The Colorado Plateau Coring Project (CPCP): 100 Million Years of Earth System History

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Lasting over 100 million years, the early Mesozoic (252 to 145 Ma) is punctuated by two of the five major mass extinctions of the Phanerozoic (Permo-Triassic and Triassic-Jurassic) plus several smaller extinction events. It witnessed the evolutionary appearance of the modern terrestrial biota including frogs, salamanders, turtles, lizards, crocodilians, dinosaurs, birds, and mammals, and spans a time of dramatic climate changes on the continents. What is arguably the richest record of these events lies in the vast (~2.5 million km^2) complex of epicontinental basins in the western part of Pangea, now largely preserved on the Colorado Plateau (Fig.1). Since the mid-19th century, classic studies of these basins, their strata, and their fossils have made this succession instrumental in framing our context of the early Mesozoic Earth system as reflected in the international literature. Despite this long and distinguished history of study of the Colorado Plateau region, striking ambiguities in temporal resolution, major uncertainties in global correlations, and significant doubts about paleolatitudinal position hamper incorporation of the huge amount of information from the region into tests of major competing climatic, biotic, and tectonic hypotheses and a fundamental understanding of Earth system processes.

A basic question posed by the exceptionally rich paleobiological record of the Plateau and adjacent areas is, what is the nature of the links between major events in the history of early Mesozoic life, climate change, and Earth System crises, particularly the mass extinct-tion events, the ascent of the dinosaurs, and the origin of modern biota. In order to elucidate these connections we have proposed the Colorado Plateau Coring Project or CPCP (Fig.1). As proposed, the CPCP is a five-year or more, three phase interdisciplinary, multi-institutional coring project designed to decipher the biotic, climatic, and tectonic evolution of the first 100 million years (Triassic and Jurassic, ~250-150 Ma) of the Mesozoic Earth System as expressed in epicontinental basins of the Colorado Plateau and its environs. The concept developed from the recommendations of a 1999 NSF-ICDP funded workshop on early Mesozoic Pangea (Olsen et al., 1999) (Western Equatorial Pangea by A. Heckert), and was more fully developed in a 2007 NSF- and DOSECC-funded workshop that provided a broad-based, community-driven science and coring plan for the CPCP. Reports of this workshop have been published in EOS (Olsen et al., 2008a), Scientific Drilling (Olsen et al., 2008b), and on the web (Olsen, 2009). An ICDP-funded international workshop was held in May 2009, in Albuquerque, NM, to refine the specific CPCP site plans and proposals (Geissman et al., 2010). These international workshops provided community-driven science and coring concepts for the CPCP. Motivating the CPCP is the need to understand the links between major events in the history of life, climate change, and Earth System crises, particularly the two major and two minor mass extinction events, the ascent of the dinosaurs, and the origin of modern biota that would be spanned by the project, and who's fossil record is exemplary in the Colorado Plateau region. The CPCP will result in a major improvement in our ability to address out- standing issues of chronology, paleogeography, paleoclimate, and biotic evolution in the Pangea supercontinent.

A scientific coring program is essential because the generally shallow bedding attitudes, lateral facies changes, and covered intervals compromise unambiguous superposition in surface sections over long geographic traverses. This problem is exemplified by the ambiguities in compiling a composite section even across small distances in the Late Triassic Chinle Formation outcropping in Petrified Forest National Park (Martz and Parker, 2010) in the state of Arizona, the area to be cored in Phase 1 of the CPCP. Furthermore, the most continuous sections in outcrop are either inaccessible in vertical cliffs or are intensely weathered and geochemically altered, making geological observations and sampling at the appropriate level of detail practically impossible. Despite the seemingly striking exposures and long history of study, by modern standards and the requirements of the scientific questions posed, the outcrops simply do not permit investigation of the physical, magnetic polarity, or chemical stratigraphy of the Plateau and environs at the appropriate levels of resolution or confidence.

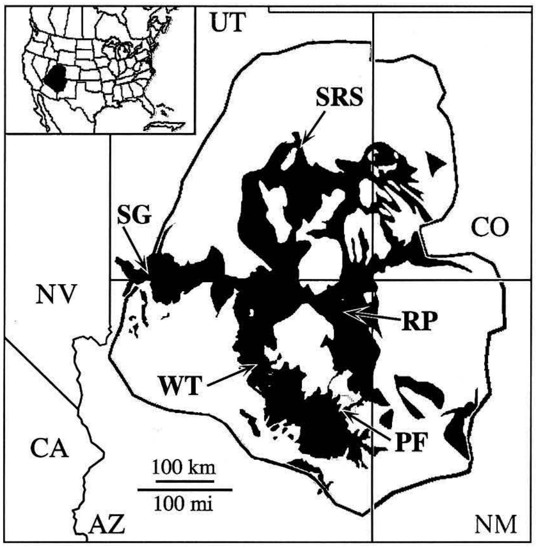

Fig.1 Map of the Colorado Plateau (black enclosed line) and adjacent areas showing distribution of Triassic and Jurassic outcropping strata (from Olsen et al., 2008a)
Drilling target areas are: PF, Petrified Forest, Arizona; RP, Rock Point, Utah; SG, St. George, Utah; WT, Ward Terrace, Arizona; SRS, San Rafael Swell, Utah. Inset shows position of the Colorado Plateau in North America.

The overall coring strategy involves at least 6 cores taken in four phases: three long (~1000 m) cores and two shorter (300-600 m) cores intended to recover the full expression of the critical early Mesozoic transitions in clear superposition and with sufficient stratigraphic overlap to minimize gaps. In total the cores would minimally span the base of the Cedar Mountain Formation (~Early Cretaceous) through the base of the Moenkopi (~Middle and Early Triassic) with enough overlap between cores to firmly tie the sections together and to provide information on lateral facies and thickness changes and stratigraphic completeness. As planned, the CPCP will result in a major improvement in our ability to address outstanding issues of global importance, involving chronology, paleogeography, paleoclimate, and biotic evolution in this sector of the Pangea supercontinent.

Science questions

The CPCP is stimulated by four compelling and intertwined, hypothesis-driven questions to address outstanding issues of Pangean biotic evolution, chronology, paleogeography, paleoclimate, and basin evolution.

1. How is the major biotic transition from the Paleozoic to essentially modern terrestrial ecosystems, including biotic events such as mass extinctions, linked to climatic and tectonic events, and what are the rates and magnitudes of these changes?

2. What are the trends in global or regional climate vs. those resulting simply from paleolatitudinal drift in "hot house" Pangea and Laurasia?

3. How did the largely fluvial systems and their biological communities respond to the climate changes?

4. How does the stratigraphy of the basin sections reflect the interplay between dynamic growth in accommodation space, uplift, and eustatic fluctuations in an intracontinental setting?

None of these questions can be addressed with the available data or, practically speaking, with the existing outcrops, and in fact virtually nothing remotely secure is known about these issues. Cases in point are illustrated in two recent papers: Rowe et al. (2007) and Lucas et al. (1998).

Rowe and others argue that the Early Jurassic age Navajo Sandstone, the product of the largest sand sea in Earth History, was deposited virtually at the equator based on comparison with a numerical climate model rather than in the subtropics as determined from apparent polar wander paths. If this model is correct, then the North American plate was virtually stationary over the entire Triassic through the Early Jurassic and the climate change expressed in the stratigraphic and paleontological records was due to true regional if not global climate change. Alternatively, North America drifted 25° northward during this time and thus the climate model is incorrect. Either way, the results are fairly shocking, but we will not know which hypothesis is more correct unless the needed temporal and stratigraphic contexts are much better developed.

Lucas and others (e.g., Lucas and Tanner, 2004, 2007; Tanner et al., 2004), using data from the Colorado Plateau, argue against the idea that the Triassic-Jurassic boundary marks a mass-extinction that literature compilations (e.g., Benton, 1995) suggest. In fact, based on such compilations, the Triassic-Jurassic extinction event is larger than the K-T boundary event and, by some metrics, even larger than the end-Permian event. The argument proffered by Lucas and others– that there is virtually no extinction event at this boundary– can be made solely because of the extremely poor constraints not only on the relative ages of the rich faunas relative to other parts of the world, but, even more importantly, relative to each other within and adjacent to the Colorado Plateau. This is because the geographically dispersed localities lack the criterion of superposition and are correlated to each other by lithostratigraphy and biostratigraphy, the same biostratigraphy that fails first-order quantitative correlation tests as witnessed by a 10 Ma change in the age strata inferred to be Carnian age to Norian age based on new U-Pb zircon ages (e.g., Mundil and Irmis, 2008) outlined below. This is most unfortunate, given that the Colorado Plateau has one of the richest Triassic-Jurassic vertebrate assemblages in the world. These types of issues that permeate the entire early Mesozoic section will not be resolved until a proper temporal context is available, as we propose to develop in the CPCP.

These are just two examples of urgent issues on which a great deal of additional science hinges. If the largest erg on Earth did lie at the equator in the Early Jurassic, then basic ideas of climate processes clearly require revision. If there is no Triassic-Jurassic mass extinction, what is the point of looking for its cause in large igneous provinces or impacts? A rigorous chronostratigraphy and paleogeographic framework, both key scientific goals of the CPCP, are essential to be able to move forward.

We expect the CPCP to stimulate an entirely new generation of field studies tying their results to the cores. Some of the signature outcomes of the CPCP are expected to include: 1, a high resolution magnetic polarity stratigraphy in combination with high-resolution radioisotopic ages for the Triassic and Jurassic epicontinental sediments which is essential for regional and especially global chronostratigraphic cor- relations to other continental (e.g., Newark, Central European, or Chinese basins) as well as marine (e.g., Tethyan) sections; 2, tight constraints on the paleogeography, particularly changes in paleolatitude, of western Pangea during the Triassic and Jurassic and the relationship to the expression of paleoclimate in the sedimentary record, particularly the apparent aridification in the Triassic and Early Jurassic; 3, a well-calibrated paleoclimate record for comparison to other parts of Pangea for tests of climate models; 4, a thorough reassessment of lithostratigraphic and biostratigraphic correlations, including pinpointing the ages and extents of proposed regional unconformities and their possible relationship to eustatic fluctuations; 5, development of a chemostratigraphic reference section for the American Southwest for the early Mesozoic; 6, development of a sufficiently detailed stratigraphic framework to establish teleconnections between the Colorado Plateau sedimentary record and rifting of Pangea, the emplacement of the Central Atlantic Magmatic Province, and the opening of the Atlantic Ocean, as well as the eruption other large igneous provinces, notably the Karoo-Ferrar, Siberian, and Paraná-Etendeka basalts; and 7, development of a quantitative tectonostratigraphic database that will allow the development and testing of models of dynamic basin evolution.

The success of CPCP will have major implications for understanding early Mesozoic global climate change, the evolution of the modern terrestrial biota, and possible linkages with the breakup of the Pangean supercontinent and the eruption of some of the world's most extensive large igneous provinces. For example, several results of this project having considerable societal relevance and these include direct tests of the ability of current climate models to address different boundary conditions, such as high-CO_2. Presently, there are apparent inconsistencies between predictions of climate models and paleogeography for the Colorado Plateau in the Permian to Jurassic (Rowe et al., 2007). These inconsistencies cannot be resolved with the existing data but are among the scientific issues that the CPCP is designed to address.

A useful model for the success of the CPCP is the NSF-funded Newark Basin Coring Project (NBCP: 1990-1994), which refocused Late Triassic chronostratigraphy by providing an astronomically calibrated geomagnetic polarity time scale for an interval of time as long and arguable at the same level of resolution as the entire Neogene. It is this magnetic polarity time scale that will serve as the template for correlation with the older part of the CPCP record, while the Late Jurassic marine magnetic anomaly record will serve a similar purpose in the younger part of the CPCP record. As the longest continuous, high-resolution record of cyclical climate forcing on the planet it has been cited in arguments as far ranging as calibrating Solar System chaos (Pälike et al., 2004), human evolution (Lepre et al., 2007), the Paleocene-Eocene boundary (Cramer et al., 2003), and thermohaline circulation controls on modern climate (Broecker, 1999). Results of the NBCP have been described in 88 papers and 130 abstracts, the subject of 11 theses, and cited in 19 papers a year on average (Web of Science). The NBCP resolved the durations of Late Triassic stages, the role of precession-related Milankovitch forcing in the Pangean tropics, correlation of the Triassic-Jurassic of Eastern North American, Morocco, and Greenland, the duration of the largest igneous event in Earth History (CAMP), and constrained the chaotic Earth-Mars gravitational system for the Triassic and more down to earth, the qualitative pattern of rift basin growth. These points have withstood every quantitative challenge (e.g., Hinnov, 2000; Furin et al., 2006; Hames et al., 2000; Bailey and Smith, 2008). We think that the approach to chronostratigraphy exemplified by the NBCP has been at least mildly transformational, and we think the CPCP will be more so.

CPCP objectives and techniques

Chronostratigraphy

A basic foundation for all aspects of the CPCP will be the greatly increased reliability of early Mesozoic chronostratigraphy developed from the cores. Three suites of chronostratigraphic tools will form this foundation: magnetostratigraphy; radio-isotopic age determination; and cyclostratigraphy. These will be registered with other observables including biostratigraphic range data, climate-sensitive lithofacies, and chemostratigraphies. The need for considerable refinements to the chronostratigraphy is illustrated by the following points:

1. Except in a nominal sense (at formation boundaries or unconformities), the stratigraphic position of the system boundaries (Permo-Triassic, Triassic-Jurassic, or Jurassic-Cretaceous) is unknown. In fact the system boundaries could be within formations (e.g., Moenave for the Triassic-Jurassic and Morrison or

Cedar Mountain formations for the Jurassic-Cretaceous).

2. Ages, both relative and absolute at a stage level are practically unknown or based on uncritical and untested correlation schemes. A prime recent example is the previously mentioned inferred age of strata in the lower Chinle Group that was long assumed to be Carnian (ca. >230 Ma) even in the recently-published geologic time scales (GTS2004 and GTS2009), but turns out, on the basis of a high precision U-Pb zircon age (Mundil and Irmis, 2008), is 10 million years too old. Many more reliable age determinations are required to establish a robust chronostratigraphic framework; this example, however, forcefully underscores the urgent need for high-precision geochronological data using multiple state-of-the-art methods.

3. Even within a given formation, it is not yet possible to place biotic assemblages from different localities in a testable temporal sequence even though most of our "knowledge" of North American vertebrate biochronology for the early Mesozoic is based on observations from strata on or adjacent to the Colorado Plateau. Thus, the fact remains that the stratigraphic understanding is pretty much still in the 19th century and incapable of being applied to useful and exciting evolutionary, climatic, or geodynamical models that have relevance not just in a regional but also in a global context. This is not for lack of effort on the part of researchers, rather it is a direct consequence of the physical limitations of the outcrop itself.

The Colorado Plateau region has been a classic source of early Mesozoic paleomagnetic data for North America, including some of the earliest magnetostratigraphic records for the Triassic and Jurassic (e.g., Steiner and Helsley, 1972; Steiner and Helsley, 1974; Steiner and Helsley, 1975, Steiner, 1978; Steiner, 1980; Steiner and Lucas, 1992; Molina-Garza et al., 1991; Molina-Garza et al., 2003; Ekstrand and Butler, 1989; Bazard and Butler, 1991, 1992, 1994; Purucker et al., 1980). To date, the longest Colorado Plateau polarity sequence is derived from outcrops of middle Chinle Group strata in the Petrified Forest National Park (Steiner and Lucas, 2000) that allowed a correlation to the only Late Triassic polarity timescale with independent time control - the NBCP astronomically-calibrated geomagnetic polarity timescale (Kent et al., 1995; Kent and Olsen, 1999; Olsen and Kent, 1996; Kent and Olsen, 2000; Olsen and Kent, 1999).

The recent U-Pb single-zircon ages from the Chinle Group in the Petrified Forest (Dickinson and Gehrels, 2008) and Six Mile Canyon, near Fort Wingate, NM (Mundil and Irmis, 2008) suggest that the magnetostratigraphic correlation proposed by Steiner and Lucas (2000) is essentially correct. The implication is that a meaningful polarity sequence can be recovered from the Chinle Group in general, despite the low implied accumulation rate (150 m/10 Ma=0.015 m/1 ka) and largely fluvial facies. For the Chinle to be sampled at Newarkian temporal levels (~20 ka) to avoid aliasing, the sampling should be done at the 0.3 m level, which would be hardly feasible in the crumbly outcrops of the bentonitic Chinle Group (e.g., Fig. 2), as driven home by the experience of Zeigler et al., with the Chinle (Zeigler et al., 2008). In addition, although the new U-Pb-zircon ages provide a more encouraging framework than had previously existed, the Six Mile Canyon date is from a tuff located over 140 km east of Petrified Forest to which it has been correlated lithostratigraphically, a correlation that needs to be confirmed. Both of these objectives are further motivation for coring and obtaining the appropriate level of sampling resolution where superposition is unambiguous.

We are confident to find additional layers at many levels that are suitable for radio-isotopic dating. In this context it is important to recognize the need for the application of multiple dating methods (where feasible) to resolve any complications resulting from systematic and random bias. The core material is particularly suited to detect primary (or re-deposited) volcanic material containing datable minerals, and recent studies have demonstrated that even minute samples recovered from cores, containing very small numbers of datable crystals (on the order of 10s) are perfectly adequate for high-precision age determinations (e.g. Mundil et al., 2006). Radio-isotopic age data from different isotopic systems, of variable vintage and quality, are available from early Mesozoic age strata on the Colorado Plateau, but a recent focus on acquiring single-crystal U-Pb zircon ages using the CA-TIMS technique (Martinson, 2005) has begun to yield meaningful and precise preliminary results. However for these to be of utmost utility and maximally parsimonious they should be from the same place as other complementary data, which is typically and practically possible only in core. The cores themselves (in combination with samples from outcrops) will provide three kinds of age information: 1) depositional ages of ashes or tuffaceous sandstones providing penecontemporaneous ages (tephrochronology); 2) zircon data from re-deposited volcanic layers providing maximum ages; and 3) correlation by magnetic polarity zone boundaries to age information acquired elsewhere. In addition, the cores should provide a continuous record of detrital minerals, including zircons that will be a valuable asset to provenance studies (e.g., Rahl et al., 2003; Riggs et al., 1996; Dickson and Gehrels, 2003). We plan to use a combination of "reconnaissance" techniques (e.g. LA-ICP mass spectrometry, in order to screen the age spectrum of zircon populations within tuffaceous deposits: 41), followed by "high-resolution" techniques including CA-TIMS applied to zircons and $^{40}Ar/^{39}Ar$ applied to K-bearing volcanic minerals.

The largely fluvial to paralic or eolian nature of most of the Colorado Plateau section, lacking independent assessments of accumulation rates, has profoundly hindered cyclostratigraphic interpretations. Available data suggest relatively low accumulations rates, so that it is unlikely that the higher frequency orbital cycles will have a faithful record. However, the eccentricity cycles, especially the 405 ky and longer eccentricity cycles (Olsen and Kent, 1999), should leave a decipherable record of environmental change in the style of the fluvial systems, the distribution of eolianites, and in the biota from the cores (pollen, invertebrates) and outcrop (vertebrates: e.g., Van Dam et al., 2006) that can be tied to the cores by magnetic polarity stratigraphy. Correlation to the astronomically-calibrated Newark record will provide a check on the local environmental response to known cyclicity. We expect that the resulting chronostratigraphic framework will be closely tied to sedimentary archives from terrestrial and marine environments elsewhere.

Biotic history and events

CPCP cores will provide a framework for a detailed chronology of faunal and floral change for the early Mesozoic of western North America by linking the rich reservoir of surface information to the core chronostratigraphy. This will allow the recognition of the positions of major biotic events, such as the end Triassic, Toarcian, and possibly the Jurassic- Cretaceous transitions. In addition the pace of faunal and floral change can be quantified once there is a chronostratigraphy developed by the CPCP and tied to outcrop.

Crucial in this vein are correlations to continental and marine sequences from elsewhere. There are, for example, major differences in the first-order composition of continental vertebrate assemblages from different areas of the globe, despite the fact that during the Triassic and Early Jurassic the existence of Pangea meant that terrestrial vertebrate could in principle walk from nearly the south pole to the north pole. Differences amongst these faunas have been attributed to differences in ages following a paradigm outlined nearly 40 years ago by Alfred Sherwood Romer (1970). However, this purely biostratigraphic argument masks the first-order pattern of real biogeographic provinciality as illustrated by the realization that Norian age assemblages from mid-paleolatitudes from both hemispheres are very distinct from tropical assemblages from the Colorado Plateau just now recognized as of contemporaneous Norian age on the basis of new U-Pb single-zircon ages (Irmis and Mundil, 2008). Similarly, continental vs. marine correlations are in limbo. The distinctive genera-level faunal turnover at the Sonsela Member of the Chinle Group of the Colorado Plateau was thought to be correlative with the marine Carnian-Norian boundary extinction event, but instead is mid-Norian in age. Such obfuscation makes it impossible to even recognize what the major biological patterns are, let alone test existing hypothesis of biotic change and their origin. These actual patterns of biotic change can only be revealed if an accurate and precise chronostratigraphy is in place, such as will result form the CPCP.

Environmental history

Key to the CPCP will be a continuous record of environmental change in the cores. Environmental changes are largely recorded via sedimentary, pedogenic, and biotic processes, sensitive to climatic and drainage basin (e.g., tectonic) changes. The CPCP cores will be an unprecedented archive of these processes spanning 100 million years. Key environ- mental observations derived from the cores will include the detailed record of depositional conditions, a pedostratigraphy (soil types), stable isotope carbonate and molecular-level biomarker chemostratigraphies (pedogenic C and organic C, O, H, etc.), and palynologies (pollen, spores, dinoflagellates). Core and downhole logs will be able to provide cross-bedding orientation for wind and current direction.

Tectonostratigraphy and tectonic history

The position of sequence boundaries identified in outcrop can be tied to the CPCP cores, the chronostratigraphy of which will allow an assessment of the duration of associated hiatuses and proposed sequence boundaries and hence tests of their regional significance. The CPCP chronostratigraphy coupled with the temporal overlap between cores will allow quantification of accumulation rates, back stripping, and elucidation of the geographically and temporally evolving subsidence history. Coupled with the detrital provenance records this will allow a synoptic view of the dynamic evolution of epicontinental basins in this huge region.

CPCP phased coring plan

We propose the CPCP cores be acquired in three phases, roughly in stratigraphic order that includes the initial description and scientific results of the coring consistent with IODP practice. Each phase builds on the others, hence a vision and a program, but each phase actually has stand-alone science. Depending on funding rates, each phase could be accomplished in around 18 months.

Phase 1: Core 1-Petrified Forest, Arizona (**PF**: Figs. 1, 2), will be a roughly 500m long core in Petrified Forest National Park, Arizona. This core will span the Late Triassic uppermost Petrified Forest Formation and the underlying rest of the Chinle Group, and the local expression of the Early to Middle Triassic age Moenkopi Formation, bottoming in the Permian Kaibab Limestone. Working in conjunction with Petrified Forest park officials, we have identified a suitable coring site that is located on the north edge of the park. This core would tie directly to critical extremely rich paleontological assemblages, a well- developed local lithostratigraphy and an existing (Steiner and Lucas, 2000) and developing (Zeigler et al., 2008) paleomagnetic polarity stratigraphy. Acquisition of this core, although modest in scope but high in profile, is selected as the first phase of this project because it will: 1) allow assessment of coring conditions in the bentonitic Chinle

Group, conditions that will be experienced at often appreciably greater depths at other core sites; 2) test the lateral continuity of specific lithologically distinctive stratal intervals and magnetic polarity zones; and 3) serve as an example of an environmentally responsible coring process for other phases of the project. We are encouraged that this phase of the project appears poised for funding.

Phase 2: Two complementary cores, one long, one short are designed to examine the Latest Triassic and Early Jurassic part of the record.

Core 2 - Ward Terrace/Moenkopi Plateau, Arizona (**WT**: Figs.1, 2), will be a 700-800m long core in the Ward Terrace/Moenkopi Plateau area in the Navajo Reservation in Arizona. This core will capture the thickest known development of the Late Triassic Chinle Group as well as a significant part of the overlying Jurassic Glen Canyon Group (Moenave and Kayenta formations at Ward Terrace/Moenkopi. This area has produced the bulk of the Early Jurassic faunal remains in the Western Hemisphere. The lower part of Core 2 nominally overlaps completely with Core 1, but will be separated by roughly ~160km and will test the lateral continuity of the physical and magnetic stratigraphy where the Chile Formation is best developed.

Core 3 - Rock Point/Lisbon Valley area in Arizona/Utah (RP: Figs.1-2), will be a 600m long core that will capture the thickest known development of the Late Triassic Chinle Group as well as a significant part of the overlying Jurassic Glen Canyon Group (Wingate formation). This core would be adjacent to the faunally richest putative Triassic-Jurassic boundary sections.

Phase 3: At least 2 cores will span the Early through Late Jurassic age section

Core 4 - St. George, Utah (SG: Figs. 1-2), will be a ~1100 m core that will recover the basal Early Jurassic Navajo Formation of the Glen Canyon Group through the base of the Moenkopi Formation. This core complements Phases 1 and 2, but differs in having an erosionally truncated Chinle Group and yet a greatly expanded section of Moenkopi, Moenave, and Kayenta strata. Both the Moenkopi and Moenave appear strikingly cyclical in these areas.

Core 5 - San Rafael Swell area, Utah (SR: Figs. 1, 3), will minimally capture the basal Cedar Mountain Formation and entire Jurassic Morrison Formation, San Rafael Group, and Glen Canyon Group in a ~1500m core. This core will sample strata documenting the return to more humid conditions in the Colorado Plateau area, as well as the interval producing arguably one of the richest Late Jurassic continental biota in the world, exemplifying the culmination of dinosaur dominance. Planning for this part of the CPCP is still in its early stages. Furthermore, it seems likely that to fully encompass the full scope of the Morrison Formation, additional cores will be required.

Conclusion

The vision of the Colorado Plateau Coring Project (CPCP) (Olsen et al., 2008; Olsen et al., 2008; Olsen, 2009) is a complete cored section through the 100 million record of the early Mesozoic of the Colorado Plateau and its environs. These workshops identified the Petrified Forest core as the first phase of the CPCP that, along with other phases of the project, will result in tests of a series of globally significant hypotheses and serve as a basis for further research to a significant segment of the community. Furthermore, the results of the CPCP will allow for high-resolution correlation with other major early Mesozoic sequences, notably those in Asia, particularly China (Zhou and Dean, 1996; Sha, 2009; Smith, 1990). Because this area has such extensive lacustrine sequences broadly coeval with the younger parts of the CPCP sections such correlations ultimately may allow the development of astrochronology for the Jurassic that would link with the Newark Basin astrochronology and time scale (Olsen and Kent, 1999). This will open the door for a truly Earth Systems approach to understand the key events of the Triassic and Jurassic and potentially result in a far more detailed knowledge of environmental forcing especially evolution of Milankovitch climatic cyclicity coupled to the uncharted deep time chaotic diffusion of the behavior of the solar system (Laskar, 2008).

Key words: Colorado Plateau; Early Mesozoic; Continental strata; Environmental change

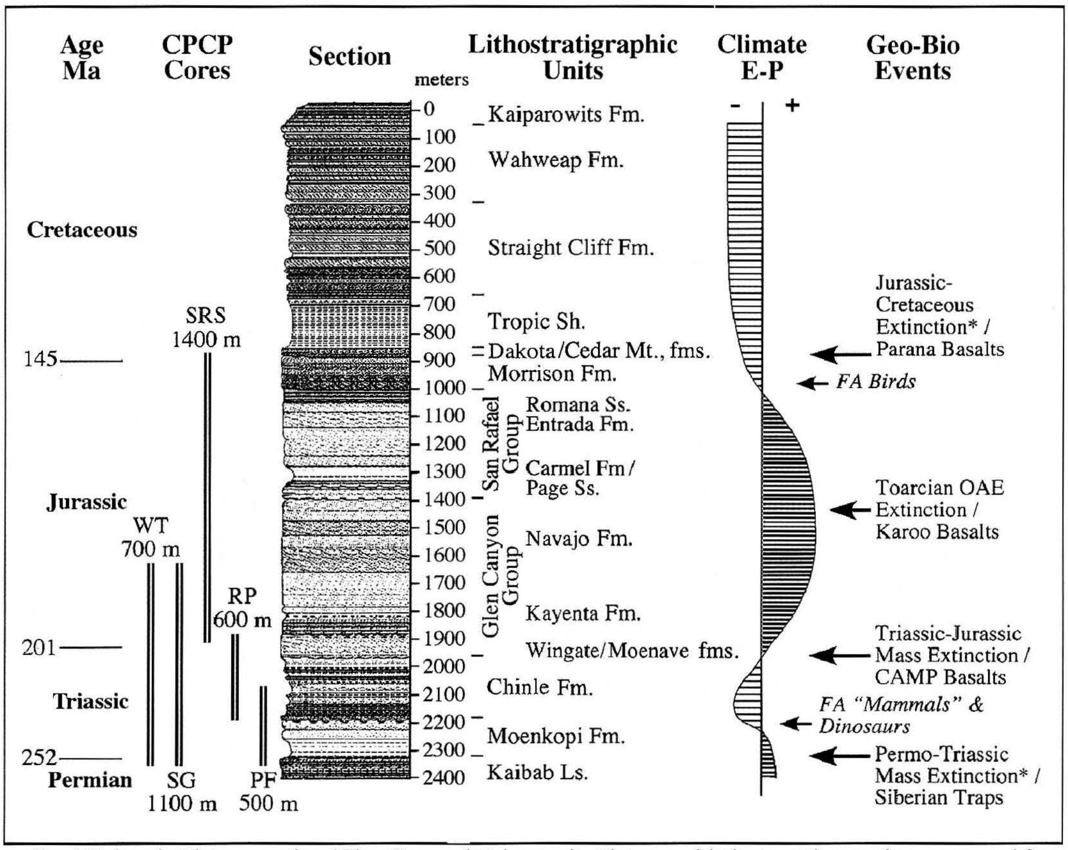

Fig.2 Generalized Colorado Plateau section (Glen Canyon/ Kaiparowits Plateau, with the tentative sections proposed for coring, as discussed by the St. George workshop participants and a very generalized evaporation – precipitation (E-P) curve loosely based on climate sensitive facies

See caption to Fig. 1 for core area abbreviations. Note that the relative thicknesses of tentative drilling intervals through stratigraphic units are in general different than what is shown in the color section and not the same among different coring target areas (from Olsen et al., 2008a)

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