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PART 1 ONE

EDITED BY PAUL KARL LINK AND BART J. KOWALLIS

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PROTEROZOIC TO RECENT STRATIGRAPHY, TECTONICS, AND VOLCANOLOGY, UTAH, NEVADA, SOUTHERN IDAHO AND CENTRAL MEXICO

Edited by
Paul Karl Link and Bart J. Kowallis

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Cover photos taken by Paul Karl Link.

Top: Upheaval Dome, southeastern Utah.

Middle: Lake Bonneville shorelines west of Brigham City, Utah.

Bottom: Bryce Canyon National Park, Utah.

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Preface

Guidebooks have been part of the exploration of the American West since Oregon Trail days. Geologic guidebooks with maps and photographs are an especially graphic tool for school teachers, University classes, and visiting geologists to become familiar with the territory, the geologic issues and the available references.

It was in this spirit that we set out to compile this two-volume set of field trip descriptions for the Annual Meeting of the Geological Society of America in Salt Lake City in October 1997. We were seeking to produce a quality product, with fully peer-reviewed papers, and user-friendly field trip logs. We found we were bucking a tide in our profession which de-emphasizes guidebooks and paper products. If this tide continues we wish to be on record as producing "The Last Best Geologic Guidebook."

We thank all the authors who met our strict deadlines and contributed this outstanding set of papers. We hope this work will stand for years to come as a lasting introduction to the complex geology of the Colorado Plateau, Basin and Range, Wasatch Front, and Snake River Plain in the vicinity of Salt Lake City. Index maps to the field trips contained in each volume are on the back covers.

Part 1 "Proterozoic to Recent Stratigraphy, Tectonics and Volcanology: Utah, Nevada, Southern Idaho and Central Mexico" contains a number of papers of exceptional interest for their geologic synthesis. Part 2 "Mesozoic to Recent Geology of Utah" concentrates on the Colorado Plateau and the Wasatch Front.

Paul Link read all the papers and coordinated the review process. Bart Kowallis copy edited the manuscripts and coordinated the publication via Brigham Young University Geology Studies. We would like to thank all the reviewers, who were generally prompt and helpful in meeting our tight schedule. These included: Lee Allison, Genevieve Atwood, Gary Axen, Jim Beget, Myron Best, David Bice, Phyllis Camilleri, Marjorie Chan, Nick Christie-Blick, Gary Christenson, Dan Chure, Mary Droser, Ernie Duebendorfer, Tony Ekdale, Todd Ehlers, Ben Everitt, Geoff Freethey, Hugh Hurlow, Jim Garrison, Denny Geist, Jeff Geslin, Ron Greeley, Gus Gustason, Bill Hackett, Kimm Harty, Grant Heiken, Lehi Hintze, Peter Huntoon, Peter Isaacson, Jeff Keaton, Keith Ketner, Guy King, Mel Kuntz, Tim Lawton, Spencer Lucas, Lon McCarley, Meghan Miller, Gautam Mitra, Kathy Nichols, Robert Q. Oaks, Susan Olig, Jack Oviatt, Bill Perry, Andy Pulham, Dick Robison, Rube Ross, Rich Schweickert, Peter Sheehan, Norm Silberling, Dick Smith, Barry Solomon, K.O. Stanley, Kevin Stewart, Wanda Taylor, Glenn Thackray and Adolph Yonkee. In addition, we wish to thank all the dedicated workers at Brigham Young University Print Services and in the Department of Geology who contributed many long hours of work to these volumes.

Paul Karl Link and Bart J. Kowallis, Editors

Carbonate Sequences and Fossil Communities from the Upper Ordovician—Lower Silurian of the Eastern Great Basin

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ABSTRACT

Upper Ordovician-Lower Silurian carbonates of the eastern Great Basin (western Utah to central Nevada) are well-exposed and allow regional comparisons of depositional facies, sequence stratigraphy, and paleontologic communities. The facies patterns indicate that a west-dipping ramp was converted to a rimmed shelf in the Early Silurian (Llandovery). Three facies comprise shelf and shallow-to-middle ramp sections to be examined during the trip: laminite facies (tidal flat), burrowed facies (low-energy subtidal), and cross-bedded facies (high-energy subtidal). Deep ramp and slope facies will not be visited during the field trip. Facies successions and exposure features (karst horizons, soils) delineate eight ramp sequences (five Ordovician and three Silurian) succeeded by three rimmed shelf sequences that are regionally correlative.

Faunal communities are stable within sequences and turnovers coincide with sequence boundaries. Ordovician communities are part of the endemic North American Zoographic Province except for the Hirnantian fauna which coincided with the glaciations and extinctions at the end of the Ordovician. The initial (sequences S1 and S2) Silurian communities were dominated by *Virgiana*, a cosmopolitan brachiopod that survived the Ordovician extinctions and invaded a range of ecological habitats during the post-extinction community reorganization. In the overlying sequence S3 (Aeronian), the *Virgiana* habitat was subdivided toward the end of the reorganization interval as communities diversified. Later communities in sequence S4 to S6 are marked by within community evolution with little ecologic innovation (i.e., ecologic stasis). Our integrated study of the sedimentology, stratigraphy, and paleontology suggests that physical changes associated with relative sea level falls (sequence boundaries) were the major disruptions of community stability.

INTRODUCTION

Great Basin outcrops expose spectacularly complete sections of Upper Ordovician-Lower Silurian carbonate units that allow comparisons of depositional facies, sequence stratigraphy, and paleontologic communities. We will argue in support of four major interpretations during the trip:

1. Facies patterns indicate that a west-dipping ramp was succeeded by a rimmed shelf in the Early Silurian (middle Llandovery). Facies are well preserved despite pervasive dolomitization.
2. A sequence stratigraphic interpretation can be built from facies patterns and the distribution of exposure features. Criteria for recognizing sequence boundaries vary across the depositional profile.
3. The Silurian faunal communities illustrate a step-wise recovery from the Late Ordovician (Hirnantian) mass extinction.
4. Our field data suggest that community reorganizations occurred during shelf exposure intervals represented by sequence boundaries. We interpret this to mean that physical parameters are important factors in long-term community stability.

The following sections on facies, sequences, and communities consider the general patterns in the Upper Ordovician-Lower Silurian strata of the Great Basin. Detailed discussions of each stop follow the main text and the road log is at the end of the article. The stops form a west-to-east traverse across the shelf. (This arrangement simplifies logistics because it allows us to stay in Ely, Nevada all three nights.) The Pancake Range section (Stop 1) shallows from middle ramp facies to shallow shelf. The southern Egan Range (Stop 2) and Barn Hills (Stop 3) sections are located in more shelfward locations. Our brief, optional Stop 4 (East Tintic Mountains) is dominated by inner shelf facies. Our goal is to stimulate your thinking about lateral and vertical changes in facies, sequences, and communities. We hope that you enjoy the trip.

GEOLOGICAL SETTING

The Late Ordovician-Early Silurian continental margin of Laurentia extended roughly north-south although it swings east-west along the north flank of the Tooele Arch (Sheehan, 1980a; Budge and Sheehan, 1980a; Sheehan and Boucot, 1991). In the Paleozoic, this arch was a basement feature that divided the shelf into a northern Tristate Basin and a southern Ibex Basin (Fig. 1) (Poole et al., 1992).

The Upper Ordovician carbonate ramp (Fish Haven Dolostone, Ely Springs Dolostone, and Hanson Creek Formation) deepened to the west (Carpenter et al., 1986; Sexton, 1994) (Fig. 2 and 3A). Glacially-driven sea-level changes created a shelf exposure surface at the Ordovician-Silurian boundary (Sheehan, 1973). Ramp facies continue into the overlying lower to middle Llandovery strata (Carpenter et al., 1986).

In the late Llandovery, tectonic collapse (probably due to basement faulting) converted the ramp into a rimmed shelf (Fig. 3B and 4) that continued into the Early Devonian (Johnson and Potter, 1975; Hurst et al., 1985; Hurst and Sheehan, 1985). Although basin, slope, and outer shelf facies differ from the previous ramp deposits, inner and middle shelf facies (Laketown Dolostone) are similar (Winterer and Murphy, 1960; Matti et al., 1975; Matti and McKee, 1977; Nichols and Silberling, 1977; Cook 1984; Hurst and Sheehan, 1985; Sheehan, 1990; Harris and Sheehan, 1996a).

FACIES

During the trip, we will examine three stratigraphic sections that consist of Upper Ordovician-middle Llandovery (Early Silurian) ramp and shelf lagoon facies capped by late Llandovery-Wenlock shelf lagoon sediments deposited behind a rimmed margin. Three facies comprise the shallow-to-middle ramp and shelf sections visited during the trip (Table 1). Each facies corresponds to a specific depositional environment and consists of several subfacies (Table 2) (Harris and Sheehan, 1996a). The laminite facies (tidal flats) is characterized by laminite-capped cycles (Fig. 5A). The cross-bedded facies (subtidal shoals) is marked by coarsening- and shallowing-upward cycles capped by cross-bedded oolitic or oncoidal grainstone

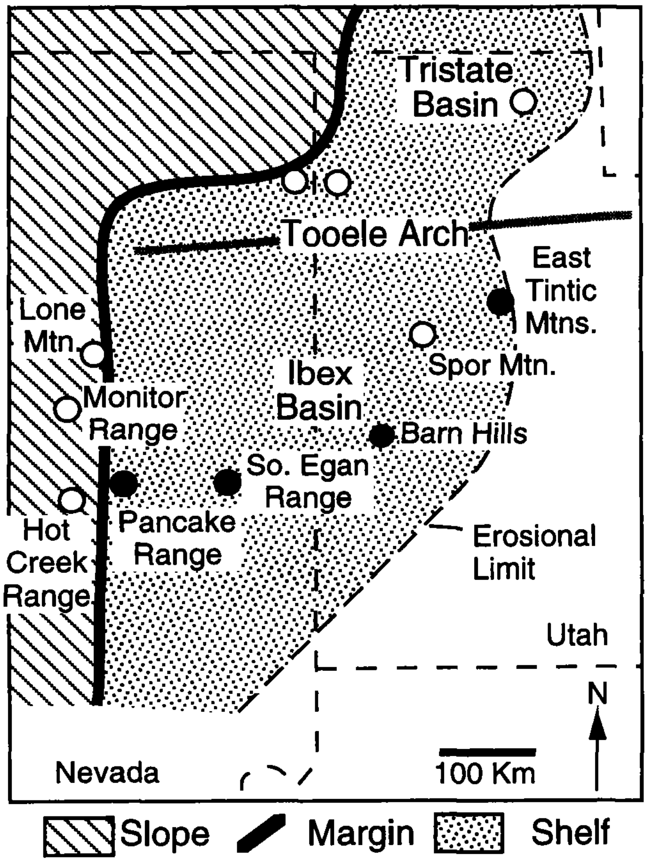


Figure 1. Late Ordovician paleogeographic map with stop locations (solid circles) and locations of other detailed measured sections. Detailed locations for all locations in Budge and Sheehan (1980a, 1980b). Locations of field stops presented in the road log.

(Fig. 5B). The burrowed facies (subtidal shelf and ramp) contains abundant burrows with scattered storm beds; textures range from grain-supported to mud-supported reflecting varied energy levels (Fig. 5C). Deeper water settings (not visited during the field trip and not summarized in Tables 1 and 2) include a bedded facies, characterized by turbidities and other redeposited sediments, and a basinal facies consisting of shales, siltstones, and carbonate mudstones.

Ramp phase

Shelf facies are dominated by laminite facies and mud-supported burrowed facies (Fig. 6) (Sheehan, 1990; Harris and Sheehan, 1996a). Tidal flats prograded from the inner shelf shoreline and the Tooele Arch, and subaerial exposure was widespread at the top of each sequence. To the west, cross-bedded facies and burrowed facies (fossiliferous wackestones and packstones) mark the shallow ramp/outer-shelf. Farther west, burrowed facies are more mud-

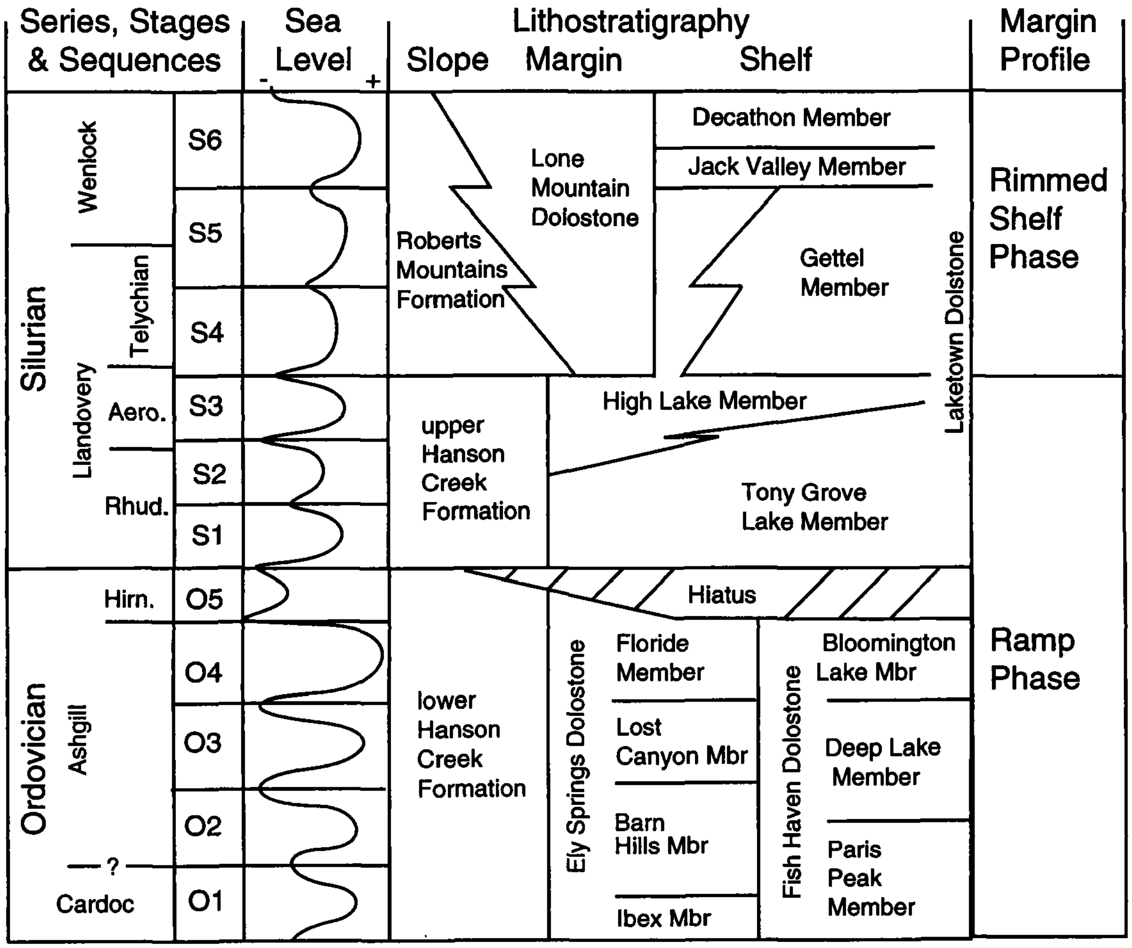


Figure 2. Stratigraphic summary. Shelf nomenclature is modified from Budge and Sheehan (1980a, 1980b). Note that high sea levels are to the right to parallel the figure design and to follow the practice of Silurian workers (Johnson, 1996) The maximum amplitude of sea-level curve is approximately 100 meters. Readers will note that we use the rock term "Dolostone" in place of the mineral "Dolomite" in the stratigraphic nomenclature throughout this article.

supported and have fewer physical structures, reflecting middle to deep ramp conditions above and below storm wave base. The most distal sections are starved-basin mudstones and shales.

Rimmed-shelf phase

Shelf facies are similar to those in the ramp phase and represent tidal flat and shallow shelf settings (Fig. 6) (Sheehan, 1990; Harris and Sheehan, 1996a). The shelf margin (Lone Mountain Dolostone) consists of stacked shoals that prograded over slope carbonates (Roberts Mountains Formation) (Hurst et al., 1985; Hurst and Sheehan, 1985). Proximal slope carbonates are marked by slumps and thick carbonate turbidites; distal deposits are argillaceous carbonates with thin turbidite beds. Lateral facies changes are abrupt rather than gradational as in the ramp phase.

SEQUENCES

The Upper Ordovician-Lower Silurian carbonate strata consist of eleven (eight ramp phase and three rimmed-shelf phase) sequences bounded updip by unconformities that extend across all or part of the shelf (Fig. 7). Overlying Silurian sequences have been eroded from shelf sections. The available macrofaunal (Berry and Murphy, 1975; Harris and Sheehan, 1997; Sheehan and Harris, 1997) and microfaunal biostratigraphic (Harris et al., 1979; Ross et al., 1979; Murphy, 1989; Kleffner, 1995; Finney et al., 1995) data indicate that each sequence is correlative across the region.

Sequence boundaries are most obvious in shelf sections because of the associated karst surfaces, soils, facies successions, and cycle stacking patterns (Fig. 3) (Harris et al., 1995). In the ramp phase, some sequence boundaries

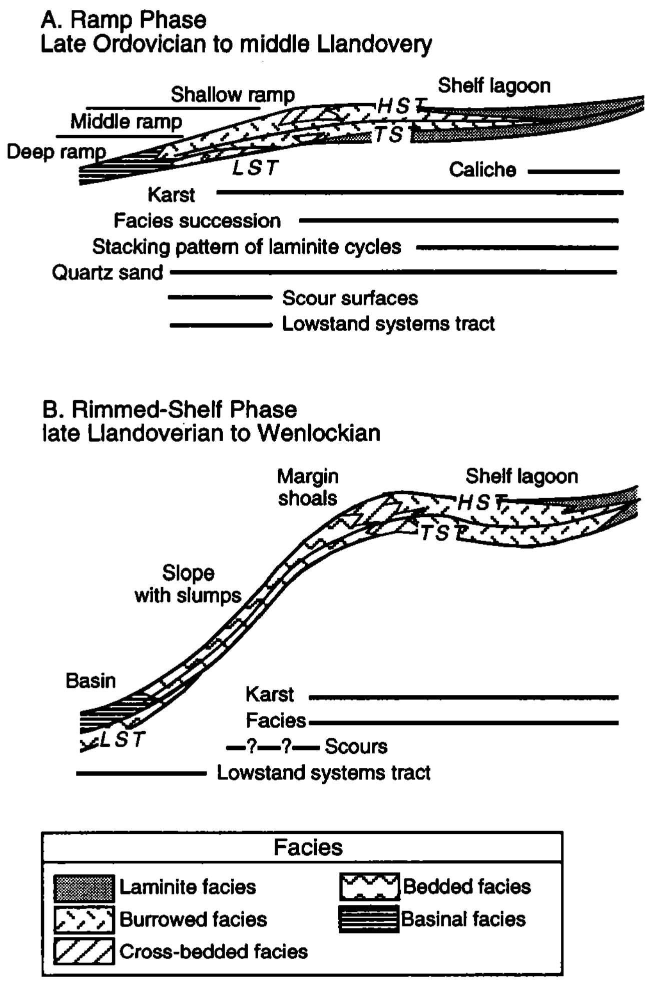


Figure 3. Sequence-keyed facies models and sequence boundary criteria for ramp (A) and rimmed-shelf (B) phases.

extend downdip into middle to deep ramp settings as karst surfaces, others pass into conformable sections with lowstand oncoid shoals, local scour surfaces, or redeposited polymictic breccias. In the rimmed-shelf phase, boundaries are difficult to detect in slope settings due to abundant slumping. In basinal settings, lowstand siliciclastics (siltstones, fine sandstones) may be useable criteria for identifying sequences.

The field stops illustrate many of the facies patterns and sequence-boundary features used to develop this interpretation. In the carbonate ramp sequences (O1 to S3), sequence boundaries occur within laminite tongues in shelf and shallow ramp positions (southern Egan Range, Stop 2, and Barn Hills, Stop 3). In deeper ramp settings, lowstand oncoidal units, scour surfaces and polymictic breccias mark these boundaries or the overlying lowstand deposits (Pancake Range, Stop 1, and the base of the southern Egan Range section, Stop 2). Karst surfaces occur along several sequence boundaries. The best developed is at the top of sequence S2 , as will be observed in the Pancake Range, southern Egan Range, and Barn Hills (Stops 1–3). Maximum flooding surfaces are represented by muddy, burrowed facies or, at the base of the Floride Member of the Ely Springs Dolostone, by platy carbonate mudstones. On a regional scale, the westward progradation of the carbonate ramp is reflected in the westward extent of the laminite facies (Fig. 5, 6).

The field trip will only visit shelf lagoon sections of the rimmed-shelf sequences. (The shelf margin, slope, and basinal facies occur farther west.) The shelf facies grade westward into the Lone Mountain Dolostone, a relatively featureless cross-bedded facies representing the shelf margin shoals. In the Pancake Range (Stop 1), the upper tongue of the High Lake Member of the Laketown Dolostone represents a shelfward extension of the Lone Mountain that pinches out farther to the east. The burrowed facies predominates in most shelf lagoon sections, reflecting the relatively low-energy setting. In some shelf sections (for example, Barn Hills, Stop 3), sequence boundaries are marked by laminite tongues and karst surfaces.

Relative sea-level changes

We can reconstruct a relative water-depth curve by combining sedimentological features and the water depth estimates proposed for Silurian benthic assemblages (Brett et al., 1993). Figure 8 illustrates such a curve for the Barn Hills section (Stop 3) (Harris and Sheehan, 1997). The depth zonation can be used to reconstruct depositional profiles along interpreted time lines corresponding to maximum shelf inundation (maximum flooding surfaces) and maximum exposure (sequence boundaries) (Fig. 9). Water depths along the maximum flooding surface provide a rough topographic profile along depositional transects (Fig. 9B and C). A relative sea-level curve can be constructed using the high and low positions of sea-level related to this profile (Fig. 9C). For example, the extent of downdip exposure features and depth-dependent lowstand facies (i.e. oncoidal shoals) constrain the extent of sea-level fall. A regional sea-level curve (Fig. 2) is produced by repeating this analysis along different profiles and averaging the results. This sea-level curve is only a rough estimate (subsidence and compaction effects have not been considered) but indicates the relative magnitude of Ordovician and Silurian sea-level changes in this region.

COMMUNITIES

Stratigraphic sequences and community ecology

The Late Ordovician extinction was one of the five great Phanerozoic mass extinction events. This event will be

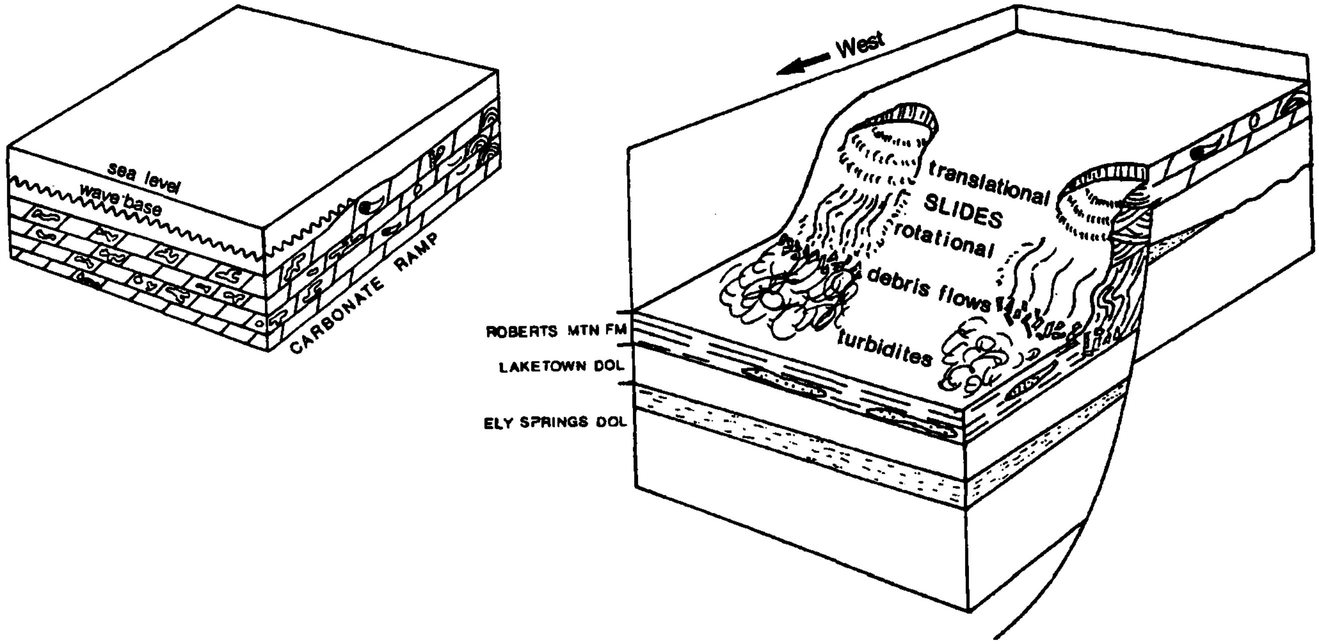


Figure 4. Conversion of carbonate ramp (left) to rimmed shelf (right) in the late Llandovery by downfaulting of the shelf margin (Sheehan, 1986). Ramp phase profile is typical of the Upper Ordovician and early-middle Llandovery (Fig. 2). Faulting downdroped the lower Laketown and Ely Springs Dolostones (as shown) and deeper ramps facies to the west (Hanson Creek Formation).

examined in each of the sections visited on this field trip. The extinction event was caused by climatic changes related to the Late Ordovician (Hirnantian) glaciation (Berry and Boucot, 1973; Sheehan, 1973, 1988; Barnes, 1986; Brenchley et al., 1991; Brenchley, 1994; Wyatt, 1995). The carbonate platform was exposed during the glacio-eustatic drawdown of sea level so that the extinction interval (Sequence O5) is absent in shelf sections. Groups, such as brachiopods and corals, were severely effected (Sheehan, 1988; Pandolfi, 1985; Budge, 1972). Late Ordovician community associations were destroyed. Completely new communities developed in the Silurian when the glaciation ended, sea level rose, and the carbonate platform was flooded once more (Sheehan, 1975, 1980a, 1988, Sheehan et al., 1996, Budge, 1972).

The extinction event marked the boundary between Ecologic Evolutionary Units P2 and P3 (Fig. 10) (Sheehan, 1996; Boucot, 1983). Ecologic Evolutionary Units were long intervals of time during which community associations were relatively stable. Evolution appears to have been constrained during EEUs, so that most clades evolved within their habitats, and few clades invaded new habitats. During EEUs incumbency dominated. Groups adapted to a particular habitat appear to have had sufficient advantage over other groups that the incumbents were resistant to being displaced. The prevalence of dinosaurs over mammals during the Mesozoic is a classic example. In the Cenozoic, mammals radiated into many niches that had been occupied by dinosaurs in the Mesozoic, but the radiation did not take place until the competitively incumbent dinosaurs were eliminated by the K/T Mass Extinction Event.

We will examine the transition between EEUs P2 and P3 in each of the field trip stops, with emphasis on how brachiopod-dominated communities recovered from the extinction and on how environmental changes that produced stratigraphic sequences controlled community evolution. During sequences O1 through O4 the Great Basin was part of the endemic North American Brachiopod Faunal Province, which was completely eliminated by the extinction event (Sheehan and Coorough, 1990). Cosmopolitan brachiopods preferentially survived the extinction event, and as a result, Silurian brachiopods were extremely cosmopolitan. At the base of Sequence S1, an entirely new brachiopod fauna appeared on the carbonate platform.

Late Ordovician brachiopod assemblages of the Great Basin have not been well described, and only preliminary information is available on faunal changes from one sequence to the next during the Ordovician. On the other hand, Silurian brachiopods have been well studied (Sheehan, 1980a, 1980b, 1982) and community changes can be tied directly to the stratigraphic sequence history (Harris & Sheehan, 1996b).

During the interval from S1 through S4, progressive increases in community diversity and complexity document

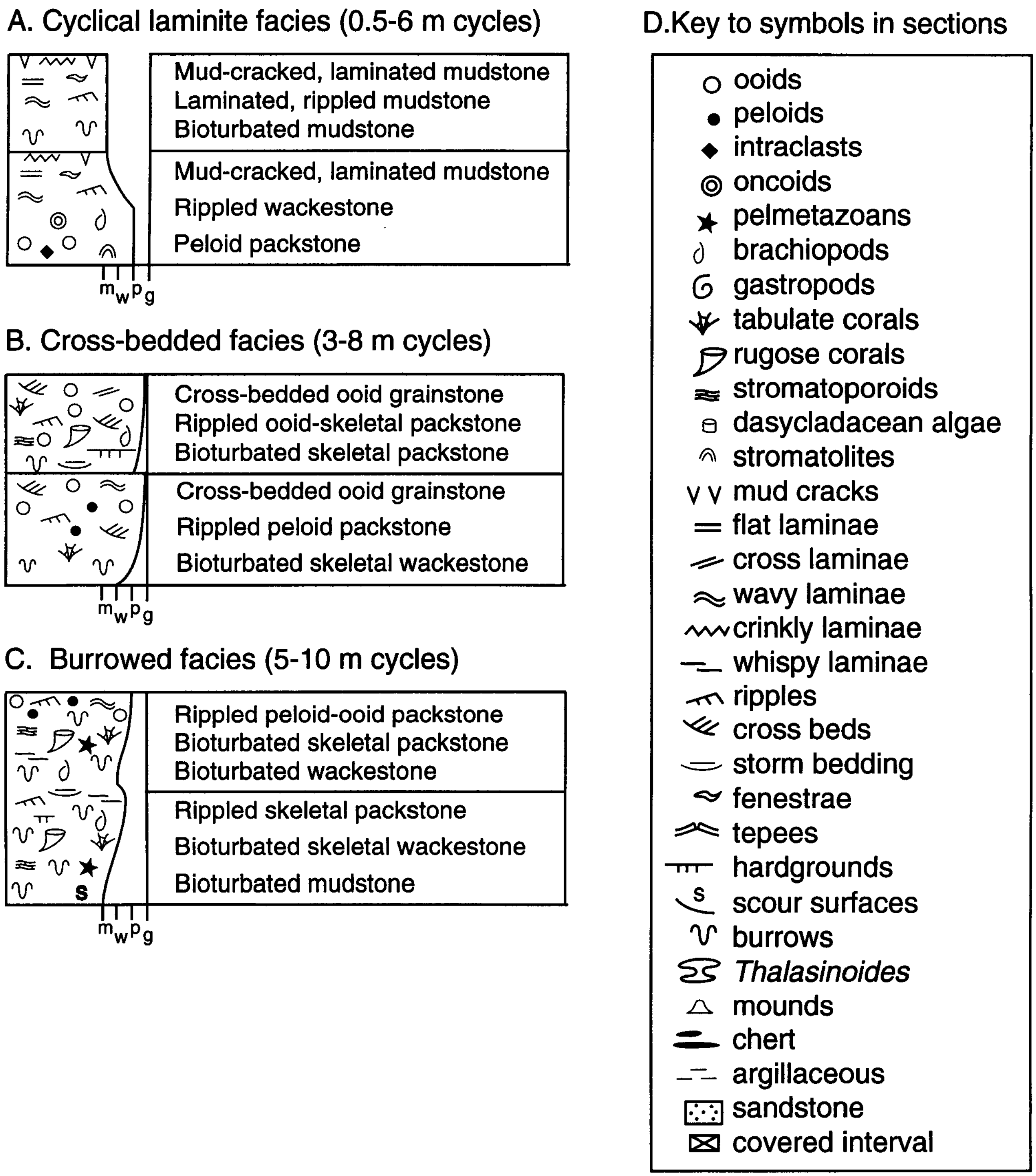


Figure 5. Facies summaries (A–C) illustrating typical meter-scale cycles. Width of column represents depositional texture: m=mudstone, w=wackestone, p=packstone, and g=grainstone. Symbol key (D) also applies to outcrop section summaries (Figures 11, 14 and 16). Modified from Harris and Sheehan (1996a).

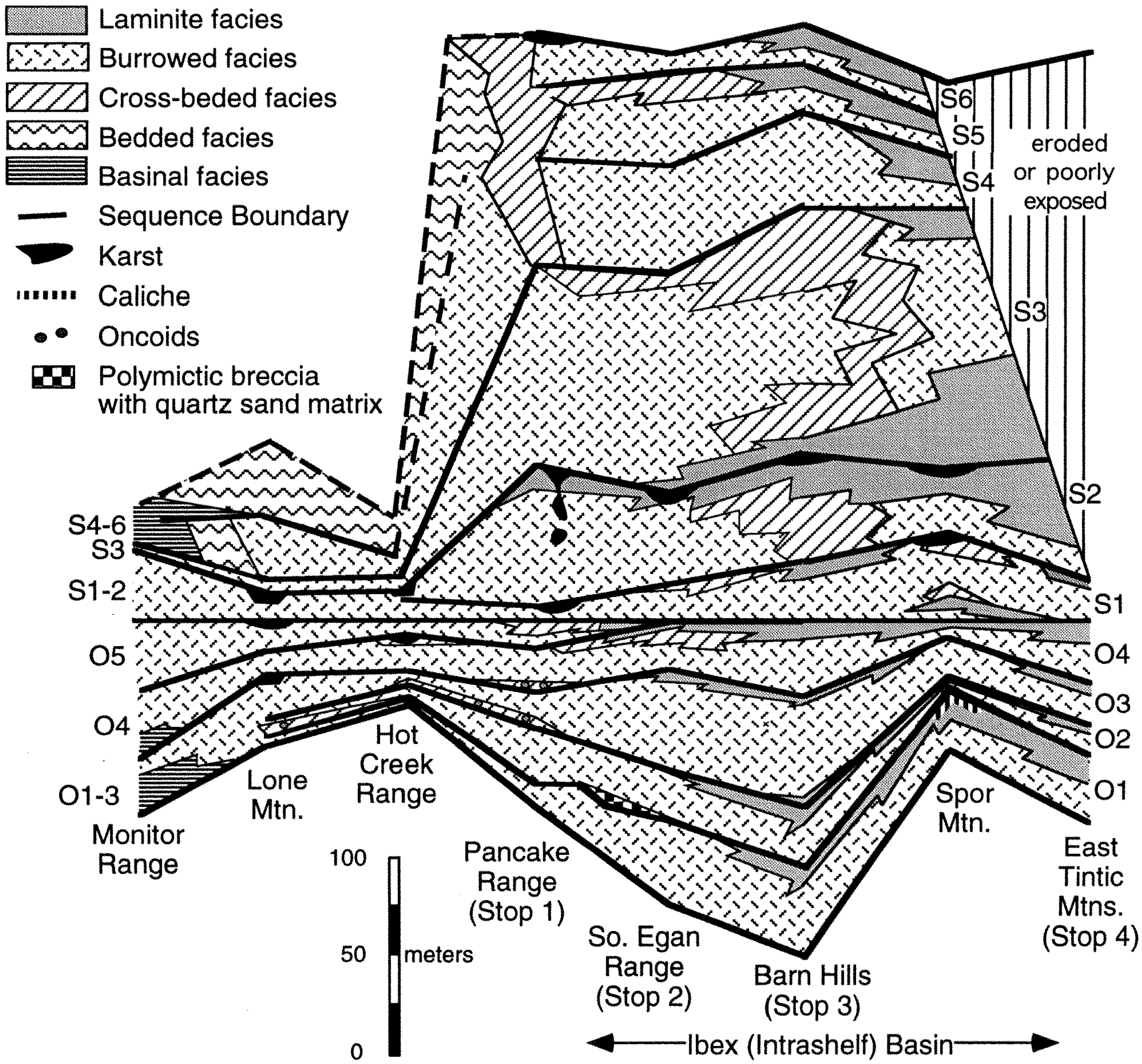


Figure 6. Facies cross section using the Ordovician-Silurian boundary as a datum. Section locations (bottom) are illustrated in Figure 1. Note that the horizontal scale varies.

the recovery from the Late Ordovician Mass Extinction. This recovery interval at the beginning of EEU P3 is known throughout the world (Sheehan, 1996). In the Great Basin, brachiopod-dominated communities have been well described, and they can be used to illustrate the recovery.

Following the extinction event, brachiopod faunas were low in diversity and had simple ecologic structure. The brachiopod community associations of the Ordovician had been destroyed. During the reorganization interval many surviving groups invaded environmental settings they did not occupy previously. The loss of incumbent taxa appears to have allowed survivors to radiate into new habitats. Within-habitat diversity increased as new taxa evolved.

The Early Silurian reorganization interval was also characterized by turnover of communities due to displacement by new associations. In addition to increasing within-community diversity, the number of communities also increased during the reorganization. As a result of increasing numbers of communities, the environmental range of individual communities narrowed. In contrast, during the stasis intervals of EEUs communities commonly persisted for

Table 1. Shelf and shallow-to-middle ramp facies (Harris and Sheehan, 1996a). The subfacies that comprise each facies are described in Table 2.

Facies	Component Subfacies	Environment
Cyclic laminite facies	Mud-cracked and crinkly laminated Laminated mudstone Muddy bioturbated Grainy bioturbated	Tidal flat complex
Cross-bedded facies	Cross-bedded grainstone Cross-laminated packstone Grainy bioturbated Muddy bioturbated	Subtidal shoal
Burrowed facies	Muddy bioturbated Grainy bioturbated *Thalassinoides* burrowed	Moderate to low-energy shelf

tens of millions of years, and evolutionary changes were marked by within-habitat evolution of clades.

Sequence stratigraphic control on community evolution

A significant finding of our study of sequence stratigraphy in the Great Basin is that reorganization of communities occurred at stratigraphic sequence boundaries. Furthermore, during each stratigraphic sequence there was little change in community composition. This was true even during the interval of reorganization following the Late Ordovician Mass Extinction, suggesting that community recovery took place in a series of very rapid reorganizations that were followed by longer intervals of community stability. The pattern resembles Silurian and Devonian patterns that Brett and Baird (1995) documented in epicontinental seas in the Appalachians.

Brachiopod-dominated communities of the Silurian carbonate platform

During sequences S1 and S2 brachiopod communities were low in diversity (Table 3). The *Virgiana* Community had few species and is found across the platform and extended down the carbonate ramp to the west. In the Late Ordovician and later in the Silurian several communities partitioned the habitat occupied by only the *Virgiana* Community. During S1 and S2 the middle to distal ramp had a very sparse fauna, possibly reflecting a lack of survivors that were adapted to this environment. The *Virgiana* Community continued across the boundary between S1 and S2 with little change.

At the boundary between S2 and S3 the *Virgiana* Community disappeared and was replaced by the *Pentamerus* Community. Species in the *Virgiana* Community did not evolve into those of the *Pentamerus* Community, which was composed of species that invaded from outside this region. The *Pentamerus* Community had a more restricted environmental distribution than the *Virgiana* Community.

Between sequences S3 and S4, diversity and faunal complexity increased considerably. The transition was abrupt and took place at the sequence boundary. Community complexity increased with the addition of the *Microcardinalia*, *Cyrtia*, and *Pentlandella* Communities in habitats below normal storm wave base. The recovery had proceeded to a stage where in-place evolution began to dominate. For example, the most common member of the S3 *Pentamerus* Community, *Pentamerus*, evolved into *Pentameroides* which dominated the S4 *Pentameroides* Community. However, new taxa were not added gradually to communities during S3 or S4, but, instead, diversity jumped suddenly across the sequence boundary.

Community changes occurred across the S4–S5 boundary, but the number of communities did not increase as it did across earlier sequence boundaries. Furthermore, lineages of taxa present in S4 communities evolved into new taxa that occupied similar environmental positions in S5 communities. Taxa were not commonly radiating into new habitats. For example, the new S5 *Pentameroides* Community was composed mostly of species that were derived from species present in the previous S4 *Pentameroides* Community. Once again, however, the transition was not gradual. Communities were stable in S4, then new communities appeared across the sequence boundary.

The recovery interval was completed by the end of S3, and the new EEU P3 was underway during S4. Most taxa

Table 2. Shelf and shallow-to-middle ramp subfacies (modified from Harris and Sheehan, 1996a).

Subfacies	Lithologies	Sedimentary Structures	Interpretation
Mud-cracked and crinkly laminated subfacies	Mudstone Intraclastic packstones	Mud cracks Crinkly to flat laminations	Supratidal tidal flat
Laminated mudstone subfacies	Mudstone Ripple cross-laminations Fenestral fabrics	Flat to low-angle laminations	Intertidal tidal flat
Cross-bedded grainstone subfacies	Ooid-skeletal grainstone	Cross-beds Cross-laminations	Subtidal shoal crest
Cross-laminated packstone subfacies	Ooid-skeletal packstone Oncoid packstone	Cross-laminations Low-angle scours	Subtidal shoal
Muddy bioturbated subfacies	Skeletal mudstone and wackestone	Burrow mottled to homogeneous Uncommon ripple to flat laminations	Subtidal, low-energy shelf or tidal pond
Grainy bioturbated subfacies	Skeletal packstone and wackestone	Burrow mottled to homogeneous Uncommon ripple to flat laminations Storm beds with basal scours	Subtidal, high-energy shelf above wave base
Thalassinoides burrowed subfacies	Skeletal packstone to mudstone	*Thalassinoides* burrows	Subtidal shelf above storm wave base

were constrained to their life styles. New species evolved, but they retained the lifestyle and habitats of their ancestors.

The nature of community reorganizations at sequence boundaries remains enigmatic. The community reorganizations took place during the intervals of carbonate-platform exposure at sequence boundaries. We infer that the intervals of sea level decline and exposure were probably much shorter than the intervals of platform submergence because karst and soil profiles are not extensively developed along some sequence boundaries.

The community studies are based collections of more than 20,000 pounds of bulk samples. Most fossils were silicified and most of the samples were obtained by acid etching. During the trip we will have the opportunity to sample several of the more productive horizons from which well-preserved silicified fossils can be collected.

STOP DESCRIPTIONS

Stop 1: Pancake Range

The Pancake Range section is the westernmost section visited on the field trip (Fig. 1). The most notable features are the prograding and shallowing ramp sequences, the sequence-boundary features including an early Silurian (late Rhuddinian) karst surface, and the latest Ordovician (Hirnantian) sequence.

This section is just east of the Llandovery shelf margin collapse that steepened the shelf to form the rimmed-shelf

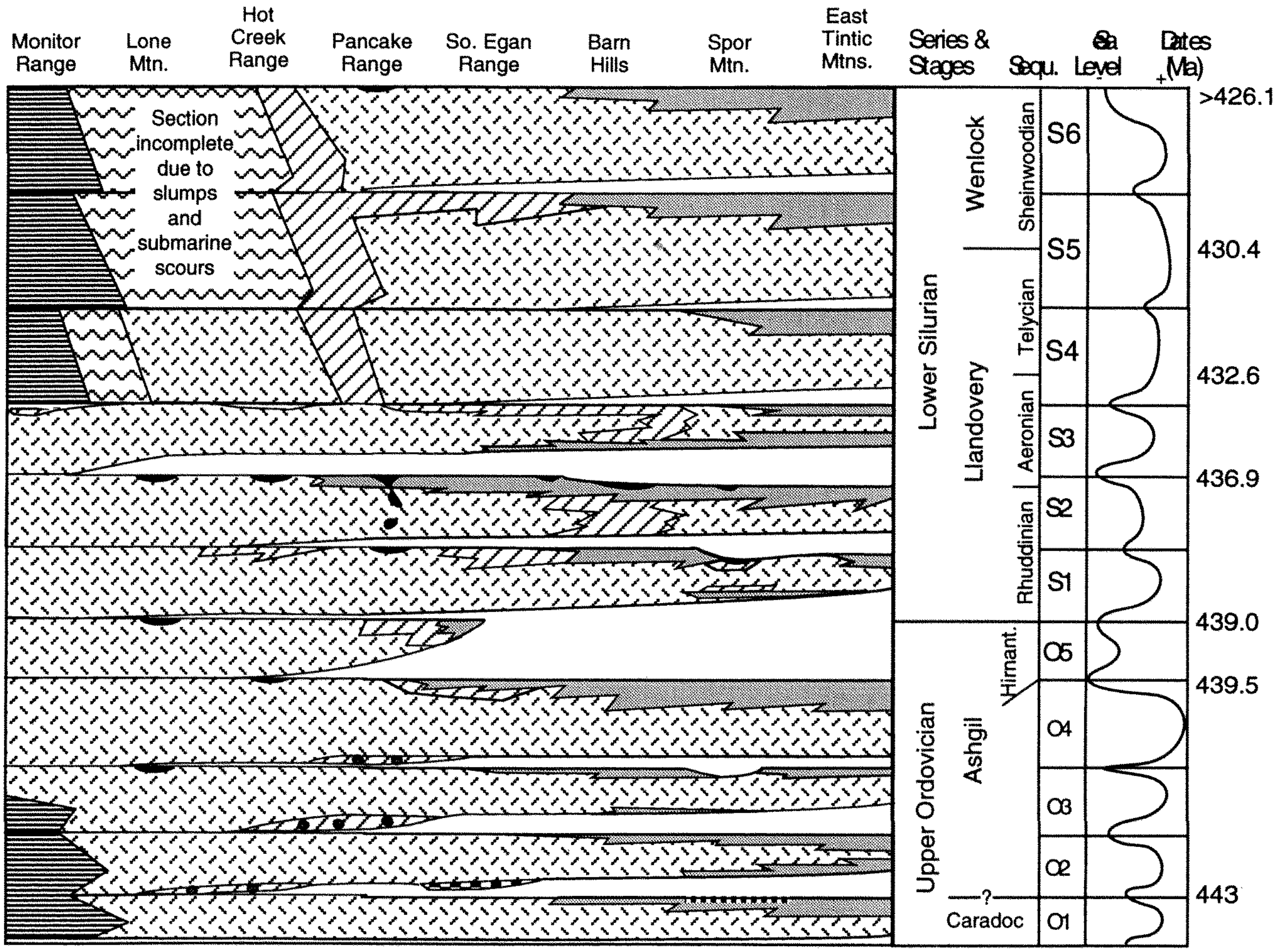


Figure 7. Time-space plot illustrating sequence stratigraphic interpretation. The key to the facies and other information is in Figure 6. Section locations (top) are illustrated in Figure 1. Note that the horizontal scale varies. Amplitude of sea-level curve is approximately 100 meters. Age dates are from Harland et al. (1990).

profile. As a result, the section consists of stacked ramp and shelf deposits. In the Hot Creek Range, 50 km to the west, the section is dominated by deeper ramp facies and the Roberts Mountains Formation (rimmed-shelf phase).

Stratigraphy

The Eureka Quartzite forms the bluff cliffs toward the base of the mountain front (Fig. 11). The overlying Ely Springs Dolostone (Upper Ordovician) is 91.5 m thick (Fig. 12). The Floride Member comprises the upper 31 meters and its base is marked by a recessive, platy dolostone. The other members of the Ely Springs cannot be differentiated. The Lower Silurian Laketown Dolostone (297.5 m) consists of five members; from the base upwards these are the Tony Grove Lake Member (76 m, dark-colored), the High Lake Member (156.5 m, light-colored), the Gettel Member (19 m, dark-colored), an upper High Lake Member tongue (18 m, light-colored), the Jack Valley Member (18.5 m, dark-colored) and the Decathon Member (10 meters, light-colored). The Sevy Dolostone overlies the Laketown. The stratigraphic nomenclature of the Laketown members is extended from eastern Nevada and Utah (Budge and Sheehan 1980a, 1980b). Our member assignments for the Gettel to Jack Valley interval differ from Budge and Sheehan (1980b).

Sedimentologic overview

Ramp sequences gradually shallowed and prograded from east to west throughout the Late Ordovician and Early Silurian. The lowest three ramp sequences (O1 to O3) consist of burrowed facies with a gradual upward increase in faunal diversity and abundance. The criteria useful for identifying the sequence boundaries vary. The top of sequence O1 is marked by submarine scour and

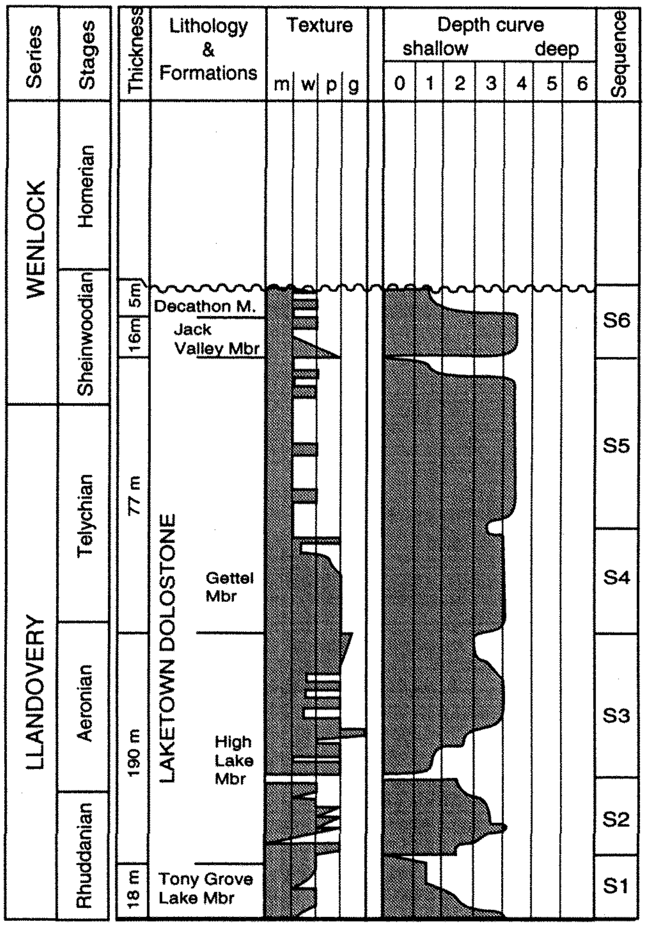


Figure 8. Depth curve for the Silurian part of the Barn Hills section (Stop 3) using benthic assemblages and sediment features to assign depth zones 0–6 (Harris and Sheehan, 1997). Zones 1–6 correspond to benthic assemblages (Brett et al., 1993) although zone 6 is absent in the shelf sections because it is restricted to basinal settings. Zone 0 indicates evidence for significant exposure such as soils or karst features.

breccia whereas the tops of sequences O2 and O3 are identified by overlying lowstand oncoidal packstone units. Exposure surfaces appear to be absent.

Sequence O4 consists of a lowstand oncoid unit overlain by deep-ramp, platy mudstones (basal Floride Member) that shallow upward into laminite facies. The Hirnantian sequence O5 includes a highstand ooid unit (cross-bedded facies). This sequence is missing in shelf sections to the east (including the southern Egan Range, Stop 2, and Barn Hills, Stop 3).

Ramp facies patterns continue through the three lower-middle Llandovery (Lower Silurian) sequences that comprise the Tony Grove Lake and lower High Lake members. The sequences are dominated by burrowed facies with evidence of shallowing toward each sequence boundary. Sequence S1 is capped by a karst surface overlain by a 40 cm-thick quartz sandstone. A laminite facies tongues forms the top of Sequence S2 and penetrative karst extends 50 m below the sequence boundary (Fig. 13). Sequence S3 shallows to within wave base although cross-bedded shoals are not present.

The upper three sequences are upper Llandovery-Wenlock shelf lagoon sediments behind the shelf-margin shoals (Lone Mountain Dolostone) to the west. Sequence S4 is the upper High Lake Member and consists of a lower and upper cross-bedded facies and an intervening burrowed-facies interval. Sequences S5 (Gettel Member and High Lake tongue) and S6 (Jack Valley and Decathon members) both consist of successions that shallow from burrowed facies into cross-bedded (S5) or laminite (S6) facies. A karst surface caps the Laketown and separates it from the overlying Sevy Dolostone.

Paleontologic overview

The fauna of the Ely Springs Dolostone is part of the strongly endemic North American Zoogeographic Province. Brachiopods are typical members of this province. Well-preserved silicified faunas in the upper part of the Floride Member include the brachiopod genera *Hesperorthis, Glyptorthis, Plaesiomys (Plaesiomys), Platystrophia, Dicero-myonia, Oxoplecia, Ptychopleurella, Lepidocyclus, and Hypsiptycha.* Associated corals identified by Budge (1972) include *Bighornia* sp., *Cyathophylloides* sp., *Deiracorallium* sp., *Palaeophyllum* sp., *Bodophyllum* sp., *Lobocorallium* sp., and *Streptelasma* sp. The thin Hirnantian (sequence O5) unit contains a brachiopod-coral assemblage that has not yet been studied.

Macrofossils change suddenly at the Ordovician-Silurian boundary. The initial Silurian community is a brachiopod-coral assemblage that is common throughout the Great Basin in the Tony Grove Lake Member of the Laketown Dolostone. The fauna is cosmopolitan rather than endemic. The brachiopod *Virgiana utahensis* is by far the most common species in the *Virgiana* Community (Sheehan, 1980b). Small solitary and large colonial rugose corals and favositid and heliolitid corals are also common. The community is present across the platform and down the carbonate ramp that borders the platform on the west and it represents a variety of habitats that range from rough to quiet water. The genus *Virgiana* is one of the most widely distributed brachiopods that ever lived (Boucot, 1975). The cosmopolitan nature of this fauna reflects the strong selection against survival of endemic taxa (Sheehan and Coorough, 1990). The low diversity of brachiopods in this community and also the wide ecologic distribution of the community are due to the effects of the late Ordovician mass extinction.

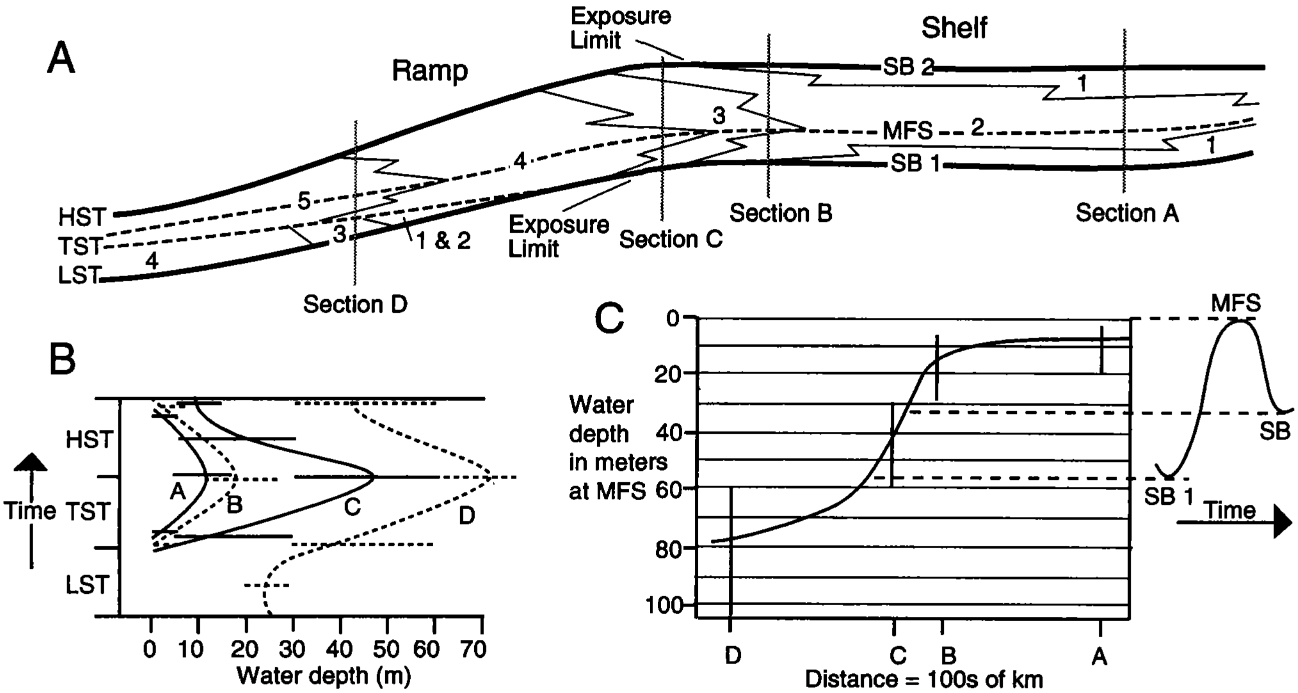


Figure 9. Conceptual model for estimating relative sea-level changes in the ramp phase (Harris and Sheehan, 1997). A. Idealized ramp facies model keyed to benthic assemblages 1–5 and including lowstand (LST), transgressive (TST) and highstand (HST) systems tracts. Positions of hypothetical sections A–D are marked. Note that the horizontal scale is several hundred kilometers. B: Water-depth curves for sections A through D drawn through midpoints of depth ranges (Figure 8). Sections A–C are exposed during LST deposition; the upper sequence boundary is marked by exposure at sections A and B. C: Depth profile along the MFS with approximate positions of the downdip exposure limits on SB 1 and SB 2 indicated. Water-depth curve derived from constraints on maximum rise (MFS facies) and maximum fall (LST facies and SB exposure).

The High Lake Member (S3 and S4) of the Laketown Dolostone contains dasycladacean algae of the *Verticillopopra* Community (Sheehan, 1980a). The poor preservation in coarse dolostones makes identification difficult. The algae are commonly mistaken for crinoid stems, but a few silicified collections have been described (Rezak, 1959). The community is locally present in the Great Basin throughout the Llandovery but is most common in S3. In this section the Community is also present in S5, in a tongue of the High Lake Member between the Gettel and Jack Valley members (Sheehan, 1980a).

Budge (1972) identified the corals ?*Amplexoides radicosi* and *Tryplasma* sp. from the High Lake Member (Sequence S3). He also identified *Palaeocyclus* sp. and *Tryplasma* sp. in the Gettel Member (S5).

Stop 2: Sunnyside, southern Egan Range

The southern Egan Range section lies 75 km east (in the present day geography) of the Pancake Range, Stop 1 (Fig. 1, 14). Ramp facies reflect this section's updip position (compared to the Pancake Range) in the greater abundance of laminite and cross-bedded facies (Fig. 15). During the rimmed-shelf phase, this section was farther removed from the shelf margin that lay to the west and contains fewer high-energy deposits.

Stratigraphy

The stratigraphy is similar to that in the Pancake Range (Stop 1). The Upper Ordovician Ely Springs Dolostone (139 m) overlies the Eureka Quartzite and includes an upper Floride Member (22 m). The Lower Silurian Laketown Dolostone (287 m) consists of five members: the Tony Grove Lake Member (72 m), the High Lake Member (102.5 m), the Gettel Member (103.5 m), the Jack Valley Member (8 m) and the Decathon Member (1–2 m). The upper High Lake tongue that occurs in the Pancake Range is not recognized. The Sevy Dolostone overlies the Laketown.

Sedimentologic overview

Facies stacking patterns in the Ely Springs Dolostone reflect progradation of Late Ordovician ramp sequences. Successive sequences are capped by more extensive shal-

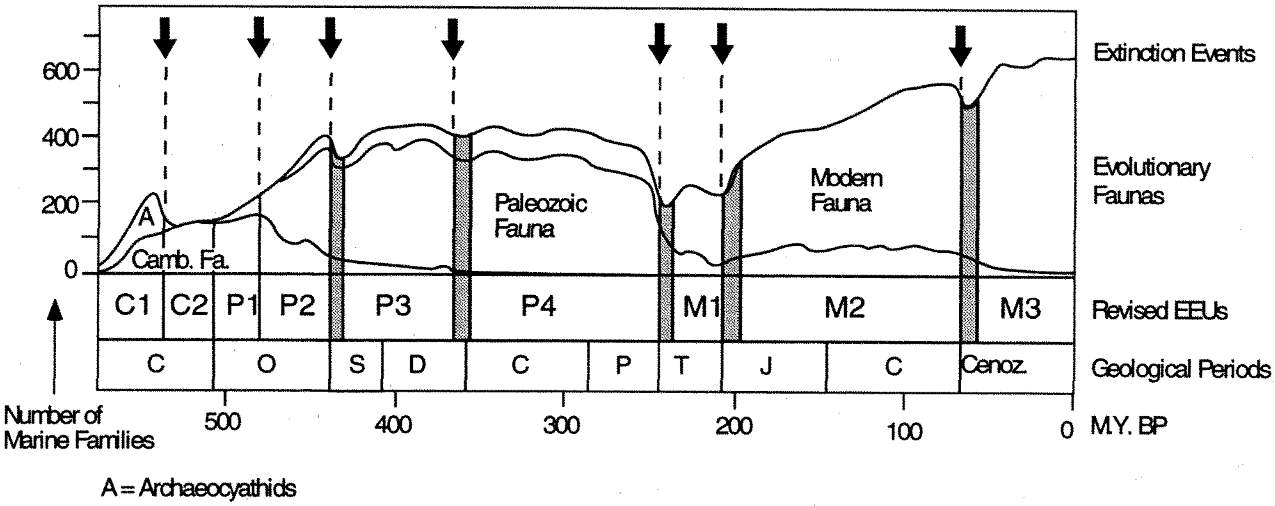


Figure 10. Summary of Ecological Evolutionary Units and Evolutionary Faunas (modified from Sheehan, 1996). EEUs are numbered to reflect the predominant Evolutionary Fauna. For example, C1 and C2 refer to the two EEUs dominated by the Cambrian Fauna. Shaded portion of each EEU indicates the duration of the recovery interval following mass extinction events (indicated by the arrows at the top of the diagram).

low-water facies. The lowest O1 sequence consists entirely of burrowed facies. Fossils are more abundant than in equivalent strata in the Pancake Range reflecting the updip position of the southern Egan Range section. We place the base of sequence O2 at a scour surface overlain by a polymictic breccia having a quartz sandstone matrix. Clasts appear to include laminite and burrowed-facies lithologies. Sequence O2 consists of burrowed facies capped by a thin (half meter thick) laminite unit. Sequence O3 is similar, except the capping laminite consists of two cycles. Sequence O4 (Floride Member) displays a shallowing succession from burrowed to cross-bedded to laminite facies. The Hirnantian sequence O5 is absent, as it is in all shelf section east of the Egan Range.

Ramp sequences S1–S3 consist of the Tony Grove Lake and High Lake members here and in most shelf sections. The upper High Lake tongue seen at the Pancake Range occurs along the western edge of the shelf as an extension of the Lone Mountain Dolostone shelf margin (cross-bedded facies). Sequence S1 is capped by cross-bedded facies without evidence of exposure (as present in Stop 3). Toward the top of sequence S2, a 4 m interval of small (30–75 cm) mound features occurs between burrowed facies (below) and the laminite facies cap of the sequence. Dolomitization has obscured the orginal fabric but the edges appear burrowed and overlying beds show compaction drape. A karst/solution collapse breccia (0.5 to 5 m thick, quartz-sand matrix) marks the top of the sequence, equivalent to the karst surface at the Pancake Range. The overlying sequence O3 is quite thick and shallows into near shoal conditions (transitional to the cross-bedded facies).

Sequences S4–S6 (Gettel, Jack Valley and Decathon members) of the rimmed-shelf phase are predominantly mud-supported shelf lagoon deposits. The top of the Laketown is a scour surface that may be a low-relief channel filled by quartz sandstone and carbonate clasts.

Paleontologic overview

The fauna of the Ely Springs Dolostone includes a diverse brachiopod and coral fauna. As throughout the platform, the fauna is endemic to North America. Well preserved, silicified brachiopods from the Lower 15 m of the section include *Hesperorthis, Glyptorthis, Platystrophia, Diceromyonia, Thaerodonta and Lepidocyclus.*

The Ordovician/Silurian contact is well exposed in this section and the *Virgiana* Community appears along with the initial transgression. As is typical of the community *Virgiana utahensis* overwhelmingly dominates the community. The community is present in both S1 and S2 sequences in the Tony Grove Lake Member, but disappears from the Great Basin during the regression at the top of S2. Brachiopod dominated communities in this section were described by Sheehan (1980a).

Sequence S3 in the High Lake Member contains the *Verticillopora* Community, as in the Pancake Range. The *Pentamerus* Community is present in Sequence S3 in many places in the Great Basin, for example, in the Barn Hills section (Stop 3) which we will examine tomorrow. But the *Pentamerus* Community is not as widely distributed as the *Virgiana* Community (which is found here and in nearly all exposures of sequences S1 and S2). Both communities are

Table 3. Silurian brachiopod-dominated communities (discussed in the text).

Sequence	Shallow Tidal flat restricted	Tidal flat open	Subtidal shoal	Deep Moderate to low-energy shelf
S6	stromatolite/ cryptalgal	rhynchonellid	*Pentameroides* sp. B	coral community, *Atrypina, Spirinella*
S5	stromatolite/ cryptalgal	rhynchonellid	*Pentameroides* sp. B	*Spirinella,* unnamed community, *Atrypina*
S4	stromatolite/ cryptalgal	rhynchonellid	*Pentameroides* sp. A	*Cyrtia,* *Mcrocardinalia,* *Pentlandella*
S3	stromatolite/ cryptalgal	—	*Pentamerus*	—
S2	stromatolite/ cryptalgal	stromatolite, *Virgiana,* rhynchonellid	*Virgiana*	*Virgiana*
S1	stromatolite/ cryptalgal	stromatolite, *Virgiana* rhynchonellid	*Virgiana,*	*Virgiana*

dominated by large, globose pentamerid brachiopods, but the younger community was distributed over a narrower range of environment, possibly because ecospace was being partitioned as recovery from the extinction proceeded.

Sequence S4 in the lower part of the Gettel Member contains the *Pentlandella* Community, to which Sheehan (1980a) assigned a possible C6 (Latest Llandovery)-Early Wenlock age, but more recent work indicates a C4–5 (Late Llandovery) age. The community is dominated by *Pentlandella merriami*, with rare *Atrypina erugata, Spirigerina* sp., plectambonitids and finely ribbed orthids. The community was adapted to quiet water and a muddy substrate. Shallower water deposits on the carbonate platform at this time were dominated by the *Pentameroides* sp. A Community of Sheehan (1980a).

The lower part of sequence S5 in the upper the Gettel Member contains Unnamed Community A, which has diverse brachiopods in strata deposited below normal wave base, but above storm wave base. This community contains elements of the shallower water *Pentameroides* sp. B Community which occurs in other sections in the southern Egan Range. Other species include *Flabellitesia flabellites, Isorthis* sp., *Dicoelosia biloba, Eoplectodonta* sp., *Microcardinalia* sp., *Atrypa?* sp., *Atrypina erugata, Cyrtia* sp., and *?Spirinella pauciplicata eganensis*. The rugose coral *Rhegmaphyllum* sp., aff. *R. conulus*, is present in this community (Budge, 1972).

The upper part of Sequence S5 in the upper part of the Gettel Member contains the *Atrypina* Community, from which 14 species have been identified (Sheehan, 1980a). *Atrypina erugata* is the most common species, and common associates include *Flabellitesia flabellites, Isorthis* sp., *Dicoelosia biloba, Eoplectodonta* sp., *Pentameroides* sp., *Cyrtia* sp., *Howellella* sp., and *Spirinella pauciplicata eganensis*. Budge identified a diverse coral fauna from this community, including *Asthenophyllum* spp., *Rhegmaphyllum* sp., aff. *R. conulus, Rhizophyllum* sp., *Tryplasma* spp., *Rhabdocylcus*, and *Amplexoides* sp.

Sequence S6 (Jack Valley Member) contains a very diverse assemblage assigned to the *Atrypina* Community. Some assemblages of this community are dominated by *Atrypina erugata*, but most commonly no single species is a clear dominant in any given collection, and no species occurs in all collections assigned to this community. Twenty-three species have been recorded in this community (Sheehan, 1980a), the most common ones include *Atrypina erugata, Flabellitesia flabellites, Dicoelosia* sp., *Camarella?* sp., *Protochonetes elyensis, Microcardinalia* sp., *Stegerhynchus estonicus, Hercotrema perryi, Atrypa (Gotatrypa)* cf. *A. (G.) gibbosa, Hedina?* sp., and *Spirinella*

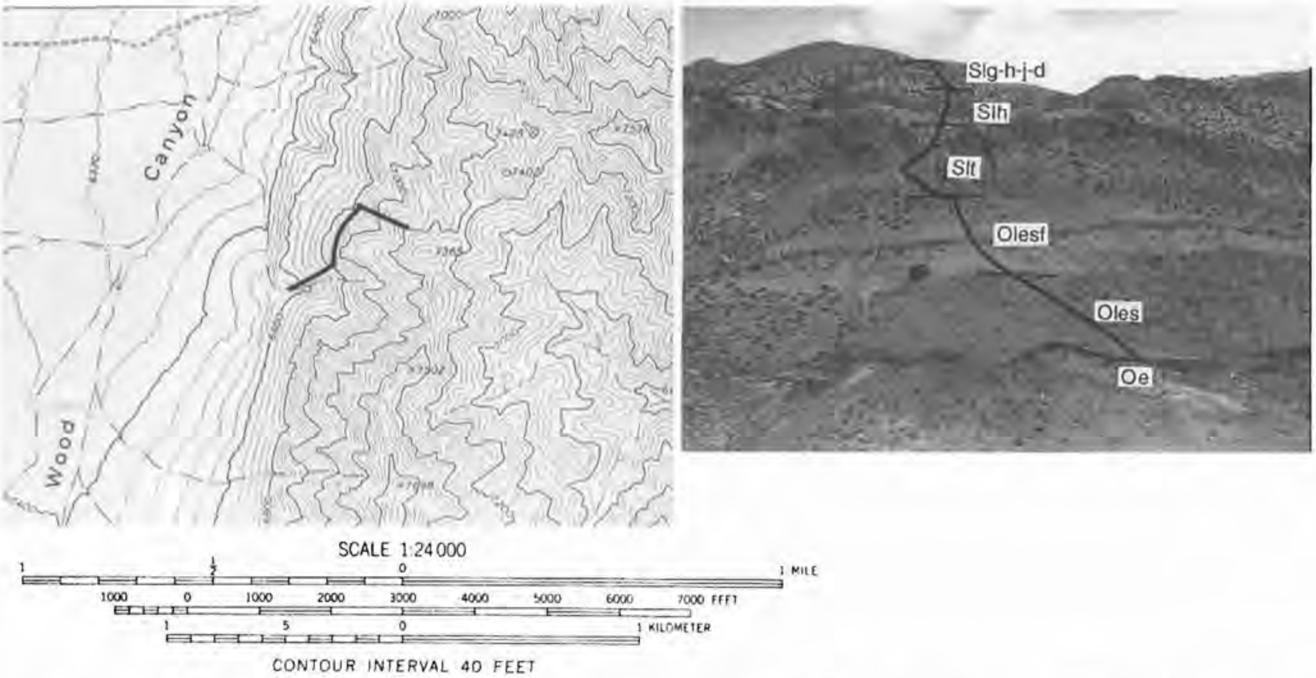


Figure 11. Location of the Pancake Range traverse on Lockes 7.5 minute quadrangle map and a field photograph from the west-northwest. Members of the Ely Springs and Laketown Dolostones are indicated by letters on the photograph (contacts marked by thin lines). The Eureka Quartzite (Oe) is at the base of the mountain. The Ely Springs Dolostone (Oles) includes the Floride Member (Olesf). The Laketown Dolostone consists of the Tony Grove Lake Member (Slt), the High Lake Member (Slh), the Gettel-upper High Lake-Jack Valley Member-Decathon Members (Slg-h-j-d). Approximate line of traverse (thick line) through Ely Springs and lower Tony Grove Lake follows line of outcrops but shifts north in Tony Grove Lake to climb through cliffs.

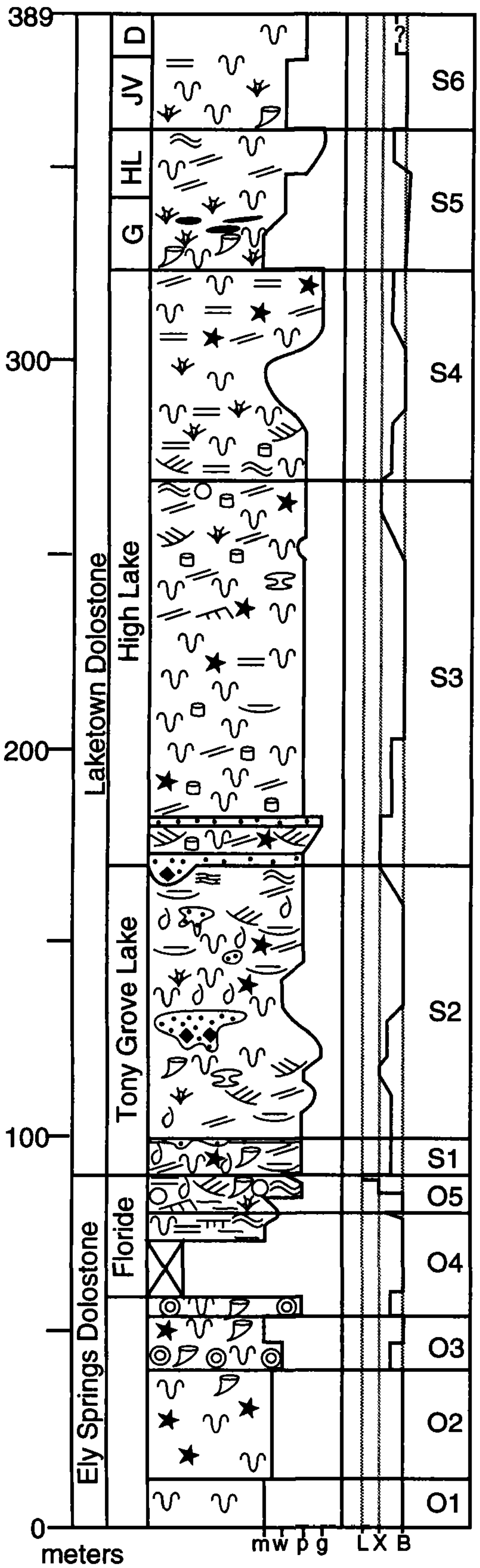
pauciplicata eganensis. This community is very similar to the *Atrypina* Community from the underlying S5 sequence. However, several species change relative abundances from the lower to the upper interval. In addition, three species present in the underlying unit are not found in the upper unit (*Isorthis* sp., *Dicoelosia biloba*, and *Howellella* sp.), and twelve species present in the upper community have not been found in the lower community (including the relatively common species *Camarella?* sp., *Protochonetes elyensis*, *Microcardinalia* sp., *Stegerhynchus estonicus*, *Atrypa (Gotatrypa)* cf. *A. (G.) gibbosa*, and *Hedina?* sp.). The pattern of change reinforces the observation that community changes seem to have occurred at the sequence boundaries, rather than by gradual change during the time the sequences were being deposited.

A diverse coral fauna in the S6 *Atrypina* Community identified by Budge (1972) includes *Asthenophyllum* spp., *Rhegmaphyllum* sp. , aff *R. conulus*, *Rhizophyllum* sp., *Tryplasma* spp., *Rhabdocylcus*, and *Amplexoides* sp., *Palaeocyclus* spp., and *Diaphragmaphyllum*.

Note that throughout the Silurian part of the section, within-habitat diversity was increasing, as the biota recovered from the extinction. On a regional scale more communities were being packed into ecospace, as communities became more narrowly niched. By the time of deposition of the upper part of the Laketown Dolostone community composition changed by in-place evolution, rather than invasion from external sources. Tomorrow we will examine another section (Barn Hills, Stop 3) from slightly different environments, where we will see community complexity on a regional scale also increases, as different communities are found in the upper part of the Laketown Dolostone.

Stop 3: Barn Hills

The Barn Hills section is located in a middle shelf position on the continental shelf (Fig. 1, 16). It is close to the center of the Ibex Basin, an intrashelf basin south of the Tooele Arch. Ramp sequences have well-developed laminite facies caps and the Lower Silurian ramp carbonates include relatively thick cross-bedded facies intervals (Fig. 17). In contrast, the overlying rimmed-shelf facies are lower energy than in the Pancake Range (Stop 1) and southern Egan Range (Stop 2) sections, continuing the pattern of decreasing energy as we move eastward across the shelf



lagoon. This stop is about 150 km east of the southern Egan Range (Stop 2) in present day geography.

Stratigraphy

As in the Pancake Range (Stop 1) and southern Egan Range (Stop 2) sections, the Upper Ordovician Ely Springs Dolostone (164 m) overlies the Eureka Quartzite. Four members are recognized in the Ely Springs (Budge and Sheehan, 1980b): the Ibex Member (19 m), the Barn Hills Member (32.5 m), the Lost Canyon Member (77.5), and the Floride Member (35 m). The Lower Silurian Laketown Dolostone (307 m) consists of the same five members that occur at the southern Egan Range section: the Tony Grove Lake Member (19 m), the High Lake Member (190 m), the Gettel Member (77 m), the Jack Valley Member (16 m), and the Decathon Member (5 m). The Gettel and Jack Valley members differ slightly from Budge and Sheehan (1980b). The Sevy Dolostone overlies the Laketown as in the other sections.

Sedimentologic overview

In this middle shelf position, Upper Ordovician (Ely Springs Dolostone) ramp sequences O1–O4 consist of burrowed and laminite facies in varying proportions. This section illustrates the use of facies stacking to delineate sequences: exposure surfaces occur in laminite facies. Within laminite facies intervals, sequence boundary placements are based on stacking patterns of the meter-scale cycles (using cycle thicknesses and subfacies types). Lower Silurian ramp sequences (Tony Grove Lake and High Lake members) contain intervals of the cross-bedded facies, indicative of higher energy shelf conditions. Laminite facies units cap sequences S1 and S2 and the top of sequence S2 is marked by a breccia with a quartz-sand matrix (as at southern Egan Range, Stop 2).

The rimmed-shelf phase sequences S4 to S6 (Gettel, Jack Valley and Decathon members) are predominately burrowed facies typical of the Ibex Basin shelf lagoon. Laminite units cap both sequences S5 and S6. The top of sequence S5 is locally channeled and filled with a breccia. The top of the Laketown is deeply eroded and channeled southwest of this section (to be viewed if time permits) below the Sevy.

Figure 12. Graphic summary of the Pancake Range section showing stratigraphy, sedimentological features (for key, see Figure 5D), facies (L=laminite, X=cross bedded, and B=burrowed), and sequences. Stratigraphic abbreviations used for the Laketown Dolostone are G=Gettel Member, HL=High Lake Member, JV=Jack Valley Member, and D=Decathon Member.

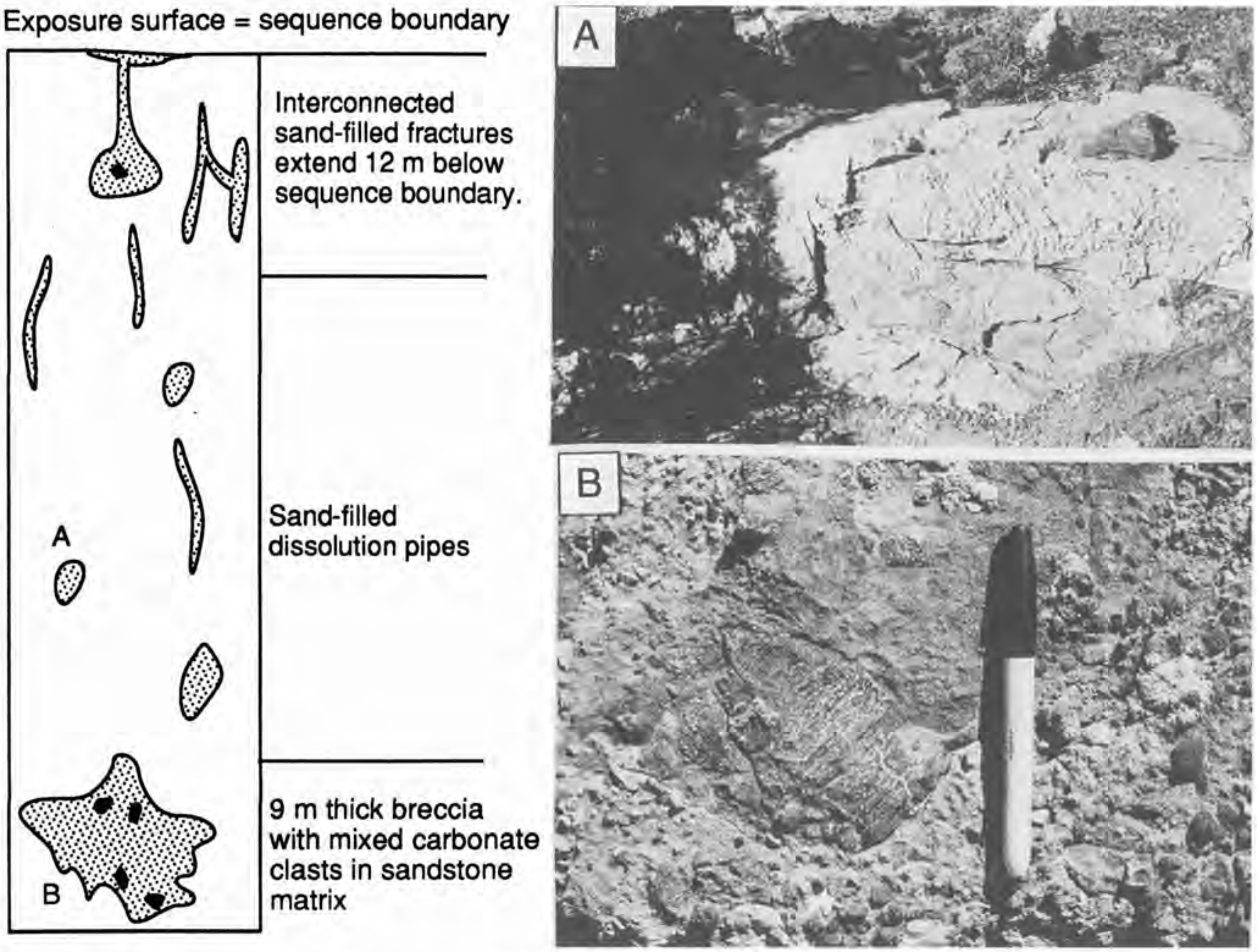


Figure 13. Schematic summary of karst features at the top of sequence S2, Tony Grove Lake Member, Pancake Range. Base of lower breccia is 48 m below the sequence boundary. Quartz sand fills karst features. Position of photographs indicated by letters on main diagram. A) Sand filled dissolution pipe (light colored) approximately 2 m in diameter. B) Clasts within lower breccia. The source of the clast with the fenestral fabrics (left of pen) occur >40 m higher in the section below the overlying sequence boundary. Pen = 14 cm.

Paleontologic overview

Time constraints and the long climb needed to reach the upper part of the section will preclude a study of the fauna of the Ely Springs Dolostone. Silicified fossils are less common here than in the southern Egan Range, and most of the fossils have been dolomitized.

The *Virgiana* Community is present again in S1 and S2 *Virgiana utahensis* dominates the community which includes very rare orthids, dalmanellids, rhynchonellids and atrypids. Silurian brachiopod communities were described by Sheehan (1980a).

The dasycladacean *Verticillopora* Community is common in S3, and is associated with the *Pentamerus* Community. The *Pentamerus* Community is dominated strongly by *Pentamerus* sp. Although similar in overall morphology, the globose pentamerids *Virgiana* and *Pentamerus* are not closely related. Rather than in-place evolution in this setting, *Virgiana utahensis* disappeared at the end of S2, and in S3 it was replaced by the invading *Pentamerus* Community. In many sections on the carbonate platform, S4 contains the *Pentameroides* Community. In this case *Pentameroides* was derived from *Pentamerus*, but the transition took place during the regression between S3 and S4. Apparently the disruption of habitats associated with sea level decline at the sequence boundaries was required to allow the replacements to proceed.

In the Barn Hills Section, S4 (the Gettel Member) contains the *Cyrtia* Community. *Cyrtia* sp. is abundant associated with rare specimens of *Flabellitesia flabellites*, *Atrypa (Gotatrypa) hedi americensis*, and *Spririnella pauciplicata*.

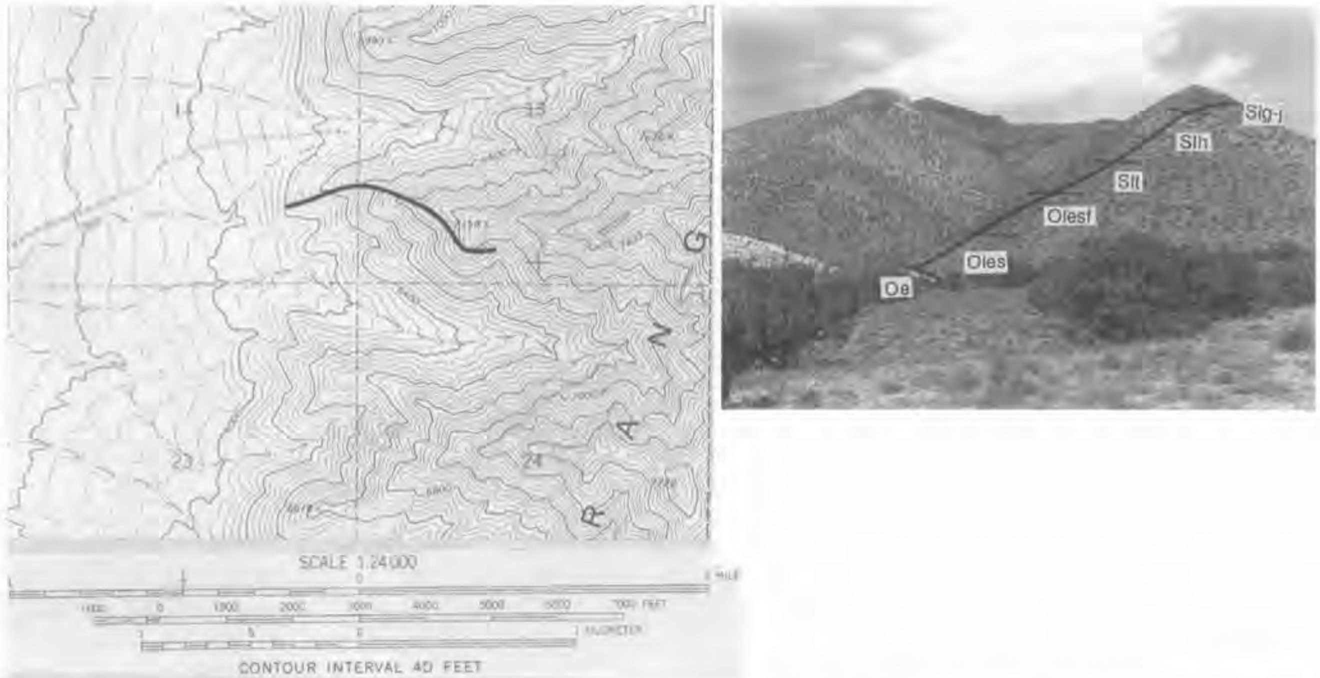


Figure 14. Location of the Southern Egan Range (Sunnyside) traverse on Cave Valley Well 7.5 minute quadrangle map and a field photograph from the west-southwest. Members of the Ely Springs and Laketown Dolostones are indicated by letters on the photograph (contacts marked by thin lines). The Eureka Quartzite (Oe) is at the base of the mountain to the lower left. The Ely Springs Dolostone (Oles) includes the Floride Member (Olesf). The Laketown Dolostone consists of the Tony Grove Lake Member (Slt), the High Lake Member (Slh), the Gettel-Jack Valley Member (Slg-j) and Decathon Member (just over hill crest to top right). Approximate line of traverse (thick line) follows ridge through lower Gettel, then shifts to south to reach Jack Valley and Decathon.

The several members of the community were adapted to live on a soft substrate (Sheehan, 1980a). In a locality that does not contain brachiopods, Budge (1972) identified the rugose coral *Rhabdocyclus*, which also has adaptations for survival on a soft substrate.

The *Spirinella* Community is found in S5. This community, also with adaptations for life on a soft substrate, contains *Spirinella pauciplicata, Hercotrema pahranagatensis*, an unidentified athyridacid, and *Brachyprion (Eomegastrophia) geniculata* subspecies A.

Sequence S6 has the *Spirinella* Community containing the same fauna as in S5, except *Brachyprion (Eomegastrophia) geniculata* subspecies B is present. S6 also has an abundant coral fauna including the rugose corals *Asthenophyllum* sp. and *Rhabdocyclus* sp. and the tabulate corals *Syringopora* sp., *Cystihalysites* sp., and *Heliolites* sp. (Budge, 1972.)

At the end of the Llandovery, the S5 communities were as numerous and diverse as they were prior to the end Ordovician extinction event. Evolution was also beginning to produce distinctive faunas around the world, and zoogeographic provinciality was recovering from the extinction event. Notice that the *Virgiana* Community dominated the range of platform environments immediately following the extinction event. By the upper part of the Laketown Dolostone, communities were much more diverse. In addition, the upper part of the formation has different communities from section to section. This suggests that community complexity was increasing as individual communities became restricted to narrow environmental tolerances and more communities were packed into the ecospace of the carbonate platform.

Stop 4: Tintic Mining District (optional stop), East Tintic Mountains

The Tintic Mining District produces silver, gold, lead, copper and zinc and it is divided into three sub-districts (Cook, 1957; Morris and Lovering, 1979). This stop is in the oldest sub-district, the Main District in which the initial discovery was made in 1869. Early mining was directed toward surface ore bodies. We will stop at the 1890 headframe of the 3000-ft deep, Bullion Beck and Champion Mining Company mine, that marks the site of the subsurface

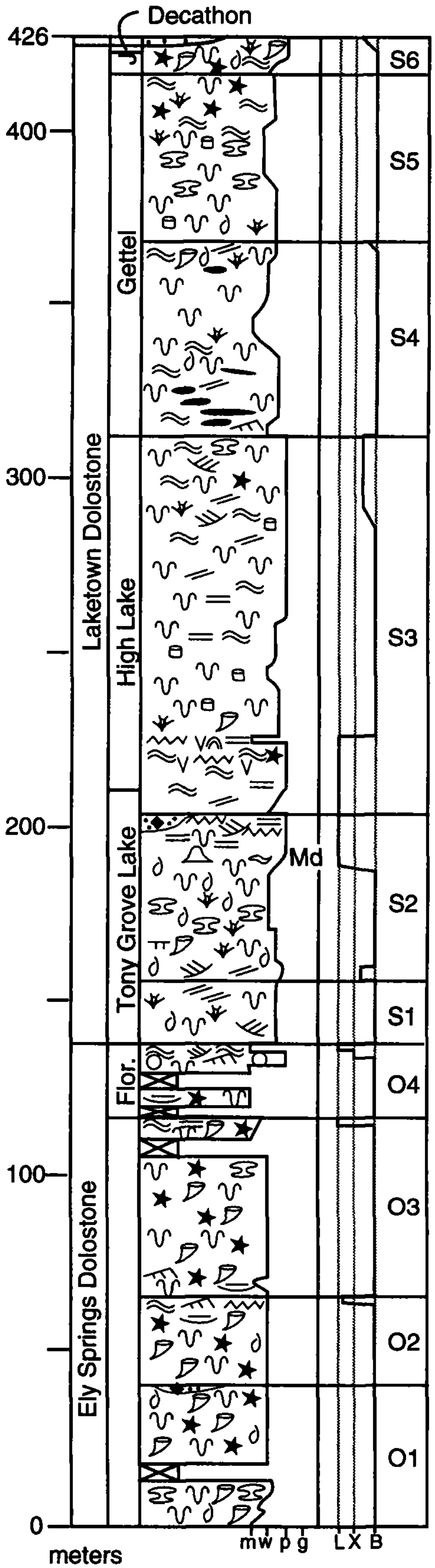


Figure 15. *Graphic summary of the southern Egan Range section showing stratigraphy, sedimentological features (for key, see Figure 5D), facies (L=laminite, X=cross bedded, and B=burrowed), and sequences. Stratigraphic abbreviations are Flor.=Floride Member and J=Jack Valley Member.*

discovery by John Beck (Fig. 18). The surrounding hills are marked by the diggings of numerous mines. Production in the Main District peaked early in the century.

From this stop, we will drive through the East Tintic District on the east side of the range. Prospecting began after the Main District discovery, but production did not really begin until the discovery of the Central ore body in 1916. The initial phase of production peaked in 1920–41 but was finished by the late 1940s. The discovery of the Burgin in 1958 and Trixie in 1969 mines resulted in a second production peak that continues to the present.

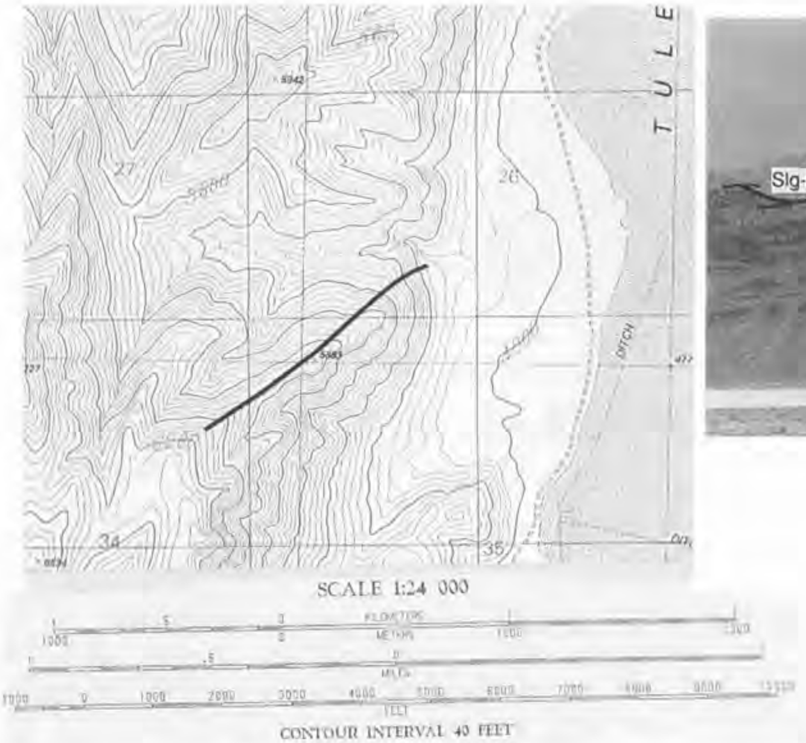
This stop is near the eastern limit of preserved Upper Ordovician-Lower Silurian strata on the northeastern edge of the Ibex Basin. We are now located 175 km northeast of the Barn Hills (Stop 3). Sequences are slightly thinner and eroded more extensively in this inner shelf setting (Fig. 6). (In fact, late Silurian-early Devonian erosion has thinned the Silurian section so that only sequence S1 remains at some localities.) Sequence are predominantly characterized by alternations of burrowed facies (maximum flooding) and laminite facies (straddling sequence boundaries). Additional criteria for identifying sequence boundaries occur in some sections. For example, Sexton (1994) identified a soil horizon at Spor Mountain (north of Delta, Utah) at the top of sequence O1.

We will not examine a section near this stop due to time constraints and the location of the most suitable outcrop (two thirds of the way up Pinyon Peak, the isolated peak north of the highway, east of the pass).

ROAD LOG

Day 1: Salt Lake City, UT to West Wendover, NV to Ely, NV

0.0	0.0	Junction of Interstate 80 and Interstate 215 in Salt Lake City. Proceed west on Interstate 80.
115.2	115.2	Exit #2 for Wendover, Utah. Set your watch back one hour because you are now in the Pacific Time zone.
2.8	118.0	Exit #410 for West Wendover, Nevada.
0.3	118.3	Turn left (south) at end of ramp.
0.2	118.5	Turn right (west) at intersection (light) on Alternate Highway 93, the main drag of West Wendover. We will stop for a one-hour dinner break.



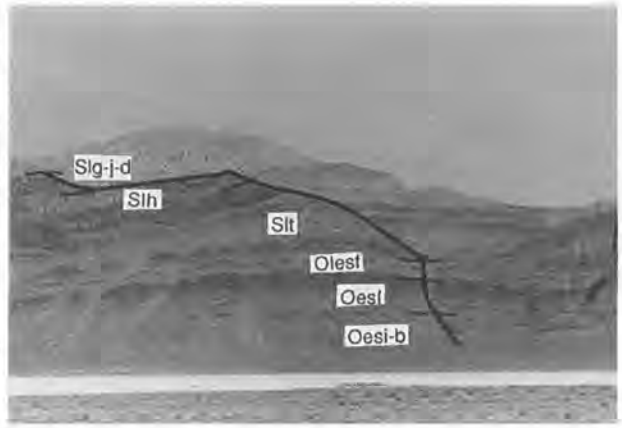
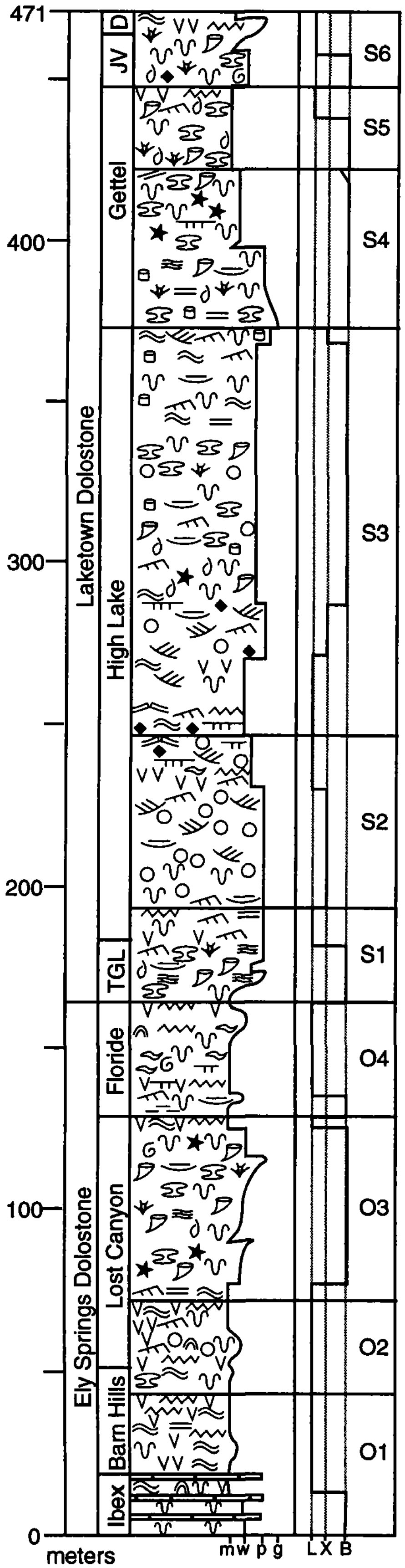


Figure 16. Location of the Barn Hills traverse on Barn 7.5 minute quadrangle map and a field photograph viewed from the east. Members of the Ely Springs and Laketown Dolostones are indicated by letters on the photograph (contacts marked by thin lines). The Eureka Quartzite (Oe) occurs in scattered outcrops at the base of the mountain. The Ely Springs Dolostone consists of the Ibex and Barn Hills Members (Oesi-b), the Lost Canyon Member (Oesl), and the Floride Member (Olesf). The Laketown Dolostone consists of the Tony Grove Lake Member (Slt), the High Lake Member (Slh), the Gettel-Jack Valley-Decathon Members (Slg-j-d). Approximate line of traverse (thick line) in the Ely Springs is along gully whereas Laketown section is along ridge line.

1.0	119.5	Turn left and proceed south on Alternate Highway 93.
58	177.5	Intersection with Highway 93. Continue straight (south).
45	222.5	McGill—site of former smelter for copper mines near Ely.
12	234.5	Intersection with Highway 6/50 (light) in East Ely. Continue straight (west) on 6/50 into Ely.
1.1	235.6	Turn right at the Hotel Nevada onto Fifth Street.
0.1	236.7	Four Sevens Motel, Ely.

<u>Day 2: Ely, NV to the Pancake Range to Ely</u>

0.0	0.0	Hotel Nevada, Ely—proceed west on Highway 6/50.
0.1	0.1	Turn left on Mill Street (Highway 6).
1.0	1.1	Turn right on Highway 6.
4.7	5.8	Murry Summit, Egan Range.
17.5	23.3	Continue straight at the junction with Highway 318, which leads to Lund and Las Vegas.
15.0	38.3	Current Summit, Horse Range. White Pine Range visible ahead to right as we descend.
12.5	50.8	Currant—Entering Railroad Valley.
11.3	62.1	Facility for Railroad Valley Field (to left). Pancake Range is low range ahead.
8.5	70.6	Milepost 98.
0.6	71.2	Right on dirt road, cross the cattle grate. Road parallels the range.
8.4	79.6	Road bends left into Wood Canyon.
0.6	80.2	Road bends right, then turn left through a 135° curve onto track.
0.5	80.7	Park. STOP 1, Pancake Range. Turn around. The measured section is located on the west side of the Pancake Range, 8.5 miles northeast of Black Rock Summit in the NE 1/4 of unsurveyed section 25, T. 9 N., R. 54 E. (Fig. 11). We will walk east-southeast across the



		draw and climb through a notch in the Eureka Quartzite to reach the base of the section.
0.5	81.2	Sharp right onto dirt road.
9.0	90.2	Turn left on Highway 6.
70.1	160.3	Turn left into Ely on Mill Street.
1.1	161.4	Turn right onto Aultman Street at junction with Highway 50.
0.1	161.5	Hotel Nevada, Ely.

Day 3: Ely, NV to Sunnyside, southern Egan Range to Ely

0.0	0.0	Hotel Nevada, Ely—proceed west on Highway 6/50.
0.1	0.1	Turn left on Mill Street (Highway 6).
1.0	1.1	Turn right on Highway 6
22.2	23.3	Turn left (south) on Highway 318.
7.5	30.8	Lane's Motel at Preston.
4.2	35.0	Carter's General Store, Lund.
24.4	59.4	Shingle Pass Road on left, continue straight.
5.4	64.8	Turn left (east) onto dirt road. Proceed through gate and turn left (north) along inside of fence.
0.9	65.7	Center of wash; gravel pit to right.
0.1	65.8	Turn right (northeast) on track at a 45° angle.
0.9	66.7	Cross wash and on the far side take the right fork at Y intersection.
1.7	68.4	Park at fork in track. STOP 2, southern Egan Range. Turn around. The measured section is located on the west side of the southern Egan Range, 2.9 miles northeast of Whipple Ranch, Sunnyside beginning in the SE 1/4 NE 1/4 of section 14, T. 7 N., R. 62 E. and ending in the SW 1/4 NW 1/4 of section 13, T. 7 N., R. 62 E.(Fig. 14). We will walk east around the south end of the Eureka Quartzite outcrop to reach the base of the section.
1.7	70.1	Left at Y intersection, cross wash.
0.9	71.0	Turn left (southwest).
1.0	72.0	Turn right (north) on Highway 318.
29.8	101.8	Carter's General Store, Lund.

Figure 17. Graphic summary of the Barn Hills section showing stratigraphy, sedimentological features (for key, see Figure 5D), facies (L=laminite, X=cross bedded, and B=burrowed), and sequences. Stratigraphic abbreviations are TGL=Tony Grove Lake Member, JV=Jack Valley Member, and D=Decathon Member.

Figure 18. Headframe of the 3000-ft deep, Bullion Beck and Champion Mining Company mine in the Tintic Mining District, Eureka, Utah.

11.7	113.5	Turn right (east) on Highway 6.
22.4	135.9	Turn left into Ely on Mill Street.
1.1	137.0	Turn right onto Aultman Street at intersection of Highway 6/50.
0.1	137.1	Hotel Nevada, Ely.

<u>Day 4: Ely, NV to the Barn Hills, Confusion Range to Salt Lake City, UT</u>

0.0	0.0	Hotel Nevada, Ely—proceed east on Highway 6/50.
1.1	1.1	Right at East Ely light on Highway 6/50/93.
21.7	22.8	Connors Pass, Schell Creek Range.
5.0	27.8	Continue on Highway 6/50. Highway 93 turns off to right (south).
19.1	46.9	Sacramento Pass, Snake Range.
10.3	57.2	Junction with Highway 487, continue on Highway 6/50.
6.7	63.9	Border Inn, Nevada-Utah stateline. Set your watches <u>ahead</u> one hour as we reenter the Mountain Time zone.
26.9	90.8	Exit King Canyon, Confusion Range. Entering the Tule Valley with the House Range ahead.
10.9	101.7	Turn right (south) onto dirt road paralleling the mountain front.
0.5	102.2	Turn left at intersection.
0.8	103.0	1959 Chevy BelAir (2 door)—go straight.
1.8	104.8	Turn right (west) on track toward playa.
0.2	105.0	Enter Gettel Playa and drive to right of "island" toward the southwest.
0.3	105.3	Park at base of fan on western edge of playa, north of isolated knob. STOP 3, Barn Hills. Return along same path. The measured section is located on the east side of the Barn Hills, Confusion Range, 2 miles north of Ibex Well, beginning in the SE 1/4 NW 1/4 of section 26, T. 21 S., R. 14 W. and ending in the NE 1/4 NE 1/4 of section 34, T. 21 S., R. 14 W. (Fig. 16). We will walk west to the mountain front to reach the base of the section. The contact with the Eureka is covered at this location but is exposed to the north.
0.3	105.6	Exit playa on track.
0.2	105.8	Turn left (north) on dirt road.
1.8	107.6	Turn right at Chevy.
0.9	108.5	Turn right on dirt road.
1.6	110.1	Turn right (east) on Highway 6/50.
1.6	111.7	Skull Rock Pass (top of roadcut), House Range. Entering the Sevier Desert with Sevier Lake ahead to the right.
47.3	159.0	Light in middle of Delta, Utah.
1.0	160.0	Turn left on Highway 6—Highway 50 separates here.
1.9	161.9	Cheese factory.
2.5	164.4	Continue straight on Highway 6 at junction.
5.8	170.2	Continue on Highway 6. Turnoff on Highway 174 to the left leads to the Intermontane Power Project and Topaz Mountain.
5.6	175.8	Lyndyl—intersection with Highway 132, continue on Highway 6. Leaving the Sevier Desert.
32.7	208.5	Highway 6 bends right into East Tintic Mining District.
1.2	209.7	Head frame for the Bullion Beck and Champion Mining Company mine in the East Tintic Mountains. OPTIONAL

STOP 4. This location is near the eastern limit of the Upper Ordovician-Lower Silurian strata in the Great Basin (Fig. 1). We will not be examining a section at this stop but intend to summarize the inner shelf facies. After stop, continue east on Highway 6.

0.5	210.2	Eureka Post Office.
0.8	211.0	Tintic High School.
19.6	230.6	Enter onto Interstate 15 headed north.
54.0	284.6	Intersection of Interstate 15 and Interstate 215, south of Salt Lake City.

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