CARBONIFEROUS SUPRATIDAL FLAT AND DESERT SABKHA SEDIMENTATION, WESTERN WYOMING

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ABSTRACT OF THE THESIS

Carboniferous Supratidal Flat and Desert Sabkha Sedimentation, Western Wyoming

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Recent paleontologic work has established that the Mississippian - Pennsylvanian boundary in Wyoming occurs within the Amsden Formation. However, the significance of the change in lithology from the carbonates of the Madison Limestone to the clastics of the Amsden Formation has yet to be evaluated.

Pre- Amsden erosion of the Madison Limestone has occurred in southeastern Wyoming. There is evidence of pre- Amsden karst development on the upper Madison surface in scattered areas of southern Montana, in the Elk Basin oil field in the northern Big Horn Basin and in the Wind River Range in Wyoming.

Sedimentation appears to have been continuous across the Madison - Amsden contact on Glory Mountain in the Teton Range, on Open Door Mountain in the Gros Ventre Range and in Hoback Canyon southeast of Jackson, Wyoming.

The upper part of the Madison Limestone in western Wyoming was deposited under supratidal conditions. Intertidal and subtidal carbonates underlie the supratidal

sediments. The Amsden Formation represents a complex of continental sabkha, dune, playa and lacustrine sediments.

It is proposed that in western Wyoming the upper part of the Madison Limestone and the Amsden Formation are time transgressive units representing regressive fill in of the depositional basin and their contact indicates the point at which continental sedimentation was initiated at any given place.

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INTRODUCTION

The Madison Limestone is recognized throughout Wyoming, Montana and the Williston basin. The unit, over 1900 feet thick in the Williston basin and over 1700 feet thick in central Montana, thins southward and is absent in the southeastern corner of Wyoming. It is about 1000 feet thick along the Idaho - Wyoming state line and thins southeastward. The Madison Limestone is underlain by Cambrian and Pre-Cambrian rocks in southeastern Wyoming and by successively younger strata toward the north and northwest until it is underlain by Devonian strata in central Montana and western Wyoming (Andrichuk, 1955). The Madison Limestone in Wyoming consists mostly of limestone, dolomitic limestone and dolomite. Shales are found in the lower part of the unit, particularly toward the southeast. Chert nodules and nodular bands of chert occur throughout (Sando, 1967). In central and western Wyoming and southern Montana the Madison Limestone is overlain by the Amsden Formation. The basal Darwin Member of the Amsden Formation is an almost pure quartz sand of variable thickness exhibiting massive bedding or high or low angle cross bedding at various localities. This is overlain by a sequence of unfossiliferous shales and siltstones with a few limestone beds containing marine fossils near its top followed by sandstones, sandy limestones and dolomites, shales and siltstones (Wanless, et. al., 1955).

Group	Formation	Member	Series	Stage	Period
	Phosphoria Formation				Permian
	Tensleep Formation		Oklan	Desmoines	Pennsylvanian
	Tensleep Formation		Oklan	Atoka	Pennsylvanian
	Amsden Formation		? Ardian	Morrow	Pennsylvanian
	Amsden Formation		Ardian ?	Springer	Pennsylvanian
	Amsden Formation	Darwin Member		Chester	Mississippian
Madison Group	Mission Canyon Formation	Bull Ridge Member		? Meramac	Mississippian
Madison Group	Mission Canyon Formation			? Osage	Mississippian
Madison Group	Lodgepole Formation			? Kinderhook	Mississippian
	Darby Formation				Devonian

Table 1: Carboniferous stratigraphy, western Wyoming (Henbest, 1956, Strickland, 1956 and Sando, 1967 & 1968)

Determination of the nature and position of the Mississippian - Pennsylvanian boundary in western Wyoming has been complicated by the various interpretations of the Amsden Formation, the basal Darwin Member of the Amsden Formation and the uppermost Bull Ridge Member of the Madison Limestone and their contact relationships. Much of the confusion on this subject arose from the desire of earlier workers to place the system boundary at the lithologic break marked by the base of the Darwin Member which many believed to be unconformable. While paleontologic evidence (Sando and Dutro, 1960; Sando, 1967) has established that the evolutionary trends which mark the Mississippian - Pennsylvanian boundary occurred during the deposition of the Amsden Formation, the significance of the change in lithology at the base of the Darwin Member has yet to be evaluated.

The Darwin Member is unfossiliferous, as are the upper beds of the Madison Limestone in western Wyoming. There is, then, no definite paleontologic evidence on the nature of the carbonate - clastic transition. One must look to sedimentology for a solution. Two alternatives are possible: 1) the Madison - Amsden contact is a regional unconformity and deposition of the two units took place under entirely unrelated circumstances, 2) the Madison Limestone and the Amsden Formation are time transgressive units representing regressive fill in of the depositional basin and their contact indicates the point at which continental sedimentation was initiated at any given place.

SEDIMENTOLOGIC MODEL

The absence of definitive paleontologic evidence, which would normally be used to determine which alternative applies, necessitates the construction of a sedimentologic model. Field evidence in western Wyoming favors the second alternative. A model of this form is proposed and evaluated.

The model proposed begins with a northwestward progradation of tide flat carbonates and evaporites. Concurrent subsidence in western Wyoming allowed the thick accumulation of supratidal sediments of the upper Madison Limestone. Wanless, Belknap and Foster (1955) point out that the Darwin Member is the first sandstone above the Middle Cambrian Flathead Sandstone, and Branson (1939) notes that the uniformity of size and shape of the fine quartz grains and the low percentage of small, well-rounded heavy minerals indicate that the Darwin Member and the Pennsylvanian sandstones of Wyoming were derived from pre-existing sandstones. The Darwin Member may indicate the time when erosion in the Ancestral Rocky Mountains cut into the Flathead Sandstone. Erosion of Cambrian sandstones and Pre-Cambrian igneous and metamorphic rocks in the Ancestral Rocky Mountains produced the Amsden clastics which buried the Madison sabkha. The term sabkha applied to the upper Madison Limestone is equivalent to the coastal sabkha of Kinsman (1969) which is basically a carbonate supratidal flat. This model is similar to that developed for the deposition of Permian strata in the Midland and Delaware basins of Texas and New Mexico (Adams et. al., 1951, Van Siclen, 1958, Tyrrell, 1969, Kendall, 1969 and Silver and Todd, 1969). Sedimentation would be analogous to that taking place along the south coast of the Persian Gulf. Deposition of the upper beds of the Madison Limestone would be similar to that taking place in the recent coastal sabkhas. Deposition of the Amsden Formation would be analogous to that taking place in the continental sabkhas and desert dunes and playas. However, the sequence of unfossiliferous shales in the Amsden Formation above the basal Darwin Member indicates the presence of more playas and lakes in Wyoming during Chester time than are found in Arabia today. The vertical sequence resulting from this model begins with subtidal and intertidal carbonates overlain by supratidal carbonates and evaporites due to regressive sedimentation which are in turn overlain by progradational continental detritus.

Silver and Todd (1969) utilizing the detailed stratigraphic and paleontologic control that has been developed for the Permian Reef Complex recognize four major depositional cycles in late Wolfcampian, Leonardian and Guadalupian rocks of the northern Midland and Delaware basins.

The sediments of each cycle represent five depositional environments (Silver and Todd, 1969, p. 2239):

> "... (1) shelf detritus (continental and nearshore terrigenous clastic material), (2) shelf evaporite - dolomite (supra-tidal-flat and lagoonal strata), (3) shelf margin (oölite banks, reefs, etc.), (4) basin carbonate (pelagic micrite), (5) basin detritus (submarine fan, turbidite, and bypass terrigenous clastic material)."

They depict, in a series of block diagrams (Figs. 4 - 7, p. 2227 - 2230), the seaward progradation and overlap of these facies as the result of regressive sedimentation. A cycle begins with shelf evaporite - carbonate and shelf margin sediments accumulating at and near sea level. Coastal and continental sabkhas prograde basinward with regression. Lagoonal and shelf margin sediments may be subaerially exposed before continental detritus progrades completely across the shelf. A relative rise in sea level reinitiates carbonate deposition on the shelf and begins a new cycle. The upper Madison Limestone and the Amsden Formation would represent one major cycle of this model with a few minor transgressions indicated by the fossiliferous limestones in the middle and upper part of the Amsden Formation.

THE MADISON - AMSDEN CONTACT

The first step in evaluating the model is an evaluation of the Madison - Amsden contact. In 1904 Darton named the strata lying disconformably between the Madison and Tensleep formations in the Big Horn Mountains the Amsden Formation. He noted (1906) the presence of Mississippian fossils in the basal section and a Pennsylvanian fauna in the upper beds. Branson (1937), working in the Wind River Range proposed the name Sacajawea for the basal Mississippian section. The Darwin Member of the Amsden Formation was named by Blackwelder (1918) who recognized only Pennsylvanian fossils above it and an unconformity at its base in the Gros Ventre Range. Love (1939), working along the southern margin of the Absaraka Range, discarded the term Sacajawea as an unmappable unit and found the Madison - Darwin contact to be conformable. He measured a section in Wiggins Fork Canyon (see Fig. 2 for localities) where the contact is a bedding plane with no relief between the sandstone of the Darwin Member and a 10 foot interval of massive, cherty limestone at the top of the Madison Limestone. He did indicate three unconformities within the upper Madison Limestone at this locality but Sando (1967) measured the same section and described solution breccia zones at the intervals of Love's unconformities. Sando considered the contact a paleo-karst surface at this locality but his evidence lies further south in the Wind River Range (see below). Love (1939) reported a Mississippian fauna about 36 feet above the Darwin Member and a Pennsylvanian fauna about 170 feet above the Darwin Member in Wiggins Fork Canyon. Love's work was followed by a long debate concerning the age of the two Amsden faunas and the stratigraphic position of the Darwin Member (Branson, 1939, Burk, 1954, Shaw and Bell, 1955, Strickland, 1956 and Sando and Dutro, 1960) which was reviewed by Sando (1967). Sando (1967) identified a fauna of Chester age about 70 feet above the top of the Darwin Member in a section near Livingston Ranch in the Wind River Range. Sando and Dutro (1960) examined the Madison Limestone in the type area near Logan, Montana. At this locality 90 feet of strata are unexposed between the uppermost Madison strata exposed and red siltstones of the Amsden Formation containing Pennsylvanian brachiopods. This may indicate that the Amsden Formation is younger toward the northwest. In 1968 Sando renamed the Sacajawea Formation, as redefined by Strickland (1957), the Bull Ridge Member of the Madison Limestone. In its type section on Bull Lake Creek the Bull Ridge Member is the upper 75 feet of the Madison Limestone. It contains a fauna dated as early Meramac (Diphyphyllum zone of Sando and Dutro (1960)) between 30 feet and 50 feet below the top of the section. Sando's data indicates that between early Meramac and late Chester time at least 30 feet of Madison sediments and over 100 feet of Amsden sediments accumulated, which leaves a geologically short period of time for post- Madison pre- Amsden erosion.

Pre- Amsden erosion has truncated the upper beds of the Madison Limestone in south-central and southeastern Wyoming (Andrichuk, 1955). In northern and eastern Wyoming, Agatston (1954) describes channels cut into the upper Madison filled with large angular blocks of limestone and chert in a matrix of quartz sand of the overlying Darwin Member. The top of the Madison Limestone appears to be a paleo-karst surface in many areas of Montana (Roberts, 1966). McCaleb and Wayhan (1969) demonstrate significant karst development on the Madison surface in the Elk Basin oil field. They believe that solution brecciation within the Madison Limestone is related to and took place at the same time as the karst development. Sando and Dutro (1960) and Sando (1967) consider the top of the Madison Limestone a paleo-karst surface in the Wind River Range and cite as evidence a sinkhole filled with sand from the overlying Darwin Member at Dinwoody Canyon. These data are consistent with the model proposed. Erosion and truncation are to be expected toward the area of uplift. Agatston's (1954) description of the channels in the upper surface of the Madison Limestone resembles that of tidal channels in the tide flats of the Bahamas (Shinn et. al., 1969) and the Ordovician Tribes Hill Formation of New York (Braun and Friedman, 1969). Local patches of the emergent tide flat might well be expected to remain exposed for longer periods of time than others during the early stages of progradation by continental detritus. While karst development in these areas represents an unconformity in a strict definition of the word the sequence of sediments preserved after burial may not indicate a significant loss of record. Solution of the tide flat carbonates and evaporites by groundwater could also occur during deposition in the continental environments or any time thereafter but this would not indicate an unconformity due to a break in sedimentation. In either case the solution cavities would be filled with the overlying sediment and a distinction between the two processes may be difficult. Dissolution of carbonates occurs above the groundwater table; therefore, there must have been a lowering of sea level prior to either karst development or the subsurface dissolution of the carbonates. Evaporites, however may be dissolved below the groundwater table by either normal marine or fresh waters. There is evidence that many of the solution breccias in the Madison Limestone are the result of the removal of evaporites. Surface exposures of solution breccias have been correlated with evaporite intervals in the subsurface in many areas (Andrichuk, 1955; Roberts, 1966).

Wanless, Belknap and Foster (1955) describe the top of the Madison Limestone as a paleo-karst surface in western Wyoming. The writer found no evidence of karsting on the

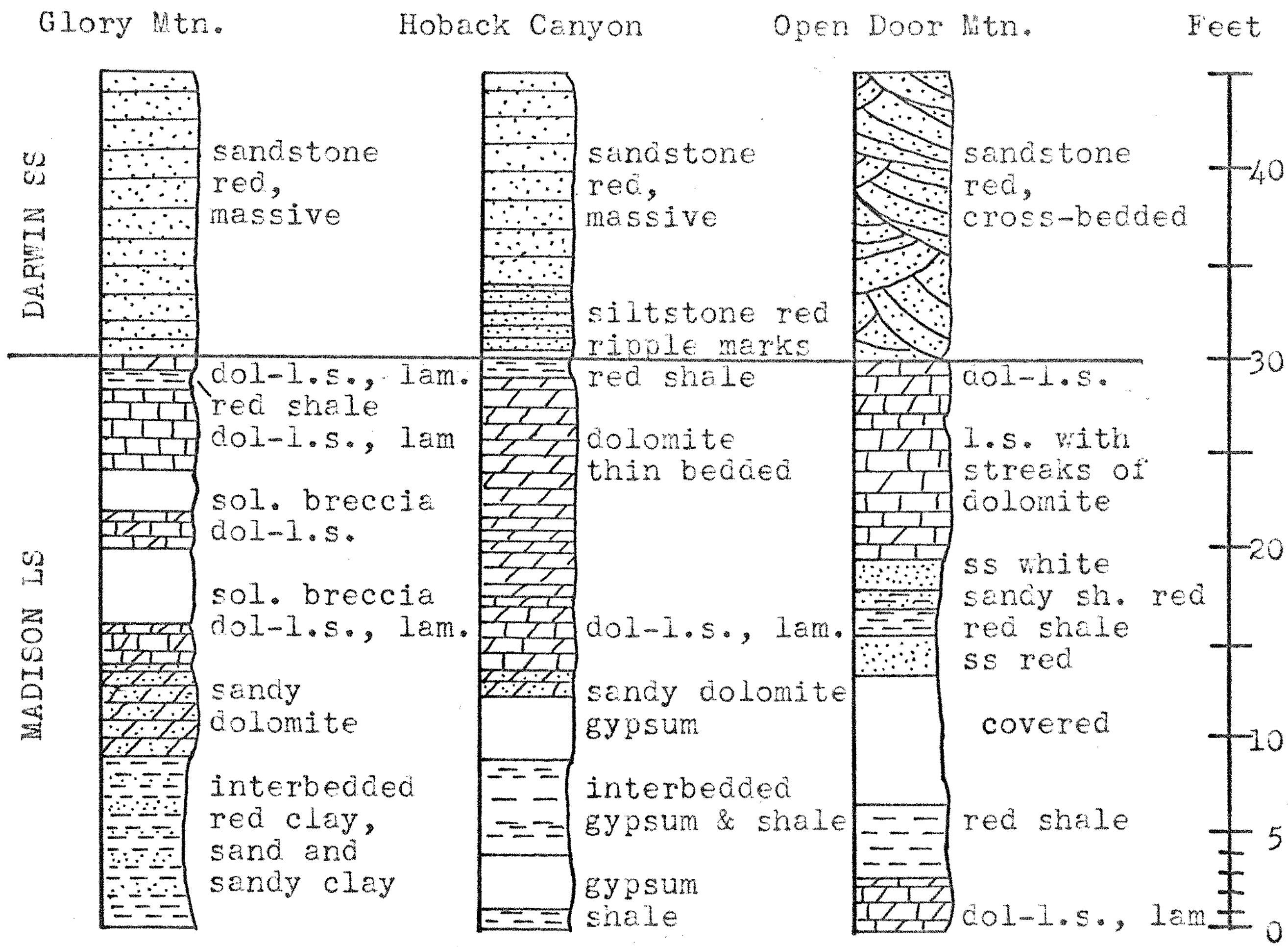

Fig. 1. Measured sections across the Madison - Darwin contact.

upper Madison surface at three of their localities (localities 7, 9 and 10; refer to their plate 6, fig. 2). In Hoback Canyon the uppermost 75 feet of the Madison Limestone (Lower Amsden Red Shale Sequence of Wanless et. al., 1955) is made up of thinly (1 inch to 3 feet) interbedded gypsum and red shales and siltstones topped by 11 feet 8 inches of dolomite which is overlain by 10 inches of dark red shale. The upper and lower surfaces of the shale are planar indicating no erosion or dissolution at this horizon. The basel 4 feet of the overlying Darwin Member is a dark red, thinly bedded siltstone with small scale ripple marks. The remaining 36 feet of the Darwin Member is a thick bedded quartz sand. On Glory Mountain at the southern end of the Teton Range the Darwin Member is immediately underlain by 8 inches of laminated limestone beneath which is a 10 inch bed of red shale. Beneath the red shale is a 40 foot section of limestones, dolomitized limestones, dolomites, solution breccias, clays, sandy clays and sandstones. The Darwin Member is over 70 feet thick on Glory Mountain and is thick bedded as in Hoback Canyon. On Open Door Mountain above Granite Creek Hot Springs in the Gros Ventre Range, the Darwin Member is over 80 feet thick and is composed predominantly of thick sets of high angle cross beds of varying orientation. At this locality the Darwin Member is underlain by 33 inches of limestone with small round vugs and a few chert nodules in the lower foot. Beneath this is 7 feet 6 inches of interlaminated limestone and dolomitic limestone which is in turn underlain by 18 inches of white sandstone, 1 foot of sandy red shale, 18 inches of red shale and 2 feet of red sandstone. A covered interval separates this section from the underlying laminated limestones and dolomites. At each of these localities up to 75 feet of the uppermost Madison carbonates or evaporites are interbedded with siltstones, shale or sandstones and the Madison - Darwin contact is a bedding plane exhibiting no relief (Fig. 1). Figure 2 illustrates the regional aspects of the Madison - Amsden contact in Wyoming.

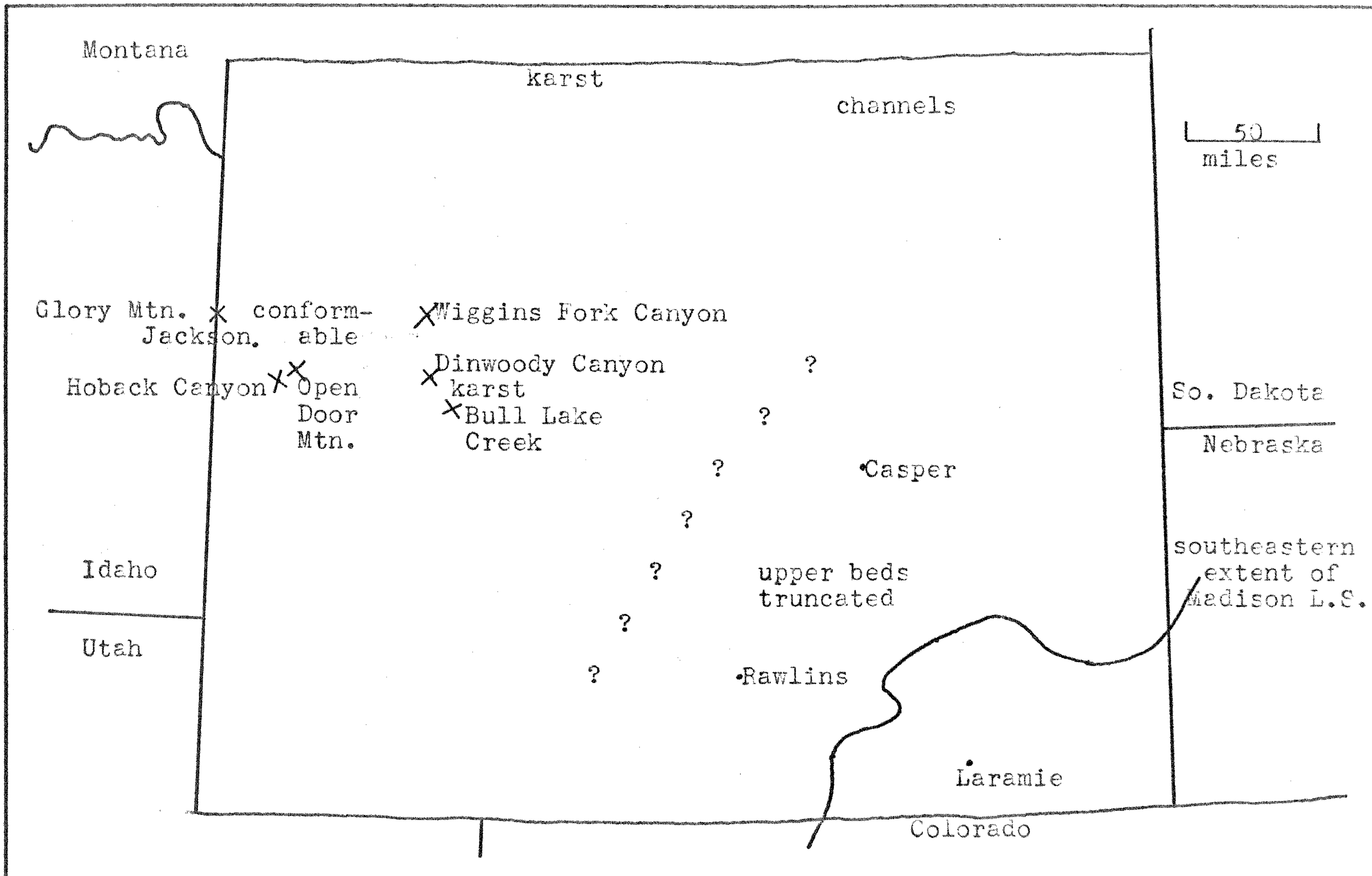

Fig. 2. Index map and the nature of the upper Madison surface.

LITHOLOGIC SEQUENCE, HOBACK CANYON

The Hoback Canyon section (Fig. 3) is unique in that it contains the only known surface exposure of evaporites in the Madison Limestone outside the area where the Charles Formation is mappable. The uppermost 650 feet of the Madison Limestone were measured on the north wall of the canyon. The basal 150 feet consists of interbedded, thin bedded mudstones and wackestones (terminology of Dunham, 1962). Wackestones predominate the lower 130 feet, many of which approach, or may be, packstones. Sparsely fossiliferous beds become more numerous in the upper 20 feet. The grains are fossil fragments; predominantly crinoids, with some corals and a few brachiopods. Whole solitary corals are found in the lower 115 feet, but not in growth position. A cluster of favosited colonies approximately 135 feet above the base of the section appeared to be _in situ_. A few other favositeds in this interval were overturned. A few small burrows were found approximately 80 feet above the base of the section. Numerous burrows were seen in talus debris below this, but none were observed in place. The entire 150 foot interval is partially to completely dolomitized and there are numerous bands of black chert nodules. This section is comparable to the lagoonal facies -- dolomitized micritic-skeletal limestone -- of Silver and Todd (1969) or the barrier flat facies of Kendall (1969) in the Permian Basin of Texas and New

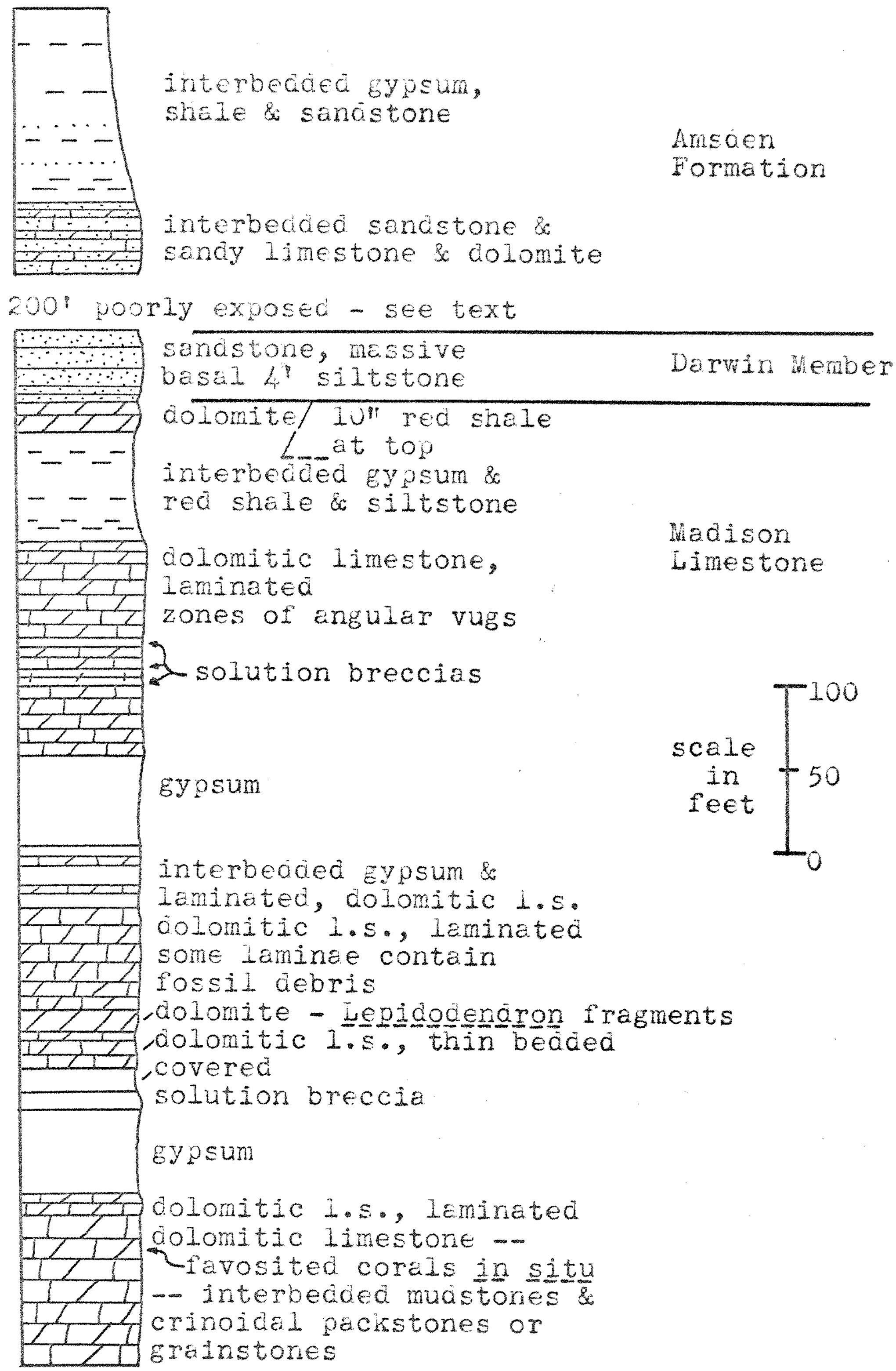

Fig. 3. Composite section: Hoback Canyon

Mexico. Kendall considers these facies analogous to the shallow marine and intertidal deposits of the Bahamas and the Persian Gulf. Kendall and Skipwith (1969) show how the distribution of mud and grains in the lagoons and shallow shelf off the Trucial Coast is related to bottom topography and water turbulence. Laporte (1967) considers the interbedding of packstones or grainstones with mudstones characteristic of the intertidal facies of the Manlius Formation (Devonian) of New York but includes this lithology in the subtidal facies; particularly where associated with favositeds.

This interval is immediately overlain by 13 feet of laminated, dolomitic limestone which is overlain by a 60 foot section of massive gypsum containing a few brecciated beds of dolomitic limestone. A covered interval separates the gypsum from the second carbonate interval which is 110 feet thick and composed of laminated dolomites and dolomitic limestones. There are fine (<1 cm.) regular laminae, fine laminae with micro-cross bedding and storm laminae containing torn up mud flakes from the immediately underlying layer. There are thin (1 to 3 or 4 cm.) layers of fossil debris scattered throughout the lower two thirds of the interval. About 26 feet above its base is a 10 foot interval of brown dolomite which contains abundant Lepidodendron fragments. Another 100 feet of gypsum and breccias separates the second from the third carbonate interval which is distinguished from the second only by its complete lack of fossil material. The upper gypsum - shale interval, already described, marks the introduction of terrigenous material to the area. The occurrence of finely laminated and storm laminated carbonates associated with evaporites is characteristic of supratidal flats. The presence of 500 feet of supratidal sediments above the subtidal and intertidal sediments demonstrates both regressive sedimentation and a significant amount of concurrent subsidence.

The complete absence of fossils indicates a non-marine origin for the Darwin Member. The varying thickness of the unit and the occurrence of massive beds and both high and low angle cross beds at various localities (Blackwelder, 1918, Wanless et. al., 1955 and Sando, 1967) suggest that the Darwin Member is the result of the coalescing of fluvial and eolian sands prograding across the carbonate environments.

In Hoback Canyon the Darwin Member is overlain by a poorly exposed interval of almost 200 feet which is made up predominantly of shales with limestones becoming more numerous towards the top. Slump and creep are evident throughout the interval. Wanless et. al., (1955) report pisolitic or "buckshot" iron ores between 10 feet and 20 feet above the top of the Darwin Member. They found marine fossils in a limestone bed about 70 feet above the Darwin Member which they considered Pennsylvanian but Sando and

Dutro (1960) identified them as Chester in age. A limestone bed near the top of the interval contains crinoid debris. This is overlain by about 40 feet of sandstones and sandy limestones and dolomites many of which are horizontally laminated. The limestones and dolomites contain many zones of vugs, many of which are angular and may be evaporite molds, while the vugs of other zones are rounded or oval in shape. These beds contain no fossils. The upper approximately 115 feet of the Amsden Formation at this locality is gypsum and gypsiferous shales with a few small limestone or dolomite intervals.

That the shales of the Amsden Formation are unfossiliferous except for the reported plant remains suggests continental deposition. Wanless et. al. (1955, p. 33) state:

> "Above the iron-ore beds in Hoback Canyon an interval of grey to dark shale and poorly bedded clay about 25 feet thick contains unidentifiable plant traces of leaves and rootlets. A small part of this is almost a coaly shale suggestive of the plant-bearing shales and underclays of the Pennsylvanian in the Eastern United States. Above this is 20 feet of pink calcareous shale."

The next higher unit contains the marine fossils so the lower part of the Amsden Formation does bear some resemblance to a cyclothem. The upper part of the Amsden Formation is more comparable to a continental sabkha. Kinsman (1969) found horizontal sheet laminations associated with dune cross bedding in the continental sabkha - dune facies near the Persian Gulf. Quartz sand dominates this environment but carbonates are present and dolomite is forming. However, in the continental sabkhas of Arabia, gypsum is precipitating in the intersticies of the sediment. The gypsum beds in the upper Amsden Formation (and those in the Madison Limestone as well) are pure and massive. The lack of a carbonate or clastic matrix indicates that they must have precipitated from a standing body of water. Playas or salt pans must have been present on the Amsden sabkha, at least in the Hoback Canyon area.

SUMMARY AND CONCLUSIONS

The key points in the evaluation of the proposed model are: 1) the demonstration that the upper Madison Limestone represents regressive sedimentation, 2) the continental nature of the Amsden Formation and 3) the interpretation of the Madison - Amsden contact.

In Hoback Canyon the upper beds of the Madison Limestone show a vertical sequence of subtidal and intertidal sediments overlain by supratidal sediments.

The Amsden Formation illustrates sedimentation under a number of continental modes of deposition. The lower sequence of a basal sandstone overlain by shales containing no marine fossils but intervals of bog iron ore, plant remains and beds resembling the underclays of coal cyclothems indicates deposition in environments similar to those in which the coal cyclothems of the central and eastern United States were formed. The upper part of the Amsden Formation is made up of sandstones, sandy limestones and dolomites and gypsum. The association of sheet and dune laminations and possibly interstitial evaporites, represented by the angular vugs in the sandy carbonates, is analogous to that found in the continental sabkha - dune facies of Arabia in the recent.

While erosional truncation of the upper beds of the Madison Limestone in south-central and southeastern Wyoming has been demonstrated by many of the authors cited above, the evidence for an unconformity becomes less definite toward the northwest. Karst development on the upper Madison surface is sporadically developed (Roberts, 1966; Sando, 1967) which is consistent with the proposed model. Interbedded lithologies and planar contacts at three localities in western Wyoming indicate a conformable contact.

These data do not establish beyond doubt the time-transgressive nature of the upper Madison Limestone and the Amsden Formation. They are consistent with the sedimentologic model proposed and, in the absence of inconsistent paleontologic or physical data, illustrate the plausibility of this hypothesis.

The geologic history of this stratigraphic interval in western Wyoming may be summarized as follows: The depositional basin is filled by regressive sedimentation. Concurrent subsidence allows the thick accumulation of supratidal carbonates and evaporites of the upper Madison Limestone. As the tide flats migrate basinward they are followed by dune fields and streams depositing the quartz sands of the Darwin Member. Further onshore shales and siltstones are accumulating in lakes and swamps and on flood plains. One indication of the proximity of the Madison tide flats and the Amsden shales is the presence of <u>Lepidodendron</u> fragments in the Madison Limestone. This observation carries the implication of land plants growing near the site of carbonate tidal flat sedimentation. Since there is no evidence of erosion between the top of the Madison Limestone and the base of the Amsden Formation, it is suggested that the plants found in the Madison Limestone were transported from the site of deposition of the plant-bearing shales in the Amsden Formation. The basinward migration and overlap of these facies is halted by a relative rise in sea level recorded by fossiliferous limestones in the Amsden Formation above the shale sequence. Regressive sedimentation is again indicated by the continental sabkha - dune facies sediments and playa evaporites and shales of the upper part of the Amsden Formation.

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