

# THE MORRISON FORMATION EXTINCT ECOSYSTEMS PROJECT



CHRISTINE E. TURNER ♦ FRED PETERSON  
U.S. GEOLOGICAL SURVEY ♦ DENVER ♦ CO  
D.J. CHURE ♦ U.S. NATIONAL PARK SERVICE ♦ JENSEN ♦ UT  
T.M. DEMKO ♦ EXXON PRODUCTION RESEARCH CO. ♦ HOUSTON ♦ TX  
G.F. ENGELMANN ♦ UNIVERSITY OF NEBRASKA ♦ OMAHA

## ♦ ABSTRACT

The Morrison Project is a multidisciplinary effort to interpret the ancient ecosystem that was present in the Western Interior of the United States during deposition of the Upper Jurassic Morrison Formation. The project began in June of 1994 and the first two years of research (1994-95, 1995-96) were devoted primarily to identifying problems and gathering information that would form the basis for later interpretations. Efforts during the final year (1996-97) were directed toward resolving remaining problems or conflicting findings and synthesizing the various research endeavors into a reconstruction of the Late Jurassic ecosystem.

During the 1996 summer field season, the Morrison Formation was studied in detail at selected areas in the central and northern parts of the Western Interior including eastern Utah, northern Colorado, Wyoming, and Montana.

Stratigraphically, significant progress was made. At Dinosaur National Monument, it was determined that the lower contact of the formation may be a simple depositional contact rather than an unconformity as previous workers had thought although there is good evidence that this contact is indeed unconformity farther south on the Colorado Plateau where, in places, the Morrison rests directly

on strata as old as the Entrada Sandstone of Middle Jurassic (middle Callovian) age.

A series of paleosols with locally abundant termite nests were found in the middle of the formation, just above the Salt Wash Member, and appear to represent a hiatus or at least a brief period of slowing in sedimentation rates. This is interpreted as a sequence boundary that probably has important implications for regional correlations and understanding varying sedimentation processes in the depositional basin.

The precise stratigraphic position and nature of the upper contact was studied in considerable detail throughout the central and northern parts of the Western Interior and the contact appears to be a regional unconformity representing a time span of roughly 16 my (million years) or more. Some beds, previously assigned to Lower Cretaceous formations, were found to be Late Jurassic in age and thus are properly included in the Morrison Formation. Work in the type area of the Morrison and Ralston Creek Formations just west of Denver demonstrates that both of these formations correlate with the entire Morrison Formation farther west in most parts of the Colorado Plateau or farther north in Wyoming. The charophytes and ostracodes also support our correlations into Wyoming and Montana that were based largely on physical stratigraphy. They demonstrate that the upper

Morrison contact there is stratigraphically higher than many previous workers had thought. The calcretes that occur either in the uppermost beds of the Morrison and in the lowermost beds of Lower Cretaceous formations were originally thought to have formed entirely by underground processes. However, recent studies suggest that at least some of the calcretes were intermittently exposed at the surface.

Sedimentologic studies of the paleosols indicate that the terrain was wetter nearer fluvial channels and became drier farther away in the overbank floodplains between the fluvial channels.

Palynological studies (that is, studies primarily of spores, pollen, and dinoflagellates) resulted in detailed dating of much of the Morrison Formation. The research showed that the bulk of the formation is Kimmeridgian in age and the uppermost beds of the formation are Tithonian in age. The spores and pollen suggest that the lowest beds in the formation (Windy Hill Member) appear to be Kimmeridgian in age although a conclusive age determination for these beds awaits age determinations from dinoflagellates. These detailed age determinations allow us to compare the Morrison ecosystem with the global Late Jurassic environment. In contrast to previous investigations, the formation was found to contain a surprisingly rich and diverse fossil flora. The palynological research also revealed that the flora was much more diverse in the Late Jurassic Western Interior than previously had been thought.

Research on charophytes (green algae) and ostracodes (crustaceans) resulted in age determinations that correspond closely with those obtained from the palynomorphs. Other conclusions derived from these micro-organisms suggest that standing bodies of water in which strata in the middle of the formation were deposited were somewhat brackish whereas the water bodies that were present during deposition of the lower and upper beds largely consisted of fresh water. More salinity-tolerant genera existed in northern Colorado and northeastern Utah than farther south or north, which might also reflect the nature of water bodies in these areas. These organisms also suggest a gradual cooling of the climate during Morrison deposition.

Studies of trace fossils that can be related to specific organisms demonstrate that horseshoe crabs,

crayfish, termites, soil-dwelling bees, dermestid beetles, caddisflies, ants, earthworms, nematodes, and other organisms were common in the Morrison ecosystem. Assemblages of these traces along with studies of paleosols can be used to define the position of the ancient water table with respect to the land surface. This gives a rough idea of soil moisture as well as whether or not permanent water existed at shallow depths and was therefore available to the plant community.

Some of the bivalves show annual growth bands whereas others do not. Perhaps those lacking these types of bands lived where equable conditions persisted throughout the year. The annual banding supports the interpretation of seasonality in the ecosystem that is suggested by other studies.

Studies of the vertebrates reveal that a wide variety of animals including dinosaurs, mammals, lizards, sphenodonts, choristodeirans, salamanders, snakes, small crocodylians, turtles, fish, lungfish, and frogs inhabited the Morrison ecosystem. With the recent discovery and recovery of a new member of the Family Allosauridae from Dinosaur National Monument, we now know of at least three genera of these theropods that existed within the Morrison animal community.

Samples from carbonate rocks (mostly limestone) were collected during the summer field season for analyses of stable isotopes and are undergoing laboratory preparation and analysis. Stable isotopes yield information on the ancient climate, plant community structure, weather patterns, storm tracks, temperature, trophic levels, and eating habits of the vertebrate land animal. A tentative conclusion based on preliminary data is that the amount of carbon dioxide in the atmosphere was appreciably higher than today. Because this is a "greenhouse" gas, it may have been responsible for the warmer global climate during the Jurassic Period as compared with today's climate, although we do not yet know why the carbon dioxide levels were so high during the Late Jurassic. Detailed studies of paleosols in the Fruita Paleontological Area (FPA) of western Colorado and elsewhere in the Western Interior suggest that the Morrison climate was at least seasonally dry. Detailed sedimentologic studies are underway in the FPA and should lead to an improved understanding of Morrison sedimentation in a relatively small area that could have important implications for the overall project interpretations. Other studies of freshwater limestone beds indicate a

variety of life forms including charophytes, ostracodes, snails, fish, sponges, stromatolites, and fish lived in Morrison lakes and will likewise shed light on this aspect of the Morrison ecosystem.

Research by  $^{40}\text{Ar}/^{39}\text{Ar}$  isotopic dating methodologies on altered volcanic ash deposits in the Morrison indicates that the formation was deposited during an approximately 8 million year time span from about 155 to 147 Ma (Ma = Millions = million years before the present). More samples were collected to better date the formation and to gain an understanding of the nature of the unconformities at the base and top of the Morrison. Tentative conclusions are that the time span represented by the K-1 unconformity at the top of the Morrison was approximately 16 my in duration but may be more or less depending on the locality. Geochemical studies of mineral grains recovered from Morrison bentonite beds (the altered volcanic ash deposits) indicate that the volcanoes that furnished the ash were rhyolitic in composition. This is consistent with the origin of the ash deposits in a volcanic belt above a subduction zone that extended along the west coast of North America during the Late Jurassic. The composition of certain mineral grains recovered from the bentonite beds and the known predominantly westerly to southwesterly winds over the Colorado Plateau region during the Late Jurassic suggest that most of the volcanoes that furnished the Morrison ash were in California, western Nevada, and western Arizona.

## ◆ BACKGROUND

The Morrison Formation is distributed throughout much of the Western Interior physiographic province of the United States and is one of science's best windows into the world of dinosaurs and nonmarine Mesozoic ecosystems. Because of its varied environments, rich fossil deposits, extensive rock exposures, and broad geographic distribution, the formation offers an outstanding opportunity for a multi-park, interdisciplinary approach to the evolution of environments, habitats, communities, and climate through some 8 million years of Earth history. The formation covers some 700,000 square miles in the Western Interior (Figs. 1, 2) and is world renowned for its rich concentration of dinosaur remains, with more than 100 dinosaur quarries identified to date and new ones discovered yearly. The formation also

contains locally abundant and diverse fossil plant and other animal communities that were contemporaries of the dinosaurs and that shed light onto the nature of the Late Jurassic ecosystem.

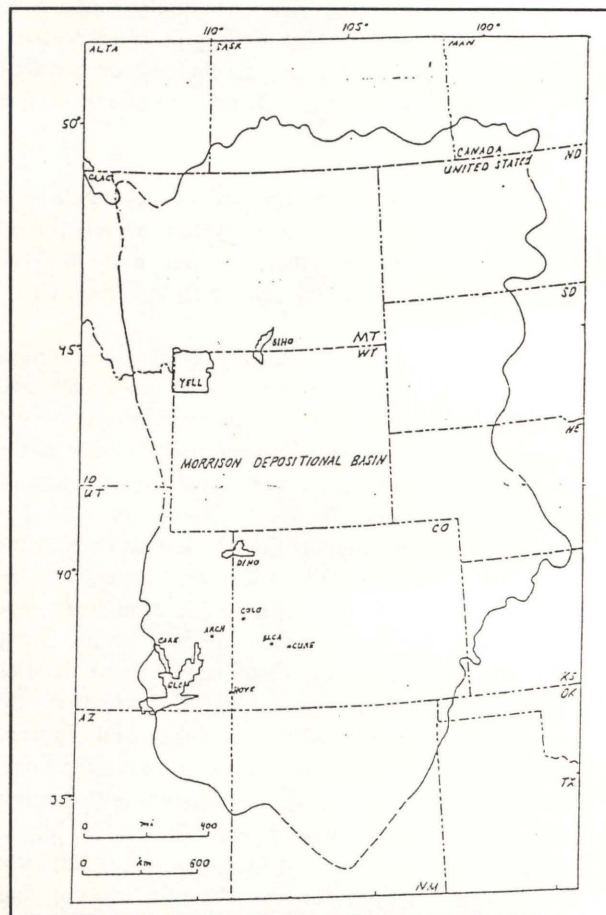


Figure 1.-The Morrison depositional basin in the Western Interior of the United States and southern Canada. Also shown are National Park Service units that contain significant exposures of the Morrison Formation.

ARCH (Arches National Park),  
 BIHO (Bighorn National Recreation Area),  
 BLCA (Black Canyon of the Gunnison National Monument),  
 CARE (Capitol Reef National Park),  
 COLO (Colorado National Monument),  
 CURE (Curecanti National Recreation Area),  
 DINO (Dinosaur National Monument),  
 GLAC (Glacier National Park),  
 GLCA (Glen Canyon National Recreation Area),  
 HOVE (Hovenweep National Monument),  
 YELL (Yellowstone National Park).

The outline of the Morrison depositional basin is modified from:

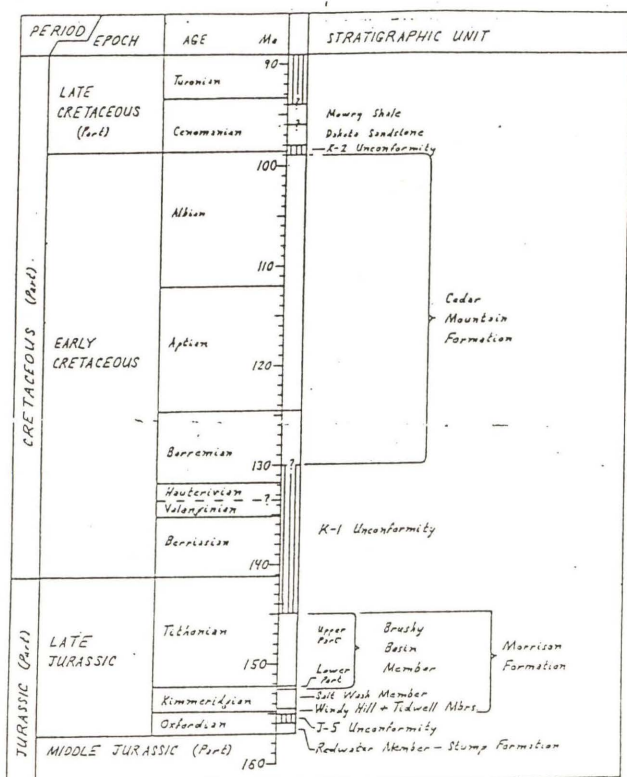


Figure 2.-The age of the Morrison Formation in northeastern Utah. Compiled from Kowallis and others (1991) and B.J. Kowallis (written communication, 1994).

The Morrison Formation has significant exposures in many units within the Western Interior of the United States. These include Arches National Park (ARCH), Bighorn National Recreation Area (BIHO), Black Canyon of the Gunnison National Monument (BLCA), Capitol Reef National Park (CARE), Colorado National Monument (COLO), Curecanti National Recreation Area (CURE), Dinosaur National Monument (DINO), Glacier National Park (GLAC), Glen Canyon National Recreation Area (GLCA), Hovenweep National Monument (HOVE), and Yellowstone National Park (YELL). In addition, the formation is not exposed at the surface but is present beneath approximately 10 other National Park Service units in the Western Interior.

The Morrison Formation Extinct Ecosystems Project, hereafter called the Morrison Project, began on June 1 of 1994. The project is a multidisciplinary and multiinstitutional endeavor designed to determine the nature, distribution, and evolution of the ancient ecosystems that existed in the Western Interior of the United States during the Late Jurassic Epoch when the Morrison Formation and related rocks were deposited.

The information obtained from the research can be used to suggest appropriate resource management actions. The project will also provide an improved understanding of the geological and paleontological history of NPS units and better information for interpretive programs and publications.

An expanded summary of progress, products, and interpretations by the individual investigators are available upon request from C.E. Turner. Because the research is continuing, any interpretations must be considered tentative and subject to revision after additional research has been accomplished.

## ◆ CONCLUSIONS

The Morrison Project is a multidisciplinary effort designed to investigate the nature and evolution of environments, habitats, communities, and climate in and near many National Park Service units in the Western Interior of the United States through some 8 million years of Earth history when the Morrison Formation of Late Jurassic age was deposited. The project was devoted primarily to gathering information that would form the basis for later interpretations. Hence, scientific interpretations concerning the ancient Morrison ecosystem are tentative in this report because of the recency of the research. The Morrison Formation was studied mostly in Utah, Colorado, Wyoming, and Montana but also to some extent in Arizona and New Mexico to provide a more accurate regional framework and to collect samples that might require long preparation time in the laboratory. Included here are brief discussions of interpretations according to major subspecialty categories. The last names of the researchers most involved in the specific topics are enclosed in brackets.

## STRATIGRAPHY AND SEDIMENTOLOGY

Regional stratigraphic and sedimentologic studies [Turner and Peterson] demonstrate that strata deposited in relatively dry environments are fairly common in the Morrison Formation in the southern and central parts of the Western Interior. These include extensive evaporite deposits (chiefly gypsum) in the lowermost part of the formation in Utah and Colorado and locally in eastern Wyoming; large eolian dune field deposits (erg deposits) at or near the Four Corners area; small eolian sandstone beds scattered through Arizona, Utah, Colorado, and extending as far north as northern Wyoming; and the rather extensive alkaline, saline lake deposits of ancient Lake T'oo'dichi' in the eastern part of the Colorado Plateau. Studies of the paleosols in the overbank floodplain areas [Demko] also suggest dry climates. Farther north in west-central Montana, extensive coal beds in the upper part of the Morrison suggest deposition there was in a more humid climate than existed farther south.

Fluvial and overbank architectural styles [Demko, Newell] are suggestive of seasonally wet-dry precipitation-discharge regimes. Floodplain paleosols in the Morrison Formation are associated with each of the fluvial deposits. Thin floodplain paleosols in the Morrison Formation, like the channel and overbank architectural styles, are indicative of at least periodic dryness.

Two sequence-bounding paleosols (or paleosol complexes) have been identified in the Morrison Formation and represent significant diastems in the part of the formation where they occur. The first is immediately above the Salt Wash Member (within the lower part of the Brushy Basin Member). This paleosol complex marks a change in fluvial style from low- to high-sinuosity planform patterns. Some contemporaneous erosion is associated with this horizon in the Dinosaur National Monument area. The climatic implication of this paleosol is no different from those of the other calcic paleosols in the Salt Wash and Brushy Basin Members and is only differentiated by its greater development and regional extent. The second sequence-bounding paleosol complex is at the top of the Brushy Basin Member, at its boundary with overlying Lower Cretaceous deposits. This paleosol represents a long period of exposure and pedogenesis (>5 my) and possibly the overprinting of different climatic regimes (wetter upon drier). This interval is also typically overprinted by later

calcretization associated with early diagenesis during deposition of overlying Lower Cretaceous deposits. These two paleosols are interpreted to mark the tops of two aggradational sequences that comprise Morrison deposition.

The calcretes in the uppermost part of the Morrison Formation and in the lowermost part of the Lower Cretaceous Burro Canyon Formation are being studied petrographically and can be classified as mostly alpha type calcretes [Skipp]. That is, they consist largely of a dense micrite to microcrystalline groundmass that contains peloids, nodules, circumgranular cracks, floating grains (both detrital and authigenic), coated grains, coated fractures, and complex arrays of micro- to macro-fractures. In addition to the microcrystalline textures, some coarse recrystallized textures were observed in samples collected in Salt Valley anticline near Arches National Park, Utah. Very few biogenic textures were observed. There are suggestions of subaerial exposure on several of the surfaces within some of the calcretes, suggesting that the calcretes formed at shallow depths in the sediment package and that they may have formed locally at the surface or were exposed briefly by subaerial erosion processes. Additional studies are underway that will characterize the calcretes further and, hopefully, will provide more information pertaining to the paleoclimatic conditions that governed their formation.

## PALEONTOLOGY

The terrestrial facies of the Morrison is fossiliferous in all areas where the formation is sufficiently exposed to allow a reasonable chance of encountering the fossils [Engelmann]. However, there is a variation in the geographic and stratigraphic distribution of some types of fossils. Both of these observations have important implications for resource management in the parks and monuments that contain outcrops of the Morrison Formation. In addition, Morrison faunas are diverse, including fossils of vertebrates, invertebrates, and traces of both, and plant fossils of various types. In some of the study areas, invertebrate trace fossils, including the burrows of crayfish, termites, ants, beetles, and other insects, were found to be abundant, particularly within the upper Salt Wash and lower Brushy Basin Members. This horizon may be explained by modeling Morrison sedimentation in that area as accumulation

in a tectonically-controlled depositional basin with climatic and ecological controls.

Based on comparative studies of the mammalian faunas of the Morrison, [Engelmann] there is some geographic variation. Mammal faunas from the Fruita Paleontological Area near Colorado National Monument and from Dinosaur National Monument lack docodonts, which is typical for Morrison faunas west of the Rocky Mountains. This lack of docodonts contrasts with the presence of them from even small samples of Morrison mammalian fossils east of the Rockies. This may be explained by the presence of a divide separating the Morrison into eastern and western geographic subareas, an interpretation that may be suggested by other stratigraphic evidence.

Illegal collecting of fossils within the Park Service units studied does not appear to have been intensive, in contrast to the evidence of extensive collecting on State and Federal lands adjacent to the Park Service lands [Engelmann]. This makes the interpretation of observations on fossil occurrences somewhat problematic. In particular, the apparent scarcity of silicified wood in the vicinity of Arches National Park and Colorado National Monument relative to occurrences at Dinosaur National Monument may be the result of intensive collecting by rock hounds.

Preliminary work indicates that the dominant group of theropod dinosaurs from the Morrison Formation belong to the Family Allosauridae [Chure]. A new and relatively primitive allosaurid from the Salt Wash Member that was recently excavated at Dinosaur National Monument is currently being studied. Reexamination of the original material of Saurophaginox (originally Saurophagus) from the uppermost Morrison of western Oklahoma has established that it is genetically separate from Allosaurus. Thus, at least three genera from Family Allosauridae (the new Salt Wash primitive allosaurid, Allosaurus, and Saurophaginox) existed during the Late Jurassic in the Western Interior of the United States.

Taphonomic analysis on the bivalve assemblage preserved in the Quarry Sandstone Bed at Dinosaur National Monument demonstrates that the shells occur in current-stable orientations, locally with imbricated stacking, in troughs of mid-channel bars within the ancient stream bed [Good].

The shells are well sorted by size; however, fragmentation and abrasion are minimal. These features indicate a transported assemblage that has not been moved very far from the original life habitat (probably less than a few kilometers, at most). The shell form of the bivalves indicate they inhabited a fast velocity, small fluvial system. The abundance of the specimens suggests that a nearby upstream optimum habitat for unionid bivalves provided shells from the dead and decayed members of the population. Only a few articulated specimens have been found and they are generally not in life position, suggesting they were transported, buried, and unable to reestablish life functions. The disarticulated valves, which dominate the bivalve assemblages, require days to weeks of postmortem decay of the ligament to disjoin the valves, suggesting that the fauna represents a transported death assemblage. The unique dispersal mechanism employed by unionacean bivalves permits documentation of paleodrainage confluence patterns, which will enhance understanding the paleogeography of the Morrison basin.

Paleoecological interpretations comparing the ostracode and charophyte genera with their modern counterparts suggest mostly nonmarine environments, although the salinity could have been slightly higher in several beds, perhaps to about 16 parts per thousand in some cases [Schudack]. An analysis of the spatial distribution of both ostracodes and charophytes suggests close but complex biogeographic relationships between North America and Europe during the Late Jurassic.

The wide variety of palynomorphs suggests that much of the Morrison depositional basin contained a highly diverse mesic flora during much or most of Morrison time [Litwin].

The integration of ichnological (i.e., trace fossil) information [Hasiotis] combined with paleontological, sedimentological, paleopedological, and geochemical data, produces a more holistic reconstruction of the paleoecological settings during Morrison times. Though some contradictions do exist between different sources of data, the results are still meaningful. In general, the traces reflect the sedimentological pattern of a drier climatic setting in the lower Morrison to a slightly more seasonally wet climatic setting at the end of Morrison deposition. The interpretations deduced from the trace fossils corroborates many of the interpretations from the molluscs, pollen, and plants that suggest there were

periods of seasonally ample rainfall during deposition of portions of the Morrison Formation. The trace fossils, along with the carbonate paleosols and geochemical analysis, support a seasonally wet-dry climatic setting for most of the Morrison, but differs in that the traces (especially the rhizoliths and crayfish) show slightly higher precipitation than what might be expected. The diversity of invertebrate and vertebrate body fossils and trace fossils (e.g. invertebrates) suggests that the overall sedimentologic and paleoenvironmental landscapes had to sustain climates analogous or roughly analogous to today's savannah of the southern African continent. The larger vertebrates probably migrated latitudinally between conterminous landscapes shaped by different depositional systems.

#### STABLE ISOTOPE GEOCHEMISTRY

Many fossil materials retain their carbon and oxygen stable isotopic compositions through geologic time. A suite of materials from the Morrison Formation (fossil soil nodules, plant materials, eggshells, teeth, lake sediments) have been analyzed [Ekart and Cerling] to determine patterns in the distribution of isotopes. Focus during the last year was on carbonate nodules from paleosols (fossil soils) in the Brushy Basin Member of the Morrison Formation. The isotopic data are evidence of a rain shadow operating in much of the Western Interior during the Late Jurassic, which is consistent with paleogeographic reconstructions that place the Morrison landscape east of a Mesocordilleran mountain range.

#### AGE DETERMINATIONS

Research on the relative age of the Morrison Formation based on studies of palynomorphs (spores, pollen, and dinoflagellates) [Litwin] and calcareous microfossils (charophytes and ostracodes) [Schudack] has established a much more refined relative age for the formation. It is now clear that all of the Morrison Formation and related beds are entirely Late Jurassic in age and were deposited during the latest Oxfordian(?), Kimmeridgian, and early Tithonian Ages. None of the microfossil evidence corroborates previously published accounts proposing an Early Cretaceous age for some of these beds.

Isotopic dating of altered volcanic ash beds in the The Morrison Formation in Utah and Colorado [Kowallis and Christiansen] yielded

numerical ages in terms of millions of years before the present (Ma). The Brushy Basin Member at the top of the formation gives single-crystal, laser-fusion and step-heating, plateau  $^{40}\text{Ar}/^{39}\text{Ar}$  ages on sanidine that range between 147.8 Ma at the top of the member and 150.2 Ma at the base of the member. The Tidwell Member at the base of the formation contains one datable ash bed about 3 m (10 ft) above the J-5 unconformity that has been found in at least two widely separated localities. This bed has been dated using  $^{40}\text{Ar}/^{39}\text{Ar}$  dating of sanidine and gives ages ranging between 154.75 and 154.87 Ma. The Morrison Formation, therefore, ranges in age from about 147 to 155 Ma. By comparison with recent standard geologic time scales that attempt to calibrate the relative time scale based upon fossils with isotopic dates, the Morrison Formation and related beds are entirely Late Jurassic in age.

The field work for the Morrison Extinct Ecosystem Project has ended and efforts currently underway are devoted to further laboratory determinations and examinations and to synthesizing the results of the research effort. A workshop among the project participants was held in April, 1996, in Denver for the primary purpose of evaluating the progress thus far and to focus the remaining field and laboratory studies toward specific or remaining problems to ensure that the project goals are attained. Participants were asked to prepare presentations of their data so that we could collectively evaluate where the group was reaching agreement (convergence) and where remaining controversies (points of divergence) remained. This report is largely a summary of research thus far accomplished, with the current but preliminary status of knowledge and interpretations that have been generated up to the date of this report by the project participants.

#### ◆ LITERATURE CITED

- Kowallis, B.J., Christiansen, E.H., and Deino, A.L., 1991, Age of the Brushy Basin Member of the Morrison Formation, Colorado Plateau, western USA: *Cretaceous Research*, v. 12, p. 483-493.

Peterson, J.A., 1972, Jurassic System; in, Mallory, W.W. (ed.), Geologic Atlas of the Rocky Mountain Region: Rocky Mountain Association of Geologists, p. 177-189 (map on p. 185).

Poulton, T.P., Christopher, J.E., Hayes, B.J.R., Losert, J., Tittlemore, and J., Gilchrist, R.D., 1994, Jurassic and lowermost Cretaceous strata of the western Canada sedimentary basin; in, Mossop, G., and Shetsen, I., (compilers), Geological Atlas of the western Canada sedimentary basin: Canadian Society of Petroleum Geologists and Alberta Research Council, p. 297-316 (map on p. 312).