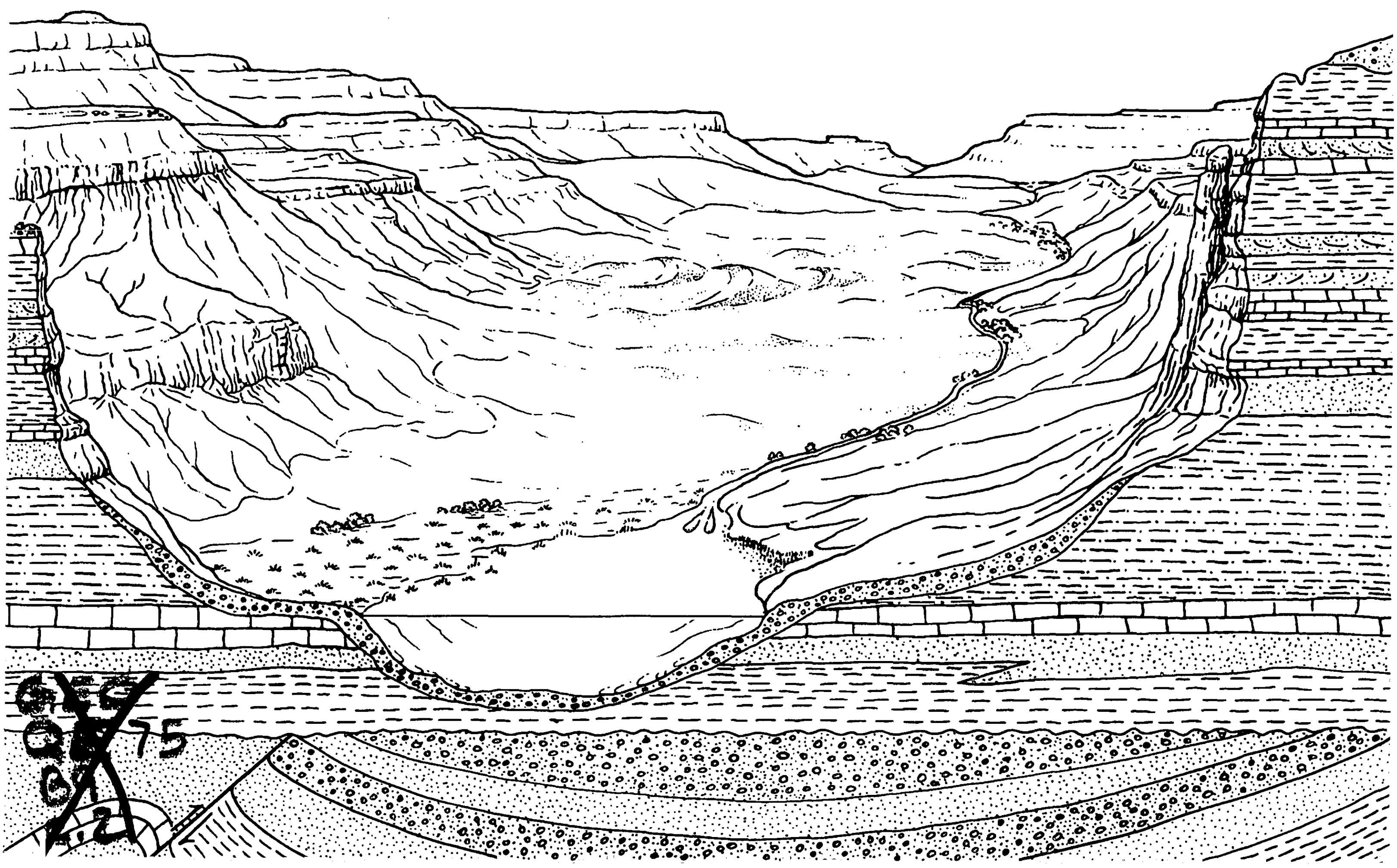
Upper Devonian–Mississippian Stratigraphic Sequences in the Distal Antler Foreland of Western Utah and Adjoining Nevada

U.S. GEOLOGICAL SURVEY BULLETIN 1988–H



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Upper Devonian–Mississippian Stratigraphic Sequences in the Distal Antler Foreland of Western Utah and Adjoining Nevada

By N.J. Silberling, K.M. Nichols, D.L. Macke, *and* Jörg Trappe

EVOLUTION OF SEDIMENTARY BASINS—EASTERN GREAT BASIN

Harry E. Cook and Christopher J. Potter, Project Coordinators

U.S. GEOLOGICAL SURVEY BULLETIN 1988–H

A multidisciplinary approach to research studies of sedimentary rocks and their constituents and the evolution of sedimentary basins, both ancient and modern

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Upper Devonian–Mississippian Stratigraphic Sequences in the Distal Antler Foreland of Western Utah and Adjoining Nevada

By N.J. Silberling,[1] K.M. Nichols,[1] D.L. Macke,[1] *and* Jörg Trappe [2]

ABSTRACT

Upper Devonian to Mississippian strata in western Utah and adjoining Nevada were deposited in the distal (continentward) part of the Antler foreland. These strata are interpreted as five successive, second- and third-order stratigraphic sequences, informally named from oldest to youngest the Langenheim, Gutschick, Morris, Sadlick, and Maughan sequences. Each of these sequences records a major episode of transgressive-regressive deposition. Their depositional histories may be expected to reflect Antler tectonism at the continental margin, but the nature and timing of this protracted orogenic event is disputed, partly because palinspastic restoration of the subsequent, large-scale contraction and extension of the Antler orogen and its foreland is poorly known.

The Langenheim sequence of late Frasnian to mid-Famennian age records the initial open-marine mid-Paleozoic flooding of the inner shelf of the Cordilleran miogeocline. Transgressive ramp limestones of this sequence in westernmost Utah and adjoining Nevada are overlain by generally progradational, fine-grained, craton-derived, siliciclastic rocks of the Pilot Shale. These deposits represent a complex delta-lobe and prodelta clastic system, the first of this kind to be preserved on the Paleozoic shelf of the eastern Great Basin. The Gutschick sequence represents renewed marine transgression and regression during late Famennian to early Kinderhookian time that is recorded by the locally preserved upper part of the Pilot Shale and its lateral equivalents. The Pinyon Peak Limestone in west-central Utah is a separate expression of the Gutschick sequence, the accumulation of which was controlled by local tectonism.

The overlying Morris sequence consists mainly of carbonate rocks of late Kinderhookian age, including much of the Fitchville Formation in west-central Utah and the lower part of the Joana Limestone farther west. The lateral distribution and lithic character of the widespread Morris sequence resulted primarily from eustatic change rather than from local tectonism. The succeeding Sadlick sequence, of Osagean to Meramecian age, has at its base a thick, aggradational, lowstand systems tract represented by the Gardison Limestone. Tectonic subsidence that accommodated the intertidal to shallow-subtidal, tide- and storm-dominated carbonate deposits of this widespread formational unit was contemporaneous with uplift of the Wendover high farther offshore on the shelf. The sea-level maximum of the Sadlick sequence coincided with initiation of the Delle phosphatic event, initial deposits of which form the transgressive systems tract that onlaps both northwestward onto the evolving Wendover high and eastward onto the craton. Highstand strata of the Sadlick sequence include both fine-grained siliciclastic and carbonate rocks that reflect restricted, poorly oxygenated depositional environments, except for the uppermost, progradational strata of the sequence, which were deposited in high-energy environments near sea level.

The initial transgressive deposits of the subsequent Maughan sequence in Utah are characteristically rhythmically bedded limestones deposited below wave base during the late Meramecian. Above these is a mixed, highstand, clastic and carbonate depositional complex, including units such as the Humbug Formation and Great Blue Limestone. Farther west, restricted limestones and black shales form the lower part of the Maughan sequence, and they grade up into progradational normal-marine, bioclastic limestones.

The restricted-marine, siliciclastic deposits that form part of the highstand systems tracts of the Langenheim, Gutschick, and Sadlick sequences may have been retained on the shelf by subsidence continentward of foreland bulges resulting from flexural loading of the margin during successive episodes of Antler orogenesis. The older of these

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hypothetical forebulges might be tectonically buried beneath Mesozoic thrusts of the Central Nevada thrust belt, if not by the Antler allochthon itself. The Wendover high, developed in concert with accumulation of the Sadlick sequence, may be the localized expression of mid-Mississippian forebulge development. The minor structural relief associated with such tectonism had a marked effect on the character and distribution of deposits of the distal Antler foreland; however, the boundaries of the sequences proposed by us in western Utah and adjoining Nevada correlate with those of the major eustatic sequences recognized by others. Thus, eustasy was the primary control on the major depositional sequences in the distal Antler foreland, and local tectonism only modulated the resulting pattern.

INTRODUCTION

Antler tectonism is generally thought to have resulted in the obduction of an allochthon of oceanic rocks onto the lower and middle Paleozoic miogeocline at the western margin of North America. Hypothetical plate tectonic mechanisms for emplacement of the Antler allochthon include arc-continent collision (Moores, 1970; Speed, 1983), collapse of a retroarc basin (Burchfiel and Davis, 1972, 1975), and amagmatic, extension-coupled, "Mediterranean-type" orogenesis (Burchfiel and Royden, 1991). In western and central northern Nevada deformation of Cambrian to Upper Devonian sea-floor, rise, and slope deposits of the presumed Antler orogen was pre-Pennsylvanian, the age of unconformably overlying strata in these parts of Nevada (Roberts and others, 1958). Farther east, in east-central northern Nevada, this tectonism is commonly interpreted to have persisted from Late Devonian to Mississippian time (Johnson and Pendergast, 1981; Sandberg and others, 1982) and to have involved transport of the Antler allochthon on the Roberts Mountains thrust. In recent years, structural and subsurface studies of the Roberts Mountains thrust system have demonstrated deformation and thrust faulting that involves Mississippian rocks and predates deposition of Late Mississippian strata (Jansma, 1988; Carpenter and others, 1993). Nevertheless, disagreement still exists regarding (1) the timing and kinematics of allochthon emplacement, (2) which rocks in central Nevada were allochthonous during Antler orogenesis, and (3) the significance of post-Paleozoic tectonic displacement of an original Antler-age allochthon (Ketner, 1983a, b; Speed and Sleep, 1983). In particular, determining which faults and other contractional structures observed in different mountain ranges of central Nevada relate to the Antler-age Roberts Mountains thrust system and which relate to the Central Nevada belt of Mesozoic thrusting (Taylor and others, 1993) has not yet been fully resolved (Ketner and Smith, 1982). To avoid the implication of a particular displacement history, the lower Paleozoic oceanic rocks that are allochthonous with respect to the miogeocline are thus referred to as the "Roberts terrane" (Silberling and others, 1987); in the model of mid-Paleozoic overthrust emplacement, they are termed the "Antler allochthon."

Evidence that the Roberts terrane interacted tectonically with the Cordilleran Paleozoic margin is provided by nonmarine or shallow-marine coarse clastic deposits of Late Mississippian age in central and northern Nevada (the "Molasse" of Sadlick, 1960) that were derived from the Roberts terrane and shed eastward onto the continent. Orogenic foredeep deposits of earlier Mississippian age are recognized in a fairly narrow belt bordering the present-day eastern limit (fig. 1) of the Roberts terrane (Sadlick, 1960, 1965; Brew, 1971; Poole, 1974; Harbaugh and Dickinson, 1981; Trexler and Cashman, 1991); however, questions remain regarding the age, nature, and structural setting of these inferred foredeep rocks. Farther east on the shelf, the oldest sedimentologic indication of the possible encroachment of the Roberts terrane onto the continental margin is the abrupt appearance of open-marine limestone above a thick succession of inner shelf deposits of the miogeocline near the top of the Frasnian Stage in about mid-Late Devonian time. These open-marine limestones both underlie and intertongue with fine-grained siliciclastics of the Pilot Shale, which also first appear locally at about an age-equivalent level (Sandberg and others, 1989). Together, these Upper Devonian strata herald the advent of tectonic instability and the end of miogeoclinal deposition that had persisted since Late Proterozoic time.

Foreland effects of Antler orogenesis are thus recorded in strata of Famennian through Mississippian age in the region from the vicinity of the Roberts terrane in Nevada eastward into the Sevier thrust belt in Utah (fig. 1). This report describes the initial application in this region of depositional sequence analysis to these strata whose relationships are complicated structurally. Both the Roberts terrane in Nevada and the Antler foreland in eastern Nevada and western Utah have been significantly rearranged by tectonism that includes (1) middle and late Mesozoic thrusting of uncertain style and magnitude in the hinterland of the Sevier thrust belt (Bartley and Gleason, 1990; Thorman and others, 1991; Taylor and others, 1993); (2) poorly understood structural unroofing of thrust-thickened crust in late Mesozoic to early Tertiary time, at least in the north-central Great Basin (Wells and others, 1990; Hodges and others, 1992); and (3) Eocene to Miocene extension in poorly circumscribed domains in which the amount of extension may average as much as 100 percent and is interpreted for some domains to be as much as 300 percent (Gans, 1987).

In addition to the many palinspastic uncertainties resulting from this structural disruption, other factors also hinder sequence analysis in this region. Although Basin and Range physiography in the eastern Great Basin enhances surface exposure, it precludes continuity between outcrop areas. And, compared to other regions where depositional

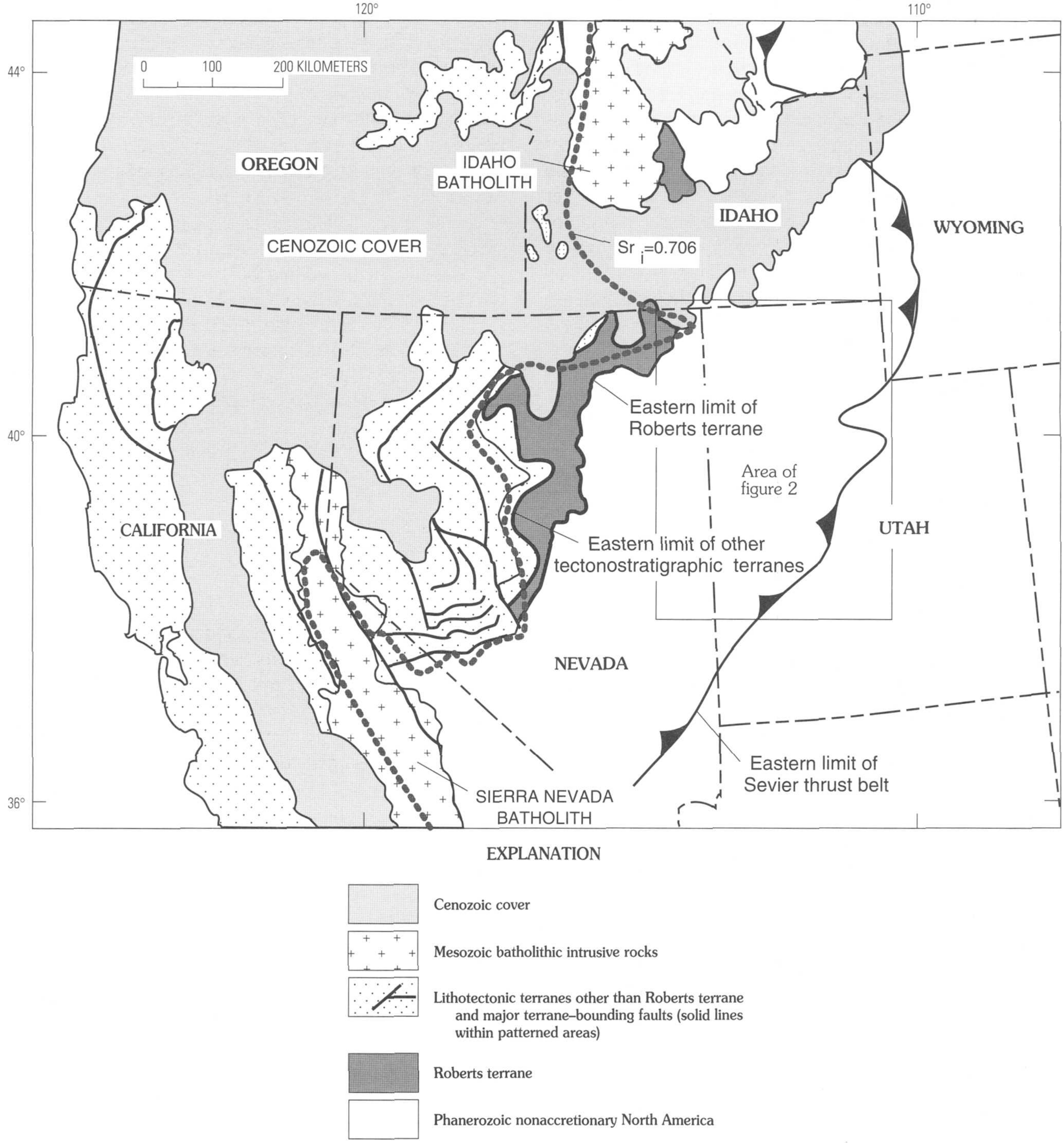

Figure 1. Map of Utah, Nevada, and adjacent States showing the location of figure 2 in relation to the eastern limit of the Roberts terrane, other accreted terranes and major terrane-bounding faults, the eastern limit of the Sevier thrust belt, and the initial strontium 0.706 isopleth (Elison and others, 1990).

sequence analysis has been successfully applied, subsurface information for the eastern Great Basin is relatively scarce. Instead, the history of local sea-level change must be interpreted primarily from surface exposures. For this, our strategy was to study the Upper Devonian to Upper Mississippian strata that represent the distal (continentward) deposits of the Antler foreland in western Utah and adjoining parts of Nevada (fig. 2). In this part of the region

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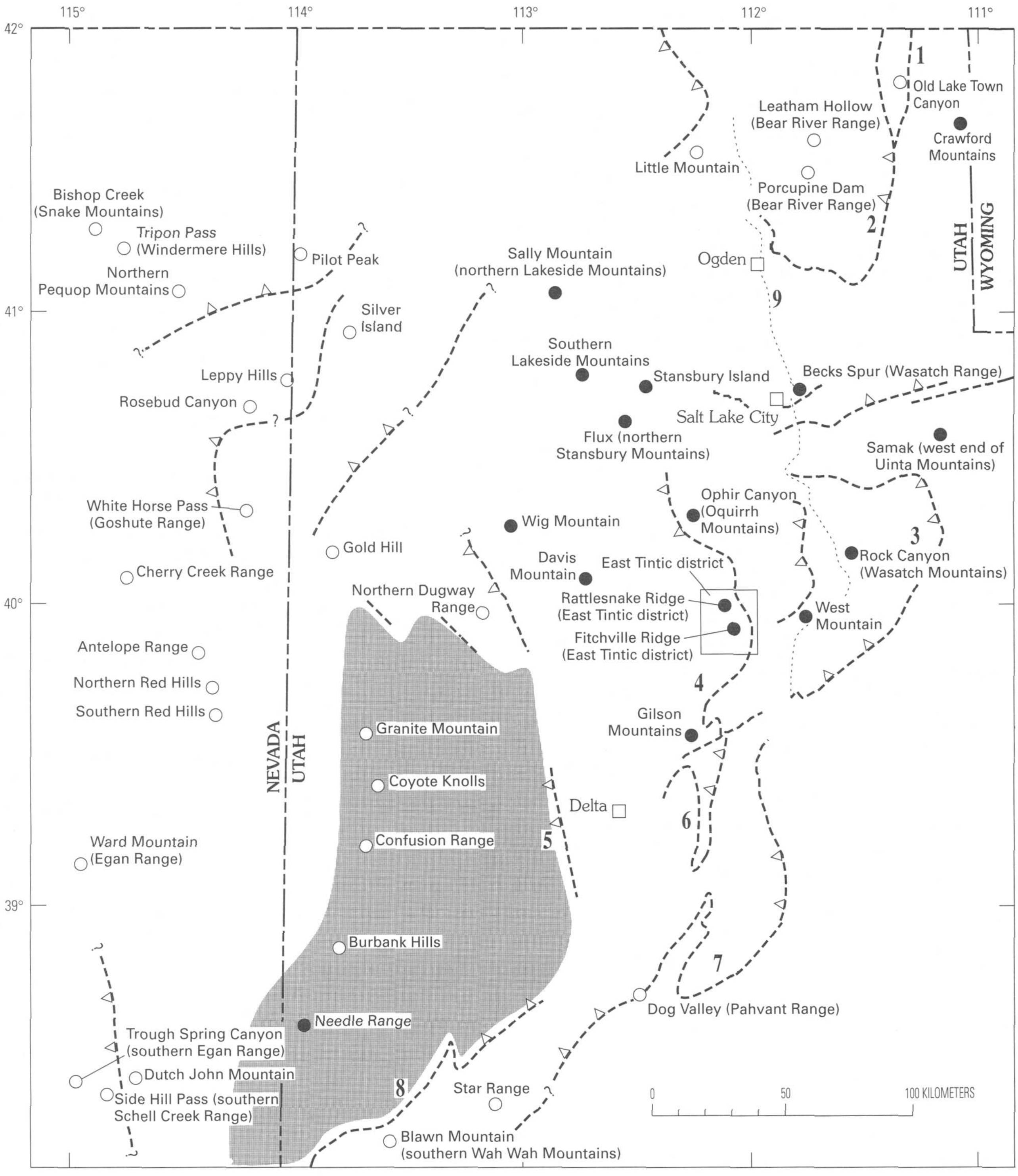


EXPLANATION

- Known or inferred thrust fault
- Wasatch normal fault zone
- ● Section at which lithosome SA. La. Pk is recognized
- ○ Section at which stratigraphic level of lithosome SA. La. Pk is included, but at which the lithosome either is not represented or a different lithosome is present

Figure 2 (facing page). Map of part of western Utah and adjoining eastern Nevada showing locations of significant Upper Devonian–Mississippian stratigraphic sections (open and solid circles). Numbers designate major faults: 1, Laketown thrust (Coogan and Royse, 1990); 2, Paris-Willard thrust; 3, Charleston-Nebo thrust; 4, East Tintic thrust (in part); 5, House Range detachment, interpreted as reactivated thrust (Villien, 1984; Royse, 1993); 6, Canyon Range thrust; 7, Pavant thrust; 8, Wah Wah thrust; 9, Wasatch fault zone. Structural features modified from Allmendinger and others (1983), Levy and Christie-Blick (1989), Miller (1990), Morris (1983), and others. Region west of Wasatch fault zone was tectonically extended a significant amount in Tertiary time; the highly extended belt of Gans and Miller (1983) is west of the shaded area, which represents the relatively undeformed House Range–Wah Wah structural plate, interpreted as the structurally highest plate of the Sevier thrust belt (Walker and Bartley, 1992).

PALINSPASTIC RESTORATION

In western Utah and adjoining Nevada significant stratigraphic sections of Frasnian to Chesterian age rocks are present at the places marked by circles in figure 2. Regional characterization of the depositional sequences requires rearranging these sections palinspastically, but the structural complexity of western Utah and adjoining Nevada and the isolated nature of exposures makes the palinspastic reconstruction shown in figure 3 problematical. Although reasonable estimates for Eocene and younger extension can be extrapolated from the analysis by Gans (1987) of the east-west strip between the 39th and 40th parallels, the correction for still earlier tectonism, especially that west of the Wasatch front, is subject to widely differing interpretations. Palinspastic reconstruction is partly dependent on understanding the pre-Tertiary facies themselves and the apparent tectonic juxtapositions among them, thus adding an inevitable element of circularity to structural interpretation.

Ignoring the possibility of significant pre-Eocene extension, the palinspastic correction incorporated in figure 3 for the known or inferred Mesozoic contractional structures shown in figure 2 utilizes the analysis of the main Sevier thrust belt by Levy and Christie-Blick (1989) as a point of departure. In addition, we restored another 80 km of shortening to compensate for structurally higher Sevier thrusts, including the Wah Wah and Canyon Range thrusts (Walker and Bartley, 1992), that are thought to have large eastward transport (Friedrich and Bartley, 1992). Major thrusts of this level are also thought by us to include dismembered segments shown diagrammatically in figure 2 such as the House Range detachment (reflection seismic events F and G of Allmendinger and others, 1983, on COCORP line 1) and hypothetical segments farther north such as those needed to explain the apparent juxtaposition of the stratigraphic sections at northern Dugway Range, Gold Hill, Sally Mountain (northern Lakeside Mountains), and southern Lakeside Mountains (fig. 2) with the next closest locations farther to the west. North of the relatively coherent House Range–Wah Wah Mountains block, of which the sections at Needle Range, Burbank Hills, Confusion Range, Coyote Knolls, and Granite Mountain are a part, and west of the seismic and outcrop structural control that exists for the Wasatch Mountains, the Devonian-Mississippian sections on our reconstruction (fig. 3) were rearranged to provide the most reasonable paleogeography.

UPPER DEVONIAN–MISSISSIPPIAN SEQUENCES

PROCEDURE

Upper Frasnian to Chesterian strata comprising the sections shown in figure 2 are subdivided into 35 lithosomes. Each lithosome is a genetic unit that represents the rocks deposited in a distinct depositional environment or set of environments that existed for a particular area during a certain time. For each of the lithosomes a lithic description, an interpretation of depositional environment, and occurrence data are provided in the appendix. As further explained in the appendix, the descriptive names of the lithosomes are abbreviated in the text and figures by letter symbols. Each abbreviation consists of two or three parts, separated by periods, that represent, respectively, (1) the name of the sequence to which the lithosome belongs, (2) terms, if any, that modify the rock type, and (3) the rock type. For example, the lithosome forming part of the Sadlick sequence and characterized by laminated dolomitic siltstone is abbreviated SA.LaDo.St, and the lithosome of the Maughan sequence formed mainly of mudstone is abbreviated MA.Ms. Lists of the terms and their symbols adopted for modifiers and rock types are given in the appendix; many of the symbols are self-explanatory.

The depositional environments inferred for the various lithosomes and their lateral and superpositional relationships allow them to be interpreted, either individually or in groups, in terms of the systems tracts of stratigraphic sequences.[3] Each of these sequences records a distinct transgressive-regressive cycle of deposition. The boundaries between sequences lie between the highstand systems tract of the preceding sequence and the lowstand systems tract, where present, or transgressive systems tract of the succeeding sequence. Certain boundaries between these sequences are more conspicuous regionally than others and

[3] For an explanation of the concepts and terminology of sequence stratigraphy see, for example, Van Wagoner and others (1988).

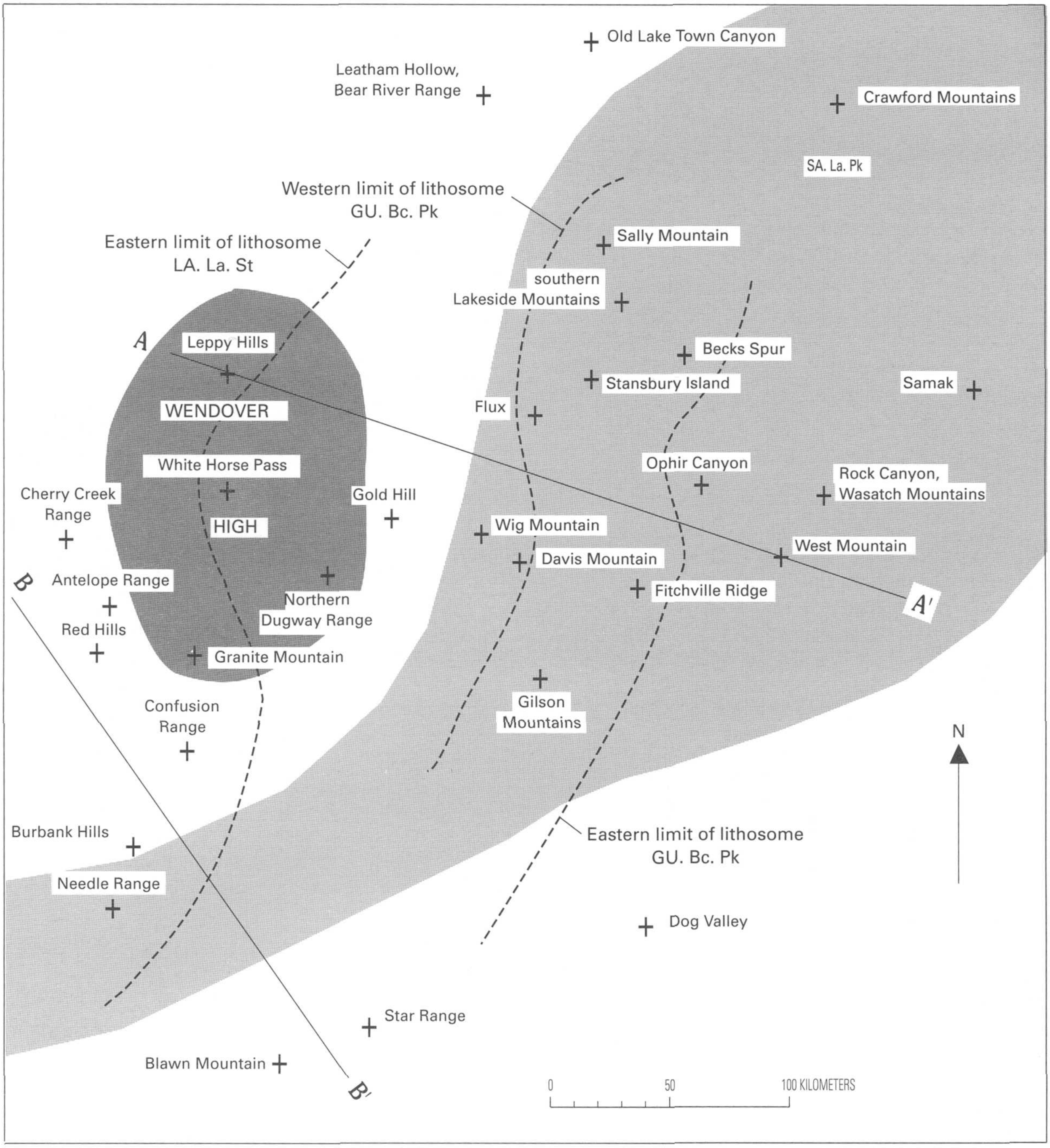


Figure 3. Palinspastic map showing selected locations from figure 2 in their structurally restored positions according to the constraints described in the text. Lines of cross sections *A–A′* (fig. 5) and *B–B′* (fig. 6) are also shown. Lithosomes LA.LaDo.St and GU.Bc.Pk are described in text and appendix. Light shading shows the extent of lithosome SA.La.Pk (in the lower part of the Sadlick sequence); dark shading indicates that part of the Wendover high in which the lower Sadlick sequence is abnormally thin or missing (and, locally, still older sequences are missing as well).

are utilized to divide the Frasnian to Chesterian section into five informally named second- or third-order stratigraphic sequences. To avoid the ambiguity inherent in designating sequences by numbers, letters, or the names of geographic features, these sequences are informally named, in ascending order, the Langenheim, Gutschick, Morris, Sadlick, and Maughan sequences in recognition of individuals who have made important contributions to the knowledge of these strata[4] (Silberling and others, 1993).

[4] Significantly, Langenheim (1961); Gutschick and Rodriguez (1979); Morris and Lovering (1961); Sadlick (1960, 1965); Maughan and Roberts (1967).

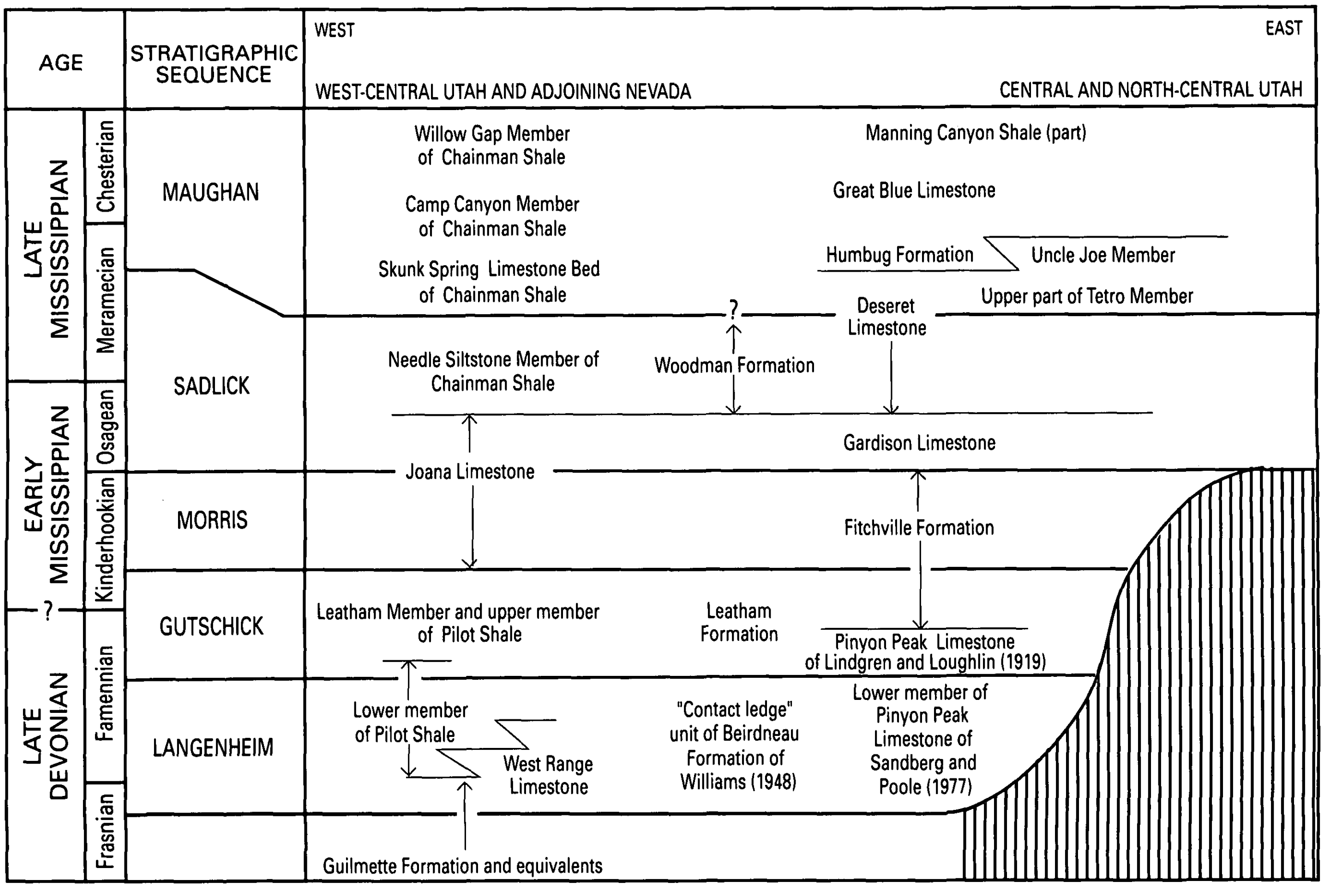


Figure 4. Chart showing the positions of the stratigraphic sequences described in the text and their relationship to widely recognized lithostratigraphic units in western Utah and adjoining Nevada. Vertical ruling represents stratigraphic hiatus.

Some of these named sequences, such as the Morris, represent a single transgressive-regressive cycle of third-order scale, whereas others such as the Langenheim and Maughan are of second-order duration and at least locally incorporate within them distinct subsidiary transgressive-regressive cycles of third-order and lesser rank. As might be expected, the sequence boundaries lie within some of the established lithostratigraphic units in the region as shown in figure 4.

The relationships among these sequences and their component lithosomes are shown in figures 5 and 6, which are palinspastic cross sections trending at a high angle to the inferred depositional strike (fig. 3). Lithosome thicknesses on each of the cross sections are interpolated from those in the nearest measured sections on either side of the lines of cross section. The more northern cross section (fig. 5, line *A–A'*) extends from the Leppy Hills on the Nevada-Utah border east-southeastward through West Mountain (fig. 3). Stratigraphic sections in the East Tintic district (fig. 2) lie just south of this line of cross section. The nature of the record at Samak at the west end of the Uinta Mountains (fig. 2)—on autochthonous North America—is projected south into this line of section. The more southern cross section (fig. 6; line *B–B'*) extends from Indian Creek in the east-central Cherry Creek Range in eastern Nevada southeastward to the vicinity of Blawn Mountain at the south end of the Wah Wah Mountains and the Star Range in southwestern Utah (fig. 3). The seemingly rapid changes in stratal thickness on the cross sections (figs. 5, 6) result from the large vertical exaggeration; the steepest actual slopes in this reconstruction are barely one part in a thousand.

Most of the Upper Devonian to Mississippian strata at the locations plotted in figure 2 can be assigned to the lithosomes whose relationships are depicted in figures 5 and 6. Exceptions are the northwesternmost locations—Bishop Creek, Tripon Pass, northern Pequop Mountains, and Pilot Peak—at which other lithosomes occur; the higher parts of the Maughan sequence in central Utah, which have not yet been adequately studied; and parts of a few other stratigraphic sections where rocks of uncertain age or structure are present, as discussed later.

LANGENHEIM SEQUENCE

The lower part of the Langenheim sequence, the oldest of the sequences discussed herein, records initial mid-Paleozoic open-marine flooding of the Devonian inner shelf as represented in the eastern Great Basin. Pre-Langenheim Devonian strata in western and central Utah are cyclic peritidal dolostone and quartz sandstone of

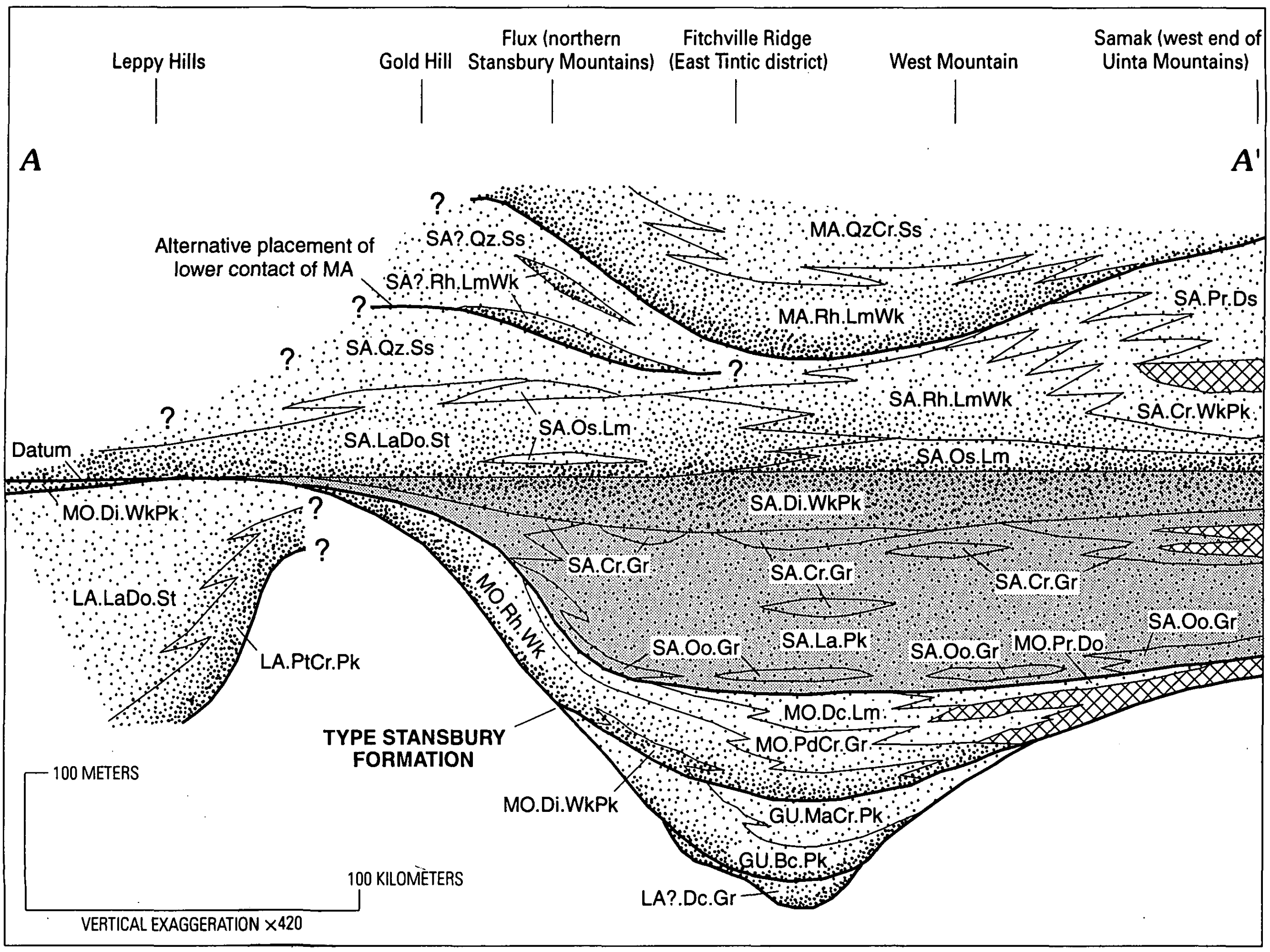
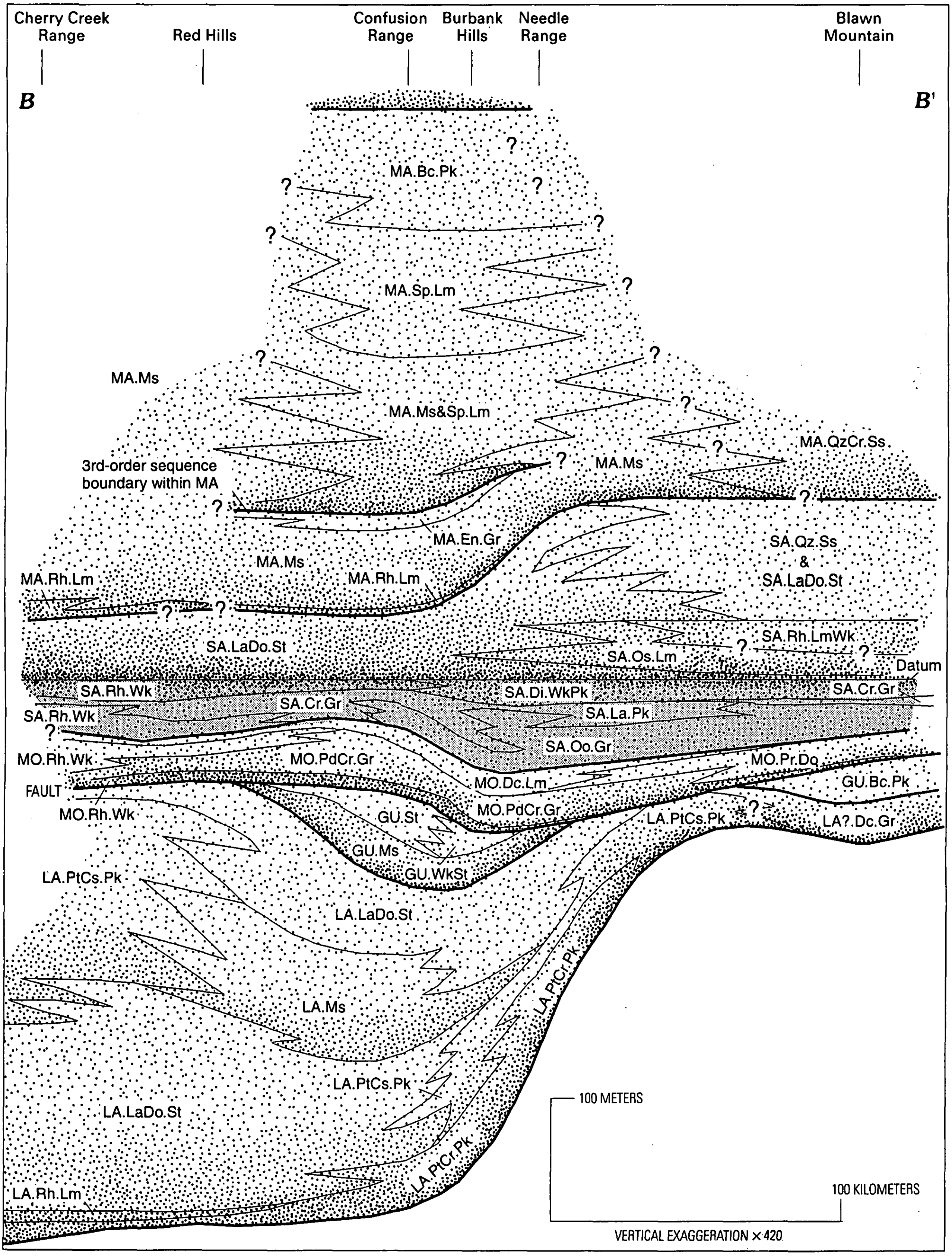


Figure 5. Palinspastic cross section *A–A'* of Upper Devonian–Mississippian lithosomes and sequences. Line of section shown in figure 3. Control for cross section projected into line of section from locations whose names are shown. Heavy lines are sequence boundaries for the Langenheim (LA), Gutschick (GU), Morris (MO), Sadlick (SA), and Maughan (MA) sequences; abbreviations for lithosome designations are described in the appendix. Datum is the initiation of the Delle phosphatic event (Silberling and Nichols, 1990, 1991) within the Sadlick sequence. Gradation in density of dot pattern expresses change in water depth interpreted for the depositional environments, the greatest density representing the relatively deepest environments. All of the sequences are shallowing upward except for the Sadlick sequence, which deepens upward (shaded area) to the level of the Delle phosphatic event, above which it shallows upward. Crosshatching represents coarse-grained secondary dolomite of uncertain protolith.

the Guilmette Formation (Middle and Upper Devonian) and its lateral equivalents. Locally, and farther to the east, sequences younger than the Langenheim onlap and overstep these Devonian rocks and rest on similar kinds of inner shelf deposits as old as Cambrian.

The most complete expressions of the Langenheim sequence are restricted to westernmost Utah (at Leppy Hills, Granite Mountain, Confusion Range, Burbank Hills, and Needle Range, fig. 2) and locations farther west in adjoining Nevada (such as at Cherry Creek Range, northern Red Hills, and Side Hill Pass, fig. 2). At most of these locations the lower, transgressive part of the Langenheim sequence consists of thin-bedded, mottled to nodular, abundantly pelletal packstone and wackestone of lithosome LA.PtCr.Pk (figs. 5, 6,

Figure 6 (facing page). Palinspastic cross section *B–B'* of Upper Devonian–Mississippian lithosomes and sequences. Line of section shown in figure 3. Control for cross section projected into line of section from locations whose names are shown. Heavy lines are sequence boundaries for the Langenheim (LA), Gutschick (GU), Morris (MO), Sadlick (SA), and Maughan (MA) sequences; abbreviations for lithosome designations are described in the appendix. Datum is the initiation of the Delle phosphatic event (Silberling and Nichols, 1990, 1991) within the Sadlick sequence. Gradation in density of dot pattern expresses change in water depth interpreted for the depositional environments, the greatest density representing the relatively deepest environments. All of the sequences are shallowing upward except for the Sadlick sequence, which deepens upward (shaded area) to the level of the Delle phosphatic event, above which it shallows upward.


Cherry Creek Range
Red Hills
Confusion Range
Burbank Hills
Needle Range
Blawn Mountain
B
B'
MA.Bc.Pk
MA.Sp.Lm
MA.Ms
MA.Ms&Sp.Lm
MA.QzCr.Ss
3rd-order sequence boundary within MA
MA.Ms
MA.En.Gr
SA.Qz.Ss & SA.LaDo.St
MA.Ms
MA.Rh.Lm
MA.Rh.Lm
SA.Rh.LmWk
SA.LaDo.St
SA.Os.Lm
Datum
SA.Rh.Wk
SA.Di.WkPk
SA.Cr.Gr
SA.Rh.Wk
SA.Cr.Gr
SA.La.Pk
SA.Oo.Gr
MO.Rh.Wk
MO.PdCr.Gr
MO.Pr.Dq
FAULT
MO.Dc.Lm
GU.Bc.Pk
MO.Rh.Wk
GU.St
MO.PdCr.Gr
LA.PtCs.Pk
LA?.Dc.Gr
GU.Ms
GU.WkSt
LA.PtCs.Pk
LA.LaDo.St
LA.PtCr.Pk
LA.Ms
LA.PtCs.Pk
LA.LaDo.St
LA.PtCr.Pk
LA.Rh.Lm
100 METERS
100 KILOMETERS
VERTICAL EXAGGERATION × 420

appendix). This lithosome is characterized by open-marine bioclasts derived mainly from crinoids and shelly fossils. Lithosome LA.PtCr.Pk has been mapped as part of the Guilmette Formation in the Leppy Hills (Schneyer, 1990) and in the Confusion Range (Hintze and Best, 1987); in the Burbank Hills it is included in the Upper Devonian West Range Limestone (Sandberg and others, 1989).

In the Burbank Hills (fig. 2), lithosome LA.PtCr.Pk grades upward into lithosome LA.PtCs.Pk characterized by pellet-calcisphere packstone. These lithosomes are similar in bedding characteristics and in their abundance of pelletal allochems, but lithosome LA.PtCs.Pk has a bioclast assemblage mostly limited to calcispheres and ostracodes. These kinds of bioclasts are indicative of restricted, lagoonal depositional environments where they are present elsewhere in Upper Devonian and Mississippian carbonate-shelf deposits (see, for example, Richards and Bergeron, 1992).

Fine-grained siliciclastic rocks of the lower member of the Pilot Shale, most of which belong to lithosome LA.LaDo.St (laminated dolomitic siltstone), are intercalated with and overlie the limestones of lithosomes LA.PtCr.Pk and LA.PtCs.Pk (figs. 5, 6). Lithosome LA.LaDo.St, together with black mudstone and shale of lithosome LA.Ms, forms much of the Langenheim sequence from the Confusion Range (fig. 2) northward. Together they are a lateral facies of the limestones of lithosomes LA.PtCr.Pk and LA.PtCs.Pk and mostly supplant them from south to north (fig. 6). Strata of all four of these lithosomes, both siliciclastic and carbonate, range in age at one place or another from the latest Frasnian to the mid-Famennian according to Sandberg and others (1989, fig. 10).

A few isolated graded beds, generally 10–50 cm thick, of intraclastic and sandy limestone that exhibit Bouma-sequence internal layering are present within the lower part of the continuous sections of laminated, dolomitic siltstone of lithosome LA.LaDo.St in the Leppy Hills, Cherry Creek Range, and Confusion Range (fig. 2). Where a number of these isolated beds are present in succession, as in the Leppy Hills (Poole, 1974; Nichols and Silberling, 1993), they vary from one to another and range from Bouma-like T_A or T_{AB} beds, some having composite and coarsely intraclastic T_A layers, to more complete T_{ABCE} beds. Because of their stratigraphic context, composite T_A layers, and variability in Bouma-sequence layering, we regard these beds as primarily storm deposits or tempestites. Storm activity was probably responsible for the initial turbid suspension of the finer grained sediment that ultimately formed these deposits, and transport was probably due primarily to storm-generated combined flow rather than to turbidity-current gravity flow.

Another minor component of significance for interpreting the depositional history of the Langenheim sequence is the slump-folded and brecciated limestone intervals that are as thick as a few meters. A few of these intervals are intercalated in the ubiquitous laminated dolomitic siltstone of lithosome LA.LaDo.St in the Confusion and Cherry Creek Ranges in westernmost Utah and eastern Nevada, respectively (fig. 2). These sedimentary breccias are monolithologic and in most cases can be traced laterally within about 10 m through slump folds into coherent, nodular, thin-bedded limestones similar to those that form lithosomes LA.PtCr.Pk and LA.PtCs.Pk. Therefore, transport by gravity flow of these deposits as breccias was minimal. In the Confusion Range some of the slump-brecciated limestone units occupy channels cut into the plane-laminated siltstone. In some channels the partly brecciated limestone either laterally cuts into earlier channel deposits of sandstone or is scoured out by subsequent sandstone channel fillings, all within 2 m of stratigraphic thickness. Similar to the partly slumped and brecciated limestone units in the Confusion Range, those in the Cherry Creek Range have been treated by others as debris flows, with the implication of appreciable transport and association with slope environments and deep-water submarine fans (for example, Sandberg and others, 1989; Jones 1990). This interpretation is unlikely, however, because these partly brecciated limestones in the Cherry Creek Range that intercalate with lithosome LA.LaDo.St and those that overlie it and form the Indian Ranch Tongue of the Guilmette Formation (Sandberg and others, 1989) are of restricted-lagoonal origin. They are monotonous, pellet-calcisphere packstones in which shelly fossils are scarce and generally restricted to gastropods, and they are included in lithosome LA.PtCs.Pk in figure 6. This lithosome also forms the upper part of the West Range Limestone in its southeasternmost sections, such as that in the Burbank Hills (fig. 2).

As compared with the stratigraphic sections of the Pilot Shale at Granite Mountain and in the Confusion Range (fig. 2), the intervening section at Coyote Knolls (fig. 2) differs in that slump folds are prevalent and conspicuous in two intervals within the lower 60 m of section (Gutschick and Rodriguez, 1979). These pervasively slumped, fine-grained clastic parts of the Coyote Knolls section contain unusually abundant graded beds. Twelve directional, soft-sediment folds measured in the upper slumped interval yield a mean downslope direction (with regional bedding rotated to horizontal) of 253° and a resultant vector having a magnitude of 0.78. The stratigraphically lowest slump-folded Pilot sandstone bed in this succession is a scant 15 m conformably and gradationally above inner platform oncolitic and *Amphipora*-bearing limestone of the underlying Guilmette Formation. These rocks are thus near the base of the Langenheim sequence. We interpret this local, sandy, slump-folded sequence at Coyote Knolls as part of a small delta along the eastern limit of Pilot deposition that was related to bypass drainage from the east across the surface of the Guilmette supratidal-carbonate and sand-sea flat. For this deltaic interpretation, it is significant that the siliciclastic rocks of this unusual part of the Pilot are evidently a lateral facies of the lithosome LA.PtCr.Pk, the limestones that are mapped with the upper part of the Guilmette (Hose and Repenning, 1964) about 20 km farther south in the Confusion Range. A different interpretation was offered by

Sandberg and others (1988), who invoke a bolide impact to explain the slump folds in the Coyote Knolls section.

Although the siliciclastic rocks of the Pilot are commonly regarded as deep-marine basinal deposits (for example, by Sandberg and others, 1989), we interpret them instead as representing a mostly restricted, but storm-influenced, shallow-marine system (appendix). The nature of the predominantly siliciclastic lithosomes LA.LaDo.St and LA.Ms reflects changes not only in the depth of water but also in sediment supply and degree of restriction of the water mass. Moreover, these strata may have been deposited concomitantly with local tectonic subsidence, and they incorporate minor retrogradational and progradational parasequence sets. Placing these lithosomes into a simple sequence-stratigraphic framework reflecting the history of sea-level change is therefore difficult. Nevertheless, we view these siliciclastic deposits as having been built out from the east in delta-lobe fashion and having prograded laterally in a complex way over the ramp limestones of lithosomes LA.PtCr.Pk and LA.PtCs.Pk. Viewed in this way, they generally represent progradation by the highstand systems tract of the Langenheim sequence. The slumped and brecciated channel limestone units reflect minor rises in relative sea level and subsidiary transgression of restricted, lagoonal carbonate deposition into this clastic system. An upward transition from laminated dolomitic siltstone to shoreface sandstones exhibiting herringbone cross-stratification is present in the uppermost part of lithosome LA.LaDo.St in the southernmost in the Burbank Hills (figs. 2, 6). This transition provides a clear expression of progradation at the top of the Langenheim sequence.

Representation of the Langenheim sequence east of the Granite Mountain to Needle Range outcrop belt in westernmost Utah (fig. 2) is problematic. Possible candidates are among the thin successions included by Sandberg and Poole (1977) in their "middle Famennian depositional complex." One of these is the limestone that forms the upper 10–15 m of the Beirdneau Formation (Upper Devonian) at Leatham Hollow (fig. 2) in the Bear River Range, northern Utah, and was informally termed the "contact ledge" by Williams (1948). This limestone may be part of the Langenheim sequence because it is similar to lithosome LA.PtCr.Pk in composition, being a peloidal, crinoidal packstone and wackestone. Moreover, the "contact ledge" limestone is separated from the overlying Upper Devonian basal siliciclastic beds of the Leatham Formation of the Gutschick sequence by a distinct disconformity (Gutschick and Rodriguez, 1979). The "contact ledge" is reported, however, by Sandberg and Poole (1977) to be slightly younger within the Famennian than any known part of the Langenheim sequence, and thus it conceivably could be the lowstand systems tract of the Gutschick sequence. Where exposed at Leatham Hollow, an attenuation fault at its base separates the "contact ledge" from inner shelf dolostone and quartzite of the Beirdneau Formation.

Another possible part of the Langenheim sequence in west-central and southwestern Utah is the characteristically light colored, megascopically unfossiliferous, desiccated peloidal grainstone of lithosome LA?.Dc.Gr (fig. 6, appendix). This lithosome does not exceed a few tens of meters in thickness and apparently has been differentially eroded beneath the Gutschick sequence. It crops out only at and near Blawn Mountain, in the Star Range, and locally within the East Tintic district (fig. 2). Erosion surfaces, accompanied by sedimentary breccia of peloid grainstone and (or) thin layers of fine-grained sandy limestone or calcareous sandstone, are present throughout all three of these known occurrences of lithosome LA?.Dc.Gr. Both the upper and lower contacts of this lithosome are abrupt and apparently disconformable where well exposed in scattered outcrops on the southeast face of Pinyon Peak in the East Tintic district (between Rattlesnake and Fitchville Ridges, fig. 2).

The formational nomenclature applied to lithosome LA?.Dc.Gr has had a tortuous history. Most recently, on the basis that the description by Morris and Lovering (1961) of the Pinyon Peak Limestone (Upper Devonian) in the East Tintic district could be construed to include rocks having the character of this lithosome, Sandberg and Poole (1977) treated this lithosome as the "lower member of the Pinyon Peak Limestone." The original description of the Pinyon Peak by Lindgren and Loughgren (1919), as well as the subsequent description by Morris and Lovering (1961), pertains, however, mostly to lithosome GU.Bc.Pk (figs. 5, 6) which we regard as part of the Gutschick sequence. In our view the erosional remnants of lithosome LA?.Dc.Gr beneath the Gutschick sequence are inshore parts of a broader shelf-carbonate deposit. They may represent an eastern, more inshore facies of the limestones of lithosome LA.PtCs.Pk and thus are part of the Langenheim sequence. On the other hand, conodonts from the uppermost part of lithosome LA?.Dc.Gr in the Star Range are regarded by Sandberg and Dreesen (1984) as being just slightly older in the upper Famennian than those that are abundant and widespread in lithosome GU.Bc.Pk of the Gutschick sequence.

GUTSCHICK SEQUENCE

The lithosomes of the Gutschick sequence are different in separate parts of the study area, depending on the structural level of the exposures within the Sevier thrust belt. A palinspastically more eastern, and structurally lower, belt of Gutschick sequence exposures, extending from the Lakeside Mountains and Becks Spur southward to Blawn Mountain (fig. 3), comprises different lithosomes than those preserved in limited outcrops farther west in the Burbank Hills and Confusion Range and to the north in the Bear River Range, as at Leatham Hollow (figs. 2, 3).

The similarity of the uppermost Famennian and lower Kinderhookian Gutschick-sequence succession that forms the upper part of the Pilot Shale in the Confusion Range with that of the Leatham Formation in the Bear River Range, and the similarity of both of these successions with the Sappington Member of the Three Forks Formation (Upper Devonian and Lower Mississippian?) in southwestern Montana, has long been recognized. These sections are well described by Gutschick and Rodriguez (1979) who show that these disjunct occurrences represent remnants of a distinct depositional belt.

Silty black mudstone and shale of lithosome GU.Ms forms the lower part of the Gutschick sequence in the Burbank Hills, Confusion Range, and Bear River Range. A conspicuous disconformity and lag deposit (appendix) mark the base of lithosome GU.Ms. In the Confusion Range we include in this lithosome both the "black shale unit" (Guschick and Rodriguez, 1979) of the Leatham Member of the Pilot Shale and the immediately underlying shaly part of the lower member of the Pilot, making the total thickness of the lithosome here about 30 m. The conodonts on which the middle Famennian age of this shaly uppermost part of the lower member of the Pilot in the Confusion Range was determined are described as having been obtained from the stratigraphic level of the conodont-rich lag at its base (Sandberg and others, 1989). Thus these shaly strata, which form the uppermost part of the lower member of the Pilot in the Confusion Range and overlie the lag deposit, are not ncessarily as old as middle Famennian. Consequently, they are included by us in lithosome GU.Ms along with the overlying "black shale unit" (of Gutschick and Rodriguez, 1979) of the Leatham Member (Sandberg and others, 1989). The top of lithosome GU.Ms is described by Gutschick and Rodriguez (1979) as a disconformity in both the Confusion Range and Leatham Hollow sections. We interpret this lithosome to be the product of low-energy, restricted-marine deposition and to be the transgressive systems tract of the Gutschick sequence.

Lithosome GU.St, which overlies lithosome GU.Ms, has at its base in the Confusion Range (fig. 6) a distinct lag deposit overlain by shaly beds containing fossils such as conchostracans that are indicative of a paralic environment (Gutschick and Rodriguez, 1979). Gradationally above this fossiliferous shale is several meters of impure, nodular, oncolitic limestone that in turn grades upward into the siltstone that forms the major share of lithosome GU.St (appendix). The siltstone is sparsely fossiliferous and calcareous and becomes increasingly dolomitic toward its top, forming the progradational highstand systems tract of the Gutschick sequence. The stratigraphic succession within lithosome GU.St at Leatham Hollow (fig. 2) is remarkably similar to that in the Confusion Range (Gutschick and Rodriguez, 1979). The stratigraphic position of lithosome GU.St is taken by lithosome GU.WkSt in the Burbank Hills (figs. 2, 3, 6), which is much closer to the Confusion Range than is Leatham Hollow. In its only exposure at Burbank Hills lithosome GU.WkSt is mainly subtidal, rhythmically interbedded wackestone and siltstone that becomes increasingly dolomitized upsection and grades into shoreface quartz sandstone at its top (appendix).

Conodonts of the *Polygnathus styriacus* Zone are reported by Sandberg and others (1980) from concretions in the "lower black shale" unit (of Gutschick and Rodriguez, 1979) that forms the upper part of lithosome GU.Ms in the Confusion Range (fig. 2). Thus the upper part of lithosome GU.Ms is no older than late Famennian, even if these conodonts are reworked. A diverse brachiopod fauna (Mackenzie Gordon, *in* Hose, 1966) and corals (Duncan, 1964) from the oncolitic limestone and the immediately overlying siltstone of lithosome GU.St have counterparts in the Louisiana Limestone, which was named for the basal unit of the original Kinderhook Group (Keyes, 1892) of the Mississippi Valley. Additionally, Sandberg and others (1980) reported the occurrence of lower Kinderhookian conodonts in a channel deposit in the siltstone of lithosome GU.St. A similar faunal succession is also reported for the Gutschick sequence at Leatham Hollow (Sandberg and Poole, 1977; Gutschick and Rodriguez, 1979). Consequently, the parallel lithologic expressions of the Gutschick sequence in the Confusion Range and at Leatham Hollow, and probably also the expression of the Gutschick sequence in the Burbank Hills, are earliest Mississippian in age, at least in their upper parts, and their stratigraphically lowest parts are no older than latest Devonian.

In Utah, east of the belt represented by outcrops in the Bear River Range, Confusion Range, and Burbank Hills (figs. 2, 3), the Gutschick sequence is characterized by lithosome GU.Bc.Pk (figs. 5, 6; appendix). This lithosome is the lithically distinctive unit recognized by us as the Pinyon Peak Limestone (or the "upper member" of the Pinyon Peak of Sandberg and Poole, 1977; see earlier discussion of lithosome LA?.Dc.Gr and the discussion in Silberling and Nichols, 1992, about their "unit 1"). Exposures of lithosome GU.Bc.Pk probably represent a structural level within the Sevier thrust system above the Pavant thrust but beneath the highest zone of Sevier thrusts that includes the Wah Wah, House Range, Canyon Range, and Paris-Willard thrust segments (fig. 2). Lithosome GU.Bc.Pk commonly represents the earliest record of open-marine flooding over Devonian and older, inner shelf dolostone and quartzite in west-central Utah (such as at Sally Mountain south to the Gilson Mountains, fig. 3), except at those few places where lithosome GU.Bc.Pk overlies limestones of lithosome LA?.Dc.Gr (such as at Pinyon Peak near Fitchville Ridge, fig. 3). The relatively thin expression of lithosome GU.Bc.Pk at Flux (fig. 2) in the northern Stansbury Mountains and at Stansbury Island (fig. 2), where it either overlies or interfingers with the uppermost part of the synorogenic Stansbury Formation (Upper Devonian), suggests that a positive area bordered the depositional site of lithosome GU.Bc.Pk. The present-day geographic relationship of the sections in different mountain ranges at Flux and Stansbury Island to that in the southern Lakeside Mountains (fig. 2), where lithosome GU.Bc.Pk is about 50 m thick and the Stansbury Formation is not represented (Silberling and Nichols, 1992), would appear to place this positive area to the east of the southern Lakeside Mountains; however, regional stratigraphic considerations and paleocurrent directions for the Stansbury at Flux (Trexler, 1992) support palinspastic restoration of Flux and Stansbury Island to the west of the southern Lakeside Mountains (fig. 3), as suggested by the structural synthesis of the region by Tooker (1983). Thus we relate the sections at Flux and Stansbury Island to a broad positive area west of the depositional site of lithosome GU.Bc.Pk, but we acknowledge the lack of conclusive structural reasons for this viewpoint.

Lithosome GU.Bc.Pk is fairly homogeneous and distinctive in both appearance and composition. Anastomosing, yellow-brown weathering streaks and thin layers of argillaceous to silty limestone enclose nodules and thin lenses of fine-grained gray bioclastic packstone and wackestone in which small crinoid columnals are the only readily visible allochems. Unlike other thin-bedded impure packstones, such as those of lithosome LA.PtCr.Pk, pellets form only a small proportion of lithosome GU.Bc.Pk limestones. The consistent age assignment of lithosome GU.Bc.Pk to the late Famennian on the basis of conodonts of the Lower or Middle *Palmatolepis expansa* Zone (Sandberg and Dreesen, 1984; Sandberg and others, 1989; Stamm *in* Silberling and Nichols, 1992) is in agreement with the occurrence of the ammonoid *Cyrtoclymenia* from the unit at Becks Spur (fig. 2) (Petersen and Stokes, 1983).

At most locations the well-oxygenated, current-agitated, open-ramp, impure limestones of lithosome GU.Bc.Pk are separated from the limestones of the overlying Morris sequence by as much as a few tens of meters of more massive limestone or secondary dolostone that by definition includes the lowest part of the Fitchville Formation (Upper Devonian and Lower Mississippian). Some of these Fitchville limestones (such as GU.MaCr.Pk, fig. 5) progradationally overlie lithosome GU.Bc.Pk and thicken to the east or southeast. Others, however, such as the limestone in the southern Lakeside Mountains that was designated "unit 2" by Silberling and Nichols (1992, fig. 3) and that was originally treated as either the top of their "cycle I" or the base of their "cycle II," clearly overlie a disconformity and belong to the Morris sequence.

The massive, solution-compacted, crinoidal packstones and grainstones of lithosome GU.MaCr.Pk form most of the lower part of the type Fitchville Formation at Fitchville Ridge (fig. 2) (the lowermost 3 m of the formation, as originally defined, is part of lithosome GU.Bc.Pk). Lithosome GU.MaCr.Pk is among the lithosomes shown schematically in figure 5 as forming the highstand systems tract of the Gutschick sequence. Evidence for the late Famennian age of lithosome GU.MaCr.Pk (most of the lower Fitchville Formation) and for its regional lateral and vertical gradation into lithosome GU.Bc.Pk (the Pinyon Peak Limestone) was initially summarized by Rigby and Clark (1962). The Devonian-Mississippian systemic boundary was placed by Sandberg and Poole (1977) on the basis of conodonts within massive or rudely layered, coarse grainstone near the top of lithosome GU.MaCr.Pk in the type Fitchville at Fitchville Ridge. No perceptible physical break is present at this level, although a distinct break in deposition and a 20-cm-thick bed of sandstone marks the top of lithosome GU.MaCr.Pk. Farther south, near Broad Canyon in the Gilson Range (fig. 2), the characteristic silty wisps within the Pinyon Peak Limestone, in the upper part of lithosome GU.Bc.Pk, become notably coarser grained, and beds of massive crinoidal grainstone are intercalated in the sand-streaked limestone, suggesting progradation of lithosome GU.Bc.Pk by shoal-water limestone representing lithosome GU.MaCr.Pk. The presence of lithosome GU.MaCr.Pk at this location is obscured, however, by normal faulting.

The relationship between the enigmatic, highly localized, coarse-clastic deposits of the Stansbury Formation in its type area in the northern Stansbury Mountains (fig. 2) and the Gutschick sequence is not clear. As much as 26 m of impure crinoidal limestone, having the distinctive lithic character and yielding the same age conodonts as lithosome GU.Bc.Pk, is present in the uppermost part of the typical Stansbury Formation (Rigby, 1958; Sandberg and Gutschick, 1978). Locally this distinctive limestone grades upward from coarse-grained sandy rocks continuous with the thick underlying section of the Stansbury, and it is overlain by as much as 12 m of gritty dolostone, dolomitic quartzite, and fine-grained secondary dolostone containing late Famennian conodonts and corals (Sandberg and Gutschick, 1978). The lithically unique type section of the Stansbury includes 450 m of coarse conglomerate and subordinate quartzite and intertidal-supratidal p-dolostone.[5] Just north of its type area in the Stansbury Range, the Stansbury Formation has within it an angular unconformity exhibiting about 20° of discordance (Trexler, 1992). Sedimentologic studies by Trexler show that the principal transport direction for the Stansbury conglomerate was to the northeast and that it was a submarine deposit derived from equivalents of the underlying formations, which range from Cambrian to Devonian in age. To the west of its type section in the northern Stansbury Mountains, the Stansbury pinches out completely within a few kilometers, and the Pinyon Peak oversteps the Stansbury and older formations, eventually resting directly on Cambrian rocks. Postdepositional

[5] The term "p-dolostone" is used for "primary" or "penecontemporaneous" dense dolostone that locally exhibits microbial lamination or desiccation features (Nichols and Silberling, 1980; Silberling and Nichols, 1992).

faulting is not significantly involved in these rapid lateral changes in the stratigraphy (Cashman, 1992).

Conodonts recovered from secondary dolostones, which are either in the lowest part of the Stansbury (Trexler, 1992) or in a Guilmette-like unit that may disconformably underlie it, have been interpreted as middle Frasnian in age (R.G. Stamm and A.G. Harris, U.S. Geological Survey, written commun., 1991). These relations require substantial uplift of the source area for the Stansbury at some time after the middle Frasnian. Within the vast expanse in the eastern Great Basin of laterally monotonous Devonian peritidal deposits such as the Guilmette, the compressional deformation responsible for this uplift would be totally unexpected were it not for the unique exposure of the type Stansbury in the northeastern Stansbury Mountains. These orogenic deposits of the Stansbury suggest that a positive area developed generally west of the depositional site of lithosome GU.Bc.Pk during Late Devonian time. These deposits also permit speculation that this uplift and the concomitant deposition of the type Stansbury might correlate with the disconformity between the parts of the Pilot Shale representing the Gutschick and the older Langenheim sequences. The location of the relatively thick section of the type Stansbury Formation is shown in figure 5; however, the Stansbury is not placed within the sequence framework because its geographic extent is so limited and because its temporal equivalency with either the Langenheim or Gutschick sequences presently cannot be demonstrated. Speculatively, it could be a lowstand systems tract of the Gutschick sequence whose accomodation space was strongly controlled by local tectonism. On the other hand, it could be entirely older than the sequences considered here and unconformably overlain by deposits of the Gutschick sequence.

Other strata assigned to the Stansbury Formation at Stansbury Island and at Becks Spur (fig. 2) are almost entirely composed of cross-stratified quartzite that probably represents a depositional system separate from that of the typical Stansbury near Flux (Trexler, 1992). These rocks are overlain by lithosome GU.Bc.Pk with no reported intercalation or intergradation with the quartzite. These quartzites can be regarded as part of the widespread Devonian inner shelf sabkha and sand-sea deposits over which lithosome GU.Bc.Pk transgressed eastward.

Palinspastically farther south and west, the occurrence of the Gutschick sequence is equivocal. Near the line of section *A–A'* at Wig Mountain and Gold Hill (fig. 3), strata that would be correlatives of the Gutschick sequence are apparently everywhere omitted from the stratigraphic succession owing to faulting. In the northern Dugway Range (figs. 2, 3) limestones originally included in the lower part of the "Madison limestone equivalent" by Staatz and Carr (1964) yielded conodonts assigned by R.G. Stamm (U.S. Geological Survey, written commun., 1991) to the upper Famennian *Polygnathus styriacus* Zone (now generally referred to as the Lower *Palmatolepis expansa* Zone). On this basis these limestones may be part of the Gutschick sequence, but they are lithically different from any of the other manifestations of this sequence in western Utah. These limestones are about 50 m thick, conformably overlie the Hanauer Formation, a thick succession of Devonian dolomitic quartzite and dolostone, and consist of burrow-mottled, thin-bedded, pellet-calcisphere packstone and interbedded storm deposits of massive intraclast grainstones whose intraclasts are derived from the associated packstones. Locally, these limestones are overlain by as much as 20 m of p-dolostone and cross-stratified quartzite beneath lithosome MO.Rh.Wk, which forms the base of the overlying Morris sequence. These supra-Hanauer, pre-Morris sequence rocks in the Dugway Range, which represent a transgressive-regressive depositional cycle, may be an inshore, western facies of lithosomes GU.Bc.Pk and GU.MaCr.Pk; however, were it not for the conodont-based age determination, they, along with the locally recognized Hanauer Formation, could be related to regionally widespread pre-Gutschick sequence units such as the Guilmette Formation.

Still farther west, the Gutschick sequence has been completely eroded, if it was ever present, on the Wendover high. For example, in the Leppy Hills (fig. 3) lithosome MO.Di.WkPk of the Morris sequence (fig. 5) rests depositionally on lithosome LA.LaDo.St of the Langenheim sequence (Nichols and Silberling, 1993); at White Horse Pass (fig. 3) lithosome SA.LaDo.St of the Sadlick sequence depositionally overlies a limestone unit that has yielded conodonts having contradictory ages (R.G. Stamm, U. S. Geological Survey, written commun., 1991), but which may be part of lithosome LA.PtCr.Pk, and at Granite Mountain (fig. 3) lithosome SA.LaDo.St rests on lithosome LA.LaDo.St.

The concept of a discrete Gutschick sequence may seem an oversimplification in view of its disparate and disjunct rock record, possible direct involvement with contemporaneous local orogenesis, and apparent age span across the Devonian-Mississippian boundary, the biostratigraphic resolution of which is fraught with semantic arguments. It is thus reassuring that the reported biostratigraphic succession is much the same for lithosomes GU.Bc.Pk and GU.MaCr.Pk in the East Tintic district at Fitchville Ridge (figs. 3, 5) as it is for lithosomes GU.Ms and GU.St farther west such as in the Confusion Range (fig. 6) (Morris and Lovering, 1961; Sandberg and Poole, 1977; Gutschick and Rodriguez, 1979; Sandberg and others, 1980). Although the former pair of lithosomes at Fitchville Ridge apparently describe a simple transgressive-regressive sequence expressed in carbonate rocks, interpretation in terms of local sea-level history of the latter lithosomes in the Confusion Range is more problematic.

MORRIS SEQUENCE

The Morris sequence is primarily composed of carbonate rocks, not only in western Utah but also in adjoining parts of Nevada, Idaho, and Wyoming. In western Utah and eastern Nevada its thickness is generally less than 100 m, commonly less than 50 m, and it represents a single, marine transgression and regression. Although broad-scale lateral changes are present within them, the carbonate rocks of the Morris sequence are noticeably more laterally consistent than are the underlying, partly clastic, Upper Devonian to lowermost Mississippian strata. The very broad, flat, late Kinderhookian carbonate ramp recorded by the Morris sequence signifies a time of relative tectonic quiescence in the distal foreland.

The Morris sequence is exemplified in much of western Utah by the Fitchville Formation, all of which except the lower member as exposed in the East Tintic district (fig. 2) represents the Morris. Lithosomes of the Fitchville included in the sequence are, from oldest to youngest, MO.Rh.Wk, MO.PdCr.Gr, and MO.Dc.Lm (fig. 5). Initial flooding for the Morris sequence is represented by lithosome MO.Rh.Wk, except in the southern Lakeside Mountains (fig. 2), where lithosome MO.Di.WkPk ("unit 2" of Silberling and Nichols, 1992, as discussed earlier) is recognized as being the lowermost deposit of the Morris sequence. Lithosome MO.Di.WkPk in the southern Lakeside Mountains is palinspastically projected into cross section *A–A′* (fig. 5) between Flux and Fitchville Ridge; it has a sharp, disconformable basal contact with the underlying Gutschick sequence and grades up into lithosome MO.Rh.Wk.

In the Lakeside Mountains, as at most locations, lithosome MO.Rh.Wk ("unit 3" of Silberling and Nichols, 1992) consists of thin to medium limestone beds separated by laterally persistent, but irregular, thin layers of secondary chert. Originally, before development of the silicified layers, this limestone was evenly bedded with fine-grained siliciclastic partings between beds, as, for example, in the East Tintic district at Fitchville Ridge (fig. 2). Most of the limestone beds that make up lithosome MO.Rh.Wk are wackestones having fine-grained, open-marine bioclasts, but some beds are more coarsely skeletal, graded packstones interpreted as storm deposits because of their stratigraphic context. This lithosome does not extend eastward of the Tintic thrust (fig. 2) or into southern Utah east of the Wah Wah thrust (fig. 2) and its equivalents. To the north at Little Mountain (fig. 2) the lithosome has the same character and consists of about 10 m of regularly bedded, chert-stringer limestone overlying Devonian p-dolostone interstratified with unfossiliferous secondary dolostone. In contrast, in the Bear River Range on the Paris-Willard thrust plate (fig. 2) and in the Crawford Mountains (fig. 2) the equivalent of lithosome MO.Rh.Wk is a much greater thickness of evenly bedded lime mudstone transitional to the Paine Member of the Lower Mississippian Lodgepole Limestone (Elrick and Read, 1991).

Massive, cross-stratified, peloidal-crinoidal grainstone of lithosome MO.PdCr.Gr represents shoal deposits that prograded over the open-ramp, rhythmically bedded, storm-deposited limestone of lithosome MO.Rh.Wk in west-central Utah (fig. 5). The allochems of lithosome MO.PdCr.Gr are distinctive because they are mainly conspicuously micritized crinoid columnals and equivalent-size peloids. Some peloids may be completely micritized skeletal grains, whereas others are rounded intraclasts.

Unfossiliferous, desiccated lime mudstone of lithosome MO.Dc.Lm overlies lithosome MO.PdCr.Gr with only a few meters of transition and continues the progradational high-stand tract of the Morris sequence. Regionally, much of lithosome MO.Dc.Lm is dense lime mudstone such as the "pink lithographic limestone" of the East Tintic district (fig. 2) (Morris and Lovering, 1961). Fenestral fabrics and desiccated peloid grainstones also are present in lithosome MO.Dc.Lm, the top part of which is commonly characterized by microbial lamination or even spectacular stromatolites, as in the "curley limestone" bed (Proctor and Clark, 1956).

In sections such as those at West Mountain and in the Gilson Range (fig. 3), palinspastically inshore and to the south and east of the East Tintic district (fig. 2), p-dolostone of lithosome MO.Pr.Do interfingers with lithosome MO.Dc.Lm in units as thick as 3 m and is associated with pervasive eogenetic (Nichols and Silberling, 1980) secondary dolomitization of much or most of the underlying parts of the Fitchville Formation (fig. 5). Farther to the south, in the Star Range and southern Wah Wah Mountains (fig. 2), lithosome MO.Pr.Do forms nearly all of the Morris sequence (fig. 6). At Blawn Mountain in the southern Wah Wah Mountains massive crinoidal eogenetic secondary dolostone that may represent lithosome MO.PdCr.Gr is present at the base, and the stromatolitic "curley limestone" is present at the top.

Most of the lithosomes of the Morris sequence, as typified in the Fitchville Formation of west-central Utah, can be recognized across the eastern Great Basin. The succession of lithosomes permits recognition of the Morris sequence within the rocks constituting the lower and commonly major part of what is customarily referred to as the Joana Limestone (fig. 4) in westernmost central Utah in the Confusion Range, Burbank Hills, and Needle Range (figs. 2, 6) and still farther to the west at Dutch John Mountain (fig. 2), in the southern Egan Range (fig. 2), and beyond in eastern Nevada. At these locations the distinctive inner ramp limestones of lithosome MO.Dc.Lm are underlain in turn by lithosome MO.PdCr.Gr, then some interstratified combination of lithosomes MO.Rh.Wk and MO.PdCr.Gr, and ultimately MO.Rh.Wk at the base. Lithosome MO.Rh.Wk forms the major share of the Morris sequence toward the northwest end of palinspastic cross section *B–B′* (fig. 3). In these more western sections, the basal part of the Lower Mississippian Joana Limestone is commonly composed of quartz sandstone as thick as a few meters. In places, such as in the Confusion Range, this sandstone has a sharp, scoured base and can be regarded as the lowstand systems tract of the Morris sequence; elsewhere, however, such as in the southern Burbank Hills, it is gradational downward into the Gutschick sequence and forms the top of its highstand tract.

In general, the lateral variations in the Morris sequence reflect increasingly offshore deposition and progradation toward the northwest during the late Kinderhookian, but this pattern was interrupted by subsequent erosion during development in Osagean time of the Wendover high (of Sadlick, 1965), an area of minor positive relief (fig. 3). Location of this Early Mississippian positive area is recorded by widely scattered sections in which the Morris sequence is missing, as at Granite Mountain and White Horse Pass (fig. 3), or only thin remnants of it are preserved, such as in the northern Dugway Range and Leppy Hill (fig. 3).

Locally within the northern Dugway Range about 3 m of nodular to thin-bedded, impure, fossiliferous upper Kinderhookian (Biller, 1976; P.E. Isaacson, oral commun., 1992) limestone is gradationally overlain by no more than 10 m of massive intraclast-peloid grainstone. These two units apparently correspond, respectively, to lithosomes MO.Rh.Wk and MO.PdCr.Gr, the latter of which is disconformably overlain by lithosome SA.Di.WkPk limestone of the Sadlick sequence. The Morris sequence is no more than several meters thick in the Leppy Hills (fig. 3), at the western end of the cross section *A–A′* (fig. 5), and here yields late Kinderhookian conodont faunas (Newman, 1980; Nichols and Silberling, 1993). Its base is a minor (?) attenuation fault, but it is disconformably overlain by lithosome SA.LaDo.St that expresses the initiation of the Delle phosphatic event within the Sadlick sequence. Most of the Morris sequence in the Leppy Hills is massive, diffusely interbedded, peloidal-crinoidal wackestone and packstone and winnowed grainstone resembling lithosome MO.Di.WkPk but at its base is as much as 2 m of nodular to evenly thin bedded, cherty, packstone-wackestone (lithosome MO.Rh.Wk?) and at its top is a bed of oncolitic bioclastic wackestone. This relatively thin expression of the Morris sequence, as preserved beneath the Sadlick sequence in the Leppy Hills, thus represents a single shallowing-upward cycle. It could be a sub-Sadlick-sequence erosional remnant that fortuitously preserves a single depositional cycle, or alternatively it may represent the original full thickness of the Morris sequence at this location. If the latter, it would indicate initiation of the Wendover high (see later; fig. 3) as a positive area during deposition of the Morris sequence.

SADLICK SEQUENCE

The lower part of the Sadlick sequence records the gradual, progressive tectonic subsidence of a broad area to the east and southeast of the Wendover high (fig. 3). Carbonate deposition on this subsiding area was entirely above wave base and almost kept pace with subsidence. The resulting aggradational to slightly retrogradational lower part of the Sadlick sequence was a tectonically controlled lowstand systems tract. It includes some or all of lithosomes SA.La.Pk, SA.Oo.Gr, SA.Cr.Gr, and SA.Di.WkPk (appendix, figs. 5, 6) that form the Gardison Limestone in west-central Utah, It also includes the upper part of the Joana Limestone in the westernmost part of southern Utah (in the Confusion Range, Burbank Hills, and Needle Range, fig. 2) and in eastern Nevada (as at Dutch John Mountain and Trough Spring Canyon in the southern Egan Range, fig. 2). The evenly bedded limestone containing graded tempestite beds (SA.Rh.Wk, fig. 6) in the upper part of the Joana Limestone represents the lower Sadlick sequence farther to the north in eastern Nevada at Ward Mountain and in the southern Red Hills (fig. 2). Still farther to the north in the Antelope and Cherry Creek Ranges (fig. 2) further study is needed to place the sequence boundary between the Morris and Sadlick sequences within the Joana because of inadequate exposure. Maximum flooding during deposition of the Sadlick sequence coincided with the transgression of areas that developed positive relief during early Sadlick time, the initiation of the Delle phosphatic event that was associated with an abrupt change to oxygen-deficient sedimentation, the onset of fine-grained terrigenous-clastic deposition, and the interruption of carbonate deposition (Sandberg and Gutschick, 1984; Nichols and Silberling, 1990; Silberling and Nichols, 1991).

Carbonate rocks of lithosome SA.La.Pk form the major part of the lowstand systems tract of the Sadlick sequence. They are lithically distinctive (appendix), widespread (figs. 2, 3), and locally exceed 100 m in thickness. As described and illustrated by Silberling and Nichols (1992) in the Lakeside Mountains (fig. 2), they are conspicuously laminated or quasilaminated, well-sorted, fine-grained, pellet-crinoid packstones having subordinate, discrete, tempestite interbeds of intraclastic, crinoidal, coralline, and shelly debris, among which large gastropod shells are common. This distinctive lithosome represents shallow-subtidal to perhaps intertidal, open-ramp deposition on a broad, gradually and evenly subsiding, carbonate flat that was swept by energetic tidal and storm currents. Oolitic grainstones (lithosome SA.Oo.Gr) commonly are present beneath the tidalites and tempestites of lithosome SA.La.Pk or else are intercalated in their lower part, separated from the stromatolitic inner platform limestones of lithosome MO.Dc.Lm at the top of the Morris sequence by as much as a few meters of nondescript, bedded, bioclastic wackestone. These lenticular ooid-shoal deposits thicken from sections in west-central Utah to those farther to the southwest (fig. 6). In the southern Wah Wah Mountains (Blawn Mountain, fig. 2), beneath the Wah Wah thrust, they form most of the section equivalent to the Gardison Limestone. On the upper plate of the Wah Wah thrust–House Range detachment (shaded area in fig. 2) in the Confusion Range and Burbank Hills, massive oolitic grainstone units as much as 10 m in thickness are intercalated with subordinate, pelletal bioclastic wackestone units and aggregate as much as 35 m in total thickness. As observed by Goebel (1991a), each oolite unit forms the bulk of a minor shoaling-upward cycle. The highest oolitic grainstone units interfinger with the overlying laminated packstones of lithosome SA.La.Pk in the Needle Range (fig. 2), and this association has been observed as far west as the southern Egan Range (fig. 2) in adjoining Nevada.

Crinoidal grainstones (lithosome SA.Cr.Gr), which commonly exhibit large-scale cross-stratification, are present in west-central Utah as intercalated units in the upper part of lithosome SA.La.Pk. and commonly separate it from the overlying limestone of lithosome SA.Di.WkPk, which forms the top of the Gardison Limestone and equivalents throughout western Utah. Lithosome SA.Di.WkPk is lithically variable and yet distinctive in consisting of diffuse, intergradational, and interstratified layers of varying thickness that are mostly composed of bioclastic wackestone or packstone, although subordinate layers and lenses of lime mudstone and winnowed crinoidal grainstone also are present. Open-marine bioclasts and megafossils are abundant, and large, irregularly shaped nodules and bedding-plane stringers of replacement chert are characteristic. These limestones of lithosome SA.Di.WkPk are believed to represent wave- and storm-influenced deposition in a deeper subtidal open-marine environment than the tidalites, tempestites, and intercalated oolitic or crinoidal shoal deposits of the underlying lithosomes. Because of this deepening trend, the stratigraphic partitioning of the oolitic and crinoidal grainstone units in the lower and upper parts of lithosome SA.La.Pk, respectively, is suggestive of a deeper, more offshore depositional setting for the crinoidal-grainstone shoals as compared to that for those dominated by ooids, a pattern characteristic of other mid-Paleozoic carbonate ramps (*see* Elrick and Read, 1991).

Maximum flooding and transgression of the Sadlick sequence in Utah, both eastward onto the craton and westward onto the Wendover high, coincided with onset of the Delle phosphatic event (Silberling and Nichols, 1990, 1991). This event was marked by an abrupt change to oxygen-deficient conditions, cessation of normal-marine limestone deposition, and retention on all but the more eastern and southeastern parts of the shelf of fine-grained siliciclastic sediment of cratonic origin, all of which are ascribed to restriction of the shelf by emergence of the Wendover high (Silberling and Nichols, 1991). The effects of the Delle event are evident throughout the study area, and the distinctive, commonly phosphatic rocks that relate to initiation of the event form the base of lithosomes SA.LaDo.St and SA.Os.Lm and of several different, formally named, Lower and Upper Mississippian rock units: the Deseret Limestone in west-central Utah, the Needle Siltstone Member of the Chainman Shale in westernmost Utah and adjoining Nevada, the Woodman Formation (originally proposed for rocks at Gold Hill, fig. 2), and the Brazer Dolomite (as in the Crawford Mountains and at Samak, fig. 2) in the western Uinta Mountains. The name "Delle Phosphatic Member," typically as a member of the Woodman Formation in the southern Lakeside Mountains (fig. 2), was proposed by Sandberg and Gutschick (1984) for the rocks affected by onset of the Delle event; however, this formal rock unit cannot be recognized away from its type area because there is no consistent way to define regionally its upper boundary (Nichols and others, 1992).

Sedimentologic interpretation of the anomalous rocks of the Delle event has been controversial (Sandberg and others, 1991), but it is important for an understanding of the systems tracts and depositional geometry of the Sadlick sequence. We interpret the onset of the Delle event as the expression of a regional change in water chemistry, coupled with continued flooding of the shelf, rather than as an episode of emergence and erosion. The disconformity and local hardground that marks initiation of the Delle event was the result of dissolution, submarine erosion, and replacement of the underlying limestone, which in most places belongs to lithosome SA.Di.WkPk and contains conodonts of early Osagean age (Sandberg and Gutschick, 1984; R.G. Stamm and B.R. Wardlaw, U.S. Geological Survey, written commun., 1990–1991). Exceptionally, in the Leppy Hills (figs. 2, 3, 5), the northwesternmost exposure of the Sadlick sequence, limestones immediately below the initial deposits of the Delle event belong to the still older Morris sequence (Nichols and Silberling, 1993). These limestones are markedly solution compacted and commonly silicified and contain phosphate either as pore fillings or as replacement peloids for as much as a meter below their top. Detrital concentrations of phosphatic grains of different types (ooids, peloids, ossicle replacements, and phosphatic fossils, such as conodonts) characteristically cap the highest coherent limestone or replacement chert beneath rocks of the Delle event and infill any cavities associated with hardgrounds as illustrated by Silberling and Nichols (1991).

The microfacies of the Delle phosphorites indicate a submarine depositional environment characterized by fluctuating anoxic and oxic conditions and temporary events of sediment reworking (Silberling and Nichols, 1991). This environment suggests a complex combination of processes resulting in termination of carbonate bioclast production, temporary stratification of the water mass to initiate phosphogenesis, partial replacement of calcareous sediment or limestone by phosphate, dissolution and erosion of carbonate and development of hardgrounds, chert replacement, and the subaqueous transport and concentration of insoluble phosphatic grains.

The onset of the Delle event is recorded at the base of lithosome SA.LaDo.St west and north of a line palinspastically (fig. 3) trending roughly from Old Lake Town Canyon south to Fitchville Ridge and southwest to the Needle Range. The predominant component of this lithosome is plane-laminated to slabby, secondarily dolomitic, siltstone and very fine grained sandstone. East of this line, onset of the Delle event marks the base of lithosome SA.Os.Lm, an ostracode lime mudstone in which ostracodes are commonly the only conspicuous, petrographically recognizable fossils, suggesting abnormal marine-water chemistry during its deposition. Individual, laterally persistent, but regionally discontinuous units of lithosome SA.Os.Lm, as thick as 10 m, are present farther to the west as intercalations at various levels within lithosome SA.LaDo.St, as indicated schematically in figure 5. Toward the east, for example, in the East Tintic district, Oquirrh Mountains at Ophir Canyon, and Gilson Mountains (fig. 2), dolomitic siltstone of lithosome SA.LaDo.St is supplanted laterally, probably with some intergradation, by rhythmically bedded, variably silty lime mudstone and wackestone of lithosome SA.Rh.LmWk (fig. 5). Although generally unfossiliferous, one or more massive, commonly graded beds of crinoidal grainstone or packstone may be intercalated within the fine-grained limestones of lithosome SA.Rh.LmWk. These coarsely bioclastic beds are regarded by us as storm deposits because of their stratigraphic context, but they also have been interpreted as deep-marine debris flows (Sandberg and Gutschick, 1984; for example, the "crinoidal wackestone" bed near the top of their "lower carbonate unit" in their fig. 9, which shows their interpretation of the section at Ophir Canyon). In the farthest southeast section, at Dog Valley (fig. 2), 35 m of rhythmically bedded, sparsely cephalopod bearing, lime mudstone, regarded as part of lithosome SA.Rh.LmWk, has at its base the phosphatic rocks that mark the initiation of the Delle event, and neither lithosome SA.Os.Lm nor lithosome SA.LaDo.St is represented. The lime mudstone unit here is abruptly overlain by about 10 m of crinoidal limestone, the stratigraphically highest of which contains large-scale cross-stratification suggesting progradation by crinoid shoal deposits of lithosome SA.Cr.WkPk over lithosome SA.Rh.LmWk. In the Star Range and southern Wah Wah Range (fig. 3) our understanding of the upper part of the Sadlick sequence and its relationship to the Maughan sequence is inferential (fig. 6) because of poor exposure and inadequate structural control.

The thicker phosphatic successions of the Delle event are in a belt that in figure 3 palinspastically trends north-northeast and includes sections such as at Old Lake Town Canyon, southern Lakeside Mountains, Flux, Gilson Range, and Needle Range and those in the East Tintic district near Fitchville Ridge. The thickest of these sections is in the southern Lakeside Mountains where phosphorites and other diagenetically unusual rocks indicative of multiple episodes of fluctuation between anoxic and suboxic to dysoxic deposition and diagenesis (Silberling and Nichols, 1991) are present at intervals through more than 30 m of section within lithosome SA.LaDo.St. Although multiple layers of detrital phosphorite are present in the thicker phosphatic sections in this belt, only at the base of these sections, at their contact with the pre-Delle event limestones, are concentrates of phosphatized bioclasts and conodonts present. The conodont-rich limestone reported by Sando and others (1976) 1 m above the base of the Brazer Dolomite at Warner Hollow (near location Crawford Mountains, figs. 2, 4), and interpreted by them as an interfingering of "starved-basin and shelf-carbonate facies," is a minor fault repeat of the underlying limestone of lithosome SA.Di.WkPk and the thin crust of reworked, concentrated phosphatic grains that caps it.

In contrast to the belt in which phosphatic rocks of the Delle event range upward through a significant amount of section, sections to the east, as in the Crawford Mountains, and to the west in the area of the Wendover high (fig. 3), contain layered phosphate that is restricted to a single, commonly detrital, concentration whose stratigraphic position coincides with the initiation of the Delle event. Nevertheless, all of the rocks of lithosomes SA.LaDo.St, SA.Os.Lm and SA.Rh.LmWk show some evidence of continuing oxygen deficiency during their deposition. For example, scattered nodules of phosphate are characteristic of the dolomitized siltstone of lithosome SA.LaDo.St, and the pervasive secondary dolomite in this lithosome probably resulted from sulfate-reducing diagenetic conditions. The limestone of lithosomes SA.Os.Lm and SA.Rh.LmWk, which are laterally equivalent to, and partly intercalated with, lithosome SA.LaDo.St, is generally devoid of larger fossils, suggesting oxygen deficiency, or else contains fossils indicative of abnormal marine-water chemistry such as a relative profusion of ostracodes.

Lithosomes SA.LaDo.St, SA.Os.Lm, and SA.Rh.LmWk formed below normal wave base as evidenced by the pervasive plane lamination of the first of these and the rhythmically well bedded nature of the latter two of these units. The widespread, aggradational character of the underlying carbonate succession of lithosomes SA.La.Pk through SA.Di.WkPk requires that the surface over which lithosomes SA.LaDo.St through SA.Rh.LmWk were deposited was essentially flat. Owing to severe stratification of the water column, only a few tens of meters of downwarping, centered in the middle part of the belt characterized by the Delle event, is necessary to account for the thicker expressions there of intense diagenetic effects.

The interpretation by Sandberg and others (1991, p. 411) that the rocks of the Delle event represent a deep-marine setting, bounded to the east by steep slopes, relies heavily on the pronounced facies difference between the obviously shelfal Brazer Dolomite in the Crawford

Mountains (fig. 2) and the section at Old Laketown Canyon (fig. 2). The section indicative of the Delle event in Old Laketown Canyon is structurally disrupted beyond objective measurement, but it is mainly an expression of lithosome SA.LaDo.St that must have been several tens of meters thick (Sandberg and Gutschick, 1978). Contrary to the assertion that "recent subsurface control has reduced the [original depositional] distance between [these sections] to only 12 km" (Sandberg and others, 1991, p. 411), the seismic interpretation of Coogan and Royse (1990, fig. 18) indicates that the sections are on separate plates of the Old Laketown thrust system (which includes the Meade thrust). The pre-Tertiary section of the Old Laketown plate is sufficiently different from that of the structurally overridden plates, such as that including the Crawford Mountains sections, so as to require at least several tens of kilometers of juxtaposition between these sections, as expressed in figure 3. Palinspastically, the actual amount of slope would be very slight and water depths for the Delle event need not have been any greater than that necessary to temporarily maintain stratification of the water column.

Another indication that water depths during the Delle event were not extreme (on the order of hundreds of meters) is the relatively thin stratigraphic thickness that separates the characteristically plane laminated dolomitic siltstone and associated phosphatic strata of lithosome SA.LaDo.St from stratigraphically higher, shallow subtidal or intertidal sandstones of lithosome SA.Qz.Ss (fig. 5). At Flux (fig. 2), for example, less than 50 m of section—mostly consisting of massive, calcareous sandstone—separates strata of lithosome SA.LaDo.St, the deposition of which was strongly influenced by the Delle event (Sandberg and Gutschick, 1978; Nichols and others, 1992), from sandstones within lithosome SA.Qz.Ss having the characteristic features of beach and bar deposits. These sandstones are medium to coarse grained and calcareous, contain both quartz and crinoidal-bioclast grains, and are distinguished by either crude planar lamination or large-scale, shallow trough cross-stratification; they form the upper part of the lowest of three shallowing-upward cycles shown in figure 5 as being within lithosome SA.Qz.Ss at this location. In each of these three cycles, sandstones of lithosome SA.Qz.Ss are overlain by limestones of lithosomes SA.Rh.LmWk or MA.Rh.LmWk whose sharp basal contacts represent successive flooding events. In the absence of biostratigraphic control at this level in the section at Flux, and in the absence of further stratigraphic control from nearby locations, an alternative to the placement of the Sadlick-Maughan sequence boundary shown in figure 5 would be to designate the base of the Maughan sequence as coincident with the base of the lower of the two units of lithosome SA.Rh.LmWk at Flux, which are shown as being discontinuous in figure 5. The total thickness of the highstand systems tract of the Sadlick sequence could thus be even thinner than implied by this figure. Continuity of this alternative placement of the sequence boundary cannot, however, be established at present.

Relatively small stratigraphic thicknesses are also characteristic of other shallowing-upward progressions that represent the highstand systems tract of the Sadlick sequence. For example, at Dog Valley (fig. 2) progradational crinoidal grainstone shoal deposits, interpreted as a tongue of lithosome SA.Cr.WkPk into SA.Rh.LmWk, are only about 50 m stratigraphically above phosphatic rocks of the Delle event at the base of lithosome SA.Rh.LmWk.

The most inshore expression of the highstand part of the Sadlick sequence is projected into the southeast end of the line of section depicted in figure 5 from Samak (fig. 2) at the west end of the Uinta Mountains. Here, ostracode-rich lime mudstone of lithosome SA.Os.Lm is overlain by fine-grained, rhythmically layered, spiculitic packstone assignable to lithosome SA.Rh.LmWk, which is overlain in turn by open-marine, well-agitated ramp and inner ramp shoal limestone of lithosome SA.Cr.WkPk that is partly secondarily dolomitized. Then, completing the upward, progradational succession is lithosome SA.Pr.Ds composed of peritidal cycles of p-dolostone and eogenetic secondary dolostone along with units of evaporite-collapse breccia (Nichols and Silberling, 1991).

Sections having relatively thick expressions of lithosome SA.LaDo.St, such as those in the Lakeside Mountains, Confusion Range, and Needle Range (figs 2, 5, 6), are in areas more remote from shoal-water settings and show less upward change to the top of the Sadlick sequence than those in west-central Utah. In sections such as those in the Confusion and Needle Ranges, which form part of the House Range–Wah Wah plate (fig. 2), initiation of the succeeding Maughan sequence is evidenced by an interruption in siliciclastic deposition and by the widespread appearance of lithosome MA.Rh.Lm at the base of the Maughan (fig. 6) that reflects at least some increase in bottom-water oxygenation and more open marine circulation. The Sadlick-Maughan sequence boundary perturbs the generally oxygen deficient sedimentary record of the Delle event in these sections, even though the nature of the ensuing strata of the Maughan sequence continues to reflect some degree of oxygen deficiency.

MAUGHAN SEQUENCE

The Maughan sequence includes Upper Mississippian strata ranging from late Meramecian to late Chesterian in age. Within the study area it includes a laterally complex variety of both carbonate and terrigenous-clastic rocks and is at least a few hundred meters thick in most places. Because of its relatively greater thickness and stratigraphic complexity as compared with the underlying sequences, unresolved structural complications within most exposures obscure the details of internal stratigraphy and the record of subsidiary marine transgression and regression within the Maughan sequence. Nonetheless, this sequence as a whole corresponds to a major cycle of transgression and regression.

The flooding event defining the base of the Maughan sequence in west-central Utah and responsible for forming its transgressive systems tract is well expressed near the line of the palinspastic cross section *A–A'* (fig. 5). Here, for example in the northern Stansbury Mountains at Flux, at Wig Mountain, and in the northern Dugway Range (figs. 2, 3), lithosome MA.Rh.LmWk is widespread. This sub-wave-base rhythmically thin to medium bedded limestone abruptly overlies the sandstones of lithosome SA.Qz.Ss that in places are markedly cross stratified beach and bar deposits. The possibility of reassigning the two units of SA.Rh.LmWk in the section at Flux (fig. 5) to MA.Rh.LmWk and of placing the sequence boundary at a lower level is discussed earlier. In the East Tintic district (fig. 2) lithosome MA.Rh.LmWk forms the upper part of the Osagean (?) to Meramecian Tetro Member of the Deseret Limestone (Morris and Lovering, 1961).

Higher parts of the Maughan sequence in west-central and northern Utah were not studied by us in detail. Despite the considerable amount of surface mapping and subsurface interpretation available, much additional effort is required to fully understand the structural and sedimentological framework of this sequence in this area. The Maughan sequence succession here includes rock stratigraphic units such as the Uncle Joe Member (Meramecian) of the Deseret Limestone, Humbug Formation (Meramecian), Great Blue Limestone (Meramecian to Chesterian), lower part of the Manning Canyon Shale (Upper Mississippian to Middle Pennsylvanian), and still other units laterally equivalent to these. This succession reportedly is more than 1,000 m thick (Hintze, 1988). Within this thick, generally progradational assemblage, there is complex interfingering among deposits representing crinoidal shoals, quartz-sandstone beach and bar complexes, richly bioclastic and fossiliferous shelf limestones, and lagoonal shales. Lithosome MA.QzCr.Ss (fig. 5) includes the crinoidal limestones and sandstones of the Uncle Joe and part of the Humbug, both of which are commonly thick bedded, conspicuously cross stratified, high-energy, intertidal to shallow subtidal deposits. Local shallowing-upward cycles within this generally prograding assemblage are indicated by units of supratidal p-dolostone within the sandstones and crinoidal limestones of the Humbug Formation at widely separated locations such as Ophir Canyon in the Oquirrh Mountains and Blawn Mountain in the southern Wah Wah Mountains (fig. 2).

Sections in westernmost Utah provide a different expression of the Maughan sequence than those farther to the east and north in Utah, and they are more akin to those in adjoining parts of Nevada (fig. 6). In westernmost Utah, along the west side of the House Range–Wah Wah plate in the Confusion Range, Burbank Hills, and Needle Range (figs. 2, 3, 6), sections of the Maughan sequence are little disrupted structurally and range from 350 to 450 m in thickness (Sadlick, 1965; Sandberg and others, 1980; Hintze and Best, 1987). The integrity of the section in the Confusion Range in the vicinity of Skunk Spring Canyon is especially well constrained by the geologic mapping of Hose and Repenning (1964), and this section best documents the complete Maughan sequence.

A few meters of evenly bedded, dense, nearly unfossiliferous lime mudstone (lithosome MA.Rh.Lm), which constitutes the Skunk Spring Limestone Bed (Meramecian) of the Chainman Shale, is at base of the Maughan sequence in the Confusion Range, farther to the south in the Burbank Hills, and in the Needle Range (figs. 2, 6). Farther to the north at Granite Mountain (fig. 2) a few lenticular beds of this limestone are intercalated through about 20 m of black shale of lithosome MA.Ms, which at this locality forms the base of the Maughan sequence, overlying lithosome SA.LaDo.St of the Sadlick sequence. At the sequence boundary here, Webster and others (1984, p. 28) reported the important discovery of a surface of disconformity overlain by a bed of coarse-grained, sandy, limestone conglomerate containing endothyrid-bearing clasts of the mid-Meramecian "Mamet Foraminifer***Zone 14." According to Webster and others (1984), at Granite Mountain goniatites and endothyrids of Mamet zone 15, a zone well up in the Meramecian, characterize the basal part of the Maughan sequence, which consists of interbeds of lithosome MA.Rh.Lm in lithosome MA.Ms. Mamet zone 15 endothyrids also were reported by Webster and others (1984) to be present in the conspicuous unit of bioclastic limestone (of lithosome MA.En.Gr) a few meters higher in the section at Granite Mountain.

In the Cherry Creek Range (fig. 2) lithosome MA.Rh.Lm is more than 20 m thick, including intercalations of black siltstone and argillite. In the Goshute Range at Whitehorse Pass (fig. 2) this lithosome, with some interbeds of calcareous siltstone, is several tens of meters thick and has at its base about a meter of cross-stratified crinoidal grainstone.

Returning to the section in the Confusion Range (figs. 2, 3, 6), above lithosome MA.Rh.Lm and forming the thickest part of the Maughan sequence in westernmost central Utah and adjacent Nevada are strata equivalent to the Camp Canyon Member of the Chainman Formation (of Sadlick, 1965). Strata of the Camp Canyon generally form an upward transition from black mudstone and shale (lithosome MA.Ms) at the base, to interbedded black mudstone and evenly bedded, notably spiculitic, organic-rich, lime mudstone (lithosome MA.Ms&Sp.Lm), and then to mainly spiculitic lime mudstone (lithosome MA.Sp.Lm). All of these lithosomes represent restricted, oxygen-deficient, stagnant-marine deposition except for the foreshoal and shoal limestones of lithosome MA.En.Gr., which are in the lower part of the Camp Canyon succession. The areally restricted lithosome MA.En.Gr grades upward from lithosome MA.Ms, through pellet, calcisphere, endothyrid packstones, to more open marine crinoidal grainstone at its top. The top of this lithosome marks a subsidiary sequence boundary, probably the top of a third-order sequence within the second-order Maughan sequence. This subdivision within the lower part of the Maughan sequence could be laterally extensive, but stratigraphic control for its recognition away from east-central Utah is presently lacking.

In the upper part of the Maughan sequence in the Confusion Range, the spiculitic limestones of lithosome MA.Sp.Lm grade upward into bioclastic limestones of lithosome MA.Bc.Pk, which is a catchall roughly equivalent to the Willow Gap Limestone Member of the Chainman Formation (of Sadlick, 1965). In its lower part, bioclastic limestones of lithosome MA.Bc.Pk are intercalated with black shale and contain a restricted-marine fauna distinguished by an abundance of gastropods. Limestones higher in the succession have more open marine shelly faunas, and those at the top of lithosome MA.Bc.Pk are crinoidal grainstones having large-scale cross-stratification. A disconformity marked by a concentration of detrital phosphorite separates these fossiliferous limestones in the Confusion Range from the overlying Jensen Member (of Sadlick, 1965) of the Chainman Shale (Sandberg and others, 1980) and marks the top of the Maughan sequence.

The sequence boundary at the top of the Maughan sequence approximates the boundary between Mamet endothyrid zones 18 and 19, and it roughly coincides with the base of the *Rhipidomella nevadensis* brachiopod zone that is customarily placed at the top of the Chesterian Series (Webster and others, 1984). Sections of the Maughan sequence from Granite Mountain southward to the Needle Range (fig. 2) are along strike and generally similar to the section in the Confusion Range (fig. 6). Together, they describe a major late Meramecian to late Chesterian cycle of marine transgression and regression, marked, at least locally, by internal subsidiary transgressive-regressive cycles and by disconformities at its bottom and top.

At locations such as the Cherry Creek Range and White Horse Pass and those farther south in easternmost Nevada (fig. 2), the Maughan sequence is mostly black mudstone and shale containing increasing amounts of quartzitic sandstone in higher parts of the section. These strata of lithosome MA.Ms (fig. 6, appendix) are mostly, if not wholly, equivalent to the upper part of the sequence, above the probable third-order sequence boundary shown within the Maughan sequence in figure 6. Their lateral relationships to the more calcareous equivalent part of the sequence in the Confusion Range and at Granite Mountain, and their relation to the black mudstone of lithosome MA.Ms below the probable third-order sequence boundary within the Maughan is presently unknown.

DISCUSSION

As would be anticipated in a foreland area, the Upper Devonian and Mississippian stratigraphic record of western Utah and adjoining Nevada is complicated by conspicuous lateral and vertical variations in sedimentation that reflect crustal instability. Comprehension of this record is hampered by a bewildering array of lithostratigraphic names used in a variety of different ways. The application of sequence stratigraphy to these rocks eliminates many semantic and interpretational problems that encumber their understanding. Recognition of the major depositional sequences among them, according to the depositional environments of the lithosomes that make up the systems tracts forming these sequences, provides a natural classification from which inference can be drawn about original paleogeographic settings, paleotectonic controls on deposition, and subsequent structural disruption.

Salient features common to all five of the upper Frasnian through Mississippian sequences recognized in western Utah and adjoining Nevada are as follows: (1) they were deposited on the shelf, rather than within deep-water basins and on slopes; (2) their highstand systems tracts generally prograded westward away from the continent, although this pattern is perturbed by paleotectonic features such as the Wendover high and possibly the Stansbury uplift; and (3) they include no terrigenous clastics that were obviously shed eastward from the Antler orogen. Parts of the Langenheim, Gutschick, Sadlick, and Maughan sequences are characterized by restriction of the shelf and by the entrapment of fine-grained siliciclastic sediment that otherwise would have bypassed the shelf. This suggests that the more outboard parts of the shelf were episodically silled by the tectonic development of positive relief during deposition of these sequences. The Morris sequence, on the other hand, is primarily composed of carbonate rocks, shows no effects of restricted environments other than those associated with evaporitic conditions in its progradational highstand systems tract, and includes some of the most regionally, even interregionally, extensive lithosomes. Its deposition was apparently controlled more by eustasy than regional tectonism.

The Pilot Shale, represented by rocks included in the Langenheim and Gutschick sequences, was interpreted by Goebel (1991b) as having been deposited continentward of the forebulge that would have resulted from initial overthrusting of the margin by the Roberts terrane according to the model of lithospheric flexural loading (Speed and Sleep, 1982). Strata assigned to the Pilot Shale are, however, recognized as far west as the eastern limit of the Roberts terrane (fig. 1) (Merriam, 1963; Johnson and Visconti, 1992), such that any such positive element that controlled deposition on the Late Devonian shelf is now buried beneath Mesozoic thrust sheets, if not by original Antler-age displacement of the Roberts terrane. Thus the nature of the

Devonian margin and its relation to the Antler orogen remains inferential, as does an explanation of the source for the fine-grained terrigenous clastics in the Pilot Shale.

A more compelling case can be made for development of an Antler-related forebulge during Mississippian time (Goebel, 1991a). The Wendover high (fig. 3) may have been part of this feature, although its trend is uncertain because of palinspastic problems resulting from the complex contractional and extensional tectonic history of this region. Another, contemporaneous positive area, the "Ely arch," was postulated by Skipp (1979) to have existed southwest of the Wendover high in Nevada, and it could have been part of the same forebulge trend; however, even more so than in the case of the Wendover high, uncertainties surround the evidence for the Ely arch and its paleogeography. By Late Mississippian time, structural relief on the Wendover high amounted at least locally to about 200 m over a distance of about 200 km (fig. 5). This relief of approximately one part in a thousand was produced during a period of time that cannot be quantified precisely on any rational basis but was probably on the order of millions of years. Thus, although the effect on strata that were deposited near sea level is dramatic, the magnitude of the tectonic deformation that produced the Wendover high is by any measure relatively minor. The localized, domelike shape of this high (fig. 3) may have resulted from intersection of a forebulge with a pre-existing Precambrian zone of weakness extending westward from the Uinta trend. Relief attributable to basement control has been interpreted by Dorobek and others (1991) to have influenced Devonian-Mississippian deposition farther to the north in the Antler foreland.

The eastern limit of fine-grained siliciclastic deposition, under restricted-marine conditions on the shelf, shifted eastward from Late Devonian to Early Mississippian time, perhaps in response to eastward forebulge migration (Goebel, 1991b); however, although the paleogeography of possible forebulge features such as the Wendover high is somewhat dependent on palinspastic assumptions, this particular positive element probably remained in generally the same position during much of mid-Mississippian time. This interpretation, and the relatively small effect of contemporaneous tectonism on the carbonate rocks of the Morris sequence, indicates that eastward migration of foreland features during Antler orogenesis was episodic rather than gradual. Either way, this eastward shift of the effects on shelf deposition of Antler tectonism tends to corroborate models for this tectonism involving progressive overthrusting of the Antler orogen onto the continental margin from mid-Late Devonian through Early Mississippian time.

The thickest accumulation of the Upper Mississippian Maughan sequence is in west-central Utah where it is mainly composed of progradational shallow-marine deposits as compared with the thinner, mainly shaly section of the sequence farther west in westernmost Utah and Nevada. At least in Utah, deposition during this time possibly was controlled by intracratonic basins whose development is not necessarily attributable to Antler orogenesis.

In view of these various indications of tectonic control on sedimentation in the distal Antler foreland, it therefore came as a surprise to us that the major-order depositional sequences that are apparent in the stratigraphic record of this foreland in Utah and adjacent Nevada are evidently the same as the worldwide eustatic ones recognized by Ross and Ross (1985, 1988). On a summary diagram correlating Lower Carboniferous depositional sequences of northwest Europe, Russia, the mid-Continent of the United States, and the southwestern United States (Ross and Ross, 1988, fig. 6), several of the most major episodes of coastal onlap stand out as being correlative in magnitude and age interregionally. In terms of the stratigraphic names applied by Ross and Ross (1988) to the Mississippi Valley–Illinois Basin succession, these major eustatic episodes in the history of Early Carboniferous sea-level history occur at (1) the base of the "'Glen Park'–Hannibal" interval (at or near the Devonian-Mississippian boundary), (2) the top of this same interval (within the Kinderhookian), (3) the top of the "Chouteau" interval (at the Kinderhookian-Osagean boundary), (4) within the "St. Louis" interval (at the boundary between Mamet endothyrid zones 14 and 15 within the Meramecian), and (5) at the top of the "Degonia–Grove Church" interval (in the upper Chesterian). The age constraints on deposition of the Gutschick, Morris, Sadlick, and Maughan sequences in Utah and adjacent Nevada strongly suggest that they correlate with these major, interregional eustatic episodes. That this is so for the sea-level record of a region not included in the synthesis by Ross and Ross (1988) is strong validation of the eustatic pattern that they observed. The meaning of this for the Antler foreland is that eustasy, not regional tectonism, was the primary control on the major—that is, second-order—depositional sequences in the distal foreland. Local tectonic features, such as the Stansbury uplift, the hypothetical forebulge(s) related to Pilot sedimentation, and the Wendover high, had the effect of modulating this eustatic cyclicity on a relatively small, but still substantial, geographic scale.

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APPENDIX—DESCRIPTION OF LITHOSOMES

This appendix includes descriptions, interpretations of depositional environments, and occurrences of the lithosomes whose relationships are shown in text figures 5 and 6. Abbreviations of lithosome names are formed of letter symbols, or groups of symbols, that are separated by periods and represent the sequences, modifiers, and rock types as listed below.

SEQUENCE		MODIFIER		ROCK TYPE	
MA	Maughan	Bc	Bioclastic	Ds	Dolostone
SA	Sadlick	Cr	Crinoidal	Gr	Grainstone
MO	Morris	Cs	Calcisphere	Lm	Lime mudstone
GU	Gutschick	Dc	Desiccated	Ms	Mudstone or shale
LA	Langenheim	Di	Diffusely interbedded	Pk	Packstone
				Ss	Sandstone
		Do	Dolomitic	St	Siltstone
		En	Endothyrid	Wk	Wackestone
		La	Laminated		
		Ma	Massive		
		Oo	Oolitic		
		Os	Ostracode		
		Pd	Peloidal		
		Pr	Primary		
		Pt	Pellet		
		Qz	Quartzose		
		Rh	Rhythmically bedded		
		Sp	Spiculitic		

MAUGHAN SEQUENCE

MA.Bc.Pk BIOCLASTIC PACKSTONE (TEXT FIG. 6)

Description.—Various limestones, mainly packstone containing crinoidal and other open-marine bioclasts; crinoidal grainstone increasingly important upsection, some beds of which are as thick as a few meters and contain large-scale cross-stratification. Crinoidal packstone and grainstone form resistant cyclic units several meters thick intercalated with recessive units of lime mudstone and wackestone. Shelly faunas are dominated by gastropods in lower part; corals are conspicuous in upper part. In the Confusion Range upper contact is a dissolution residue of crinoidal limestone about 1 m thick overlain by about 10 cm of detrital phosphorite at the base of the overlying Jensen Member of the Chainman Formation (of Sadlick, 1965).

Depositional environment.—Subtidal, increasingly open marine and high energy conditions upward within this cyclic, composite lithosome.

Occurrence.—Typified by the Willow Gap Limestone Member of the Chainman Formation (of Sadlick, 1965) in the Confusion Range.

MA.Sp.Lm SPICULITIC LIME MUDSTONE (TEXT FIG. 6)

Description.—Evenly medium bedded, impure, spiculitic, lime mudstone; minor interbedded black mudstone and yellow-brown siltstone. Body fossils are generally absent except for a few levels that contain a restricted fauna dominated by gastropods and *Leiorhynchoidea*-like brachiopods.

Depositional environment.—Restricted, low-energy marine.

Occurrence.—Camp Canyon Member of Chainman Formation (of Sadlick, 1965), especially upper part in the Confusion Range and also in the Burbank Hills and Needle Range and at Granite Mountain.

MA.Ms&Sp.Lm MUDSTONE AND SPICULITIC LIME MUDSTONE (TEXT FIG. 6)

Description.—Black mudstone with interbeds and intercalated units of impure, spiculitic lime mudstone; rare planar-laminated beds as thick as 20 cm of bioclastic (crinoidal, brachiopod, endothyrid, and so forth), spiculitic packstone.

Depositional environment.—Restricted, mainly low energy marine. Bioclastic packstones are interpreted as storm deposits by stratigraphic context.

Occurrence.—Camp Canyon Member of Chainman Formation (of Sadlick, 1965), especially middle part in the Confusion Range and also in the Burbank Hills and Needle Range and at Granite Mountain.

MA.En.Gr ENDOTHYRID GRAINSTONE (TEXT FIG. 6)

Description.—Grades upward in the Confusion Range from discrete thin to medium beds of fine-grained bioclast-pellet packstone and grainstone with impure limestone partings in lower part to diffusely layered, vaguely cross stratified, massive bioclast-intraclast grainstone in upper part. Bioclast assemblage near base mainly consists of endothyrids, bryozoa, and calcispheres; crinoid columnals and brachiopod fragments are more important upsection, but endothyrids are conspicuous throughout. At Granite Mountain, bioclasts have oolitic coatings.

Depositional environment.—Upward progression from restricted, low-energy marine to foreshoal and shoal.

Occurrence.—Recognized only within the lower part of the Camp Canyon Member of the Chainman Formation (of Sadlick, 1965) in the Confusion Range and at Granite Mountain. Lithosome was misassigned to the "Skunk Spring Limestone" by Webster and others (1984) at Granite Mountain where base is locally a bedding-parallel fault.

MA.Ms MUDSTONE (TEXT FIG. 6)

Description.—Black mudstone and shale; sparse phosphatic, goniatite-bearing concretions in lower part (as in the Needle and Confusion Ranges and at Granite Mountain). Minor discontinuous interbeds of crossbedded quartzite and coal are present in the Cherry Creek Range and at other locations in easternmost Nevada.

Depositional environment.—Restricted, mainly low energy marine to paralic.

Occurrence.—Forms lower part of Camp Canyon Member of the Chainman Formation (of Sadlick, 1965) from the Needle Range north to Granite Mountain; predominant in the Maughan sequence in easternmost Nevada, as at Trough Spring Canyon, Dutch John Mountain, and Ward Mountain, and in the Cherry Creek Range. As discussed in the text, these thick sections of MA.Ms in easternmost Nevada are mostly, if not entirely, above the level of the probable third-order sequence boundary within the Maughan sequence. They correspond to the typical concept of the Chainman Shale.

MA.QzCr.Ss QUARTZOSE AND CRINOIDAL SANDSTONE (TEXT FIGS. 5, 6)

Description.—Quartz sandstone, crinoidal quartz sandstone, and quartz-sandy crinoidal grainstone; rudely tabular to cross-stratified bedding; some herringbone cross-stratification. Lithosome includes some calcareous siltstone and rare units of evaporitic p-dolostone; sandstone is locally cemented by secondary dolomite.

Depositional environment.—Shallow-marine foreshore, backshore, and offshore bar.

Occurrence.—West-central and southwestern Utah; included in either the Uncle Joe Member of the Deseret Limestone or the Humbug Formation. Only the lower part of this lithosome is represented in text figures 5 and 6; its total thickness is nowhere well constrained because of structural complications but is on the order of hundreds of meters.

MA.Rh.LmWk RHYTHMICALLY BEDDED LIME MUDSTONE AND WACKESTONE (TEXT FIG. 5)

Description.—Rhythmically thin to medium bedded lime mudstone and wackestone containing siliciclastic partings or calcareous siltstone interbeds. Silicification of limestone outward from siliciclastic partings or interbeds transforms some sections into thinly interlayered limestone and chert. Bioclasts are inconspicuous but are open-marine types such as crinoid columnals. Lithosome may include intercalated units of calcareous siltstone where transitional into MA.QzCr.Ss.

Depositional environment.—Open marine, mainly below wave base.

Occurrence.—West-central Utah in the northern Dugway Range, East Tintic district, and Gilson Mountains and at Flux and Wig Mountain; generally equivalent to the Tetro Member of the Deseret Limestone or to the upper and main part of the Tetro where lithosomes SA.Qz.Ss and SA.Rh.LmWk have been included in the Tetro as at Ophir Canyon (Sandberg and Gutschick, 1984).

MA.Rh.Lm RHYTHMICALLY BEDDED LIME MUDSTONE (TEXT FIG. 6)

Description.—Rhythmically bedded lime mudstone; no megafossils; sparse radiolarians and ostracodes visible in thin section.

Depositional environment.—Low-energy marine; below wave base.

Occurrence.—Skunk Spring Limestone Bed of Chainman Shale in the Needle Range, Burbank Hills, and Confusion Range. Farther to the north at Granite Mountain, lithosome is represented by individual beds of decimeter-scale thickness in black shale of lithosome MA.Ms containing phosphate nodules. In the Cherry Creek Range, lithosome is more than 20 m thick and contains black siltstone and argillite in graded beds near top. At White Horse Pass, lithosome is several tens of meters thick and is in part interbedded with calcareous siltstone; both basal and uppermost parts of lithosome are composed of cross-stratified, crinoidal grainstone.

SADLICK SEQUENCE

SA.Pr.Ds PRIMARY DOLOSTONE (TEXT FIG. 5)

Description.—Peritidal cyclic dolostone; alternating units of finely crystalline, partly laminated and fenestral, light-colored, dense p-dolostone and massive, sugary, eogenetic secondary dolostone; minor interstratified quartzite. Lithosome overlies partly dolomitized, thick-bedded, crinoidal packstone or grainstone.

Depositional environment.—Supratidal evaporitic restricted marine to intertidal carbonate shoal.

Occurrence.—Upper part of Brazer Dolomite at Samak ("unit 8" of Nichols and Silberling, 1991) and in the Crawford Mountains.

SA.Cr.WkPk CRINOIDAL WACKESTONE AND PACKSTONE (TEXT FIG. 5)

Description.—Diffusely interstratified, conspicuously crinoidal, bioclast-peloid wackestone, packstone, and lime mudstone.

Depositional environment.—Open marine, above wave-base carbonate ramp.

Occurrence.—In lower part of Brazer Dolomite at Samak ("unit 7" of Nichols and Silberling, 1991).

SA.Qz.Ss QUARTZOSE SANDSTONE (TEXT FIGS. 5, 6)

Description.—Cross-stratified, massive, or plane-bed-laminated quartz sandstone; mostly carbonate cemented. Lithosome includes some cross-stratified sandstone with crinoidal bioclasts admixed, locally grading into quartz-sandy crinoidal grainstone, and it commonly includes interstratified units of lithosome SA.LaDo.St.

Depositional environment.—Variety of shallow-marine foreshore, backshore, and offshore bar environments.

Occurrence.—West-central and southwestern Utah from the northern Dugway Range and Ophir Canyon southward to Blawn Mountain.

SA.Rh.LmWk RHYTHMICALLY BEDDED LIME MUDSTONE AND WACKESTONE (TEXT FIGS. 5, 6)

Description.—Rhythmically thin to medium bedded lime mudstone and spiculitic wackestone; siliciclastic and bioclast-drift partings weakly developed; bioclasts are comminuted shelly fossils and crinoid columnals. Rare, massive to graded (storm?) beds of crinoidal grainstone are present at Ophir Canyon and Rock Canyon.

Depositional environment.—Low-energy marine; some open-marine influence.

Occurrence.—Lower parts of Brazer Dolomite and Deseret Limestone in west-central Utah at Samak ("unit 6" of Nichols and Silberling, 1991), Ophir Canyon (lower carbonate unit of Tetro Member of Deseret Limestone of Sandberg and Gutschick, 1984), Rock Canyon (upper limestone unit of phosphatic member of Deseret Limestone of Sandberg and Gutschick, 1978), and Dog Valley (lower part of Delle Phosphatic Member of Deseret Limestone of Sandberg and Gutschick, 1984). The two units of this lithosome intercalated with quartzose sandstone in the upper part of the Sadlick sequence at Flux (text fig. 5) could be assigned to the overlying Maughan sequence, as discussed earlier.

SA.Os.Lm OSTRACODE LIME MUDSTONE (TEXT FIGS. 5, 6)

Description.—Regularly thin to medium parted dense lime mudstone, megascopically featureless except for characteristic nodules of secondary wood-grained chert (DeCelles and Gutschick, 1983); lime-mudstone fabric of very finely comminuted bioclastic material; microscopically recognizable bioclasts of mainly ostracodes.

Depositional environment.—Restricted, low-energy marine; oxygen-deficient marine water possibly of abnormal salinity.

Occurrence.—Widespread in all but the northwest part of the study area as persistent units in deposits influenced by the Delle phosphatic event in the Delle Phosphatic Member of the Woodman Formation (southern Lakeside Mountains; Sandberg and Gutschick, 1984; Silberling and Nichols, 1991), and the lower parts of the Deseret Limestone (for example, Ophir Canyon), Brazer Dolomite (for example, Samak; Silberling and Nichols, 1991), and Needle Siltstone Member of the Chainman Formation (of Sadlick, 1965). In more eastern sections, as in the Crawford Mountains, and at Samak, Dog Valley, and Blawn Mountain, initial deposition of this lithosome coincides with onset of the Delle phosphatic event.

SA.LaDo.St LAMINATED DOLOMITIC SILTSTONE (TEXT FIGS. 5, 6)

Description.—Secondarily dolomitic siltstone to very fine grained sandstone; characteristically planar laminated except where intensely burrowed on stratification; planar or irregular platy parting. Initial deposition of this lithosome coincides with onset of the Delle phosphatic event; base is marked by a hardground developed on the underlying carbonate rocks and a basal lag of detrital phosphate. Chertified phosphatic radiolarian limestone, isolated beds of ostracode lime mudstone, and layers of phosphatic mudstone and detrital phosphate are interstratified in lower part.

Depositional environment.—Restricted; oxygen-deficient to anoxic, abnormal marine water undergoing prolonged episodes of stratification; highly organic and reducing in-sediment conditions (Silberling and Nichols, 1992).

Occurrence.—Widespread, except for the northwesternmost and easternmost sections in study area. Lithosome forms most of the Needle Siltstone Member of the Chainman Shale (as at Whitehorse Pass, Cherry Creek Range, Trough Spring Canyon, and Granite Mountain south to Needle Range), the Woodman Formation (at Gold Hill and northern Dugway Range), and the lower part of the Deseret Limestone. In the southern Lakeside Mountains, lower part of lithosome is defined as the Delle Phosphatic Member of the Woodman Formation (Sandberg and Gutschick, 1984).

SA.Dl.WkPk DIFFUSELY INTERBEDDED WACKESTONE AND PACKSTONE (TEXT FIGS. 5, 6)

Description.—Diffuse, irregular, and gradational interlayering of medium to thick layers of conspicuously crinoidal packstone and pelletal wackestone, subordinate winnowed lags of crinoidal grainstone. Besides crinoid columnals, a variety of brachiopods, corals, and mollusks are well represented as megafossils and bioclasts. Nodules and bedding-plane stringers of secondary chert are commonly abundant.

Depositional environment.—Open marine, above wave base, subtidal ramp.

Occurrence.—Widespread as the upper unit of the Gardison Limestone and locally also the Joana Limestone. Lithosome extends beyond limits of underlying lithosome SA.La.Pk, which are shown in text figures 2 and 3.

SA.Cr.Gr CRINOIDAL GRAINSTONE (TEXT FIGS. 5, 6)

Description.—Massive, medium to very thick parted crinoidal grainstone; locally exhibits large-scale cross-stratification.

Depositional environment.—Open marine, subtidal dunes and shoals.

Occurrence.—Widespread in the Gardison Limestone and upper part of Joana Limestone as isolated units as thick as several meters; thicker successions interrupted by subordinate units of lithosome SA.Rh.LmWk.

SA.Oo.Gr OOLITIC GRAINSTONE (TEXT FIGS. 5, 6)

Description.—Massive, thick to very thick parted, commonly cross stratified oolitic grainstone.

Depositional environment.—Open marine, subtidal to intertidal shoals.

Occurrence.—In lower part of Gardison Limestone and the correlative upper part of the Joana Limestone. Lithosome is particularly well developed from the Confusion Range south to Blawn Mountain and at Samak and is represented by thin units or stringers as far north as Sally Mountain and as far west as Trough Spring Canyon.

SA.Rh.Wk RHYTHMICALLY BEDDED WACKESTONE (TEXT FIG. 6)

Description.—Thin- to medium-bedded lime mudstone, wackestone, and packstone; bedding rhythmic in evenly to nodular fashion; partings between beds marked by fine-grained siliciclastic material and bioclast drifts. Allochems include pellets and varying abundances of open-marine bioclasts such as crinoid columnals. Occasional large (to diameter 0.3 m), oblate-hemispheroid shape, colonial corals in growth position within wackestone beds. Occasional stratigraphically isolated T_A or T_{AB} beds of crinoidal grainstone.

Depositional environment.—Offshore ramp, mostly below normal wave base but containing discrete bioclastic storm beds.

Occurrence.—Forms most or all of upper part of Joana Limestone at Ward Mountain north to the Cherry Creek Range in eastern Nevada and uppermost unit of the Joana in the Confusion Range in easternmost central Utah.

SA.La.Pk LAMINATED PACKSTONE (TEXT FIGS. 2–3, 5, 6)

Description.—Conspicuously laminated or quasilaminated, pelletal, uniformly fine grained packstone and grainstone including occasional, discrete, mostly medium thick, normally or reverse-graded interbeds of coarse intraclasts and skeletal fragments. Laminated limestone is present in planar sets having low-truncation-angle crossbedding and contains abraded, mainly well sorted crinoidal bioclasts, as well as pellets. Coarsely bioclastic beds contain mainly crinoid columnals, coralline debris, and conspicuous large gastropods (Silberling and Nichols, 1992).

Depositional environment.—Open marine, shallow subtidal to intertidal. Coarsely bioclastic interbeds are interpreted as tempestites.

Occurrence.—Widespread in Utah as shown in text figures 2 and 3; forms greater share of Gardison Limestone from Crawford Mountain south to the Gilson Mountains, west to Sally Mountain and Wig Mountain, and east to Samak; also in the Needle Range in the upper part of the Joana Limestone.

MORRIS SEQUENCE

MO.Pr.Ds PRIMARY DOLOSTONE (TEXT FIGS. 5, 6)

Description.—Peritidal cyclic dolostone. Units of light-colored, finely crystalline, p-dolostone overlie and are intercalated with massive, sugary, eogenetic (Nichols and Silberling, 1980) secondary dolostone.

Depositional environment.—Supratidal and intertidal; evaporitic restricted marine.

Occurrence.—Southeastern sections in study area; observed as a discrete unit at West Mountain, Gilson Range, Star Range, and Blawn Mountain. Beds and thin units of p-dolostone are present within lithosome MO.Dc.Lm as far northwest as the East Tintic district and the Needle Range.

MO.Dc.Lm DESICCATED LIME MUDSTONE (TEXT FIGS. 5, 6)

Description.—Dense, mostly massive, partly fenestral, lime mudstone, peloid grainstone, and microbially planar laminated to stromatolitic lime mudstone.

Depositional environment.—Mainly intertidal; restricted, partly evaporitic lagoonal.

Occurrence.—Widespread at top of Fitchville Formation, observed from Sally Mountain southward to Blawn Mountain and as far east as West Mountain. In west-central Utah lithosome includes the "pink lithographic limestone" (Morris and Lovering, 1961) and the spectacularly stromatolitic "curley limestone bed" (Proctor and Clark, 1956). Farther to the west, lithosome is present in middle part of the Joana Limestone in the Confusion Range, Burbank Hills, Needle Range, Trough Spring Canyon, and southern Red Hills.

MO.PdCr.Gr PELOIDAL CRINOIDAL GRAINSTONE (TEXT FIGS. 5, 6)

Description.—Massive grainstone, commonly exhibiting large-scale crossbedding. Crinoidal allochems are conspicuous but characteristically heavily micritized and commonly subordinate to peloids, which, as viewed in thin section, represent both rounded intraclasts and totally micritized parts of crinoidal grains.

Depositional environment.—Subtidal shoals.

Occurrence.—Widespread, as a continuous, progradational unit within the Fitchville Formation of west-central Utah. Lithosome forms the major part of cycles as thick as several meters in the lower part of the Joana Limestone in westernmost Utah and is present as units interstratified with lithosome MO.Rh.Wk in eastern Nevada south of the Wendover high.

MO.Rh.Wk RHYTHMICALLY BEDDED WACKESTONE (TEXT FIGS. 5, 6)

Description.—Rhythmically thin to medium bedded wackestone and packstone; beds planar, undulating, or even nodular depending on diagenetic and later alteration. Fine-grained siliciclastic impurities define partings between beds, or repetitive, laterally continuous chert layers replace partings and adjacent parts of limestone beds. Lithosome has markedly diverse assemblage of recognizable bioclasts derived from bryozoans, mollusks, brachiopods, ostracodes, foraminifers, and corals; crinoidal grains are conspicuous. Grain size of bioclasts from bed to bed is commonly conspicuously different; some beds are normal graded. Basal contact is sharp and is commonly marked by a sandstone bed as at Fitchville Ridge. In the Confusion Range, 1.7 m of quartz sandstone at base of the Joana Limestone grades upward into this lithosome and disconformably overlies lithosome GU.St.

Depositional environment.—Well-oxygenated offshore ramp; below fairweather wave base but storm influenced.

Occurrence.—Widespread in lower parts of Fitchville Formation and Joana Limestone; forms a larger proportion of the Morris sequence toward the west and northwest within the study area.

MO.Di.WkPk DIFFUSELY INTERBEDDED WACKESTONE AND PACKSTONE (TEXT FIG. 5)

Description.—Diffuse, irregular, and gradational medium to thick interlayers of crinoidal packstone and pelletal wackestone. In addition to crinoid ossicles, allochems are bioclasts of comminuted brachiopod and bryozoan debris as well as some peloids.

Depositional environment.—Open-marine; above wave base, subtidal carbonate ramp.

Occurrence.—Locally the basal lithosome of the Morris sequence (and Fitchville Formation) in the southern Lakeside Mountains, where its base is a sharp contact marked by a concentration of conodonts and other insolubles ("unit 2" of Silberling and Nichols, 1992). Lithosome forms most of Joana Limestone in the Leppy Hills where it gradationally overlies a few meters of lithosome MO.Rh.Wk (Nichols and Silberling, 1993).

GUTSCHICK SEQUENCE

GU.MaCr.Pk MASSIVE CRINOIDAL PACKSTONE (TEXT FIG. 5)

Description.—Massive crinoidal and peloidal packstone. Bedding characteristics at Fitchville Ridge are obscured by solution compaction, but diffuse, irregular grain-size interlayering is suggested in lower part of lithosome and large-scale cross-stratification in upper part; coarsely intraclastic layers are present near top.

Depositional environment.—Open marine, shoal, and inner ramp continentward of lithosome GU.Bc.Pk.

Occurrence.—Lower part of Fitchville Formation; best exposed at Fitchville Ridge. Elsewhere, as at West Mountain, Gilson Mountains, and Star Range the nature of this lithosome is obscured by secondary dolomitization or by faulting.

GU.Bc.Pk BIOCLASTIC PACKSTONE (TEXT FIGS. 3, 5, 6)

Description.—Thin-bedded, irregularly slabby to platy, mottled impure limestone composed of nodules and thin lenses of fine-grained, gray bioclastic packstone enclosed in anastomosing streaks and layers of argillaceous to silty limestone. Lithosome contains well-sorted, fine-grained bioclasts derived mainly from crinoids, brachiopods, and bryozoans, and their predominance over pellets or other kinds of allochems is characteristic. Figures 7–10 in Silberling and Nichols (1992) illustrate this lithosome.

Depositional environment.—Well oxygenated, open ramp.

Occurrence.—West-central Utah southward from Sally Mountain and Becks Spur to Gilson Mountains and probably Star Range as the Pinyon Peak Limestone (or upper member of the Pinyon Peak of Sandberg and Poole, 1977). Palinspastically, it forms a well-defined north-northeast-trending belt (text fig. 3).

GU.St SILTSTONE (TEXT FIG. 6)

Description.—Mainly platy, irregularly parted, carbonate-cemented, quartzose siltstone that grades into secondarily dolomitic siltstone and fine-grained silty secondary dolomite in upper part. Lithosome is calcareous and contains sparsely distributed brachiopod shells in lower part. Nodular interbeds of pyritic, pelletal packstone contain oncolitic or foraminifera-encrusted shell fragments and diverse body fossils (Gutschick and Rodriguez, 1979) in lowest several meters.

Depositional environment.—Semirestricted shallow marine near base to evaporitic marine at top.

Occurrence.—Leatham Member and upper member of the Pilot Shale of Sandberg and others (1989) in the Confusion Range; similar to upper part of Leatham Formation at Leatham Hollow.

GU.WkSt WACKESTONE AND SILTSTONE (TEXT FIG. 6)

Description.—Rythmically thin bedded to nodular, neomorphosed, spicular (?) wackestone containing partings and interbeds of calcareous siltstone; sparse crinoid columnals and brachiopod shells as drifts on siliciclastic parting surfaces; progressively dolomitized toward top. At top lithosome grades up into 2.5 m of quartz sandstone disconformably underlying lithosome MO.Rh.Wk.

Depositional environment.—Subtidal marine; upper part obscured by dolomitization.

Occurrence.—Unique to Burbank Hills, where it forms the highest part of the Pilot Shale.

GU.Ms MUDSTONE (TEXT FIG. 6)

Description.—Black, finely fractured mudstone or fissile shale; calcareous near base, silty in part; partly silicified and radiolarian bearing near top. Base is marked in the Confusion Range by distinct lag deposit that contains coarse quartz grains, abraded crinoid columnals, and a concentration of conodonts. Lag deposits were also reported at bottom and top of silicified upper part in the Confusion Range by Gutschick and Rodriguez (1979)

Depositional environment.—Low energy, at least partially marine.

Occurrence.—In upper part of Pilot Shale in the Confusion Range and Burbank Hills; lower part of Leatham Formation at Leatham Hollow. In the Confusion Range the lithosome includes the "lower black shale" (Gutschick and Rodriguez, 1979) of the Leatham Member and the uppermost part of the lower member of the Pilot (Sandberg and others, 1989); at Leatham Hollow it includes the "lower black shale" of the Leatham Formation (Gutschick and Rodriguez, 1979).

LANGENHEIM SEQUENCE

LA?.Dc.Gr DESICCATED GRAINSTONE (TEXT FIGS. 5, 6)

Description.—Massive, light-colored, megascopically unfossiliferous, peloidal grainstone, peloid-calcisphere wackestone, and lime mudstone, some having fenestral texture. Bioclasts are poorly represented and mainly calcispheres and ostracodes. Erosion surfaces are present throughout beneath thin layers of fine-grained sedimentary breccia, peloid grainstone, or stringers of calcareous sandstone. Upper and lower contacts with other lithosomes are abrupt, marked by a concentration of quartz grains, and interpreted to be disconformable.

Depositional environment.—Restricted lagoonal to desiccated intertidal.

Occurrence.—Blawn Mountain, Star Range, and on Pinyon Peak (which lies between Rattlesnake Ridge and Fitchville Ridge in the East Tintic district). Lower member of the Pinyon Peak Limestone of Sandberg and Poole (1977).

LA.LaDo.St LAMINATED DOLOMITIC SILTSTONE (TEXT FIGS. 3, 5, 6)

Description.—Predominantly planar laminated or quasi-laminated, secondarily dolomitic, yellow-brown-weathering siltstone and very fine grained sandstone and silty secondary dolostone, which in exceptional exposures are present as meter-scale, coarsening- and thickening-upward cyclic intervals. Silt and sand is composed mainly of quartz and minor amounts of feldspar and mica. Subordinate intercalated units include (1) slump-folded to monolithologically brecciated, thin-bedded, impure wackestone and packstone; (2) discrete graded beds exhibiting Bouma-sequence internal layering (in the Cherry Creek Range, Confusion Range, and Leppy Hills);

(3) tongues of lithosomes LA.PtCs.Pk and LA.Bl.Ms; (4) discrete packets of ripple-drift, crosslaminated fine-grained sandstone (in the Cherry Creek Range); (5) massive sandstone; and (6) gutter casts (in the Cherry Creek Range). Transition upsection to foreshore sandstone having herringbone cross-stratification at top of lithosome in the Burbank Hills.

Depositional environment.—Mainly storm influenced, subtidal, and restricted lagoonal by stratigraphic context.

Occurrence.—Forms much of the lower member of the Pilot Shale, widespread from the Leppy Hills southward to the Needle Range and palinspastically west of limit shown in text figure 3.

LA.Ms MUDSTONE (TEXT FIG. 6)

Description.—Black siliciclastic mudstone or shale and subordinate laminated siltstone in platy-weathering stringers to thin intercalated units. Infrequent impure lime mudstone concretions and lenticular beds contain radiolarians; other fossils are conspicuously absent. Lithosome is gradational and intercalated with underlying and overlying lithosomes.

Depositional environment.—Low-energy, restricted marine by stratigraphic context.

Occurrence.—Lower member of Pilot Shale; thickest continuous section in the Confusion Range but also present as conspicuous units in the Burbank Hills, northern Red Hills, and Cherry Creek Range and at Granite Mountain and Ward Mountain.

LA.PtCs.Pk PELLETAL CALCISPHERE PACKSTONE (TEXT FIG. 6)

Description.—Thin-bedded, characteristically burrow mottled to nodular, pelletal packstone and wackestone distinguished by restricted bioclast assemblage mostly limited to calcispheres and ostracodes.

Depositional environment.—Restricted lagoonal.

Occurrence.—Upper part of West Range Limestone, as in the Burbank Hills; Indian Ranch Tongue of the Guilmette Formation of Sandberg and others (1989) in the Cherry Creek Range.

LA.PtCr.Pk PELLETAL CRINOIDAL PACKSTONE (TEXT FIG. 6)

Description.—Thin-bedded, characteristically burrow mottled to nodular, pelletal packstone and wackestone distinguished from lithosome LA.PtCs.Pk by conspicuous crinoid columnals and comminuted shelly bioclasts. Body fossils are mostly absent. Rare massive (storm?) beds of crinoidal grainstone are present locally.

Depositional environment.—Open-marine subtidal carbonate flat.

Occurrence.—West Range Limestone, forming either all of this formational unit (as in the Needle Range) or its lower part gradationally beneath lithosome LA.PtCs.Pk (as in the Burbank Hills). Commonly included in the Guilmette Formation, forming its upper part as recognized in the Leppy Hills (Schneyer, 1990), Confusion Range (Hintze, 1974), or Needle Range (Hintze and Best, 1987). Transitional upward through a few meters into lithosome LA.LaDo.St in the Confusion Range.

LA.Rh.Lm RHYTHMICALLY BEDDED LIME MUDSTONE (TEXT FIG. 6)

Description.—Rhythmically thin to medium bedded, nodular, dense, bioturbated lime mudstone; mostly devoid of allochems but characterized by rare rhynchonellid brachiopod shells.

Depositional environment.—Restricted lagoonal.

Occurrence.—"*Calvinaria*-bearing limestone unit" of Sandberg and others (1989) in the northern Red Hills and Cherry Creek Range (Jones, 1990). Lithosome forms one or more units at or just above base of Langenheim sequence.

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Silberling and others—UPPER DEVONIAN–MISSISSIPPIAN STRATIGRAPHIC SEQUENCES, UTAH AND NEVADA—U.S. Geological Survey Bulletin 1988–H