Paleoenvironmental Implications of Carbonate Nodules

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Abstract

Calcium carbonate nodules ranging from 5 cm to 75 cm in diameter are abundant in floodplain deposits within the Cedar Mountain Formation in Dinosaur National Monument, Utah. The Cedar Mountain Formation is a Sauropod-bone bearing sequence of interbedded shale and sandstone. Several continuous layers of the calcium carbonate nodules are exposed in outcrops to the east and west of the main dinosaur bone quarry in the monument. Some of these nodule-rich beds are well indurated and create an impermeable layer. In other beds, carbonate nodules are rare. The carbonate nodules have two main macrostructures: (1) a spherical micritic center; and (2) radial epitaxial calcite crystals evenly dispersed on the outside of the micrite. The micritic center formed in a phreatic zone environment. The radial epitaxial crystals formed when the floodplain-like area was underwater and the crystals were able to grow. The significant accumulation of calcium carbonate nodules is indicative of highly evaporitic conditions, which indicates that the nodules formed in an arid to semi-arid environment. There are several measured and documented river channel beds within these outcrops that indicate that the carbonate nodules occur in floodplain-like deposits. The results of this thesis are significant because they provide insight regarding the paleoenvironment that Sauropod dinosaurs lived in during the Cretaceous period.

Acknowledgments

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I dedicate my thesis to Mathew Wintzer, my hero.

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Introduction

Dinosaur National Monument ("DNM") extends across the Utah/Colorado state border, and the dinosaur-bone-bearing beds the monument is named after are on the Utah side of DNM (Figure 1). The dinosaur-bone-bearing beds are within the Jurassic Morrison Formation. The Cedar Mountain Formation overlies the Morrison Formation, and was deposited during the Albian and Aptian Ages of the Cretaceous Period (Figure 2). Although dinosaur bones are not as common as in the Morrison Formation, dinosaur bones are present within the Cedar Mountain Formation. A recent discovery of an almost complete Sauropod skeleton in the Cedar Mountain Formation brings light to the importance and utility of understanding paleoenvironmental conditions during deposition of the Cedar Mountain Formation.

The Ruby Ranch Member of the Cedar Mountain Formation contains multiple layers of calcium carbonate nodules that vary in diameter, degree of cementation, and lateral continuity. The crystal morphology of the nodules provides insight regarding the depositional environment of Cedar Mountain Formation (Figure 3). The goal of this project is to study the macro and micro textures of the calcium carbonate nodules and thereby deduce paleoenvironmental conditions.

Literature Review

Carbonate nodules are a type of calcrete. Calcretes are defined as "a near surface, terrestrial, accumulation of predominantly calcium carbonate, which occurs in a variety of forms from powdery to nodular to highly indurated. It results from the cementation and displasive and replacive introduction of calcium carbonate into soil profiles, bedrock and sediments, in areas where vadose and shallow phreatic groundwaters become saturated with repect to calcium carbonate" (Wright and Tucker, 1991, p. 1). This definition is widely accepted and used (e.g., Currie, 1998; DeWet, 1998).

Calcareous soils form in areas where rainfall is between 200mm and 600mm/yr and where evaporation surpasses this precipitation. These soils form in a variety of sediments, including river floodplain sediments. Calcretes most often form in Aridisols, Vertisols, and Mollisols (Soil Survey Staff, 1975) (Wright and Tucker, 1991).

Wright and Tucker recognize a "two end-member" calcretes, and use the end members as the basis of a classification system (Figure 4) where the two members are termed alpha and beta. Carbonate microstructure and macrostructure are used to classify carbonates in Wright and Tucker's system. Many calcretes show alpha or beta calcrete characteristics exclusively. Alpha calcretes are associated with both an arid to semi-arid environment with relatively low biological activity or a groundwater environment; where as beta calcretes are associated with a semi-arid environment only and relatively high biological activity. Alpha calcretes are more likely to accumulate carbonate as a result of evaporation and degassing in arid environment. Carbonate accumulation in beta calcretes is most likely biologically stimulated.

There is a paucity of Sauropod fossils in the lower Cretaceous Period sediments in the United States that makes the discovery of the Sauropod skeleton in the Cedar Mountain Formation in Dinosaur National Monument significant. Consequently, over that last ten years interest has grown for study of Sauropod dinosaurs in the lower Cretaceous Period. Excavation of the Sauropod skeleton in the Cedar Mountain Formation began in 1996 and presently continues (Scott Madson, Pers. Comm).

According to Currie (1998), the stratigraphically oldest calcium carbonate layer in the Cedar Mountain Formation is the basal layer and marks the unconformity between the Morrison Formation and the Cedar Mountain Formation. Currie (1998) also states that the existence of the basal calcrete layer signifies the paleoenvironment as arid to semi-arid.

Methods and Materials

Study Area

Fieldwork was conducted in Dinosaur National Monument, Utah, which is at approximately 109 degrees west longitude and 40 degrees north latitude (Figure 5). Three Members of the Cedar Mountain Formation are present in the monument: The Mussentuchit Member; The Ruby Ranch Member; and The Yellow Cat Member (J. Maxson, 2002, written communication). Continuous calcium carbonate nodule horizons are present in the Ruby Ranch member. The age of the Cedar Mountain Formation was determined by Argon-Argon dating, and is 98.39 ± 0.07 Ma (Albian-Aptian ages) (Currie, 1998).

Field Methods

Outcrops were studied on 11 ridges that are east and west of the main dinosaur quarry in DNM. The ridges are composed of tilted sediment layers that are being continually weathered creating outcrops (Figure 3 and 5) (Pers. Comm. Julie Maxson). The analyzed calcium carbonate nodules were collected from 8 outcrop ridges. The ridges were numbered 1 through 11 for note taking purposes. The study area is two and a half kilometers long and 100 meters wide. A classification system was created to accurately document the character of the nodules (Appendix B). This classification scheme is based on degree of cementation, lateral continuity, and nodule diameter. Empirical consensus was used to assess degree of cementation and lateral continuity. Nodule diameters were measured using a metric measuring tape (Appendix A). Notes were also taken on rock structure and character.

Petrographic Analysis

Approximately 35 calcium-carbonate nodule hand samples were collected, and 13 thin sections were made from selected samples. Each was analyzed with a petrographic microscope, and significant features were documented (Appendix C).

Results

Outcrops

The outcrops consist of three calcium carbonate nodule layers laterally continuous along strike that are a meter thick on average. The calcium carbonate nodules are within a mudstone bed (Currie, 1998). Among these three continuous carbonate layers are several thinner layers that are less than half of a meter in thickness. These thinner layers are also laterally discontinuous not forming one consistent layer. Two main pockets of nodules with radial epitaxial calcite crystals are present on ridges 2 and 7-11. The basal carbonate layer, as identified by Currie (1998), outcrops on ridges 1 through 5, 8, and 10 (Appendix A). Most nodules were type III C (Appendix B). The abundance of the remaining types are as follows in decending order: III B, IV C, III D, IV D, II C, and II B.

Macrostructure

Some of the nodules have spherical micritic centers with radial epitaxial spar crystals evenly dispersed on the outside of the micrite (Figure 8). Calcite and chert veining of the micritc core is present on most nodules. Approximately half of the nodules exhibit micrite brecciation. Weathered nodules are light orange, and their fresh nodule surfaces are light lavender (Appendix A).

Microstructure

The centers of the calcium carbonate nodules are micritic and rarely have calcite veins cutting through their matrices (Figure 9). The outer crystal layer has rhombohedral

cleavage, which is indicative of the mineral calcite (Figure 10). A uniaxial interference figure is present that indicates calcite (Klein, 1993).

Discussion

The microstructure of calcium carbonate nodules reveal paleoenvironmental conditions. The dense microfabric and rhombic calcite crystals seen in the thin section (Figure 9) reveal the micritic center of the Cedar Mountain Formation carbonates to be alpha type. The dearth of beta calcrete characteristics also indicates they are Alpha calcretes (Figure 4). Phreatic carbonates tend to be nodular, massive, or brecciated in character (Wright and Tucker, 1991). Calcium carbonate nodules in the Cedar Mountain Formation exhibit characteristics typical of Alpha calcretes (Appendix A). The presence of calcretes that have alpha-type microfabrics are indicative of a arid to semi-arid paleoenvironment (DeWet, 1998). It is important to note that the conclusions of this thesis are based on the assumption that the carbonate nodules formed shortly (within a few 100 k.y.) after deposition.

The sedimentology, stratigraphy, and petrology of the Morrison and Cedar Mountain Formations are discussed in detail by Brian Currie in his paper published in 1998. The calcium carbonate layers in the Ruby Ranch Member are noted, and it is concluded that "the presence of the basal calcrete indicated an arid to semi-arid climate during the time of formation" (Currie, 1998, p 639). The carbonate nodule microstructure and the presence of the basal calcrete both support an arid to semi-arid paleoenvironment.

I propose one possible model for the formation of the calcium carbonate nodules with a rim of epitaxial crystals. The micritic center formed in the phreatic zone, and the radial epitaxial crystals formed when the floodplain-like area was underwater and the crystals were free to grow in all directions. Most minerals can grow only when

surrounded by a fluid because the fluid is easily displaced (Plummer, 2001). The induration of the calcium carbonate layers of the Ruby Ranch Member of the Cedar Mountain Formation can denote recrystallization due to fluctuating groundwater levels (Currie, 1998). Stratigraphic data indicates that there were two to possibly three river channels present at the time of Cedar Mountain Formation deposition (Engle et al., 2002). Crossbeds in the stratigraphic record were used to determine paleocurrents in the Cedar Mountain Formation (Engel et al., 2002). Since water is required for crystal formation for most minerals and water was decisively present during the deposition of the Cedar Mountain Formation, it is feasible that the radial epitaxial crystals formed during times of advancing and ponded water. Although this is not the only one way in which these nodules could have formed, there is some evidence to support this model.

Conclusions

The conclusions of this thesis are based on the assumption that the carbonate nodules formed shortly (within a few 100 k. y.) after deposition. The significant accumulation of calcium carbonate that creates carbonate nodules indicates highly evaporitic conditions, which is associated with arid to semi-arid environments. The micritic structure of the nodule core is an alpha type calcrete that formed in phreatic conditions. Alpha type calcretes are associated with arid to semi-arid paleoenvironments. Also, the radial epitaxial calcite crystals had molecular freedom to attach, precipitate, and molecularly orientate accordingly, so the crystals formed in a floodplain-like environment. This is only one possible explanation for the calcium carbonate nodule macrostructure. The presence of the basal calcrete, which marks the unconformity between the Morrison and Cedar Mountain Formation, reveals the paleoenvironment to be arid to semi-arid. Based on the previously mentioned assumption, the carbonate nodule's depositional environment is arid to semi-arid. Similarly, the Sauropod discovered should have died in an arid to semi-arid environment.

Figures

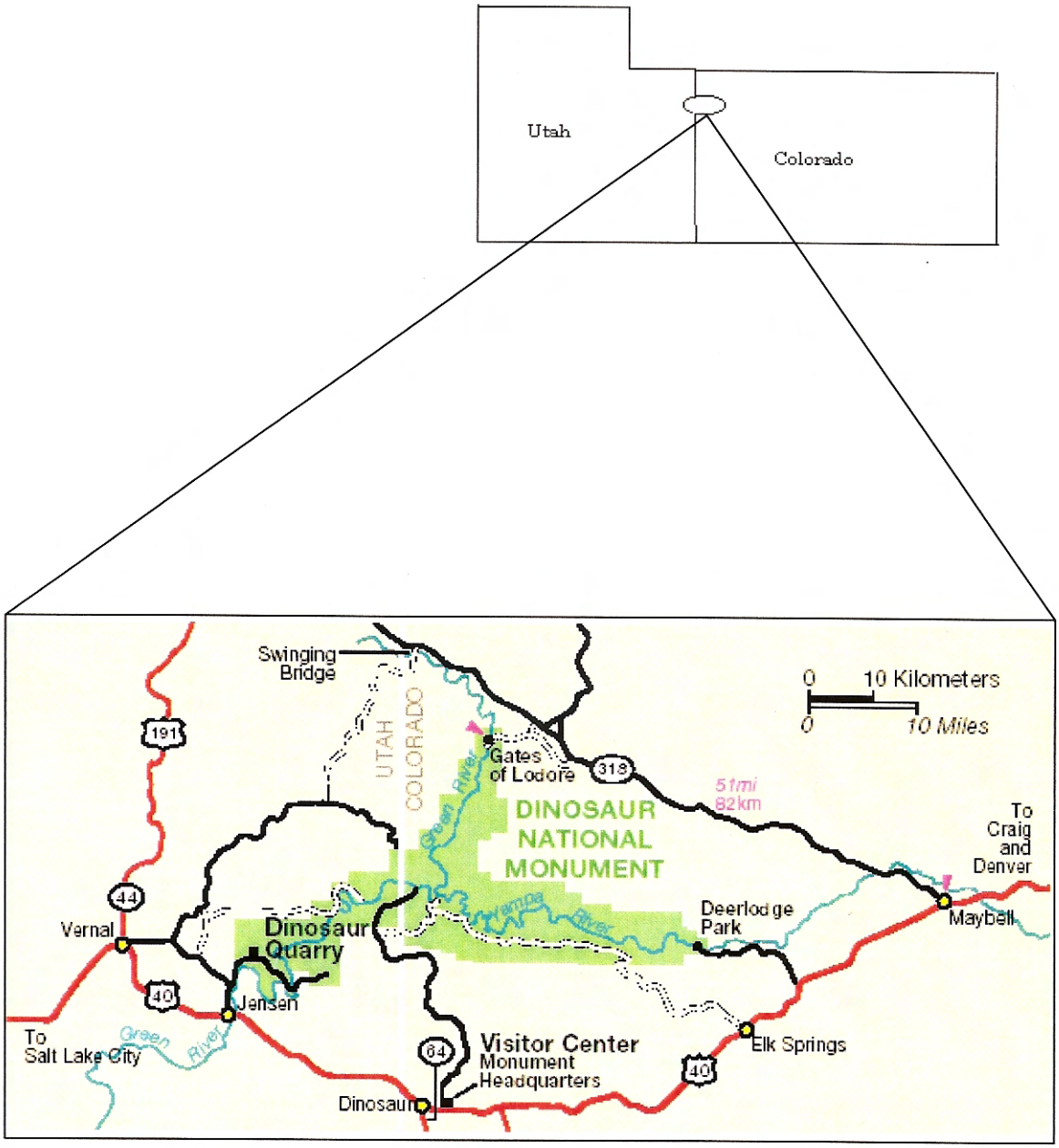

Figure 1. Utah/Colorado Area Map. Fieldwork was conducted along strike to the east and west of the dinosaur quarry in Dinosaur National Monument. (Map courtesy of www.myareamap.com)

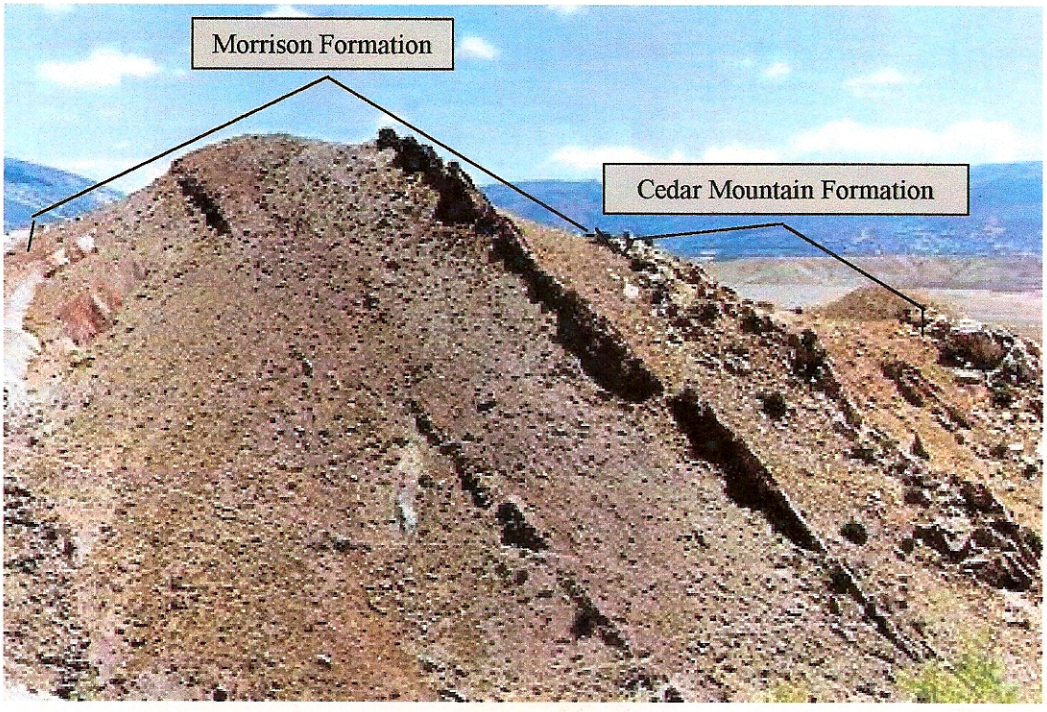

Figure 2. This is an eastward view of the ridge that the main dinosaur quarry is excavated in.

Figure 3. Photograph of carbonate-nodule bearing Ruby Ranch Member of the Cedar Mountain Formation on the quarry ridge. This photograph displays an indurated calcium carbonate layer with nodules 75cm in diameter.

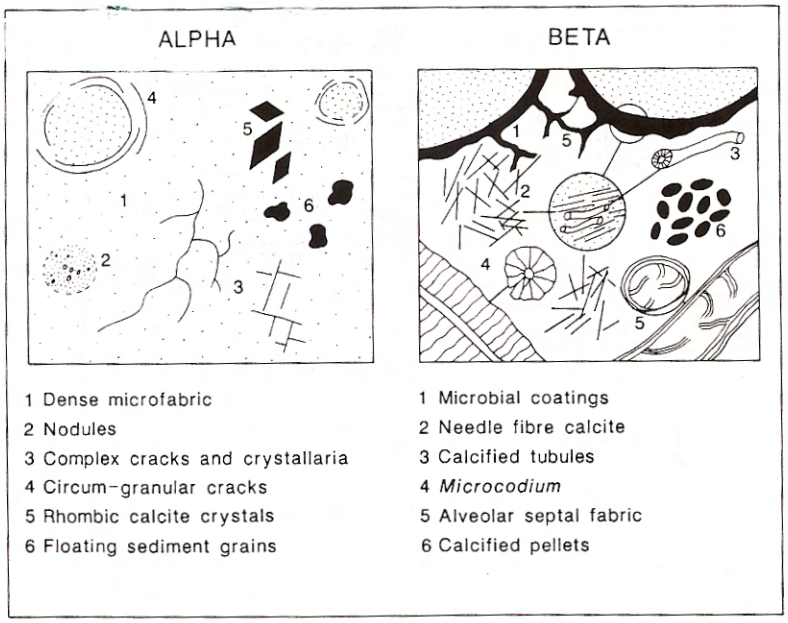

Figure 4. Classification of calcretes based on mircomorphology (Wright and Tucker, 1991).

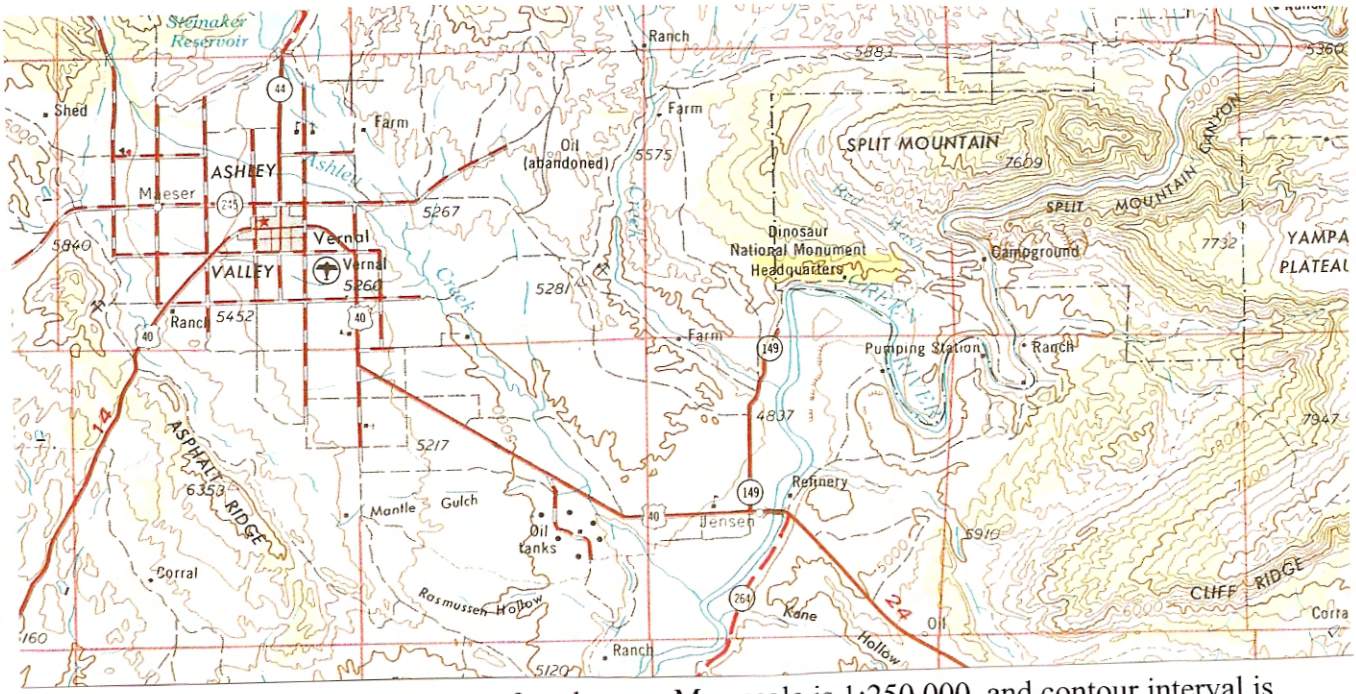

Figure 5. Topographic map of study area. Map scale is 1:250,000, and contour interval is 200ft. Study area is shown in yellow.

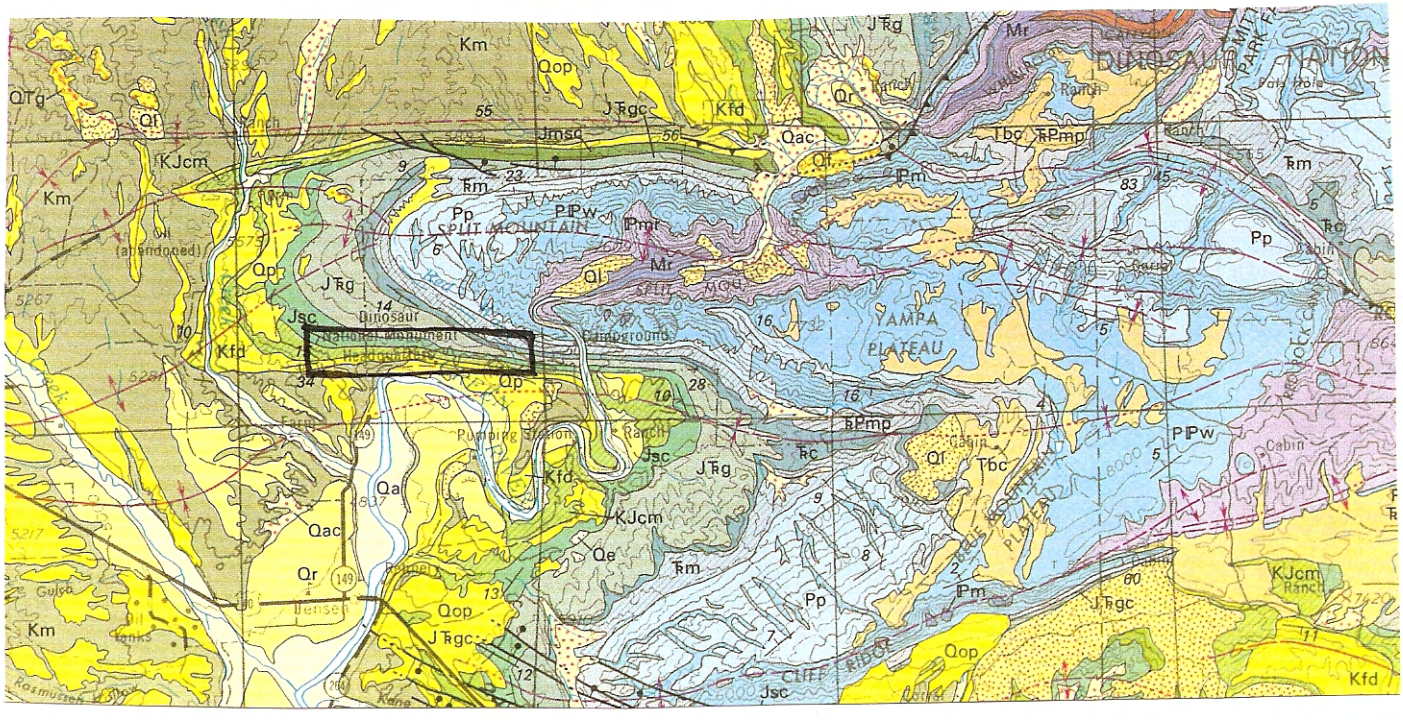

Figure 6. Geological map of study area. Map name is Vernal 7.5 minute quadrangle I-1526. The map scale is 1:250,000, and contour interval is 200ft. Study area is outlined in black. US Geological Survey.

Figure 7. Hand sample photograph with penny for scale.

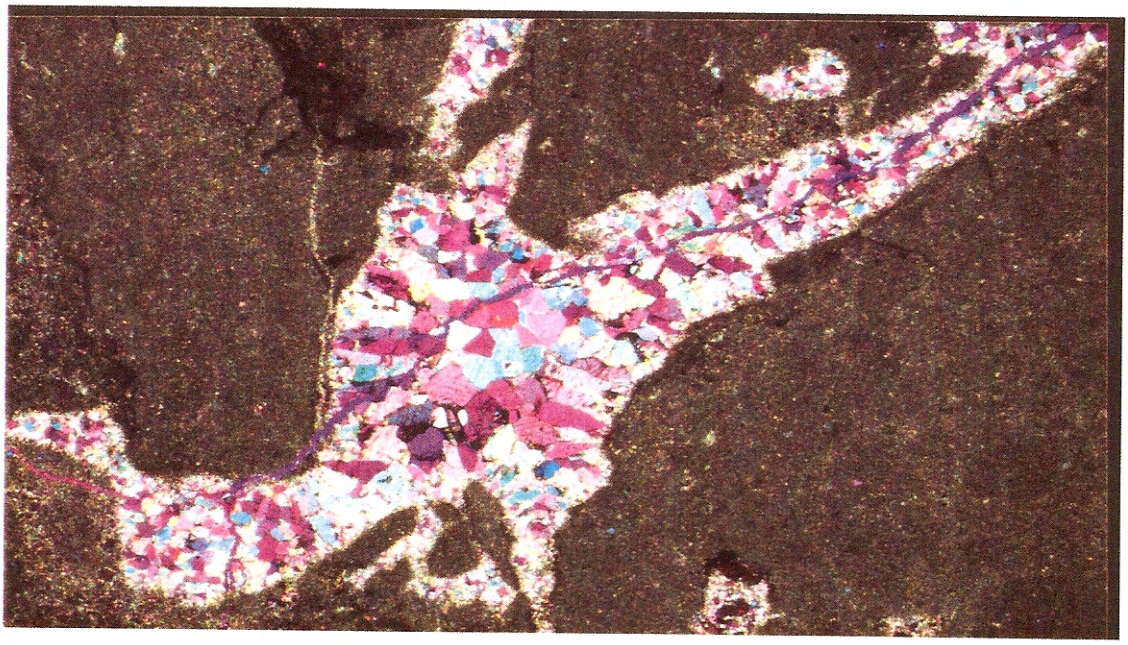

Figure 8. Thin section showing spar vein in dense micrite matrix. (Prepared by Paul Kosmidis)

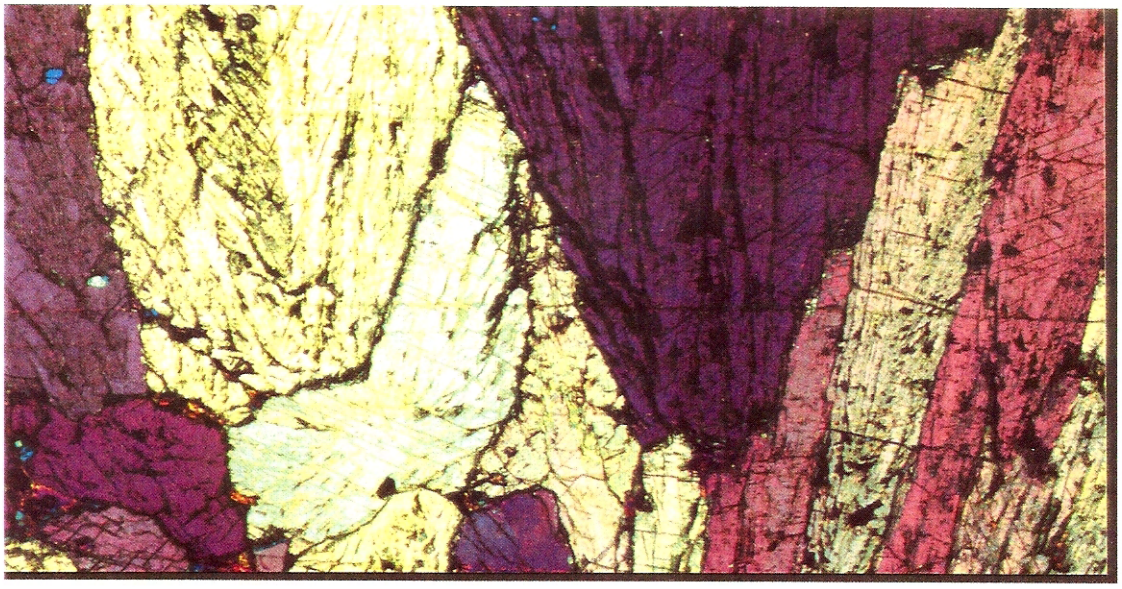

Figure 9. Thin section showing radial epitaxial calcite crystals. Rhombohedral cleavage is visible. (Prepared by Paul Kosmidis)

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Appendix A

Abbreviated Typed Field Notes

The following notes are organized numerically according to what page they are written on in the corresponding field notebook. Each page number is prefaced by the location and date. The ridges studied from Dinosaur National Monument are numbered 1 through 11 and the calcium carbonate layers studied are numbered 1 through 5 starting with the basal calcium carbonate layer.

Location: West of Quarry
Date: 7-23-02
Page #: 65

Ridge # 1:
There are four calcrete layers on this ridge.

Layer # 1

- Class III C[1] basal calcrete
-

Layer # 2

- Class III C
- Some nodules present without calcite crystals.
- Minimal chert and chalcedony veining.
- Partly covered by eolian sand at top of ridge.

Location: West of Quarry
Date: 7-23-02
Page #: 66

Layer # 3

- Class III C
- Nodules have calcite crystals.
- Extensive red chert veining in nodules (veining only occurs in micritic centers of nodules).
- Some nodules are brecciated.

Layer # 4

- Class IV C
- Nodules have extensive calcite crystals.
- Abundant calcite veining.

[1] Refer to Appendix B for explanation of coinciding calcrete classification scheme.

Location: West of Quarry
Date: 7-23-02
Page #: 67

Ridge # 2:
-Possibly 3 carbonate layers.
-Thick sandstone layer under basal calcrete layer.
Layer # 1

- Class IV C
- Calcite crystals present on nodules.
- Calcite veining in nodules.

Layer # 2

- Class III C
- Calcite veining.

Location: West of Quarry
Date: 7-23-02
Page #: 68

- Calcite crystals found on 2nd calcrete layer.
- Crystal length on average 1.5 centimeters.
- There are numerous thinner calcrete layers within the 3 major layers.

Layer # 3

- Class III D
- Calcite crystals on nodules.
- Some calcite veining in nodules.

Ridge # 3:
Layer #1

- Class III C
- Calcite crystals present.

Location: West of Quarry
Date: 7-23-02
Page #: 69

- Some brecciation.
- Calcite veining in nodules.

Layer # 3

- Class III D
- Calcite veining in nodules, Orange brown with lavender tint on weathered surface. Fresh surface is light gray.

Location: West of Quarry
Date: 7-23-02
Page #: 70

Ridge # 4:

-There are two total carbonate layers on this ridge.

Layer # 1
- Class III B
- Calcite veining in nodules.

-This is a highly covered section, outcrops not easily distinguishable.

Layer # 2
- Class III B
- Slight calcite veining in nodules.

Location: West of Quarry
Date: 7-23-02
Page #: 71

Layer #3
- Class III B
- Calcite veining.
- Some brecciation on nodules.

Location: West of Quarry
Date: 7-24-02
Page #: 72

Ridge # 4:

Sample: DINO-375 PK-02-06

Location: West of Quarry
Date: 7-24-02
Page #: 73

Ridge # 5:

Layer # 1
- Class IV D
- Calcite crystals and calcite veining abundant in nodules.

- Calcite crystals in nodules in the indurated carbonate layer between basal and 2nd carbonate layer.

Layer # 2
- Class III C
- Calcite veining in nodules.

Layer # 3
- Class III B

Location: West of Quarry
Date: 7-24-02
Page #: 74

Ridge # 6:
Layer # 1
- Class III C
- Extensive calcite veining.

Location: West of Quarry
Date: 7-24-02
Page #: 75

Layer # 2
- Class IV D
- Extensive calcite veining.

Layer # 3
- Class III C
- Slight calcite veining.

Layer # 4
- Class II B
- Angular weathering.
- Little to no calcite veining.
- Carbonate and sandstone layers are coalesced into one big carbonate layer 2.5 meters thick.

Location: West of Quarry
Date: 7-24-02
Page #: 76

Ridge # 7:
Layer # 1
- Class III C
- Extensive calcite veining.
- Calcite crystals coat carbonates nodules.

- Nodules are insitu.
- Nodules are abundant.
- Slight brecciation.

Location: West of Quarry
Date: 7-24-02
Page #: 77

Layer # 2
- Class II C
- Nodules are highly weathered
- Slight calcite veining in nodules.
- Nodules are brecciated.

Layer # 3
- Calcite crystals on nodules.
- Calcite and chert veining in nodules.

Layer # 4
- Sub-angular weathering of rocks.

Location: West of Quarry
Date: 7-24-02
Page #: 78

- Sandstone layer with trough cross bedding.
- Sandstone weathers light gray and dark brownish gray.

Layer # 2
- Sandstone layer present
- Burrows present in sandstone matrix.

Location: Quarry and East of Quarry
Date: 7-26-02
Page #: 81

Ridge # 8:

-3-meter thick silcrete silica or calcite flecks. Dendrites present, silica or calcite stringers at top of bed
- Silcrete layer directly overlaying by basal calcrete layer. Brecciated.

Layer # 1
- Class IIIC

Location: Quarry and East of Quarry
Date: 7-26-02
Page #: 82

Layer #2
- Class IV D
- Brainy texture and calcite crystals together on rocks.

Layer # 3
- Class III C
- Calcite crystals on nodules.
- Slight calcite and chert veining in nodules.

Layer # 4
- Calcite veining in nodules.
- Calcite crystals present.

Location: Quarry and East of Quarry
Date: 7-26-02
Page #: 83
- Calcite crystals abundant in float.
- Very consistent along strike.

Ridge # 9:

Layer # 1
- No class given for amount of covering.

Layer #2
- Class IV C
- Calcite crystals on nodules.
- Nodules are brecciated.

Location: Quarry and East of Quarry
Date: 7-26-02
Page #: 84

- Class III B
- Calcite veining in nodules.

Layer # 3
- Class III B
- Extensive calcite crystals on nodules.
- Calcite veining in nodules.
- Nodules slightly brecciated.

- There is a thick layer of expitaxial crystals.

Location: Quarry and East of Quarry
Date: 7-26-02
Page #: 85

Layer # 4
- Class III B
- Abundant calcite veining in nodules.
- Calcite crystals on nodules.

Layer # 5
- Class III B
- Abundant calcite crystals.

Ridge # 10 (two over from quarry)

Location: Quarry and East of Quarry
Date: 7-26-02
Page #: 86

Layer # 1
- Class IV C
- Some calcite veining.

Layer # 2
- Class III B
- Nodules have calcite and chert veining
- Nodules are brecciated.
- Calcite crystals in float.

Layer # 3
- Class III B
- Calcite veins in nodules.
- Calcite crystals on nodules.

Layer # 4
- Nodules are angularly weathered.

Location: Quarry and East of Quarry
Date: 7-26-02
Page #: 87

Sample #: DINO-375 PK-02-11

Last Ridge # 11:

Layer # 1

- Class II C
- Calcite and chert veining in nodules.
- Calcite crystals are on nodules.

Layer # 2

- Class III D
- Nodules are broken in to angular fragments.
- Calcite veins are present.

Location: Quarry and East of Quarry
Date: 7-26-02
Page #: 88

Layer # 3

- Class III C
- Abundant calcite crystals on nodules.
- Calcite and chert veining in nodules.
- Nodules are brecciated.
- There are multiple layers of calcite crystals on top of one another. Crystals are approximately 4. 5 cm in length on average.

Appendix B

Calcrete Classification Scheme

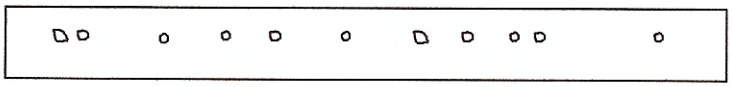
Paul Kosmidis and Niki Schaefer created this classification scheme on The 26th of July 2002 in Dinosaur National Monument, Utah. There are two parts to the rating. First, a Roman numeral that indicates the nodule's diameter measured in centimeters. Second, a letter of the alphabet that indicates the level of lateral continuity measured along strike and amount cementation of the nodules together.

Nodule Size

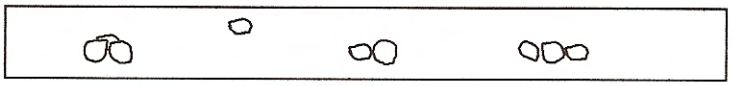
I. Very small micritic nodules dispersed throughout white chalky soil. Nodule size less than 5 centimeters in diameter.
II. Small nodules diameter mean range 5 –15 centimeters.
III. Nodule's diameter mean range 15-35 centimeters.
IV. Nodule's diameter mean range 35-55 centimeters.
V. Nodule's diameter mean range 55-75 centimeters.
VI. Greater than 75 centimeters in diameter.

Cementation/Lateral Continuity

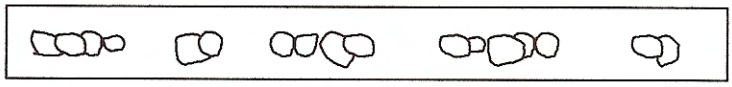
A. Friable, not cemented, not lithified, loose soil between nodules.



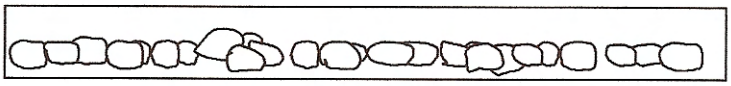
B. Not well indurated, consistent rubble in a zone.



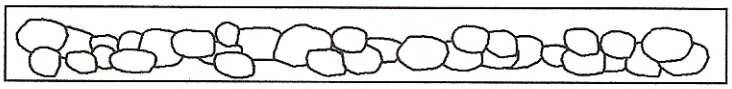
C. Continuous indurated, consistently coalescing nodules



D. Well indurated, very continuous, coalesced nodules



E. Very well indurated impermeable carbonate layer.



Appendix C

Petrographic Notes

1. DINO-375 PK-02-10[1]
   Multiple Expitaxial Crystals
   - Rhombohedral cleavage
   - Calcite interference figure [2](Uniaxial)
   - No interference figure seen in micritic portion of thin section
   - "Chopped up" appearance
   - More crystallized than other micritic center

2. DINO-375 PK-02-09
   Micrite Bands
   - Calcite interference figure seen throughout all thin section
   - Rhombohedral cleavage seen
   - Brown mineral present (unknown)
   - Some calcite grains choppy, some rectangular, over shape, and some radiate
   - Looking at the slide with the naked eye, the texture appears in a band texture

3. DINO-375 NP-02-09
   Expitaxial Crystals with Micritic Center
   - Expitaxial crystals part has rhombohedral cleavage
   - Calcite interference figure seen on expitaxial crystals
   - Micritic center looks choppy
   - Expitaxial crystals not well developed when seen

4. DINO-375 PK-02-08
   Micritic Ball with Layers of Expitaxial Crystals Separated by Dark Lines
   - This is a large (3 x 7.5 cm) thin section
   - Rhombohedral cleavage on expitaxial crystals area mean calcite
   - In the micrite area there are quartz stringers
   - Interference figure is uniaxial with many rings

5. DINO-375 PK-02-07
   Small Calcite Balls
   - Interference figure in biaxial (both indicate aragonite)

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[1] The sample number series includes all of the following parts: DINO-375 indicate that the samples were taken from Dinosaur National Monument, PK for Paul Kosmidis or NP for Niki Schaefer, 02 represents the calendar year in which the sample was taken, and the last number in the series is the sample number.
[2] All parenthetical phrases are elaboration on original notes and not from time of observation.

6. DINO-375 PK-02-03
   Expitaxial Crystals with Becky Balls on Top
   - Rhombohedral cleavage on N-texture
   - Could not find interference figure for either mineral
   - "Flash Figures"

7. DINO-375 NP-02-21
   Carbonate Ball with Expitaxial Crystals on Top
   - Calcite crystals, rhombohedral cleavage
   - Micritic section is micritic with calcite and another veining
   - Need an X-ray (to identify)

8. DINO-375 PK-02-14
   Micritic?
   - It appears to be micrite
   - Mineral bits- no cleavage seen
   - Brown mineral seen with polarizing (lens on)

9. DINO-375 JER-02-01
   Silcrete Sample
   - Brown mineral seen with polarizing light
   - Some micritic textures
   - Major mélange of stuff

10. DINO-375 PK-02-13
    Niki Texture and Paul Weathering (texture)
    - Pale yellow is spots- quartz?
    - Rhombohedral cleavage seen in spots towards top of thin section
    - "Chopped up" appearance, cleavage not as easily seen

11. DINO-375 PK-02-09
    Expitaxial Crystals with Micritic Center
    - I think they only took a thin section of the micritic part

12. DINO-375 PK-02-04
    Tuffacious?
    - Calcite vein [rhombohedral (cleavage in) vein]
    - Looks micritic
    - Brown mineral (present)
    - Compared it with tuff thin section and they do not look similar at all

13. DINO-375 PK-02-05
    No Notes About Sample (in field book for reference- possibly is Paul's field book)
    - No interference figure