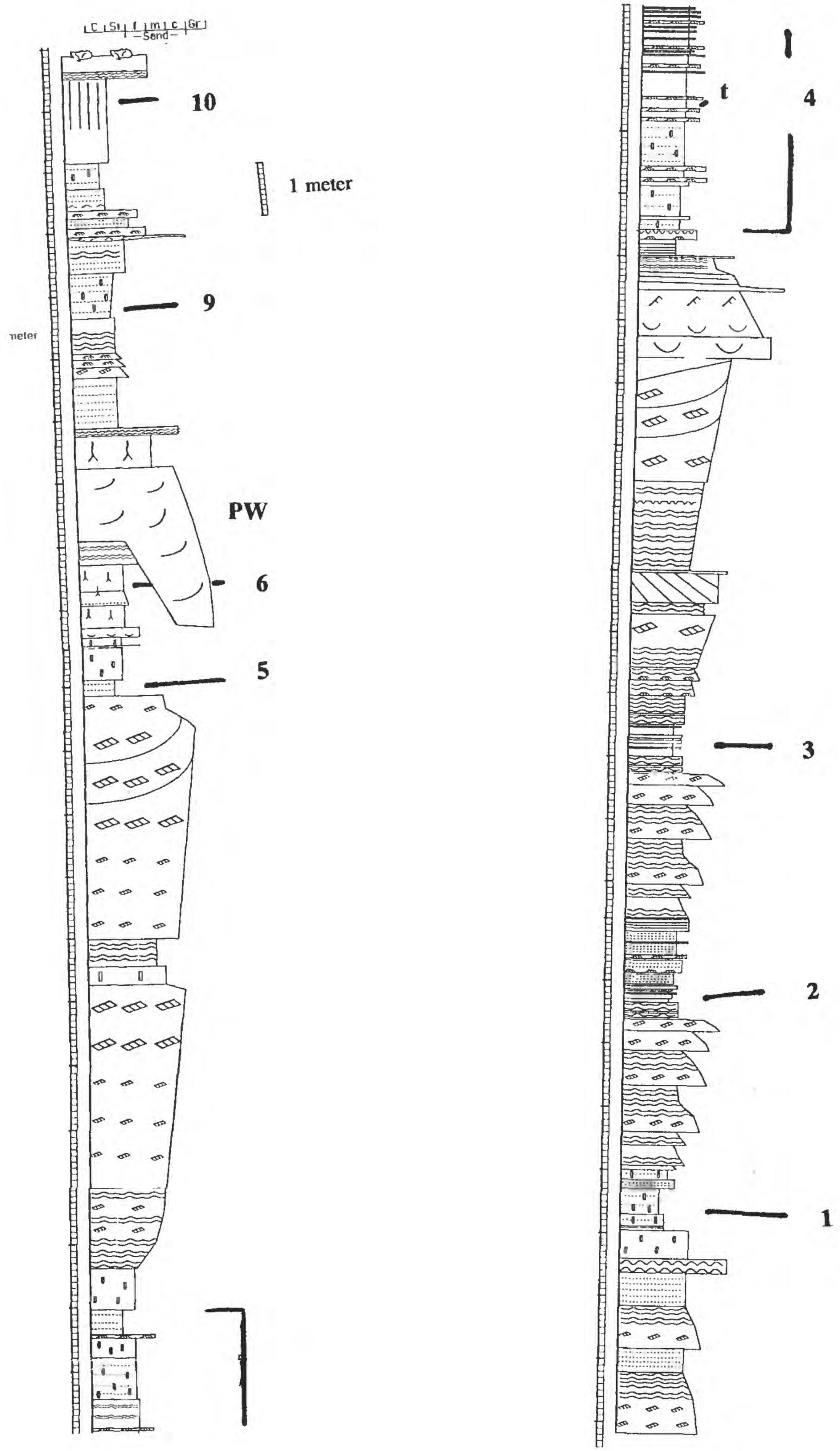

Unit 5
W
Unit 4

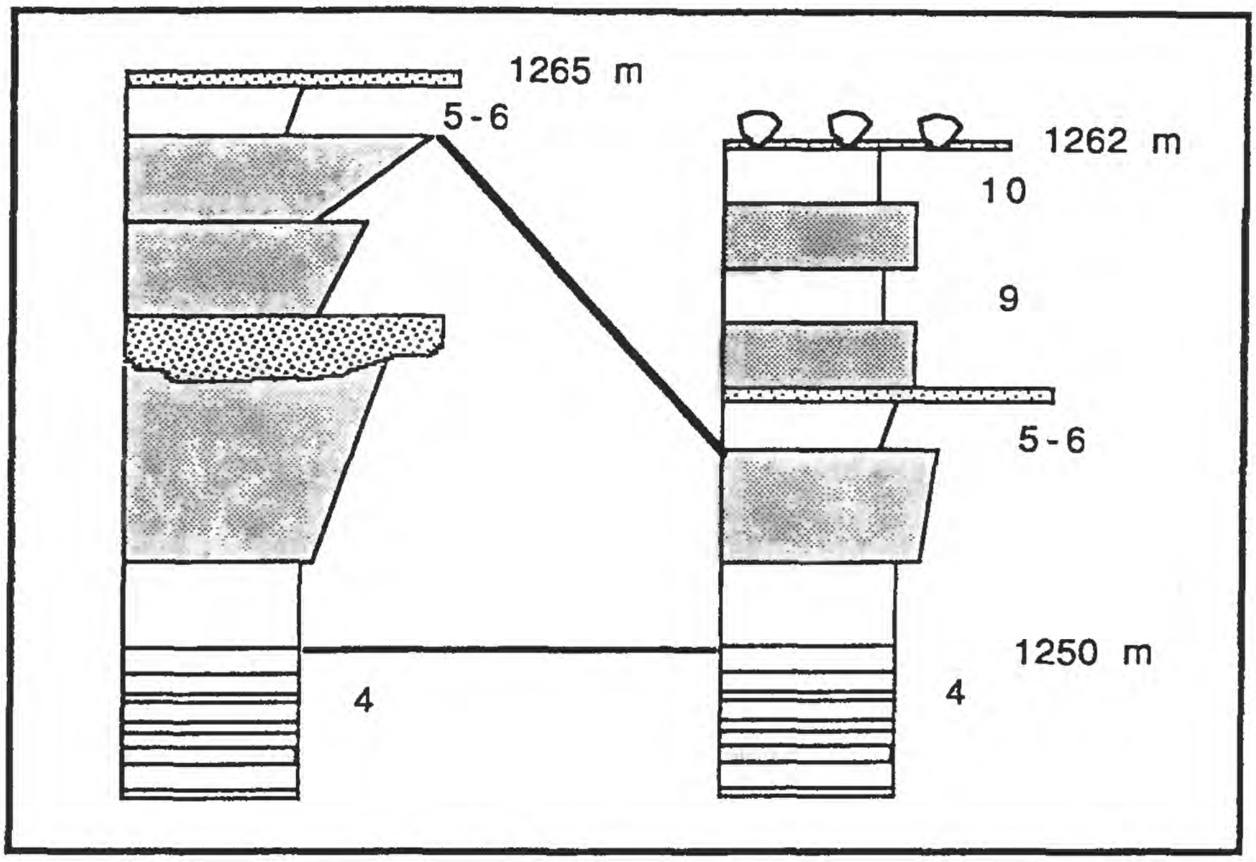
Figure 9. Stratigraphic section at STOP 4. See Figure 4B for explanation of symbols.



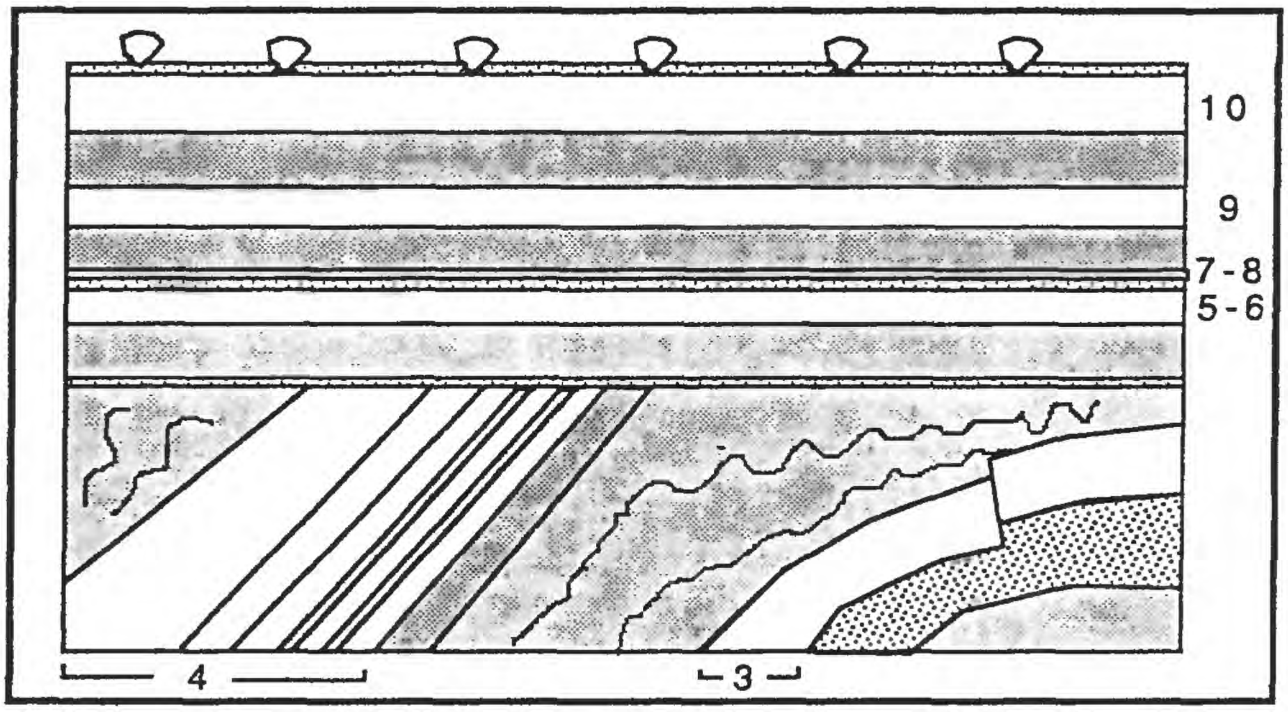
C Si f m c Gr
Sand
10
1 meter
9
PW
6
5
t
4
3
2
1

Figure 10. (A) Correlation of deposits near the railroad line crossing the pipeline road (RR on (fig. 1) and the deposits near STOP 4. Numbers refer to correlable clay beds in (fig. 4, 7, and 9. (B) Relationships of slumped lacustrine deposits unconformably overlain by lacustrine deposits at STOP 5. Numbers refer to correlable clay beds in (fig. 4, 7, and 9. Squiggly lines in medium to fine sand (shaded) indicate soft-sediment deformation. (C) Schematic diagram showing slumped lacustrine beds (1) into the Wymaha canyon, drape of younger lacustrine beds (2) at different elevations, and wave-cut terrace with tufa heads (3) during later transgression up the Truckee River canyon.

A




B




C

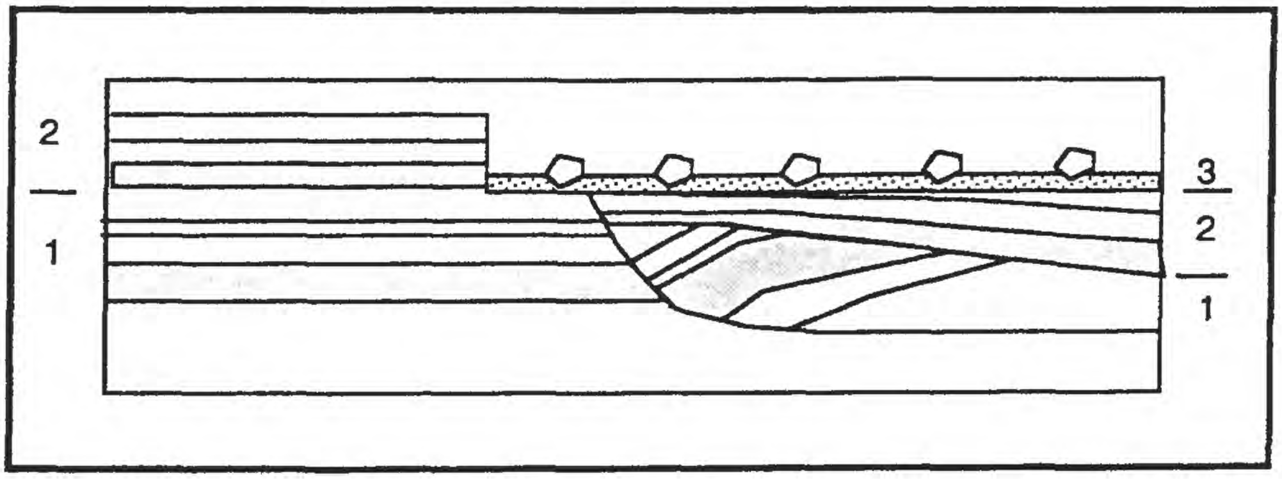


Figure 11. Wave-formed conglomerate bar at STOP 6 draped by lacustrine silt and ostracodal sand (shaded area) and capped by tufas (white). Largest tufa heads have sandy layer separating two growths. Thickness of outcrop is about 4 m.