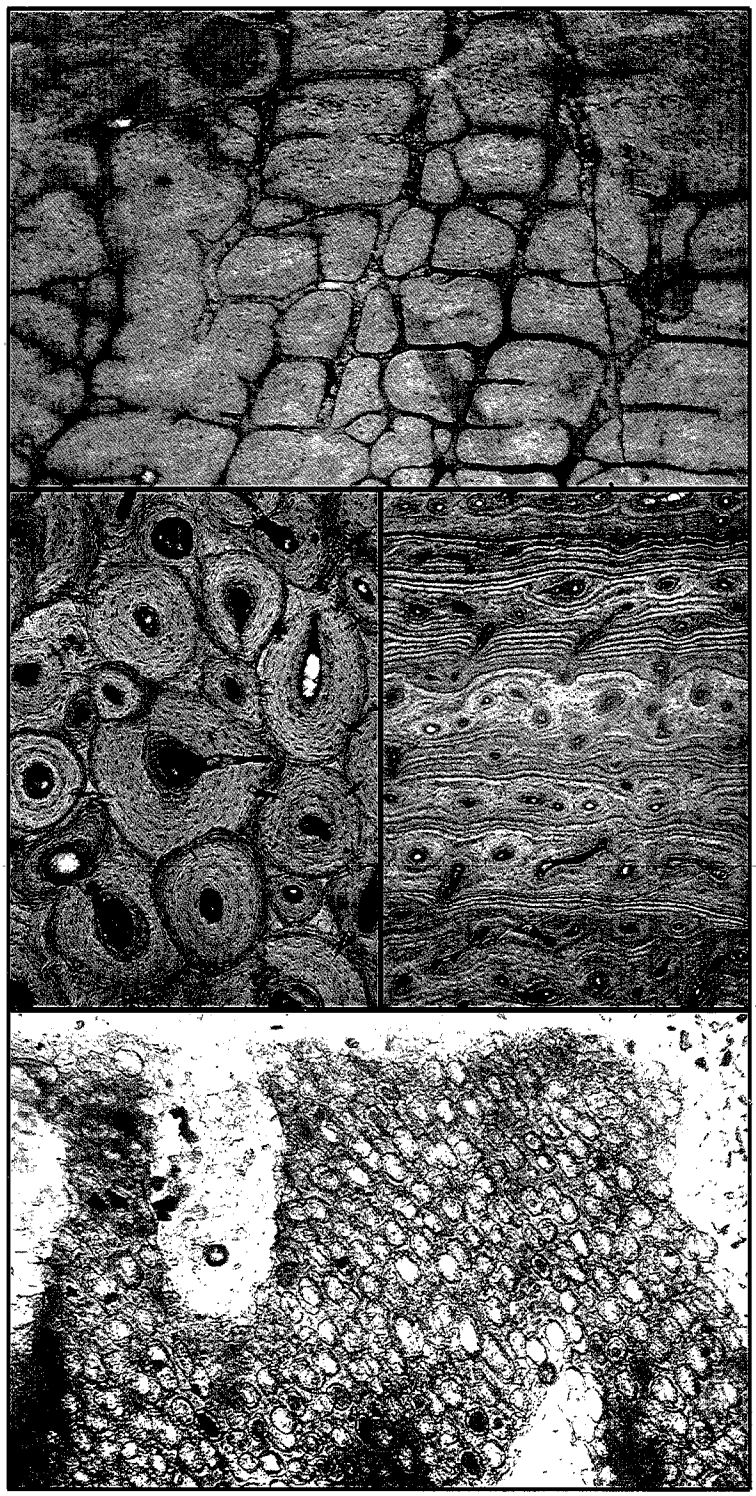
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



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Cover: Fossil tissues from Cleveland-Lloyd allosaurs.

Top: Uniform periosteal bone with reticulating primary vascular canals, some of which are aligned longitudinally (left to right) and radially. Caudal vertebra, centrum; longitudinal section; C-LQ 087.

Middle left: Vascular zonal bone with lamellated annuli and non-lamellated zones. Local development in a right radius; transverse section; C-LQ 109.

Middle right: Dense Haversian bone showing secondary osteons, secondary vascular canals at their centers, and the concentric arrangement of osteocyte lacunae (small dark bodies) around them. Dorsal rib; transverse section; C-LQ 106.

Bottom: Calcified cartilage showing the rounded form of the spaces (lacunae) once occupied by chondrocytes. Proximal end of a fibula; longitudinal section; C-LQ 014.

In all sections the direction of the external surface is upward.

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The Cleveland-Lloyd Dinosaur Quarry, Emery County, Utah: A U.S. Natural Landmark (Including History and Quarry Map)

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ABSTRACT

The Cleveland-Lloyd Dinosaur Quarry has yielded a diverse, late Jurassic fauna that has elicited international public and scientific recognition. Nevertheless, relatively few articles, especially ones that are widely accessible, have been published concerning this quarry. The present paper is intended as a comprehensive review of all pertinent work, and it details current views of the quarry and its fauna. The accompanying quarry map is the most extensive record of its kind, representing a compilation of all mapping data for the Cleveland-Lloyd Quarry to date. A bibliography of published works pertaining to this quarry has also been included.

Scientific collecting first began at the quarry in 1929, continued to 1931, and then was conducted on an intermittent basis until 1990. Four separate institutions served as the directing agency during various years. The first and major agency was the University of Utah, followed by Princeton University, the Antiquities Section of the Utah Division of State History, and then Brigham Young University. Combined efforts produced nearly 10,000 excavated and cataloged bones. Of these, approximately 80% represent *Allosaurus fragilis*. Type specimens of two other carnivorous taxa, *Marshosaurus bicentesimus* and *Stokesosaurus clevelandi*, also come from the Cleveland-Lloyd Dinosaur Quarry. In total it has produced eleven species of dinosaurs, one of chelonian, four of gastropods, and three of charophytes.

LOCATION AND SETTING

The Cleveland-Lloyd Dinosaur Quarry lies in north central Emery County, Utah, which is in the east central part of the state (Fig. 1). In map distances the quarry lies about 32 km (20 miles) south-southeast of the city of Price in Carbon County and 13 km (8 miles) east of the small town of Cleveland in Emery County. Physiographically it lies at the northern end of the San Rafael Swell, just northwest of Cedar Mountain and on the northern flank of Cottonwood Wash. The area surrounding the quarry exhibits sparse desert vegetation. Rock exposures dominate the setting (Fig. 2). The Cleveland-Lloyd Quarry is approximately 1753 m (5750 ft) above mean sea level. It is plotted on the U.S. Geological Survey Cow Flats 7.5-Minute Quadrangle map in section 21, Township 17 South, Range 11 East. The quarry and surrounding region are administered by the United States Department of the Interior, Bureau of Land Management. In 1967 the Cleveland-Lloyd Dinosaur Quarry was designated a U.S. Natural Landmark.

INTRODUCTION AND BACKGROUND

This paper primarily presents a review of all pertinent data that relate to the Cleveland-Lloyd Dinosaur Quarry and includes a large-scale, detailed quarry map. Additionally, it includes updated information on field and research work pertaining to this quarry (Table 1). The Cleveland-Lloyd Quarry ranks among the most important dinosaur quarries in North America as well as the world for the quantity, quality, and significance of its vertebrate fossils.

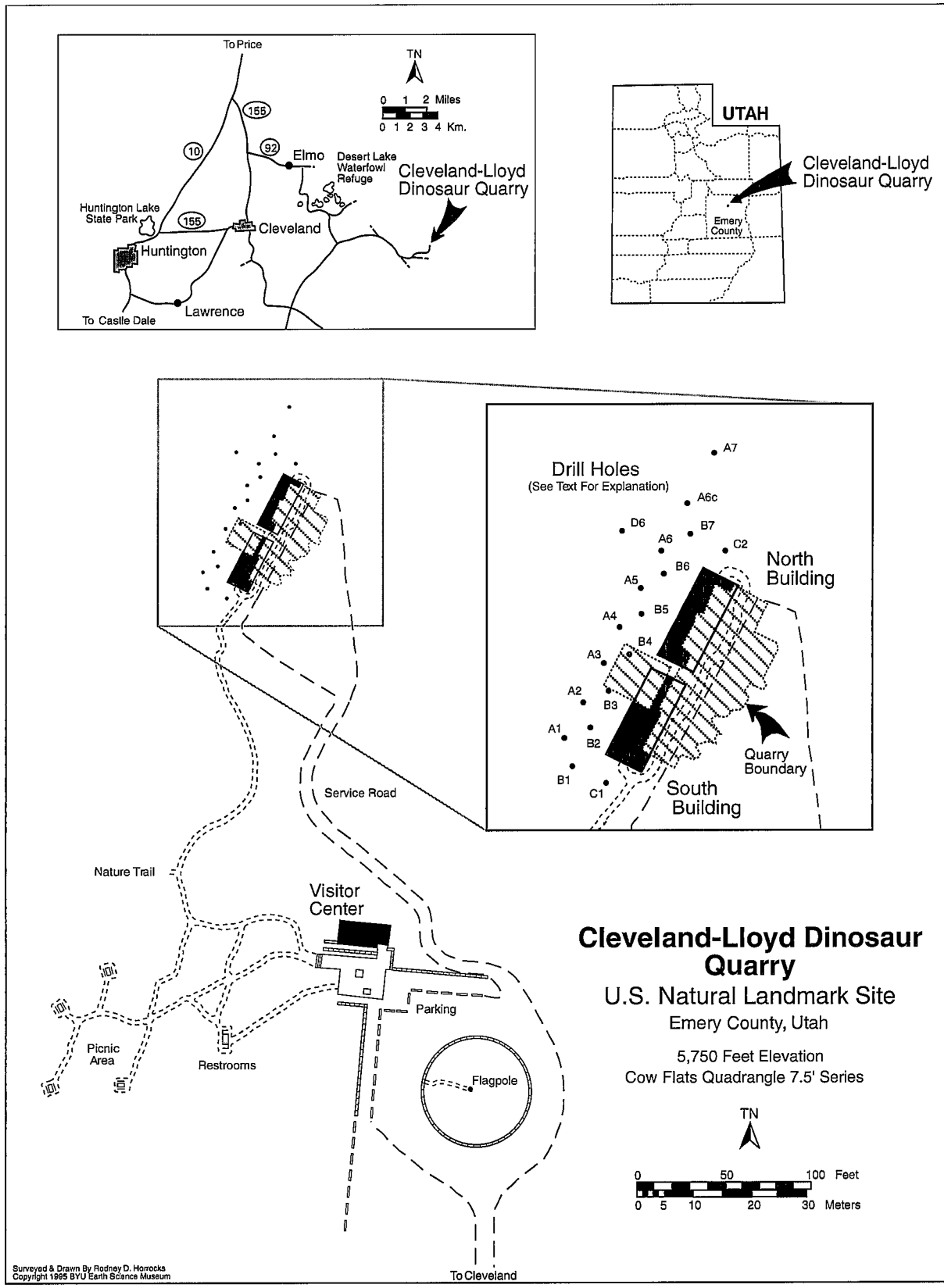

Figure 1. Index map of the Cleveland-Lloyd Dinosaur Quarry showing quarry boundary, North and South Buildings as well as the Visitor Center.

Figure 2. Helicopter view looking west at the Visitor Center (left) and quarry buildings (right).

To date, approximately 10,000 elements have been collected and cataloged. It is estimated that 75% of the collected specimens have been prepared.

The first reported scientific excavation at the Cleveland-Lloyd Quarry began in the summer of 1929 by Golden York working under the direction of Dr. Frederick J. Pack, head of the Department of Geology, University of Utah (Pack, 1929). Prior to this time, Dr. Pack had instructed Mr. York to search for dinosaur bones in the San Rafael Swell of Emery County in the same Morrison Formation stratum that yielded them at Dinosaur National Monument in eastern Utah. York, probably with the assistance of local residents, discovered a site 13 km (8 miles) east of the town of Cleveland (Stokes, 1992, pers. comm.). Because fossil bones were exposed at the surface when York located the site, it is assumed that bone had been picked up by casual collectors for years before careful scientific collecting began. Early collecting at the quarry under York's supervision was limited. Records show that 949 specimens were collected over a three-year period, ending in 1931.

Dr. William Lee Stokes, who was raised in the town of Cleveland, Utah, had been made aware of the local fossils by his father, William P. Stokes, at about the same time the University of Utah began its collecting there. The senior Stokes in turn had been told of the site by a cowboy friend, Lou Buffmeyer (Stokes, 1992, pers. comm.). Stokes did not, however, have the opportunity to scientifically excavate fossils from this site until he became a graduate student in geology at Princeton University. Under the guidance of his major professor, Dr. Glen L. Jepsen, and with the limited financial backing of a philanthropic lawyer and Princeton alumnus from Philadelphia, Malcolm Lloyd, Jr., Stokes returned to Utah to collect dinosaurs. With a small crew he worked the quarry for three successive summer field seasons from 1939 to 1941.

William (Willy) Warner and John Boyd, both undergraduate students majoring in geology at Princeton University, came to the developing Cleveland-Lloyd Dinosaur Quarry in the summer of 1941 to rendezvous with their geology professor, Dr. Glen Jepsen. Along with a Brigham Young University geology student, Don Hansen, and Lee Stokes and his brother, Grant, they made up that summer's field crew. Also joining this group during the 1941 season for a short visit was their sponsor, Malcolm Lloyd, Jr. During this field season several photographs (Figs. 3–10) were taken by John Boyd (Fig. 11)—the earliest photos available of the Cleveland-Lloyd Dinosaur Quarry.

Approximately 1,500 bones were collected during this interval (Stokes, 1991, pers. comm.). Of these bones collected for Princeton University, nearly 1,000 were returned to Utah in 1964, when they were purchased by the University of Utah Cooperative Dinosaur Project (see below). At the suggestion of Dr. Jepsen, Stokes recognized Mr. Lloyd for his financial support of dinosaur collecting at the quarry by including his name in the official quarry

Table 1. A Summary of Collecting Activity at the Cleveland-Lloyd Dinosaur Quarry

Season	*UUVP Numbers	Specimens Collected	Directing Institution
1929–31	30-001–30-949	949	University of Utah
1939–41	40-001–40-450	450	Princeton University
1960	001–1520	1,520	University of Utah
1961	001–1844	1,844	University of Utah
1962	2001–2980; 3000–4038	2,019	University of Utah
1963	4050–5050	1,001	University of Utah
1964	5129–5624	496	University of Utah
1975	10000–10378	379	Utah Division of State History
1976	10379–10591	213	Utah Division of State History
1978	10592–10758	167	Utah Division of State History
1979	10759–10871	113	Utah Division of State History
1980	10872–10897	26	Utah Division of State History
1987	11501–11584	84	Brigham Young University
1988	11585–11626	42	Brigham Young University
1989	11627–11681	55	Brigham Young University
1990	11682–11688	7	Brigham Young University

*University of Utah Vertebrate Paleontology Collections
(Although this sequence of numbers has been continued in cataloging to the present time, specimens are not all located in the paleontological collections at this institutuion.)

title. However, he also wanted to recognize his hometown of Cleveland, Utah; hence the appellation, Cleveland-Lloyd Dinosaur Quarry.

A major goal of Mr. Lloyd was to provide his alma mater, Princeton University, with a mounted dinosaur skeleton. This was not achieved until 1961, when a mounted *Allosaurus* skeleton was unveiled in Princeton's Guyot Hall. It remains on exhibit to this date. When Princeton's major vertebrate fossil collections were transferred to Yale University in the 1980s, most of the Cleveland-Lloyd material was included (Mary Ann Turner, 1991, pers. comm.). However, there is no complete curation data available for these specimens at this writing. Of the bones collected under Stoke's direction while he was a student at Princeton, only those in the exhibit skeleton and a few in the Geology Department's teaching collection remain there at the present time.

After the 1941 Princeton field season, it was not until 1960 that authorized collecting was renewed at the Cleveland-Lloyd Quarry. It is assumed, though, that during the 19-year period of official inactivity, some unauthorized collecting occurred. In 1960, Stokes, then head of the Department of Geology at the University of Utah, devised a plan to again collect dinosaurs at the quarry (Fig. 12). With James H. Madsen Jr., then curator of the Earth Science Museum at that university, the University of Utah Cooperative Dinosaur Project was organized (Stokes, 1985; Madsen, 1987). This endeavor was undertaken to finance collecting at the Cleveland-Lloyd Quarry and to insure that participating museums and universities would be provided with dinosaur research specimens and/or exhibit material of their choice. A coincidental project goal was to assemble a significant research collection at the University of Utah. Quarrying operations began under the direction of L. Grant Stokes in 1960. In 1961 James H. Madsen Jr. (Fig. 13) assumed direction of fieldwork and continues to direct field and research activities to the present time.

The Cooperative Dinosaur Project continued for five successive summers, ending in 1964 (Madsen, 1987). Funding from this project provided all the money for operating the Cleveland-Lloyd Dinosaur Quarry and the only money for preparation of the fossils and construction of the mounted dinosaur specimens in the Utah Museum of Natural History. Potential sources for financing the collection, preparation, and research of valuable fossils from the quarry, such as the National Science Foundation, the National Geographic Society, and the University of Utah, were regularly petitioned for funding by those directing the project. However, these requests were repeatedly denied. The University of Utah did provide housing and laboratory space for the Cleveland-Lloyd collection from 1960 to 1976, and this consideration was repaid by prepared and mounted exhibit specimens from the quarry that went to the University of Utah Museum of Natural History (Madsen, 1987).

Collecting at the Cleveland-Lloyd Quarry was most intensive in the five summer field seasons from 1960 through 1964 (Figs. 13–17). Nevertheless, a significant number of

Figure 3. View looking east of the Princeton University excavation at the Cleveland Lloyd Dinosaur Quarry and surrounding terrain, 1941. Quarry marked by arrows.

elements have been collected at irregular intervals since then. This intermittent collecting began in 1975, and excavations were usually of short duration lasting a few days to two or three weeks each summer. Although no organized collecting was done at the quarry from 1965 to 1974, there was some activity. By 1966, plans were underway to designate the Cleveland-Lloyd Dinosaur Quarry a Registered U.S. National Natural Landmark (one level below a National Monument) under the Historic Sites Act of 1935. By 1967 this plan became a reality. The lead agency charged with administering the quarry has always been the U.S. Department of the Interior, Bureau of Land Management. Also in 1967, construction began on a small visitor center with attendant facilities (Figs. 18 and 19). This visitor center was dedicated and opened to the public in 1968.

In 1975 limited collecting and maintenance at the quarry was resumed under the direction of Madsen, which continued through the following summer as well (Fig. 20), mainly to prepare the site for installation of two Butler buildings for protective cover for future excavations and security for the *in situ* exhibit (Fig. 21). The excavations also served as a paleontology field laboratory (Madsen and Stokes, 1977a). Limited collecting took place in 1977. From 1975 to 1980, institutional sponsorship was by the Antiquities Section of the Utah Division of State History.

Figure 4. View looking south of the Princeton University excavation at the Cleveland Lloyd Dinosaur Quarry campsite, 1941.

As Utah's first state paleontologist, Madsen continued directing the limited collecting and research activities at the Cleveland-Lloyd Quarry. Beginning in 1977, some of the curated collection of Cleveland-Lloyd fossils was transferred to the Crane Building in Salt Lake City, which temporarily housed the Utah Division of State History. In 1981 essentially all the collection not on exhibit was assembled at a single place, the Denver and Rio Grande Building in Salt Lake City, the then new and current home of the Utah Division of State History.

In 1987 the Earth Science Museum at Brigham Young University was issued a collecting permit by the Bureau of Land Management for the Cleveland-Lloyd Quarry. At approximately the same time, the *Allosaurus* fossils, constituting the largest part of the collection, along with some *Camptosaurus*, *Stegosaurus*, and unprepared materials, were loaned to Brigham Young University. These specimens are housed at the BYU Earth Science Museum, where they have been utilized in a variety of studies by many scientists on an international basis. The Earth Science Museum personnel conducted brief collecting and maintenance work at the Cleveland-Lloyd Quarry during the summers of 1987 through 1990 (Fig. 22). Fossils collected during these years were cataloged and curated into

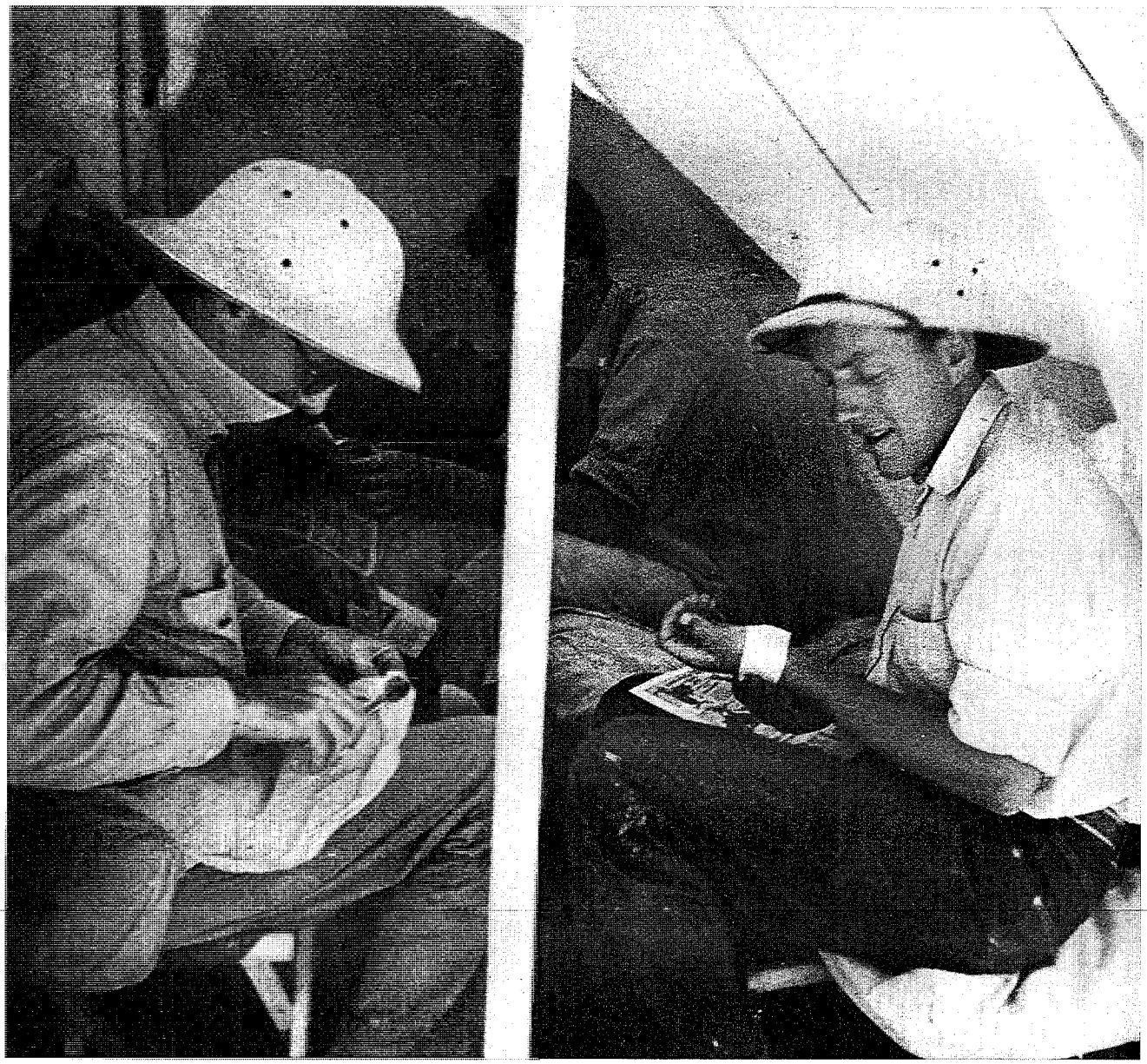

Figure 5. Personnel of the Princeton University excavation at the Cleveland Lloyd Dinosaur Quarry, from left to right: Dr. Glen Jepsen, Don Hansen, Grant Stokes, 1941.

the BYU Earth Science Museum collections. The remainder of the available Cleveland-Lloyd collection was transferred from the Utah Division of State History to the University of Utah Museum of Natural History in 1990. Completion of the transfer took place under an order from the Utah State Office of the BLM. Records of specimens collected at the Cleveland-Lloyd Dinosaur Quarry are presently available at both the University of Utah Museum of Natural History and at Brigham Young University. It should be noted that the Cleveland-Lloyd Quarry excavations and the University of Utah Cooperative Dinosaur Project are unique in that they have essentially paid their own way. No significant public funds were used in the removal and preparation of the abundant fossils.

CHRONOLOGICAL MAPPING HISTORY AND FIELD METHODS

Mapping at the Cleveland-Lloyd Dinosaur Quarry, which began in 1939, shares a similar history with other large Jurassic quarries. Like the Howe Quarry in Wyoming

Figure 6. Princeton University geology undergraduate student and quarry worker Willy Warner, 1941.

Figure 7. Activity in the quarry, summer of 1941, left to right: Glen Jepsen with pith helmet, Don Hansen with dark hat, Lee Stokes bending over being watched by Malcolm Lloyd with back to camera, Grant Stokes in middle wearing dark shirt and pith helmet, Willy Warner in white shirt, and Richmond Reed to the far right. The view is looking westerly toward the hill.

(Brown, 1935), Dinosaur National Monument in Utah (Chure and McIntosh, 1990), and the Dry Mesa Quarry in Colorado (Miller and others, 1991), the Cleveland-Lloyd Quarry is a concentrated deposit of randomly scattered or partially articulated remains of many individual dinosaurs (Fig. 23). The scattered nature of the bones, together with the number of taxa and individuals represented, made large-scale mapping techniques necessary (Fig. 24). Because several quarry workers did the mapping over the many years of collecting, some with little experience, errors were made. While some of the mistakes have been corrected on the accompanying quarry map, it was not possible to correct them all. Typical errors were in scaling, orientation, and vertical control. Despite these deficiencies, the completed Cleveland-Lloyd Quarry map, together with the specimen catalog, is an impressive record, second only in importance to the specimens themselves.

As mentioned above, the first excavations at the Cleveland-Lloyd Dinosaur Quarry were conducted by Golden York under the direction of Frederick J. Pack in 1929; and in spite of the collecting experience of York, who had worked earlier at Dinosaur National Monument, there was apparently no map compiled nor other record kept of this earliest scientific collection at the quarry. Based upon field notes taken during the University of Utah Cooperative Dinosaur Project in 1962 and 1963, it appears that York's excavation was possibly located in squares C-22 through C-25, D-25, and E-25 on the modern grid (see accompanying quarry map).

The 1939–1941 Princeton University summer excavations (Fig. 13), organized and led by William Lee Stokes, opened new ground. Apparently this excavation was started about 12 m (40 ft) to the southwest of the University of Utah's earlier excavations (Stokes, 1989, pers. comm.). Of the approximately 1500 elements collected for Princeton, more than 950 were sent to the University of Utah in 1963. Only 450 of these received UUVP numbers after their acquisition.

Beginning with the first bone discovered, a *Camptosaurus* ilium, crude planimetric maps were prepared of the Princeton excavation. By interpreting 1940 photos, the established grid used appears to have been 2 by 2.75 yds (1.8–2.5 m). These mapping units were laid out perpendicular to the edge of the nearby hillside instead of being oriented to magnetic north. Each unit was marked with wooden corner stakes and given a Roman numeral identification, starting with numbers I and II in the southeast corner.

L. Grant Stokes, younger brother of the project director, did most of the mapping. He plotted the fossil bones by visually transforming his staked square to fit the size or shape of the paper he was using for a particular unit. Because different sizes of paper were used, bones that fell

Figure 8. Malcolm Lloyd, benefactor of the Princeton Dinosaur Expedition.

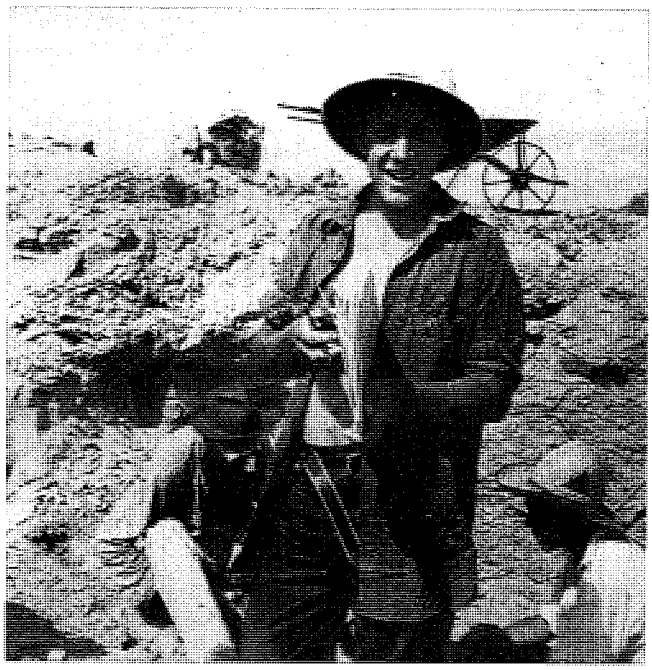

Figure 9. Grant Stokes in the quarry.

across grid lines did not match when the drawings were laid side by side. Although field numbers were assigned to the bones and recorded on the maps, the numbering was repeated at each arbitrary excavation level within each mapping unit. This procedure resulted in duplication of some numbers. No field maps have been found for the last two units excavated, numbers XI and XII. These maps were either lost or never prepared. The unrecorded units probably represent at least part of the 1941 season. In 1963, previously compiled maps were combined onto a single sheet by Madsen, who arranged them in reference to the two remaining index maps originally compiled by Grant Stokes from 1939 to 1941.

Sometime between 1941 and 1960, a road was bulldozed across the southern margin of the Cleveland-Lloyd Quarry, destroying or damaging an estimated 1,000 bones. Apparently the road was made to fulfill assessment requirements for a uranium claim (Glenn Ungerman, 1991, pers. comm.). Whenever this graded section was encountered during subsequent excavations by the University of Utah Cooperative Dinosaur Project, numerous fossil bone fragments were recovered, many of which were matched with previously collected ones.

Heading the Cooperative Dinosaur Project, William Lee Stokes returned to the quarry in May of 1960. The fieldwork that year was supervised by his brother, Grant, who again took over mapping duties (Stokes, 1990, pers. comm.). With the help of Grant, Madsen set up a 1-yard-square grid system along the general alignment of the 1940 excavation. The corners of each square were staked with temporary markers, chaining pins, or wooden stakes placed in sand-filled cans. The new quarry baseline was at N 42° E. The squares along the baseline were numbered, whereas those along the meridian were assigned letters beginning with "A" and "1," respectively, at their intersection. Specific squares were referenced by coordinates from the intersecting letter and number designations. For example, grid (A-1) is in the southeastern square (Fig. 25). This same system is used at the present time. Madsen drew his 1960 plan map on a 55-×-20-inch piece of graph paper, at a scale of 1 ft to the inch. Although the 1,520 specimens collected during the 1960 season were mapped and recorded, their numbers were not written on the map with the individual bone outlines. The recovered specimens were numbered sequentially in a catalog, UUVP 001 through 1520, and were given a grid coordinate assignment in accordance with their location (e.g., A-2). Since these map references were recorded in the catalog, it is possible to locate some of the more diagnostic elements from the 1960 season on the map.

During the summer of 1961, all 1,844 bones collected that field season were plotted and numbered by Madsen. The first bone collected in 1961 was numbered UUVP 001. During routine curation and preparation, a prefix

Figure 10. Don Hansen.

Figure 11. John Boyd, who took a series of photos, Figs. 3–10, in the summer of 1941.

was attached to the catalog numbers assigned to each element from the two earlier excavations. The bones collected during the University of Utah excavations from 1929 to 1931 were given a prefix of "30," with catalog numbers listed from 30-001 to 30-949. The bones collected during the Princeton excavations were assigned a prefix of "40" and received the catalog numbers 40-001 to 40-450. This numbering was done for curation purposes and in the slim hope that some of the bones in the collection could be correlated with drawings from the Princeton map. When the excavation continued southwest of the quarry beyond the 1961 meridian, the additional tiers were designated as 2-1, 3-1, etc. In 1962, when the excavation continued southeast of the quarry baseline, the squares were designated as A′, B′, etc. (see Fig. 25).

The 2,019 bones collected during the 1962 season were numbered UUVP 2001 through 2980 and UUVP 3000 through 4038, following a numerical rather than a chronological sequence. Each bone also received a grid position, obtained by dividing each 1-yard square into nine 1-ft squares. Although the grid did not follow a north-south alignment, these sections were laid out as if the quarry meridian were on a north-south line. These labels were NW, N, NE, W, C (center), E, SW, S, and SE (Fig. 25). After the 1962 season this type of additional labeling was abandoned, but was reinstated again starting with the 1975 season. In 1963, 1,001 bones were collected (UUVP 4050–UUVP 5050). During this season Grant Stokes resumed mapping, and Madsen was reassigned to laboratory preparation and curation by Wm. Lee Stokes. Only 496 bones were collected in 1964 (UUVP 5129–5624). Fewer bones were collected that season because a more detailed mapping technique was introduced. Stokes began the 1964 season by installing a 3-by-3-ft cement block as a datum point. A 4-ft-long rod, which acted as a platform for a Brunton compass, could be screwed into a plate in the center of the cement block (still in place). This datum point was installed to the northeast of the present North Building (Fig. 25). The datum was used to maintain vertical control and as a permanent reference point. Using a Brunton compass from this point, a standard azimuth reading was taken to the proximal and distal ends of each bone found. In addition, using a stadia rod, a vertical measurement was recorded from the highest point of each element. Since that time, all mapped specimens have had a vertical measurement recorded in addition to the horizontal ones.

Between 1960 and 1964, the field maps were constructed to the same scale as Madsen's 1960 map, 1 ft to the inch (Fig. 25). However, subsequent maps were compiled by several individuals, and errors were made, recognizable in unusual fossil bone concentrations along grid lines and in multiple assignments of the same catalog number to unrelated elements. The artificial concentrations, which are readily identified on the quarry map, may be attributed to

Figure 12. Lee Stokes examining a sauropod ilium in the quarry, ca. summer 1961.

two factors: first, errors in laying out the grid from year to year; and, second, failure to plot elements collected next to a square that had been previously mapped. From 1929 to 1985, at least 3,331 collected specimens were either unmapped or not numbered on the maps. Those that were not mapped included UUVP 30-001 to 30-949, and 10900 to 11310. It should be noted that some of these bones represent Cleveland-Lloyd fossils supplied to various institutions, fossils that were later reassigned UUVP numbers by Madsen for curation purposes. Many of these same elements had preexisting numbers on them. When bones were exchanged during the assembly of skeletons under the University of Utah Cooperative Dinosaur Project, the original numbers were sometimes lost. Another common error found on the field maps was the multiple assignment of UUVP numbers to more than one element. Although this was purposefully done for closely associated elements of the same individual, some unassociated elements also inadvertently received the same number.

In preparation for the dedication of the completed Cleveland-Lloyd Dinosaur Quarry Visitor Center, a Bureau of Land Management (BLM) survey crew prepared a contour map of the area in August of 1966. As part of the 1967 dedication, Madsen supervised a token collection of fossil bones. Although a sketch map was made at the time, it cannot now be located. Also in 1966, one of Madsen's assistants, Megan Anderson, compiled a 7-by-4-ft plan map of fossils collected in the 1960–1964 seasons. She resketched each bone at the same scale as shown on the field maps. If a bone could not be identified from the field maps, she used a description of the element from the field notes. On her map she adjusted some of the artificial grid concentration problems by filling in the blank sections with bones transferred from nearby, densely concentrated areas.

Following the 1964 cessation of the University of Utah Cooperative Dinosaur Project, fieldwork of consequence was not resumed at the quarry until 1975. During the 11-year hiatus, the UUVP numbers 7000–9999 were assigned to non–Cleveland-Lloyd fossils. In 1975 Madsen reestablished the quarry grid with a series of measurements from an "X" cut on a large nearby boulder that had not been moved by the bulldozing in 1964 (grid location K-16, NE). This linear excavation was necessary to prepare the quarry for construction of the two steel Butler buildings that

Figure 13. University of Utah Cooperative Dinosaur Project at the Cleveland-Lloyd Dinosaur Quarry—1960 opening of quarry; James Madsen supervising bulldozing.

were to be erected over part of the unexcavated areas. The foundations or curtain walls for these buildings required a trench, 2 × 3 × 90 ft long, to be dug along the east side of the buildings. Foundations were required only for the east walls because the west walls were to be placed directly on top of the limestone cap that covers the fossiliferous deposit. Madsen collected 379 bones during a two-week period. These elements are numbered UUVP 10000 through 10378. Although some of the unprepared bones were not mapped, the coordinates of their positions were recorded. It is anticipated that the map will be updated when those bones are eventually prepared. There were also many bones collected in blocks of matrix or as fragments in the digging of the foundations for the two buildings. They have not yet been prepared or cataloged, nor were they mapped.

In 1976 Madsen collected 213 bones during a one-week period immediately prior to the erection of the two buildings over the quarry site (UUVP 10379–10591). The Butler buildings were aligned parallel to the 1960 baseline, and the southeast corner of the North Building was set at the corner of grid square I-15. The grid corners that fell along the walls were permanently marked on the steel beam supports inside the building, and the corners of the remaining squares were identified by tags attached to wires that ran the length of the building. The southeast corner of the South Building did not coincide with a corner grid but fell within square I (6-1). Because the location of the Princeton excavation had not been positively located at the time, the South Building may have been inadvertently placed over part of it. The Princeton quarry location was provisionally determined in February of 1990 by Horrocks and Mr. Kenneth Stadtman using photos taken in 1941 and remaining landmarks. However, their placement depends upon the presumed scale of the Princeton map, which was estimated from the photographs. (When Lee Stokes reviewed the manuscript for the present article, he stated that the Princeton quarry's location was immediately outside the South Building at its southeast corner.) A more certain placement will have to await an eventual excavation where the South Building now stands. There was no fossil collection of record at the Cleveland-Lloyd Quarry in 1977.

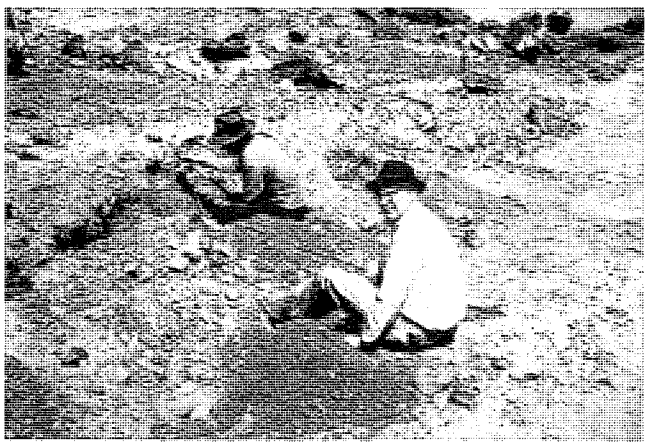

Figure 14. University of Utah Cooperative Dinosaur Project at the Cleveland-Lloyd Dinosaur Quarry. William Lee Stokes, right; L. Grant Stokes, left, 1960.

In 1978, as a consequence of heavy rains and a resulting flood that covered the quarry surface under the steel buildings with mud, Madsen removed and mapped 167 bones (UUVP 10592–10758). Each of these fossils was given an accession number in the field that was composed of the last two digits of the year followed by consecutively assigned numbers. For example, the third bone collected in 1978 was given the number 78-003. In addition to the accession number, an elemental description, taxon, and grid location for each fossil were also recorded in the field book.

The 1979 season consisted of a limited excavation, with 113 elements removed (UUVP 10759–10871). In 1980 Madsen prepared a display and installed a catwalk for the Bureau of Land Management in the North Building. While exposing the larger elements for display, he removed 26 bones (UUVP 10872–10897). Starting with that season, the elevation data was also recorded again.

In 1982, in order to determine the remaining extent of the fossil deposit, the BLM had 18 holes drilled to a depth of 20 ft (6.1 m) on the west side of the two Butler buildings (Fig. 26). The results suggested that these buildings

Figure 15. University of Utah Cooperative Dinosaur Project at the Cleveland-Lloyd Dinosaur Quarry. Layout for grid system with Dwayne Stone, 1962.

Figure 16. University of Utah Cooperative Dinosaur Project at the Cleveland-Lloyd Dinosaur Quarry. Dwayne Stone, foreground, with group of quarry visitors, 1962.

could be moved to the west once the deposit has been completely excavated under the current buildings. It has been estimated that as many as 9,000 bones may remain unexcavated (Madsen, 1987).

During the early 1980s, 91 elements that had received numbers from the 7000 series were reassigned (UUVP 11311–11401). In addition, 100 specimens that had no number were assigned UUVP numbers 10900 through 10999.

Excavations resumed at the quarry in 1987, when the BLM issued Brigham Young University a permit to participate in a working exhibit in the North Building. Stadtman directed field excavations, and Horrocks mapped the fossils as they were uncovered. The purpose of the excavation was to show paleontologists at work, as well as to uncover new material for display at the quarry. During the operation of this working exhibit, the BYU team collected 84 bones (UUVP 11501–11584, as well as assigned BYU numbers).

By 1988, under the direction of Madsen, all field data had been computerized with collaboration by personnel from the BYU Earth Science Museum. This record replaced Madsen's original catalog system. The following information was entered for each element: UUVP number, element, taxon, repository, standard measurements, and map grid coordinates. BYU personnel under the direction of Stadtman returned to the North Building in 1988 and collected, mapped, and cataloged an additional 42 bones (UUVP 11585–11626). They were also assigned BYU catalog numbers.

In 1989 Stadtman assumed responsibility for the mapping of the fossil bones. That year he collected 55 bones (UUVP 11627–11681). The fossils also received BYU numbers. Because of uncertain curation plans for the entire Cleveland-Lloyd collection, only a one-day excavation was carried out during the 1990 field season. The seven specimens collected were assigned UUVP numbers 11682 through 11688, in addition to BYU numbers. During the four field seasons the BYU Earth Science Museum conducted the working display in the North Building at the Cleveland-Lloyd Quarry, a total of 188 fossils were collected.

Figure 17. University of Utah Cooperative Dinosaur Project at the Cleveland-Lloyd Dinosaur Quarry. Golden York viewing Camarasaurus *sacrum, 1964.*

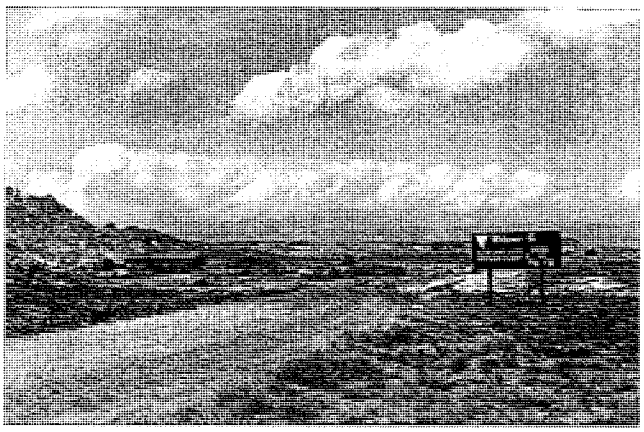

Figure 18. View looking north at the Cleveland-Lloyd Dinosaur Quarry Visitor Center, circa 1968.

Beginning with the 1929 collecting expedition by Pack and York at the Cleveland-Lloyd Dinosaur Quarry to the present time, nearly 10,000 fossils have been excavated and cataloged. Including the fossils destroyed by bulldozing a road through the quarry, those collected but unprepared, and those removed by unauthorized collecting, it seems safe to say that the quarry has yielded at least 12,000 specimens to date. Presently, there remains a significant number of unexcavated fossils under the North Building. The South Building has served as living quarters for quarry workers since its construction, and the extent of the deposit under that structure is undetermined.

MAP COMPILATION METHODS

Although the present compilation of the quarry map was initiated under a small BLM grant to the BYU Earth Science Museum, both entities have shared in the cost of producing the finished map. Horrocks obtained all preexisting Cleveland-Lloyd Quarry maps and interviewed available past participants in earlier map work at the quarry in order to make the accompanying map as accurate as possible. Using Anderson's 1967 map as a base, Horrocks divided the present map into four 30-x-48-inch quadrants. Conforming with the original field maps, a UUVP number was assigned to each element. In order to maintain historical and scientific accuracy, any element found to be out of place on earlier maps was mapped in its correct position. Because grid squares were uniformly constructed, it was necessary to draw the elements from each square as a separate unit. Since every corrected square had to be reentered on each preexisting map, much repositioning of the elements was necessary. Once the 1967 map had been redrawn and corrected, the new version was completed by adding the 1975–1990 season field maps to it. There has been no authorized collecting of record at the Cleveland-Lloyd Quarry from 1991 through 1995.

Upon completion of the pencil sheets, each was reduced to 75% of its original size. All four sheets were then scribed onto a 6-by-3-ft sheet of scribecoat. The UUVP numbers and legend were then laser printed at 1200 dots per inch and transferred to Copy Proof clear film. These were individually attached to a registered 6-by-3-ft sheet of Mylar. As a final step, every element was proofed for errors and corrected as necessary. After a negative was made from the Mylar, the final map was photographically printed on a contact board.

AGE

The late Jurassic Morrison Formation is still not well understood in terms of its age, paleoenvironments, and detailed stratigraphy. While most authors have ascribed an entirely late Jurassic age to this formation (e.g., Stokes, 1944a; Thorman and others, 1990), others have suggested that its uppermost strata, at least locally, might be early Cretaceous. This assertion is based on radiometric datings (Kowallis and others, 1986; Peterson, 1988), as well as on faunal content (Miller and others, 1991). Some early authors regarded the Morrison as entirely Cretaceous (e.g., Lee, 1915). A series of radiometric dates have been compiled for the Morrison Formation by Kowallis and others (1991). These authors also relate past differing opinions on the age of this formation. With the considerable areal extent of the Morrison at the time of its deposition (coverage of more than 1 million square km, Dodson and others, 1980), it would not be surprising to find that ages of the same

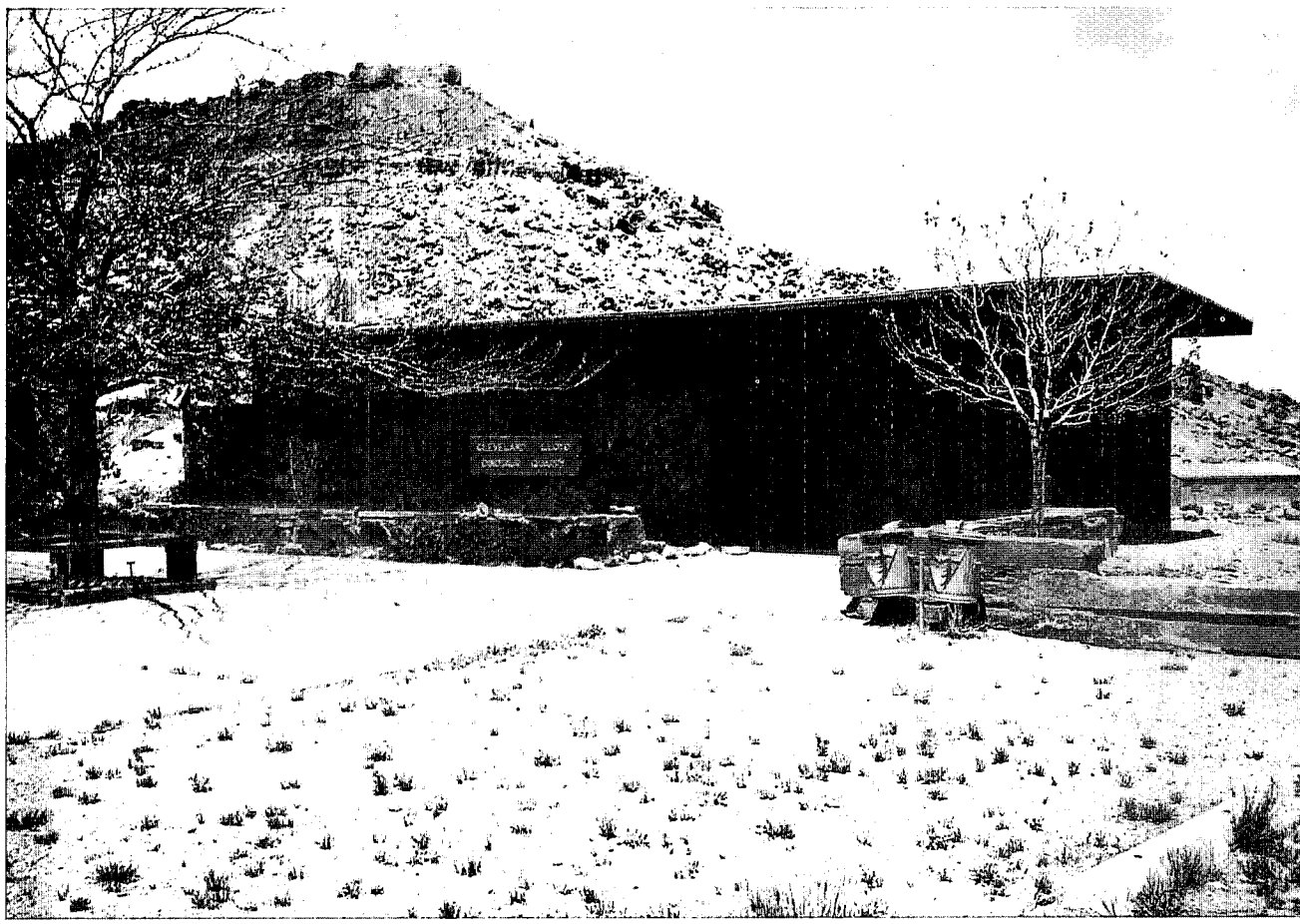

Figure 19. Close-up view of the Cleveland-Lloyd Dinosaur Quarry Visitor Center, 1992.

members were not uniform throughout their expanse. The temporal span of this formation could exceed 5 million years, based on evolution of the fauna and some of the dates reported in the above-mentioned references.

The Cleveland-Lloyd fauna has been recovered from the Brushy Basin Member, the youngest member of the Morrison Formation. Two ^{40}K–^{40}AR ages derived from biotite samples collected about 1 m above the main bone deposit were reported by Bowman and others (1986). Ages obtained were 147.2 and 146.8 Ma. According to Bilbey (1991, pers. comm.), the samples were taken a few meters west of the North Building enclosing the quarry. Another biotite sample was taken from a bentonitic lens immediately beneath the major bone-bearing layer. This sample came from a site about 30 m (98 ft) east of the quarry building. A 152 Ma ^{40}K–^{39}AR total gas age was determined from this sample by J. D. Obradovich (Kowallis and others, 1986). Kowallis (1992, pers. comm.) indicated that ^{40}K–^{40}AR ages are presently being determined based on sanadine samples, which generally are more reliable than those of biotite. A sanadine sample was taken about 1 m above the upper contact and another about 1 m below the lower contact in the Brushy Basin Member. These samples were from Cedar Mountain, about 18 km (11 miles) southwest of the quarry.

In a general comparison of faunas, the dinosaurs from Cleveland-Lloyd appear to be less advanced than those from the Dry Mesa Quarry in Colorado, which also lies in the Brushy Basin Member of the Morrison Formation. Since the thickness of the main fossil-bearing unit at the Cleveland-Lloyd Quarry does not exceed 1.5 m, the time of fossil accumulation probably was very brief, in absolute as well as in geologic terms. Its fauna, then, represents an instant in time. The Dry Mesa Quarry fauna from western Colorado also represents an equally brief time interval, but appears somewhat more advanced. This is in part based on its larger sauropods and theropods, several of them new (e.g., *Supersaurus* and *Ultrasaurus* [?=*Brachiosaurus*], exceptionally large sauropods; *Torvosaurus;* and an apparently larger species of *Allosaurus* [Britt,

Figure 20. Student group from Foothill Junior College in California who assisted in collecting fossils at the Cleveland-Lloyd Dinosaur Quarry, 1976.

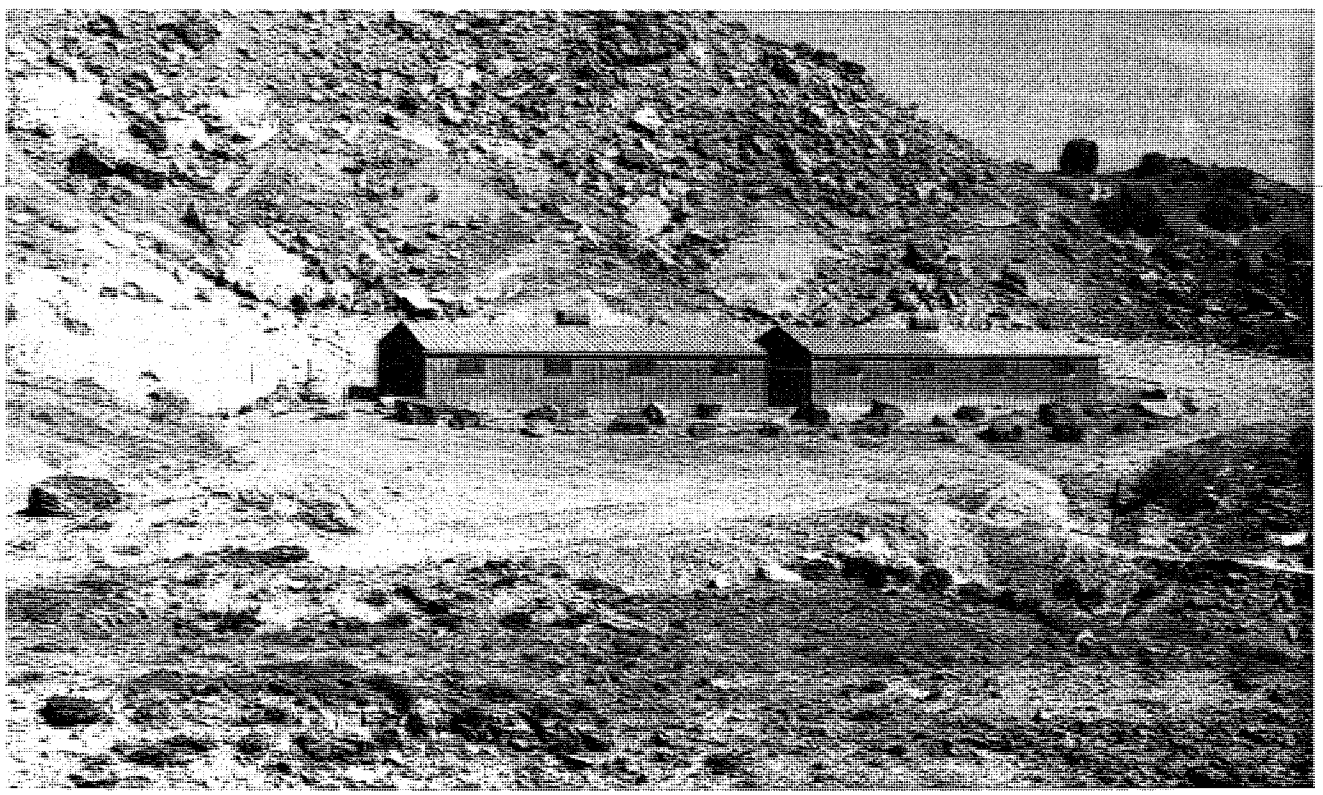

Figure 21. Protective Butler buildings at the Cleveland-Lloyd Dinosaur Quarry, looking northwest, 1978.

Figure 22. Inside North Building at the Cleveland-Lloyd Dinosaur Quarry. Dee Hall with dinosaur egg, 1987.

1991]). Also, an ankylosaurid, generally considered part of Cretaceous rather than Jurassic dinosaur faunas, occurs at Dry Mesa. While a possible nodosaur has been found at the Cleveland-Lloyd Quarry, *Haplocanthosaurus* has been positively identified from there, which, according to Bakker (1990), indicates older Morrison time. The Dry Mesa fauna seems to represent an especially young stage of the Morrison (Miller and others, 1991), whereas the Cleveland-Lloyd fauna correlates well with presumably somewhat older and typical Brushy Basin Member faunas known throughout the Rocky Mountain states (Dodson and others, 1980; Dodson and others, 1983). These authors accept a late Jurassic age for all such faunas. Based on faunal, floral, and present radiometric dating, it appears that the Cleveland-Lloyd Dinosaur Quarry is late Jurassic in age.

GEOLOGY

Despite the fact that the Morrison Formation is well-known, there are many aspects of its geology that have not been studied in detail. This especially applies to its uppermost member, the Brushy Basin (Peterson, 1988), which is renowned for its widespread and abundant dinosaur fossils. Stokes (1945) indicated that the Cleveland-Lloyd Dinosaur Quarry lies in the middle part of this member. Madsen (1976a) gave a more precise stratigraphic position, indicating that the quarry was approximately 150 ft (45.7 m) beneath the overlying Cedar Mountain Formation. Bilbey (1991), in a detailed geologic study of the quarry area, placed the top of the fossiliferous deposit at about 50 m (164 ft) below the Cedar Mountain–Brushy Basin contact, which outcrops on a ridge immediately above and west of the quarry. Her research has provided the most detailed stratigraphic and lithologic data for the locality.

Above the quarry the Brushy Basin Member of the Morrison Formation consists of typical variegated mudstones and claystones with some interbedded gray and red sandstones. Volcanic ash is interspersed in these layers. Strata in the immediate vicinity of the Cleveland-Lloyd Quarry show a slight dip to the northwest from 3° to 6°. Relatively few fossil bones have been found in the upper beds near the quarry. The main bone layer of the Cleve-

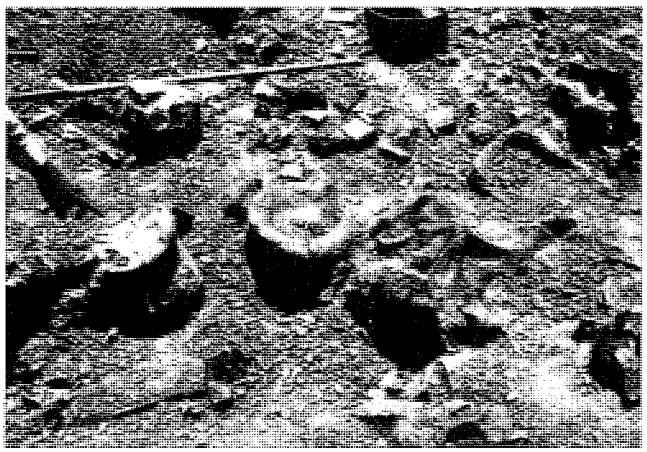

Figure 23. Scattered dinosaur bones at the Cleveland-Lloyd Dinosaur Quarry, 1978.

Figure 24. Bryce Tripp plotting dinosaur bones in situ *on quarry map, 1975.*

land-Lloyd Quarry lies immediately beneath a micritic limestone layer that blankets most of the area. The thickness of the bed varies from a few centimeters to nearly 2 m (6.5 ft) some distance from the quarry (Bilbey, 1991). In the quarry it generally ranges from about 1/2 to 1 m (1.6–3.2 ft). Some bone fragments have been recovered near the base of the thin limestone unit. Beneath this limestone lies a blocky calcareous claystone that contains the main concentration of fossils. This fossiliferous layer varies in thickness from about 0.5 to 1.3 m (1.6–4.3 ft). It is light to medium brownish gray in color. Calcareous concretion-like structures commonly occur throughout and often adhere to the fossils. Occasionally some bones are found nearly encased by calcareous nodules. This occurrence tends to be more common near the base of the fossil zone. Although all fossil quarrying has apparently taken place in this relatively thin fossiliferous bed, core drilling along the western edge of the quarry (Fig. 26) has revealed fossil bone 2 to 4 m (6.5–13.2 ft) beneath the bottom of this zone in both claystones and sandstones (Bilbey, 1991). Also, some bone, mostly fragmentary, occurs away from the quarry at lower levels in the Brushy Basin Member.

As is true for most of the Brushy Basin Member of the Morrison Formation, there is a predominance of claystones and mudstones with occasional thin layers of limestone and lenses of sandstone. According to Peterson (1988), this member represents primarily mud-flat and lacustrine environments, with some floodplain and fluvial environments being represented. The depositional record in and adjacent to the Cleveland-Lloyd Quarry seems to fit this general pattern. The limestone layer capping the quarry was probably deposited in a shallow lake. According to Stokes (1985), boggy conditions, probably along the margins of this lake, were responsible for the entrapment of dinosaurs as well as for their preservation.

FAUNA

The Morrison Formation, especially the uppermost Brushy Basin Member, contains one of the most prolific dinosaur faunas in North America, if not in the world. Study by numerous researchers for more than a century has provided much, if not most, of what is known about Jurassic dinosaurs. The dinosaur fauna from Cleveland-Lloyd has not been described or studied in toto. However, many researchers are currently working on various aspects of the collection. The most extensive study has been made by Madsen (1976a)—a study that primarily concerns the genus *Allosaurus*, which dominates the fauna. This fauna is especially significant in that it contains far more specimens of a single taxon of Jurassic carnivorous dinosaur (*Allosaurus*) than any other. There may be as many as 50 individuals represented, ranging from juvenile to old adult.

Fossil bones recovered from the Cleveland-Lloyd Dinosaur Quarry all came from the 0.5–1.3-m-thick (1.6–4.3 ft) brownish gray calcareous claystone. They are charcoal in color and, as stated by Madsen (1976a), are extremely well preserved. Both Madsen (1976a) and Stokes (1985) commented on the extensive disarticulation and scattering of bones in the deposit. This is dramatically shown on the accompanying quarry map. However, it can also be seen that a few bones are in articulation and association, especially vertebrae. Less than 50 non-dinosaurian bones are recognized. Of these only one chelonian, *Glyptops* (Stokes, 1985), has been identified.

Since the Cleveland-Lloyd fauna has not been studied in its entirety, a complete and accurate listing of its taxa to species cannot be presented here. However, most of the dinosaurs have been recognized to at least the generic level (Madsen, 1976a; Stokes, 1985). The following dinosaurs are

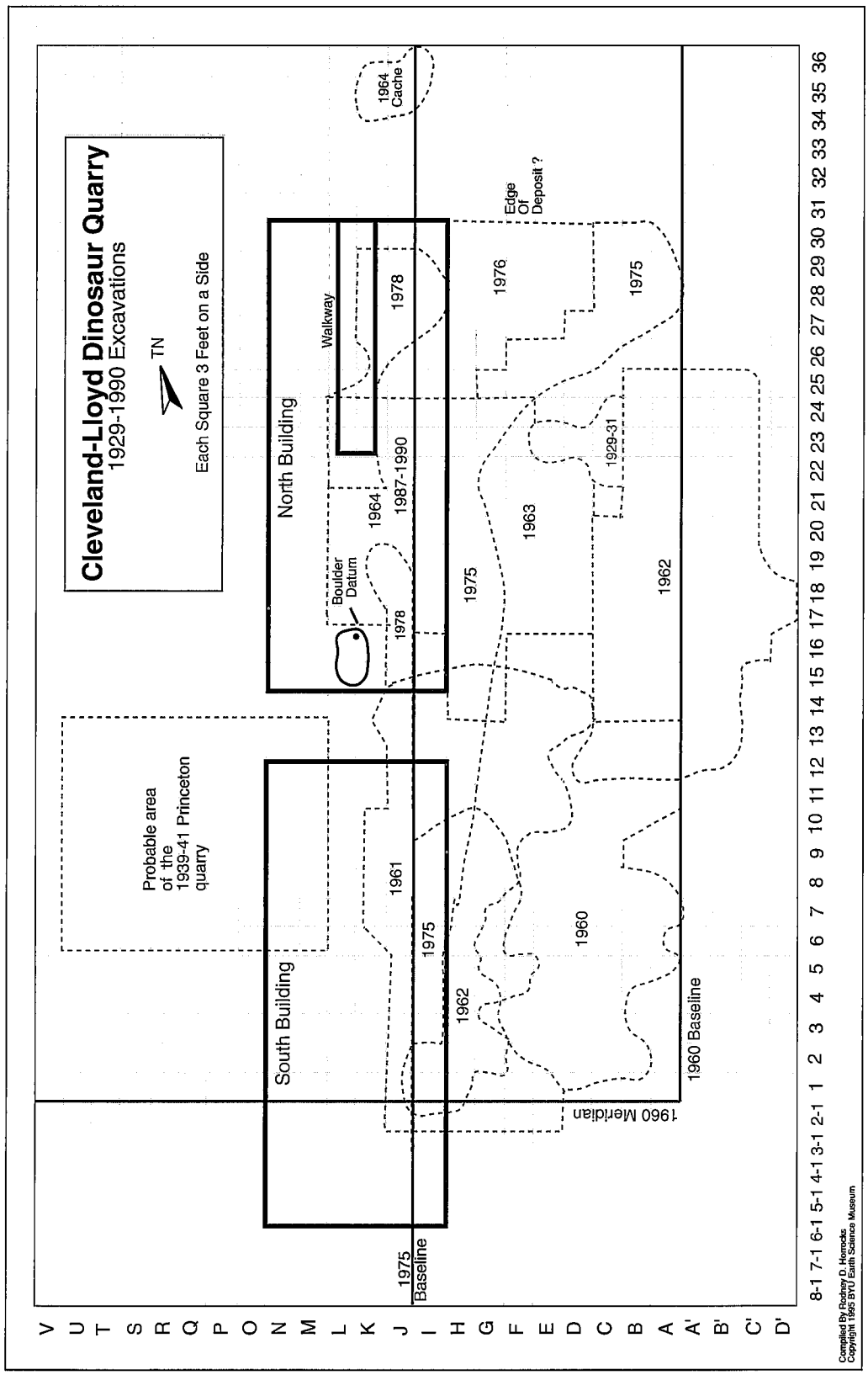

Figure 25. Map showing North and South Buildings at the Cleveland-Lloyd Dinosaur Quarry in relationship to quarrying operations conducted from 1929 to 1990.

Figure 26. Area on west side of North and South Buildings showing where 20-ft drill holes were made, looking northeast.

recognized from the Cleveland-Lloyd Dinosaur Quarry: *Allosaurus fragilis, Ceratosaurus* n. sp. (to be described), *Marshosaurus bicentesimus, Stokesosaurus clevelandi, Haplocanthosaurus* sp., *Camarasaurus lentus, Barosaurus* sp., *Amphicoelias* ?, *Camptosaurus* sp., *Stegosaurus stenops,* and a possible nodosaur. The type locality for *Marshosaurus* and *Stokesosaurus* is the Cleveland-Lloyd Dinosaur Quarry. Of the approximately 10,000 dinosaur bones collected, 6,112 have been identified at least to the generic level as indicated by available records. Almost 85% of the identified fossils represent carnivorous forms, and of those, approximately 90% are *Allosaurus*. Certainly, the Cleveland-Lloyd fossil deposit is indicative of a predator trap. Other fossils from the quarry consist of three genera of charophytes, four genera of gastropods, and one genus of chelonian, *Glyptops.*

A most interesting find occurred in September of 1987, when Dee Hall of the BYU Earth Science Museum uncovered a nearly complete dinosaur egg, *Prismataolithus coloradensis* (Hirsch, 1994), the only one found at the Cleveland-Lloyd Quarry (Fig. 22). In addition to containing a probable early-stage embryo, this egg is among the oldest known for a dinosaur from North America (Hirsch and others, 1989). While it probably cannot be determined which dinosaur is represented, the fact that the vast majority of identified fossils from the quarry are *Allosaurus* makes this genus a likely candidate.

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The list of people who have contributed to development of the Cleveland-Lloyd Dinosaur Quarry and its remarkable collection is long. We thank all involved for their efforts over the years: Megan Anderson, David Atkinson, Susan Barnhill, Trisha Bizuk, John Boyd, Mary Carey, Sam Gary Jr., John Hale, Don Hansen, Kermit Horn, Debbie Hopkins, James Howell, Tawny Isakson, Glen Jepsen, Dianna Jones, Prudence Jones, Lori Kepner, Jim Madsen, Joe Owens, Bob Randolph, Kristen Peterson, Russ Peterson, Bryce Tripp, Alan Staker, Grant Stokes, Lee Stokes, Will Stokes, Dwayne Stone, Glen Ungerman, Willy Warner, Bill White, Phyllis Wilkin, Jack Winkler, Ann Wissler, and Golden York.

Dr. William Lee Stokes, one of the major figures in the history of the Cleveland-Lloyd Quarry, deserves special recognition for his extensive work. The new theropod dinosaur, *Stokesosaurus clevelandi,* was named in his honor and in recognition of the town where he was born, Cleveland, Utah. Dr. Stokes provided useful data, including photographs, for the present article and is gratefully acknowledged for them. Martha Hayden, of the Utah State Paleontologist's Office, spent considerable time on computer entries of catalog data and is thanked for her efforts. Donald Burge, director of the Prehistoric Museum in Price, Utah, also kindly assisted with information and photographs. Kenneth L. Stadtman, assistant curator and field director of fossil collecting for the BYU Earth Science Museum, and Dee A. Hall, senior preparator and collector at that institution, are recognized for the work that they have done at the quarry and with the collection. Both have helped in various other ways toward this paper as well. Several student workers did some collecting in conjunction with the BYU sponsorship, and their efforts are appreciated. Bureau of Land Management personnel in Utah, mostly from the Price Resource Area Office, have been very cooperative. We appreciate their help. Thanks are also extended to Marge Morgan for typing the manuscript.

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