# Conodont Database and Analysis of Conodont Color Alteration patterns in the Las Vegas $30^{\prime} \times 60^{\prime}$ quadrangle, Clark and Nye Counties, Nevada, and Inyo County, California 

By Anita G. Harris, William R. Page, Andrea P. Krumhardt, John E. Repetski, and Kenzie J. Turner

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# Conodont Database and Analysis of Conodont Color Alteration patterns in the Las Vegas $30^{\prime} \times 60^{\prime}$ quadrangle, Clark and Nye Counties, Nevada, and Inyo County, California 

Anita G. Harris ${ }^{1}$, William R. Page ${ }^{2}$, Andrea P. Krumhardt ${ }^{3}$, John E. Repetski ${ }^{4}$, and Kenzie J. Turner ${ }^{2}$


#### Abstract

Conodonts were the primary index fossils used for dating and characterizing the marine depositional environments of the thick section (at least 4,500 meters in the Spring Mountains) of uppermost Cambrian through Lower Triassic rocks in the Las Vegas 30' x 60' quadrangle. The color alteration index (CAI) of conodonts also was used to establish thermal maturation levels in these same rocks. Age and thermal maturation data for 215 productive collections are shown on a generalized geologic map of the Las Vegas quadrangle, and the biostratigraphic position of each sample is plotted on an accompanying stratigraphic column. A database in Microsoft Excel format provides all our significant information for each collection. Nearly 75 percent of the productive collections is from Mississippian and Ordovician rocks.

Late Mesozoic and Cenozoic tectonic, igneous, and geothermal events considerably influenced the distribution of CAI values so that CAIs may vary widely within an area and even within individual samples. The heterogeneity of CAI values observed in many of our conodont collections indicates the rocks were subjected to more than one thermal regime and that the younger thermal imprint(s) is irregularly distributed and likely related to Neogene Basin and Range extension and transform faulting. In general, CAI values in the same age rocks increase upward and westward through the stack of thrust plates and, in some plates, southwestward within a single plate. For example, in the Spring Mountains, latest Cambrian conodonts from the upper level Wheeler Pass plate have a CAI of 4.5 whereas conodonts of latest Cambrian through


[^0]Devonian age in the structurally lower Keystone plate, to the southwest, have CAIs of only 2.53.0. This contrast reflects the much thinner Paleozoic section in the Keystone plate than in the Wheeler Pass plate ( 300 meters of uppermost Cambrian to uppermost Devonian rocks in the Keystone plate versus $1,700 \mathrm{~m}$ in the Wheeler Pass plate). The Las Vegas Valley shear zone separates the Wheeler Pass plate from the Gass Peak plate. The stratigraphic succession in these plates indicates they were once contiguous; CAI values confirm this relation.

## Introduction

Since the 1970s, geologic investigations involving Paleozoic and Triassic rocks in the Great Basin have increasingly relied on conodonts for biostratigraphic, paleogeographic, and thermal maturation data. Early studies were mainly stratigraphic and paleontologic and were associated with geologic mapping and(or) earth resource investigations. These studies demonstrated that conodonts were relatively common in Great Basin strata and could provide significant biostratigraphic, paleogeographic, and thermal maturation data for many of the Paleozoic and Triassic rocks in this large region (for example, Clark and others, 1979a, b; Harris and others, 1979, 1980; Sandberg, 1979; Sandberg and Gutschick, 1979). Conodonts now have become the premiere micropaleontologic index fossils for marine rocks of latest Cambrian through Triassic age as well as indices of thermal maturity for sedimentary and metacarbonate rocks (for example, Epstein and others, 1977; Harris and others, 1978; Harris, 1979; Rejebian and others, 1987; Nöth, 1991; Königshof, 1992). In the Las Vegas map area, the thickness of conodont-bearing carbonate rocks of latest Cambrian to Early Triassic age varies considerably with structural position. These rocks reach a thickness of at least $4,500 \mathrm{~m}$ in the Spring Mountains (Page and others, 2005). For all of the above reasons, we preferentially used conodonts for biostratigraphy and correlation and used their color alteration index (CAI) for identification of thermally and hydrothermally altered rocks and interpretation of thermal history and patterns in the Las Vegas quadrangle.

In the Las Vegas $30^{\prime} \times 60^{\prime}$ quadrangle, the thickness of conodont-bearing carbonate rocks of latest Cambrian to Early Triassic age varies considerably in relation to original
paleogeographic setting. These rocks reach a maximum thickness of at least $4,500 \mathrm{~m}$ in the Spring Mountains and have a minimum thickness of about 2,000 m at Frenchman Mountain (Pages and others, 2005). This report is a derivative of the Las Vegas geologic map of Page and others (2005). The conodont database (table 1) is the foundation for many of our stratigraphic and structural interpretations presented in the geologic map.

## Conodont Database

All productive conodont collection sites are shown on a generalized geologic map of the Las Vegas $30^{\prime} \times 60^{\prime}$ quadrangle (pl. 1; geology generalized from Page and others, 2005) and the biostratigraphic position of most are plotted on the accompanying stratigraphic column (pl.2). Each site is marked on plate 1 by a symbol indicating the age or age range of the collection (for example, a filled circle indicates an Ordovician age, an open circle a Silurian age, and so on). An italicized map number to the upper left of the symbol is keyed to table 1 (column 2) and the RED number(s) to the upper right is the CAI value(s) of the collection (also shown in table 1, columns 8 a and 8 b ). The 7.5 ' quadrangles that produced these collections are listed alphabetically in table 1; collections are numbered consecutively for each quadrangle and identified by an alphanumeric abbreviation (for example, AP-5 indicates collection 5 in the Angle Peak 7.5' quadrangle).

The conodont database for the Las Vegas map area contains 215 entries in Microsoft Excel format (table 1). Many of the collections are in measured sections that were sampled to establish a biostratigraphic framework for correlation within and between thrust plates in the area. Some collections were taken to aid structural interpretation and identification of isolated, poorly exposed, metamorphosed, and(or) hydrothermally altered rocks. All collections are surface samples. Most of the collections (206) were made and analyzed by the authors (table 1, columns 11 and 12); other geologists in the course of their studies collected the remainder. L.J. Garside (Nevada Bureau of Mines and Geology) collected six samples and F.G. Poole (U.S. Geological Survey) collected three samples from the Las Vegas map area that we
analyzed and subsequently incorporated in our study. J.W. Collinson (Ohio State Univ.) and G.D. Webster (Washington State Univ.) kindly provided us the data from three of their conodont collections from the Las Vegas map area. Most of the collections in the database are reposited in the conodont laboratory of the U.S. Geological Survey (USGS), Reston, Va. The catalog number of each USGS collection and the number of the paleontologic report are given in table 1 (column 10).

About 98 percent of the collections were processed in the USGS conodont laboratory in Reston, Va. A written report is available for most of the samples analyzed by A.G. Harris (formerly A.G. Epstein). CAI and age determinations for USGS collections were chiefly made by A.G. Harris. J.E. Repetski, USGS, refined the age of many of the latest Cambrian and Early Ordovician collections.

Most of our conodont samples were collected from 1991 to 1998. Some of the earlier collections ( 37 from the Las Vegas map area collected in 1991 and 1992) are from the northern Spring Mountains and were collected by A.G. Harris in conjunction with geologic studies at the Nevada Test Site (Grow and others, 1994). Nearly all other collections were made during the geologic mapping and compilation of the Las Vegas 30' $\times 60$ quadrangle .

The database has 16 columns (table 1).

## Column 1 (County)

All collections are from Clark County except one sample from Nye County in the Pahrump quadrangle (PA-1).

Column 2 (7.5' quadrangle and map number)
The primary arrangement of the database is alphabetical by $7.5^{\prime}$ quadrangle name and secondarily by map number within each quadrangle; quadrangle name abbreviations are shown on plate 1. For example, BDNE-3 indicates Blue Diamond NE quadrangle, collection 3.

Columns 3a, 3b, 4a, 4b (Latitude and longitude coordinates)

The latitude and longitude coordinates for samples collected by USGS personnel prior to 1996 were calculated from points plotted at the outcrop on 1:24,000-scale topographic maps; coordinates for samples collected after 1995 were determined using Global Positioning Satellite receiver data. Other coordinate values are listed as in the original sources and are assumed to be based on collection sites plotted on topographic maps.

## Columns 5, 6a, 6b (Age and numeric age range)

Column 5 provides the most refined age, age range, or biozone that the conodont data allow (period, epoch, age, subage, and zone).

Columns 6 a and 6 b display a numeric code for the age data that expedites computer sorting. From left to right, the first digit indicates ERA: 2 is Mesozoic; 3, Paleozoic. The second digit indicates PERIOD: for the Paleozoic Era, 1 is Permian; 2, Pennsylvanian; 3, Mississippian, and so on. The third digit indicates EPOCH: 1, Late; 2, Middle; and 3, Early. The fourth digit indicates informal AGE: 1, late; 2, middle; and 3, early. Thus, an age range given in columns 6 a and 6 b as 3622 and 3621 reads as middle to late Middle Ordovician. If an age is within a single age or zonal interval within an age, then the number in columns $6 a$ and $6 b$ are the same.

## Column 7 (Stratigraphic unit)

The stratigraphic unit may be a member, formation, group, or an informal unit such as tectonic breccia. Collections within a measured section typically include meters above base or below top of a stratigraphic unit.

## Column 8a and 8b (CAI minimum and CAI maximum)

Conodont CAI (color alteration index) values within any sample typically have a half index range (for example, CAI min. may be 3.0 and CAI max. 3.5). However, samples from hydrothermally altered or contact metamorphosed rocks can have a wide range of CAI values within a section and even within a single sample (Wardlaw and Harris, 1984; Rejebian and others, 1987). A range of CAI values in a local area or
within a sample is a valuable indicator of relatively short-lived thermal overprinting due to contact metamorphism and(or) hydrothermal activity. Conodonts with a surficial gray patina generally indicate a short-term thermal event and(or) the effect of hydrothermal or saline fluids. The latter can produce dolomitization of limestone bedrock as well as corrosion and concomitant bleaching of conodont organic matter.

## Column 9 (Field number)

Field number designations vary; many geologists use the last two digits of the collection year, their initials, and consecutive numbering of samples within a calendar year.

## Column 10 (USGS catalog no. [Report no.])

The USGS catalogue number is the number assigned a paleontologic collection in the fossil collection catalogs of the USGS. Conodonts are listed in four separate age-based catalogs; the age designation is part of the catalog number and is used as a suffix or prefix: 11111-CO, Cambrian-Ordovician; -SD, Silurian-Devonian; -PC, Permian-Carboniferous; and Mes. 22222, Mesozoic. All cataloged conodont collections are housed in the conodont laboratory of the USGS National Headquarters, Reston, Va.

A number is assigned to reports on fossil collections written by USGS paleontologists. The report number generally contains the last two digits of the year the report was written or the fossil collection was submitted for examination and an abbreviation of the organizational unit of the collector. For example, report no. CNGMT-96-6 indicates the collector was part of the Central National Geologic Mapping Team and the fossils were submitted and(or) the report written in 1996.

## Column 11 (Collector(s))

The person(s) submitting a conodont sample for analysis.

## Column 12 (Analyst(s))

The paleontologic analyst(s) who wrote or contributed to the report on a conodont collection. A copy of most conodont reports is available from the conodont laboratory at the USGS National Headquarters, Reston, Va.

## Relation of CAI Values to Age and Structural Position

The rocks of the Las Vegas quadrangle are part of the Cordilleran orogen, "the backbone of North America," that stretches northward from Mexico to Alaska and westward from the eastern limit of the Rocky Mountains to the Pacific. The current physiography of the Las Vegas area, however, mostly reflects late Mesozoic and Cenozoic tectonic events that produced a Cretaceous fold-and-thrust belt. Cenozoic extensional and transform faults and accompanying intrusive, volcanic, and hydrothermal activity subsequently disrupted this folded and uplifted belt. These same late Mesozoic and Cenozoic tectonic, igneous, and geothermal events considerably influenced the distribution of CAI values in the Las Vegas quadrangle.

Discussion of conodont collections in the report identifies samples in relation to their structural position within Cretaceous thrust plates in the Las Vegas quadrangle; these plates are shown on figure 1, plate 1. The thrusts generally strike northeast and were emplaced from northwest to southeast. The structurally highest thrust in the quadrangle is the Wheeler Pass thrust in the northwest Spring Mountains and the equivalent Gass Peak thrust in the Sheep Range. The structurally lowest thrust is the Bird Spring thrust in the easternmost Spring Mountains.

The Las Vegas Valley shear zone of late Cenozoic age is the most notable tectonic structure in the Las Vegas area (pl. 1 and pl. 1, fig. 1), although it is concealed beneath thick basin-fill deposits in the Las Vegas Valley along most of its trace, and its position is based mostly on geophysical studies (Page and others, 2005). The shear zone was active between 14 and 8 Ma (Guth, 1981; Duebendorfer and Black, 1992) as a
transform tear fault between the relatively unextended Spring Mountains and the highly extended ranges north of the Las Vegas Valley shear zone (Guth, 1981). The zone shows as much as 50 kilometers of separation between the southeasternmost thrust plates in the Spring Mountains and their once contiguous segments in the southern Sheep and Las Vegas Ranges and in ranges further east (Wernicke and others, 1988). The tectonic history of blocks north and south of the Las Vegas shear zone differs in the amount of Neogene extension--greater extension to the North may have been accompanied by increased heat flow or thermal waters. We discuss the two blocks separately below.

## Spring Mountains

The Spring Mountains contain the largest outcrop area of Paleozoic and Triassic rocks in the Las Vegas $30^{\prime} \times 60^{\prime}$ quadrangle. During Sevier orogenesis, from Cretaceous to early Eocene time (Cowan and Bruhn, 1992; Miller and others, 1992), these predominantly marine rocks and continental Mesozoic strata were uplifted and transported southeastward to form an imbricate stack of thrust plates. Subsequent Cenozoic extension and transform tectonic events accompanied by igneous and volcanic activity further complicated original depositional and late Mesozoic and early Cenozoic structural and thermal patterns.

## Triassic localities

In the Las Vegas quadrangle, exposures of Triassic rocks are limited to the eastern and south-central Spring Mountains (pl. 1). Early Triassic conodonts were recovered from five samples of the Virgin Limestone Member of the Moenkopi Formation (pl. 1 and text-fig. 1). The Triassic conodonts have relatively low CAI values that increase structurally upward and westward from 1.0 in parautochthonous rocks (text-figs. 1 and 2R, BDSE-2) to 1.0-1.5 and 1.52.0 in the overlying Bird Spring plate (BDSE-5A, 5B; BD-7; text-fig. 2S), and 2.5 in the westernmost collection in the succeeding Keystone plate (LCS-1; text-fig. 2T), 25 km west of the Bird Spring plate collections.

## Permian localities

Permian conodont collections are from the Kaibab Formation and upper part of the Bird Spring Formation. The Kaibab, chiefly the Fossil Mountain Member, yielded 13 collections of predominantly late Early Permian age (Artinskian and Kungurian Age; table 1). Of the 16 collections from the upper part of the Bird Spring Formation, nine merely indicate a Pennsylvanian or Permian age (table 1 and text-fig. 1). The seven other collections are restricted to the Early Permian: one is of very latest Wolfcampian age (GRP-2), two approximate a narrow interval straddling the Wolfcampian-Leonardian boundary (table 1, GS-1 and WW-2), two others are Artinskian (MS-10) and Kungurian (MS-10), and another two merely indicate the Early Permian (CPNE-3 and MS-3).

Along the southeastern margin of the Spring Mountains, nine Permian collections from the Kaibab Formation (three from parautochthonous rocks and six from the overlying Bird Spring thrust plate; pl. 1, fig. 1 and text-figs. 1 and $2 \mathrm{~N}, \mathrm{O}$ ) have CAI values of 1.0 or 1.0-1.5 indicating a low thermal history and temperatures not exceeding $50-80^{\circ} \mathrm{C}$ for any substantial duration (Epstein and other, 1977; Harris and others, 1978). In areas of average geothermal gradient, such temperatures occur at burial depths of 1,200-2,000 m. Eight Permian collections from the overlying Keystone plate (four each from the Kaibab and Bird Spring Formations) have slightly higher CAI values of $1.5,1.5-2.0,2.0$, or 2.5 (text-figs. 1 and 2 P ); CAIs of 2.0 and 2.5 are most common. A single collection from the Bird Spring Formation in the Deer Creek plate (text-fig. 1, AP-6; fig. 2M), sampled near the northwest exposed limit of the Keystone plate, has a CAI of mostly 1.5-2.0. This value is near the lower end of CAI values found in Permian rocks of the Keystone plate (text-fig. 1). In addition, some of the conodonts from locality AP-6, though undeformed and texturally well preserved, have high CAIs of 7.0 and 8.0 suggesting a local, very short-lived heating event. Two collections from the structurally higher Macks Canyon plate have disparate CAI values. One collection in the northern part of the Las Vegas map area (CPNE-3) has a low CAI of 1.5 whereas the second collection from about 20 km southwest (WW-2) has CAIs of 3.0 and 4.0 and a slight gray patina. These values and the gray
patina suggest a local, possibly short-lived thermal event. The database contains five other collections from the Macks Canyon plate; four are from Mississippian strata but the fifth, from the Bird Spring Formation (text-fig 1, WP-9), is of Middle Pennsylvanian to very Early Permian age (text-figs. 1, 2L, and 3). The five collections have high CAI values but one of these (textfig. 3, CPNE-5) has a mix of high and low values suggesting incomplete overprinting of a younger and higher temperature event on a CAI produced during an earlier lower thermal regime. It seems likely that these less common low CAI values were typical for upper Paleozoic rocks of the Macks Canyon and underlying plates (text-figs. 1, 3, 4, and 5) and prior to development of Basin and Range extension and possibly elevated thermal regimes by Miocene time.

## Permian or Pennsylvanian localities

Nine conodont collections from the Bird Spring Formation were assigned a Permian or Pennsylvanian age (pl. 2). Three from the Keystone plate contain conodonts having low CAI values of 1.0 to 2.0 , similar to values of Permian conodonts in the same plate (text-fig. 1). A fourth collection (text-fig. 2L, GRP-1), assigned to the Keystone plate, has a CAI of 3.5, a value more like those in the higher Lee Canyon plate. This sample was collected close to but east of the concealed trace of the Lee Canyon thrust. Mapping, however, indicates that the rocks are part of the Keystone plate and that the collection is likely from an area of locally higher than average thermal levels for the Keystone. Generally, CAI indices of Permian or Pennsylvanian conodonts increase upward in the stack of thrust plates (text-fig. 1): usually 1.0 to 2.0 in the Keystone plate (text-fig. 2L), 2.0 to 3.0 in the Kyle Canyon and Deer Creek plates (text-fig. 2M), and 3.0 to 4.0 in the Lee Canyon plate (text-fig. 2Q). One collection from the Deer Creek plate (AP-2) and another from the succeeding Mack Canyon plate (WP-9, text-fig. 2Q) have anomalously high CAI values of 4.5 and 6.0 , respectively. Both collections are from the central part of the Spring Mountains. WP-9 is from the northeast margin of a major northwest-trending fault block that transects the central Spring Mountains. The block is bounded on the north by the La Madre fault and on the south by the Griffith fault (pl. 1). The high CAI value of the WP-9 collection may be related to its proximity to the La Madre fault, which could have served as a
thermal conduit. Although the conodonts have a CAI of 6.0 , many specimens are incompletely baked as they preserve an inner core of CAI 4.0. In addition, the conodonts are not much corroded or recrystallized. Taken together, this combination of features suggests a relatively dry heat source.

Our analysis of the CAI values of conodont collections of similar age and structural position shows that (1) some collections have comparable CAI values (Permian collections in the Keystone plate, text-figs. 1 and 2P); (2) some have a range of values from low to high (Pennsylvanian samples from the Lee Canyon plate, text-figs. 1 and 2Q); (3) others have considerably elevated CAIs (text-fig. 1, WP-9 from the Macks Canyon plate); and (4) still others have rather consistent low CAIs (Permian and(or) Pennsylvanian collections from the Keystone plate, text-fig. 2L). The persistence of low CAI values in conodont collections of the same age and structural level and even within the same sample strongly indicates that most of the high CAI values in the Spring Mountains were produced after late Mesozoic Sevier orogenesis and during Neogene extension.

## Pennsylvanian localities

Pennsylvanian conodonts were recovered from five localities in the Spring Mountainstwo from the Keystone plate (text-fig. 2L) and three from the Lee Canyon plate (text-fig. 2Q). Conodonts from one locality in each of these plates have CAI values of 2.0 (text-fig. 1, GS-14 and WW-1). Three other Pennsylvanian collections have a mix of CAI values within a single sample 2.0-4.0+6.0 (text-fig. 1, CPNE-4), 3.0-4.0+6.0 (text-fig. 1, PA-1), and 4.0+6.0 (text-fig. 1, LS-1). This mix of CAI values indicates local and even microscopic variations in heat-flow patterns. Even more significant is the survival, in many collections and areas, of the low CAI values (CAIs of 1.0 to 2.0) that must have been pervasive in these rocks until Neogene extension. The CAI values demonstrate that most of the exposed Triassic, Permian, and Pennsylvanian strata in what is now the Spring Mountains were not subjected to elevated thermal regimes because CAIs of 1.0-2.0 still persist in upper Paleozoic rocks.

## Mississippian and Mississippian or Devonian localities

In the Spring Mountains, 37 Mississippian and 4 Mississippian or Devonian conodont collections from six structural levels were examined (pls. 1, 2, and text-fig. 2). Collections from Mississippian rocks in the Spring Mountains are more numerous than from all younger conodont-bearing rocks combined (compare text-figs. 1 and 3) because of preferential sampling. We were especially interested in the Mississippian for its depositional setting and lithology, as both are favorable for conodont abundance and diversity.

CAI values in 22 Mississippian and 2 Mississippian or Devonian collections from the Keystone plate include lesser 1.5-2.0, 2.0, 6.0, and 6.0-6.5, common 2.5, 2.5-3.0, and 3.0, and rare 3.5 (text-fig. 3). The lowest CAIs of 1.5-2.0 lie just above the trace of the easternmost Keystone thrust (pl. 1, BDNE sites). The lowest values of 1.5-2.0 in Mississippian rocks of the Keystone plate overlap part of the lower range of CAI values in (compare text-figs. 1 and 3) (1) younger Paleozoic and Triassic rocks in the underlying Bird Spring plate (BD-7); (2) younger Paleozoic rocks of the Keystone plate (AP-1, GRP-2, MS-12, among others); and (3) younger Paleozoic rocks and some Mississippian rocks in the overlying Kyle Canyon and Deer Creek plates (AP-3, 6 and CCSNW-1). The persistence of low CAI values within what is now chiefly higher CAI domains indicate at least two thermal regimes. The lower CAIs developed during deposition and subsequent Sevier thrusting in the Cretaceous. This early thermal imprint is still preserved, albeit irregularly, in the Paleozoic and Triassic strata now exposed in the Spring Mountains. The higher CAI values are possibly related to the extension and transform faulting and associated thermal regimes of the Neogene.

The only Mississippian conodonts from the Kyle Canyon plate have an anomalously low CAI value of 1.5-2.0 (text-fig. 3, AP-3). These conodonts, however, have a heavy gray patina that suggests rapid, relatively short-term heating. Three samples from the succeeding Deer Creek plate produced conodonts of consistent CAI 4.0. All Mississippian collections from the superjacent Lee Canyon plate are from the Pahrump area; their CAI values include 4.0 and(or) 4.0-4.5 and 6.0 ( 2 samples) and 5.5-6.0 ( 1 sample). These high and variable CAIs suggest an
elevated thermal regime irregularly distributed in space and time. The only other conodont collection from the Lee Canyon plate in the Pahrump area is of Middle Pennsylvanian age (textfig. 1, PA-1); these conodonts have lower CAI values of 3.0-4.0 and minor 6.0. The relatively lower CAIs of the Pennsylvanian conodonts could reflect a somewhat greater distance from thermal conduits, a lower thermal regime, or a shorter heating interval.

Our database includes four Mississippian samples from the Macks Canyon plate (pl. 1 and text-fig. 2J; text-fig. 3, CC-1 and CPNE-1, 2, 5). Three samples produced conodonts with CAIs of chiefly 4.0-4.5 and 4.5; one of these also has values of 6.0 and 6.5 (text-fig. 3, CPNE-2). The fourth sample contains conodonts with a wide range of CAIs including 2.0, 2.5, 4.0, and 5.06.5 (text-fig. 3, CPNE-5). The preservation of low, medium, and high CAI values in this and many other conodont collections from Mississippian and younger conodont-bearing strata throughout the Spring Mountains suggests the elevated CAI values may be related to postCretaceous tectonic events and associated igneous activity. Until the Tertiary, it is likely that CAI values of conodonts in Mississippian through Lower Triassic rocks that are now exposed in the Spring Mountains were probably in the range of 1.0-2.5. Under conditions of average geothermal gradient, burial depths of these rocks would range from at least $1,200 \mathrm{~m}$ to probably no more than $5,000 \mathrm{~m}$ (Harris and others, 1978).

Four Mississippian and two Mississippian or Devonian conodont collections are from the Wheeler Pass plate along the northwest flank of the Spring Mountains. Collections from this plate have rather consistent CAI values (text-figs. $2 \mathrm{~K}, 3$ ). Mississippian collections yield conodonts with CAIs of 3.5-4.0 and(or) 4.0 and conodonts near the Devonian-Mississippian boundary have slightly higher consistent values of 4.0.

## Devonian localities

The 31 Devonian conodont localities in the Spring Mountains are distributed in four structural levels (text-figs. 2D-G and 4); these include the Keystone, Deer Creek, Lee Canyon, and Wheeler Pass plates (pl. 1, fig. 1 and pl. 2). Similar to collections from younger rocks, the largest number of samples is from the Keystone plate (text-fig. 4 and pl. 1, 18 collns.). Each of
the Devonian samples from the Keystone plate has a rather consistent CAI with a range of only half an index. Comparison of CAI values from sample to sample, however, shows moderate variations between collections: 2.0-2.5 (1 collection), 2.5-3.0 (5), 3.0 (5), 3.0-3.5 (1), 3.5 (2), and 3.5-4.0 (2). The most common CAIs are in the range of 2.5 to 3.0 (text-fig. 2D). CAI values in Devonian rocks of the Keystone plate increase from northeast to south-southwest and southwest, from the Tule Springs Park and Grapevine Spring quadrangles to the La Madre Spring and Mountain Springs quadrangles (pl. 1 and text-fig. 4).

The four Devonian collections from the Deer Creek plate have higher CAIs than most Devonian collections in the Keystone plate; these range from 4.0 to 5.0-5.5 (compare text-figs. 2E and 2D). Two collections from the structurally higher Lee Canyon plate have disparate CAIs. The collection from the more central part of the Spring Mountains (text-fig. 4, CP-3) has CAIs of 5.0 and 6.0 and the second collection nearly 8 km to the northeast (text-fig. 3, CPNE-6) has CAIs of only 2.0 and 3.0. The sample with higher CAIs may indicate closer proximity to part of the Tertiary thermal system.

Seven collections of very Late Devonian age (Famennian) from the Wheeler Pass plate have uniform CAI values within a collection and nearly the same CAI value for all collections. Six collections have a CAI of 4.0, and one other has a CAI of 3.5-4.0 (text-fig. 2G).

## Silurian localities

Only four Silurian conodont samples were collected from the Spring Mountains (pl. 2); three are from a section of the Laketown Dolomite in the Wheeler Pass plate, northwestern Spring Mountains (text-figs. 2G and 4, WP-6-8), and the fourth is from the Mountain Springs Formation in the Keystone plate, southeastern Spring Mountains (text-fig. 4, LS-3). CAIs of Silurian conodonts in the Wheeler Pass plate are high (4.5-6.5) and vary within a sample. As noted by Rejebian and others (1987), some higher CAI values of 5.5, 6.0, and 6.5 may be more related to dolomitization than to temperature. Dolomitizing saline fluids can corrode conodont apatite and simultaneously bleach the organic matter (conodont tissue) that had been sealed between and protected by apatite lamellae. This is particularly true of dolomitized carbonate
rocks such as occur in the Mountain Springs and Laketown Formations. The sample from the Mountain Springs Formation in the Keystone plate, however, has a CAI of 3.5 and is consistent with the low end of CAI values in nearby collections from Devonian and Ordovician rocks in the same plate and area (see pl. 1 and text-fig. 4).

## Ordovician localities

A total of 27 productive Ordovician samples were collected from three structural levels in the Spring Mountains (pl. 1); most are from composite measured sections and were taken primarily for biostratigraphic control.

Thirteen samples were collected from the Ordovician part of the Mountain Springs Formation in the Keystone plate (text-fig. 4, LS-7-19). This is the same section measured and sampled for conodonts by Miller and Zilinsky (1981). Although these rocks are now almost pervasively dolomitized, conodont species associations indicate the protolith was mainly limestone. Conodonts from these rocks are abundant and diverse and include normal-marine tropical cosmopolitan, cosmopolitan, and Laurentian species. The Ordovician stratigraphy is variable and complex because of Ordovician karstification. In addition, a disconformity of considerable magnitude separates uppermost Lower Ordovician Pogonip Group equivalent rocks of the Re. andinus Zone from 7-8 m of Upper Ordovician Ely Springs Dolomite equivalent. CAI values in these mostly bleached dolomitized rocks are varied (text-figs. 2A and 4) and include $3.0,3.0-3.5,3.5,3.0-4.0+\mathrm{gp}, 4.0,4.5-5.0,5.0$, and 6.0 . CAIs of 3.0-4.0 are most common and, in some areas of the Spring Mountains, are appropriately higher than CAI values in younger Silurian and Devonian rocks of the Keystone plate (see text-fig. 4). In the La Madre Spring and part of the Mountain Springs quadrangles, however, CAI values in Silurian and Devonian rocks have mostly the same CAI values of 3.0-4.0 that are most common in Ordovician rocks of the La Madre Spring section (text-fig. 4). Although much of the dolomitization of the Ordovician part of the Mountain Springs Formation probably occurred during the Ordovician, it seems likely that more than one fluid system affected these rocks. The only other Ordovician conodont collection from the Keystone plate is also from the southeastern part of the Spring Mountains (text-fig. 4,

BDNE-6). Its CAI of 4.0 lies within the most common range of CAIs for Ordovician conodonts in the Keystone plate.

Five conodont collections from mostly dolomitized beds in the uppermost Pogonip Group in the Deer Creek plate (text-fig. 4, CCSNW-5-9) and one collection from the Charleston Peak quadrangle in the same plate have a wide range of CAI values. These include 3.5-4.0, 4.0, minor $5.0,5.5,6.0,6.5$, and rare 7.0. Because of the wide range of values, it is likely that the lower CAIs of 3.5-4.0 and 4.0 are related to depth and duration of burial and geothermal gradients during the Paleozoic and Mesozoic. The higher values may be the result of bleaching by warm dolomitizing fluids that irregularly overprinted the earlier CAI values during the Cenozoic.

The six Ordovician collections from the Wheeler Pass plate are all from the Wheeler Peak quadrangle (text-fig. 4). Like other conodont collections from this plate, exclusive of conodonts from Silurian dolostones, CAI values within a collection are very consistent and vary by only one-half an index. CAI values increase only slightly in older, more deeply buried strata so that Mississippian conodonts have CAIs of 3.5-4.0 or 4.0, Devonian conodonts are predominantly 4.0 with minor 3.5-4.0, Ordovician conodonts are chiefly 4.0-4.5 with lesser 4.0 and 4.5, and latest Cambrian conodonts are at 4.5.

## Cambrian localities

Latest Cambrian conodonts were recovered from two localities in very different parts of the thrust stack. One Cambrian sample (text-figs. 2A and 4, TSP-1) is from the Keystone plate near the central eastern limit of the Spring Mountains; conodonts in this sample have a CAI of 2.5-3.0. Our database contains no other conodont collections of pre-Devonian age from the Tule Springs Park area. Nevertheless, nearby Devonian collections have the same or slightly lower CAIs as the latest Cambrian collection (pl. 1 and text-fig. 4, compare TSP-1 and TSP-2-4). The comparable CAI values of conodonts in Devonian and Cambrian rocks is predictable because only 300 m of strata separate the uppermost Cambrian collection from the lowest Devonian collection (Page and others,

2005, fig. 2, section 5). On the other hand, the CAI value of the Cambrian collection is lower than the lowest CAI values found in the nearest Ordovician and Silurian collections from the Keystone plate, mainly from the La Madre Spring section about 18 km southwest (text-fig. 4, LS-7-19). The slightly to considerably higher CAI values of Ordovician and Silurian collections in the La Madre Spring section suggest that thermal gradients and hydrothermal patterns in that area were more variable and generally higher than in the Tule Springs Park area.

The other Cambrian collection is from the much higher Wheeler Pass plate at a locality about 37 km northwest of Tule Springs Park (text-fig. 4, WP-15). Its CAI of 4.5 is consistent with CAIs of Ordovician conodonts and proportionately (in relation to depth of burial) slightly higher than Upper Devonian (mostly CAI 4.0 and lesser 3.5) and Mississippian (a mix of CAI 3.5-4.0 and 4.0) conodonts in the same plate and area (textfigs. 3 and 4). Approximately 1,700 m of strata (Page and others, 2005, fig. 2, section 2) separate this latest Cambrian collection (near the base of the Goodwin Limestone) from upper Upper Devonian collections (upper Guilmette and Crystal Pass formations). Thus, the preserved thickness of Ordovician through Devonian strata increases sixfold northwestward in the Spring Mountains from the Keystone plate to the structurally highest Wheeler Pass plate (from 300 to at least $1,700 \mathrm{~m}$ ). In comparison to some other structural levels in the Spring Mountains, CAI values in the Wheeler Pass plate show more consistent relation to stratigraphic position. It appears that CAI patterns in the Wheeler Pass plate are more the result of Late Cretaceous and early Tertiary burial patterns and thermal gradients and, at least in the Spring Mountains area, are less overprinted by Neogene Basin-and-Range thermal events.

## Southern Sheep and Southern Las Vegas Ranges

The northeast part of the Las Vegas map area includes the southern part of the Sheep Range and southern part of the Las Vegas Range. Based on comparable stratigraphy and structural relationships, previous authors (see discussion in Page and others, 2005) have
demonstrated that Paleozoic rocks exposed in this area are distributed in three structural levels that were once likely contiguous with thrusts in the Spring Mountains prior to development of the Las Vegas Valley shear zone. From highest to lowest exposed structural levels (pl. 1), the proposed correlations are: the Gass Peak thrust with the Wheeler Pass thrust (Guth, 1981, 1990; Wernicke and others, 1988; Burchfiel and Davis, 1988); the Valley thrust with the Lee Canyon/Macks Canyon thrust (Lundstrom and others, 1998); and the Dry Lake thrust with the Deer Creek thrust (Lundstrom and others, 1998).

## Permian and(or) Pennsylvanian localities

The only conodonts from the Dry Lake plate are three collections from Permian, Pennsylvanian, and Permian or Pennsylvanian rocks (text-figs. 5 and 6E). The Early Permian (VA-23) and Middle Pennsylvanian (VA-19) collections have high CAIs of 4.0 and 6.0 and a third collection of Permian or Pennsylvanian age has even higher values (VA-20; 5.5-6.5). These CAI values are higher than those in many collections from chiefly older as well as structurally higher rocks in the Gass Peak and Valley plates (text-fig. 5). The high CAI values of these samples may be explained by their proximity to the Las Vegas Valley shear zone, which may have acted as a thermal conduit. CAI values of Permian and (or) Pennsylvanian conodonts in the structurally correlative Deer Creek plate in the Spring Mountains display a range of values areally from consistently low ( 1.5 and 2.0 ) within a single sample to a mix of CAIs with a single sample (text-fig. 1, AP-6; 1.5-2.0 together with 7.0 and 8.0) age continues westward into the adjoining Dry Lake NW and Apex 7.5' quadrangles (northwestern edge of the Lake Mead 30' x 60 ' quadrangle), where Permian conodonts have CAIs of 3.5-4.0 and Pennsylvanian conodonts have values of 4.0, 4.0-4.5, and 6.0 (A.G. Harris and W.R. Page, unpublished data). Further south and east in the Dry Lake NW and Apex quadrangles, Permian and Pennsylvanian collections generally revert to lower CAIs of 1.0 to 2.0 that are more typical of thermal patterns related to depth and duration of burial under conditions of relatively average geothermal gradient. CAI values of Permian and (or) Pennsylvanian conodonts in the structurally correlative Deer Creek plate in the Spring Mountains display a range of values areally from
consistently low ( 1.5 and 2.0 ) within a single sample to a mix of CAIs within a single sample (text-fig. 1, AP-6; 1.5-2.0 together with 7.0 and 8.0). Like the Spring Mountains collections, a mix of high and low CAI values in a single collection or in collections from the same area and structural level clearly indicate variability in age, duration, maximum temperature, and location of thermal overprinting.

CAI values in one Permian and two Pennsylvanian collections from the Valley plate have CAIs of 3.0 (text-fig. 5, GP-1) and 4.0, 4.5-5.0, and 6.0 (text-fig. 5, GPSW-1 and VA-21). This is like the mix of medium and high CAIs observed in collections of the same age in the correlative Lee Canyon/Macks Canyon plates in the Spring Mountains, with one exception. Location CPNE-3 produced only conodonts of CAI 1.5 (text-fig. 1) reflecting the persistence of the low CAI values typical of Permian rocks before the onset of Basin and Range Neogene extension. In contrast, two collections, one Permian and the other Permian or Pennsylvanian, from the Gass Peak plate have relatively low CAI values (text-fig. 5). Rocks of postMississippian age are not exposed in the correlative Wheeler Pass plate in the Spring Mountains, but Mississippian collections from that plate have consistent values of 3.5-4.0 and 4.0 (text-fig. 2).

## Mississippian and Devonian localities

Twenty Mississippian, two latest Devonian, and one latest Devonian or very Early Mississippian conodont samples were taken from the Valley plate in the southern Las Vegas Range (pls. 1 and 2). CAI values of conodonts from these collections are chiefly 4.0 commonly accompanied by $6.0,3.5-4.0$, and 5.5 (text-fig. 6C). About 65 percent of the collections have CAI values that vary by one-half index or chiefly have values of 4.0 and lesser numbers of 6.0 . Most of the remaining collections have much higher values than the common range of 3.0-4.0. Mississippian and latest Devonian collections from the Valley plate have mixed values within an area and between samples in a measured section (text-fig, 5). CAI values of collections include $2.5+5.5$ ( 1 collection), 3.0 (1), 3.0+4.0 (1), 3.5-4.0 (4), 4.0+5.0 (2), 4.0 (9), 4.0-4.5 (1), 4.0+6.0 (3), $5.5+6.5$ (1), and 6.0 (1). This wide range of CAI values indicates variations in heat-flow
patterns (related to variations in intergranular and fracture porosity), temperature, and duration of heating. Although collections from Mississippian rocks in the correlative Lee Canyon/Macks Canyon plate in the Spring Mountains are about one-third the number of those from the Valley plate, the CAI values are comparable (compare figs. 3 and 5). In addition, CAI values of the six Mississippian and Mississippian or Devonian collections from the structurally higher Wheeler Pass plate of the Spring Mountains also are much the same as the most common values observed in the Mississippian rocks of the Valley plate.

CAI values in two Mississippian and two Upper Devonian collections from the Gass Peak plate have rather consistent CAI values of 4.0-4.5 or 4.0. These values average one-half index higher than values in collections of the same age and structural level in the correlative Wheeler Pass plate in the Spring Mountains.

## Silurian localities

Five samples of Early Silurian age (late Llandovery and early Wenlock) are from the Gass Peak plate at the southwest end of the Sheep Range (text-figs. 5, 6B, and pl. 2). One sample is from the upper part of the Ely Springs Dolomite (CCS-3), and four others are from the middle part of the Laketown Dolomite. Like CAI values found in the Laketown dolostones of the correlative Wheeler Pass plate in the Springs Mountains (text-fig. 4, 4.5 to 6.5), the Gass Peak plate collections have nearly the same mix and variability of high CAI values. The lower and upper ranges of CAI values in the Gass Peak collections (text-fig. 4, 4.0-4.5 to 6.0) are a half index lower than in Wheeler Pass collections. As mentioned previously for some Spring Mountains collections, the mix of high (>5.0) and moderate or low CAI values observed in many dolostone samples likely is the result of dolomitizing fluids corroding conodont element apatite and bleaching interlamellar organic matter. In our collections from Silurian dolostones, CAI values of 5.0 and lower are mostly related to thermal alteration, but values of $>5.0$ may not be primarily temperature related and could just as well result from oxidation of conodont organic matter by relatively low temperature dolomitizing fluids. In their initial papers describing conodont color alteration, Epstein and others (1977) and Harris and others (1978) were careful to
state that their field data, with few exceptions, were from conodonts recovered from limestones and that dolostones were avoided because some dolostone collections produced a range of CAI values.

## Ordovician localities

Twenty-six Ordovician conodont samples were collected from a well-exposed composite measured section of Ordovician rocks in the Gass Peak plate at the southwest end of the Sheep Range (pls. 1 and 2). About 530 m of the Pogonip Group were measured and sampled, including the upper 65 m of the Goodwin Limestone and most of the Antelope Valley Limestone. The contact between the Eureka and overlying Ely Springs Dolomite is exposed on the north side of Yucca Gap; five samples of Late Ordovician age were collected from the lower 130 m of the Ely Springs Dolomite.

All collections from Ordovician rocks older than the Ely Springs Dolomite are from limestone and those from the Ely Springs are dolostone (collections CCS-26-30). CAI values of conodonts from the Goodwin and Antelope Valley Limestones range from 4.0 to 7.0 (text-fig. 6A). However, most collections have one or two predominant CAI values within the range of 4.5-5.5 with or without subordinate values in the range of 5.5-7.0; two collections have a CAI of only 4.0 (text-fig. 5, CCS-20, 21). The range in CAI values in this area, even though the bedrock is mostly limestone, is not surprising as the amount of brittle deformation in these rocks is impressive and undoubtedly due to bending of the range near the Las Vegas Valley (transform) shear zone (see geologic map of Maldonado and Schmidt, 1991, Guth, 1981, and Page and others, 2005). CAI values of conodonts from the Ely Springs Dolomite (text-fig. 5, CCS-26-30) also range from 4.0 to 7.0, but the range of CAI values in individual collections is greater and skewed toward the high values. Once again, comparison of CAI values of conodonts from dolostones and limestones of the same age and area shows that collections from dolostones generally have proportionately more conodonts with CAI values of 5.5 or greater.

## Uppermost Cambrian localities

Two collections from near the base of the Goodwin Limestone at the southeast end of the Sheep Range and approximately 1 km northeast of the base of the Pogonip composite measured section restrict the age of the base of the Pogonip Group in the Gass Peak plate to the very late Late Cambrian (highest Eoconodontus Zone through the succeeding Cordylodus proavus Zone). Conodonts from the lowest collection have a CAI of 4.0-4.5 (text-fig. 5, CCS-35); the second collection produced only a few small, thin-walled conodonts of indeterminate CAI (table 1, CCS36). Our two other collections are just above the base of the composite measured section for lower Paleozoic rocks in the southern Sheep Range (text-fig. 5, CCS-5, 6). Conodonts in the lowest collection, 60 m below the top of the Goodwin Limestone, indicate the Cambrooistodus minutus Subzone of the Eoconodontus Zone and a very late Late Cambrian age. The collection 10 m higher in the section produced the same age conodonts. This age was unexpected for rocks only 60 and 50 m below the top of the Goodwin. If, as reported by Maldonado and Schmidt (1991), the Goodwin Limestone in the Gass Peak plate is 220 m thick, then most of the Goodwin is of Late Cambrian age and mostly older than the upper part of the Eoconodontus Zone. The lowest Ordovician collection in the measured section is only 30 m above ( 21 m below the top of the Goodwin) the higher of the two Cambrian collections. It contains abundant and relatively diverse conodonts of the Rossodus manitouensis Zone. Elsewhere in much of eastern Nevada and western Utah, a substantial thickness of carbonate deposits accumulated during the time interval that includes the upper part of the Eoconodontus Zone (very late Late Cambrian) through the Ro. manitouensis Zone (about 250 m in the Ibex area of central western Utah according to Ross and others, 1997). The relatively thin interval of uppermost Cambrian and lower Lower Ordovician rocks at the base of our composite section could have been produced by an unrecognized fault that juxtaposed lowermost Goodwin strata against upper Goodwin beds. But, neither Maldonado and Schmidt (1991) nor we recorded evidence of a fault along our line of section. In some areas of the eastern Great Basin and Rocky Mountains, however, a relatively widespread cryptic disconformity (Myrow and others, 2003) separates rocks of upper Eoconodontus Zone age from overlying Ro. manitouensis Zone deposits.

This may indeed explain the absence of this interval in the southwest Sheep Range. The two collections from the base of the composite Ordovician section have a CAI of about 4.5. CAI values of latest Cambrian conodonts from the southwest end of the Sheep Range are at the low end of the range of common CAI values in overlying Ordovician rocks (4.5-5.5) in the same area. This probably is because the Cambrian conodonts are thinner walled (have less organic matter) and smaller than many Ordovician conodonts and, therefore, are lighter colored.

The only Cambrian collection from the correlative Wheeler Pass plate in the Spring Mountains also is from the base of the Goodwin Limestone (text-fig. 4, WP-15). The conodont fauna is very slightly younger but less restricted in age than the Gass Peak plate collections, extending from the Co. proavus Zone through the Co. intermedius Zone. Its CAI is 4.5 and matches the values in Cambrian collections from the correlative Gass Peak plate.

## CONCLUSIONS

The Las Vegas quadrangle displays a wide range of CAI values within an area and even within individual samples. In general, CAI values in the same age rocks increase upward through the stack of thrust plates and increase westward and, in some plates, southwestward within a single thrust plate. The range of CAI values (lowest, most common and highest) observed in conodonts are shown in figure 7. This figure summarizes data for uppermost Cambrian through Lower Triassic rocks and from the lowest to highest structural levels, from parautochthonous rocks to rocks in the Wheeler Pass and correlative Gass Peak plates. The heterogeneity of CAI values observed in many of our conodont collections indicates the rocks were subjected to more than one thermal regime and that the younger thermal imprint(s) is irregularly distributed and likely related to the Neogene Basin and Range extension and transform faulting. By early Cenozoic time, most CAI values in the oldest conodont-bearing rocks in the Las Vegas area (uppermost Cambrian and Ordovician) were no higher than 4.0 or 4.0-4.5 (probably lower) in the correlative Wheeler Pass and Gass Peak plates. These are the
lowest CAI values still preserved in both plates. Nearly the same lowest values are still present in Silurian and Devonian strata but values as low as 3.5-4.0, occur in Devonian rocks of the Wheeler Pass plate. Mississippian strata in the Wheeler Pass plate have CAIs as low as 3.5-4.0 and CAIs in the same age beds in the Gass Peak plate are 4.0-4.5. Pennsylvanian and Permian age beds are not present in the Wheeler Pass plate in the Las Vegas quadrangle; two collections of Permian and Permian or Pennsylvanian age from the Gass Peak plate contain low CAIs of 2.0 and $\sim 1.5$ (text-fig. 7). In general, CAI values of conodonts from the Dry Lake, Valley, and Gass Peak plates have a slightly higher and wider range of CAI values within a sample than conodonts from correlative plates to the west of the shear zone in the Spring Mountains. This suggests higher temperatures and(or) longer-lived thermal activity northeast of the Las Vegas Valley shear zone than to the west.

The Keystone plate has the most complete age coverage for CAI values. The lowest CAI values present in collections of Cambrian through Triassic age in the Keystone plate are latest Cambrian (TSP-1: CAI 2.5-3.0); middle Early and Late Ordovician (LS-7, 14; CAI 3.0); Late Ordovician-Early Silurian (LS-3; CAI 3.5); Middle-Late Devonian (BDNE-5; CAI 2.0-2.5) and late Late Devonian (TSP-3; 2.0-2.5); Mississippian (TSP-5; CAI 1.5-2.0) and late Early Mississippian (BDNE 2-4; CAI 1.52.0); early Middle Pennsylvanian (GS-14; CAI 2.0); early Early Permian (GRP-2; CAI 1.5) and latest Early Permian (AP-1; CAI 1.5); and Early Triassic (LCS-1; CAI 2.5). Some of the reversals in low CAI values (for example, early Early Permian low CAI of 1.5 versus Early Triassic low CAI of 2.5) is simply because we have only one Triassic collection from the Keystone plate. Two of the eight Permian collections from the Keystone plate also have CAI values of 2.5, but two others have the lowest values of 1.5. The lowest CAI values still preserved in the Keystone plate, with the exception of the Triassic collection, generally increase from 1.5 in the Permian to 2.0 in the

Pennsylvanian, 1.5-2.0 in the Mississippian, 2.0-2.5 in the Devonian, 3.0 in the Ordovician, and 2.5-3.0 in the Cambrian.

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Table 1. Conodont database for the Las Vegas 30 ' x $60^{\prime}$ quadrangle, Clark and Nye Counties, Nevada, and Inyo County, California. The database contains 215 collections in Microsoft Excel format.
[See text for description of column headings. Abbreviations: CAI, conodont color alteration index of Epstein and others (1977) and Rejebian and others (1987); see text for explanation of geologic age numerical code (columns 6a and 6b). Collectors and paleontologic analysts (columns 11 and 12) are: 1) U.S. Geological Survey personnel: AGH (A.G. Harris), FGP (F.G. Poole), WRP (W.R. Page), JER (J.E. Repetski), DJW (D.J. Weary), and JW (J. Workman); and 2) Other contributors: JWC, J.W. Collinson, Dept. Geological Sciences, Ohio State Univ.; LJG, L.J. Garside, Nevada Bureau of Mines and Geology; APK, A.P. Krumhardt, Dept. Geology and Geophysics, Univ. Alaska Fairbanks; SAM, S.A. Marcus, Dept. Geological Sciences, Indiana Univ.; G.D. Webster, Dept. Geology, Washington State Univ.]

|  | TRIASSIC | PERMIAN | PERMIAN OR PENNSYLVANIAN | PENNSYLVANIAN |
| :---: | :---: | :---: | :---: | :---: |
| WHEELER PASS PLATE |  |  |  |  |
| MACKS CANYON PLATE |  | CPNE-3: 1.5 <br> WW-2: $\begin{gathered}3.0+\text { sgp, } \\ 4.0+s g p\end{gathered}$ | WP-9: 6.0 |  |
| LEE CANYON PLATE |  |  | $\begin{aligned} & \text { GRP-3: 3.0-4.0 } \\ & \text { GRP-1: } 3.5 \end{aligned}$ |   <br> CPNE-4: $2.0-4.0,6.0$ <br> PA-1: $3.0-4.0+$ gp, <br>  minor 6.0 <br> WW-1: $2.0+$ gp |
| DEER CREEK \& KYLE CANYON PLATES |  | $\begin{array}{\|c\|} \hline \text { AP-6: } \\ 1.5-2.0, \\ 7.0,8.0(\mathrm{kc}) \end{array}$ |   <br> AP-2: $4.5+\mathrm{gp}$ <br> CCSNW-1: $\sim 2.0$ <br> CP-1 (k): 3.0 |  |
| KEYSTONE PLATE | $\text { LCS-1: } 2.5$ |   <br> AP-1: 1.5 <br> GRP-2: 1.5 <br> GS-1: 2.0 <br> GS-18: 2.0 <br> GS-2: 2.5 <br> MS-3: 2.0 <br> MS-10: 2.5 <br> MS-12: $1.5-2.0$ |   <br> GS-15: $2.0+\operatorname{lgp}$ <br> GS-16: $1.0-2.0+\operatorname{lgp}$ <br> GS-17: 1.0 | $\begin{array}{ll} \hline \text { GS-14: } & 2.0 \\ \text { LS-1: } & 4.0,6.0 \end{array}$ |
| BIRD SPRING PLATE | $\begin{array}{\|l\|l\|} \hline \text { BD-7: } & 1.5-2.0 \\ \text { BDSE-5A, B: } & 1.0-1.5 \\ \hline \end{array}$ |   <br> BD-2: $1.0-1.5$ <br> BD-9-11: 1.0 <br> BDNE-1: 1.0 <br> BDSE-4: $1.0-1.5$ |  |  |
| PARAUTOCHTHON | BDSE-2: 1.0 | $\begin{array}{\|ll\|} \hline \text { BDSE-1: } & 1.0 \\ \text { BDSE-3,6: } & 1.0-1.5 \end{array}$ |  |  |

Figure 1. CAI values of conodont collections from Triassic and upper Paleozoic rocks in major thrust plates of the Spring Mountains, Las Vegas 30' X 60' quadrangle. Collection localities and accompanying CAI values shown on plate 1 ; collection site coordinates, and other data given in table 1 ; letter symbol indicates 7.5' quadrangle name (BDNE, Blue Diamond NE quadrangle; quadrangle names and their abbreviations are shown on plate 1 map index); localities numbered consecutively in each quadrangle; gp, gray patina; lgp, light-gray patina; sgp, slight gray patina; (kc), Kyle Canyon plate.


Figure 2. Distribution of CAI values in uppermost Cambrian through Lower Triassic rocks in parautochthonus beds and overlying thrust plates in the Spring Mountains. These are, from southeast to northwest: the parautochthon and succeeding Bird Spring, Keystone, Kyle Canyon, Deer Creek, Lee Canyon, Macks Canyon, and Wheeler Pass plates. Distribution of major structural elements is shown on figure 8 (pl. 1).

|  | MISSISSIPPIAN | MISSISSIPPIAN OR DEVONIAN |
| :---: | :---: | :---: |
| WHEELER PASS PLATE |   <br> CC-2: $3.5-4.0$ <br> CC-4: 4.0 <br> IS-1: $3.5-4.0$ <br> WP-4: $4.0+\mathrm{gp}$ | CC-3, 5: 4.0 |
| MACKS CANYON PLATE | CC-1: $\quad 4.0-4.5$ CPNE-1: $4.0-4.5$ CPNE-2. $4.5+$ gp, $6.0,6.5$ CPNE-5: 2.0, $2.5,4.0,5.0-6.5$ |  |
| LEE CANYON PLATE | PANE-3: 5.5-6.0 <br> PANE-4: $4.0-4.5,6.0$ <br> PANE-5: 4.0+ hgp, 6.0 |  |
| DEER CREEK \& KYLE CANYON PLATES | AP-3(kc): $1.5-2.0+\mathrm{hgp}$ <br> CP-5: 4.0 <br> CCSNW-2,4: 4.0 |  |
| KEYSTONE PLATE | BD-1, 3, $8:$ 2.5 <br> BD-4-6: $2.5-3 . \mathrm{gp}$ <br> BDNE-2-4: $1.5-2.0$ <br> BDNE-7: 2.0 <br> GSS-7: $2.0-2.5,2.0$ <br> GS-8,9, $11:$ $2.5 \operatorname{lgp}$ <br> GS-10: $:$ $2.5-3.0$ <br> GS-12. $13:$ $3.01 g \mathrm{lg}$ <br> MS-2: $2.0,6.0$ <br> MS-11: 3.5 <br> PANE-1, $2:$ $6.0-6.5$ <br> TSP-5: $1.5-2.0$ | $\begin{array}{\|l\|l\|} \hline \text { GS-5: } 3.0 \\ \text { GS-6: } & 3.0 \end{array}$ |
| BIRD SPRING PLATE |  |  |
| PARAUTOCH- THON |  |  |

Figure 3. CAI values of conodont collections from Mississippian and Mississippian or Devonian rocks in major thrust plates of the Spring Mountains, Las Vegas 30' X $60^{\prime}$ quadrangle. Localities and accompanying CAI values shown on plate 1 ; age, collection site coordinates, and other data given in table 1; letter symbol indicates 7.5 ' quadrangle name (BDNE, Blue Diamond NE quadrangle; quadrangle names and their abbreviations are shown on plate1 map index); localities numbered consecutively in each quadrangle; lgp, light-gray patina; gp, gray patina; hgp, heavy gray patina; (kc), Kyle Canyon plate.

|  | DEVONIAN |  | SILURIAN | ORDOVICIAN | LATEST CAMBRIAN |
| :---: | :---: | :---: | :---: | :---: | :---: |
| WHEELER PASS PLATE | $\begin{aligned} & \hline \mathrm{CC}-6-8: \\ & \mathrm{CC}-9: \\ & \text { WP-2, 3: } \\ & \text { WP-16: } \end{aligned}$ | $\begin{aligned} & 4.0 \\ & 3.5-4.0 \\ & 4.0 \\ & 4.0+\mathrm{lgp} \end{aligned}$ | $\begin{aligned} & \text { WP-6 }: 4.5+\mathrm{gp}, 5.0, \\ & 5.5+\mathrm{gp} \\ & \mathrm{WP}-7: 4.5+\mathrm{gp}, \text { minor } \\ & 6.0,6.5 \\ & \mathrm{WP}-8: 5.0,6.0 \end{aligned}$ |    <br> WP-1: 4.5  <br> WP-10,11: $4.0-4.5$  <br> WP-12-14: 4.0  <br> WP-5: $4.0-4.5+$ lgp | WP-15:4.5 |
| MACKS CANYON PLATE |  |  |  |  |  |
| LEE CANYON PLATE | CP-3 : CPNE-6: | $\begin{aligned} & \hline 5.0,6.0 \\ & 2.0,3.0+\mathrm{gp} \end{aligned}$ |  |  |  |
| DEER CREEK PLATE | CP-2: CCSNW-3: CCSNW-10 CCSNW-11 |  4.0 <br> $4.5-5.0$  <br> $5.0-5.5$  <br> $:$ 4.5 |  | CP-4: $\quad$ 6.0, 6.5, minor 5.5 CCSNWW-5: $5.5,6.0$, minor 4.0 CCSNW-6: 4.0 , minor 6.0 CCSNWW-7: $3.5-4.0$ CSNW-8: $5.5,6.0$, minor 5.0 CCSNW-9: 5.5, rare 7.0 |  |
| KYLE CANYON PLATE |  |  |  |  |  |
| KEYSTONE PLATE | AP-4 : BDNE-5 : GS-2, 4: GS-3 LS-4 : LS-5, 6: MS-1: MS-4, 5, 9 : MS-6-8: TSP-2 : TSP-3: TSP-4 : | $3.0-3.5$ $2.0-2.5 \mathrm{gp}$ $23.0+\mathrm{gp}$ 3.0 $3.5-4.0$ 3.5 $3.5-4.0$ 3.0 $2.5-3.0$ $2.5-3.0$ $2.0-2.5$ $2.5-3.0+\mathrm{gp}$ | LS-3 : 3.5 | BDNE-6: $4.0+$ lgp <br> LS-8,17,19 4.0 <br> LS-1: $:$ $3.0-3.5$ <br> LS-9: $5.0-5.5$ <br> LS-10: $4.0 .4 .5-5.0$ <br> LS-11 $:$ $3.5,4.0,6.0$ <br> LS-12,13: $:$ $3.0-4.0+$ gp <br> LS-7, 14: 3.0 <br> LS-15: $5.0,6.0$ <br> LS-16: $3.0+$ gp | TSP-1 : 2.5-3.0 |
| BIRD SPRING PLATE |  |  |  |  |  |
| PARAUTOCHTHON |  |  |  |  |  |

Figure 4. CAI values of conodont collections from Devonian through uppermost Cambrian rocks in major thrust plates of the Spring Mountains, Las Vegas 30' X 60' quadrangle. Collection localities and accompanying CAI values shown on plate 1 ; age, collection site coordinates, and other data given in table 1; letter symbol indicates 7.5' quadrangle name (BDNE, Blue Diamond NE quadrangle; quadrangle names and their abbreviations are shown on plate 1 map index); localities numbered consecutively in each quadrangle; lgp, light-gray patina; grp, gray patina.

\begin{tabular}{|c|c|c|c|c|c|}
\hline  \& PERMIAN \& PERMIAN OR PENNSYLVANIAN AND PENN. (P) \& MISSISSIPPIAN, MISSISSIPPIAN OR DEVONIAN (M/D), AND DEVONIAN (D) \& SILURIAN \& ORDOVICIAN AND LATEST CAMBRIAN ( $\epsilon$ ) <br>
\hline GASS PEAK PLATE \& $$
\begin{array}{cc}
\text { CCS-1 }: & 2.0+\mathrm{gp}, \\
3.0+\mathrm{gp}
\end{array}
$$ \& GP-5 : ~1.5 \& CCS-4 : $4.0-4.5+\mathrm{gp}$
GP-2 $:$
4.0+ hgp, 5.5,
6.0 (D)
GP-3:
GP-4 $:$

$4.0-4.5$ (D) \& |  |  |
| :--- | :--- |
| CCS-3 : | 5.5 |
| CCS-31, | $4.0-4.5$, |
| $32:$ | 6.0 |
| CCS-33: | $5.5-6.0$ |
| CCS-34 : | $4.5-5.0$, |
|  | $5.5,6.0$ | \&  <br>

\hline VALLEY PLATE \& GP-1 : 3.0 \& GPSW-1 $\quad: 4.5-5.0(\mathrm{P})$

VA-21: $\quad 4.0,6.0(\mathrm{P})$ \& |  |  |
| :--- | :--- |
| GPNE-1: | $4.0-4.5$ |
| GPNE-2: | $2.5,5.5$ |
| GPNE-3: | $3.5-4.0$ |
| GPNE-4: | $4.0,5.0+\mathrm{gp}$ |
| GPNE-5: | $3.0+\mathrm{gp}$ |
| GPSW-2: | $4.0,5.5,6.0$ |
| GPSW-3: | $4.5+\mathrm{gp}, 6.0$ |
| VA-1: | $4.0+\mathrm{gp}, 6.0$ |
| VA-3: | $3.5-4.0$ (D) |
| VA-4: | 4.0 (D) |
| VA-5: | 4.0 (M/D) |
| VA-6: | $4.0,5.0+\mathrm{gp}$ |
| VA-7: | 6.0 |
| VA-8,16: | $3.5-4.0$ |
| VA-9: | $3.0,4.0+\mathrm{gp}$ |
| VA-11: |  |
| 13, 15: | 4.0 |
| VA-12: | rr4.0, 6.0 |
| VA-14: | $4.0+\mathrm{hgp}$ |
| VA-18: | $4.0+\mathrm{hgp}$ |
|  | rr 6.0 |
| VA-22: | $5.5,6.5$ | \& \& <br>

\hline \[
$$
\begin{aligned}
& \hline \text { DRY } \\
& \text { LAKE } \\
& \text { PLATE }
\end{aligned}
$$

\] \& VA-23: 4.0, 6.0 \& | VA-19: $4.0,6.0(P)$ VA-20: $5.5,6.5$ |
| :--- |
| VA-20: 5.5, 6.5 | \& \& \& <br>

\hline
\end{tabular}

Figure 5. CAI values of conodont collections from Paleozoic rocks in the major thrust plates of the southern Sheep and Las Vegas Ranges, Las Vegas 30' X 60' quadrangle. Collection localities and accompanying CAI values shown on plate 1 ; collection site coordinates and other data given in table 1 ; letter symbols indicate 7.5' quadrangle name (GPNE, Gass Peak NE quadrangle; quadrangle names and their abbreviations are shown on plate 1 map index); localities numbered consecutively in each quadrangle; gp, gray patina; hgp, heavy gray patina; rr, rare; com, common.


Figure 6. Distribution of CAI values in uppermost Cambrian through Permian rocks in the thrust plates of the southern Sheep and southern Las Vegas Ranges. These are, from southeast to northwest: the Dry Lake, Valley, and Gass Peak plates and are correlative with the Deer Creek-Kyle Canyon, Lee Canyon-Macks Canyon, and Wheeler Pass plates of the Spring Mountains.

| $\qquad$ | TRIASSIC | PERMIAN | PERMIAN OR PENN. | PENNSYLVANIAN | MISSISSIPPIAN | MISS. OR DEVONIAN | DEVONIAN | SILURIAN | ORDOVICIAN | LATEST CAMBRIAN |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| WHEELER PASS PLATE |  |  |  |  | $\begin{aligned} & \text { L: 3.5-4.0 } \\ & \text { H: 4.0 } \\ & (4 \text { collns. }) \end{aligned}$ | MC: 4.0 (2 collns.) | $\begin{aligned} & \mathrm{L}: \quad 3.5-4.0 \\ & \mathrm{MC}: 4.0 \\ & \mathrm{H}: \quad 4.0+\mathrm{lgp} \\ & \left(\begin{array}{ll} \text { collns. } \end{array}\right) \end{aligned}$ |  | L: 4.0 <br> MC : 4.0-4.5 <br> H: 4.5 <br> (7 collns.) | $\begin{aligned} & \mathrm{MC}: 4.5 \\ & (1 \text { colln. }) \end{aligned}$ |
| GASS PEAK PLATE (east of LVVSZ ) |  | $\begin{aligned} & \mathrm{MC}: 2.0,3.0+\mathrm{gp} \\ & (1 \text { colln. }) \end{aligned}$ | $\begin{aligned} & \text { MC : } \sim 1.5 \\ & (1 \text { colln. }) \end{aligned}$ |  | $\begin{aligned} & \text { MC : 4.0-4.5 } \\ & \text { (2 collns.) } \end{aligned}$ |  | $\begin{gathered} \mathrm{L}: 4.0-4.5 \\ \mathrm{H}: 4.0+\mathrm{hgp}, \\ 5.5,6.0 \\ \text { (2 collns. ) } \end{gathered}$ | $\begin{array}{lc} \hline \mathrm{L}: & 4.0-4.5 \\ \mathrm{MC}: 5.5 \\ \mathrm{H}: ~ & 5.5-6.0 \\ \text { (5 collns. }) \end{array}$ | L: 4.0 <br> MC : 4.0-4.5 <br> H: 7.0 <br> (26 collns.) | L: 4.0-4.5 <br> MC: ~4.5 <br> (3 collns.) |
| MACKS CANYON AND |  | $\begin{aligned} & \text { L: } 1.5 \\ & \text { H: } 3.0,4.0+\text { sgp } \\ & (2 \text { collns. }) \end{aligned}$ | MC: 6.0 (1 colln.) |  | $\begin{aligned} & \mathrm{L}: \quad 2.0,2.5,4.0, \\ & \quad 5.0-6.5 \\ & M C: 4.0-4.5 \\ & \mathrm{H}: \\ & \text { (4 collns. }) \\ & \text { ) } \end{aligned}$ |  |  |  |  |  |
| LEE CANYON PLATES |  |  | $\begin{aligned} & \text { MC : 3.0-4.0 } \\ & \text { (1 colln.) } \end{aligned}$ | $\begin{aligned} & \text { L: } 2.0+\mathrm{gp} \\ & \mathrm{MC}: 2.0-4.0,6.0 \\ & \mathrm{H}: 3.0-4.0+\text { gp, } 6.0 \\ & (3 \text { collns. }) \end{aligned}$ | $\begin{aligned} & \mathrm{L}: ~ 4.0+\mathrm{hgp}, 6.0 \\ & \mathrm{MC}: 4.0-4.5,6.0 \\ & \mathrm{H}: 5.5-6.0 \\ & (3 \text { collns. }) \end{aligned}$ |  | $\begin{aligned} & \text { L: } 2.0,3.0+\mathrm{gp} \\ & \text { H: } 5.0,6.0 \\ & (2 \text { collns. }) \end{aligned}$ |  |  |  |
| - correlatives - VALLEY PLATE (east of LVVSZ ) |  |  |  |  | L: 2.5 <br> MC : 4.0 <br> H: 5.5, 6.5 <br> (20 collns.) | $\begin{aligned} & \mathrm{MC}: 4.0 \\ & (1 \text { colln. }) \end{aligned}$ | $\begin{array}{\|l\|} \hline \mathrm{L}: \\ \mathrm{Li} \\ \mathrm{MC}: 4.0-4.0 \\ \text { (2 collns.) } \end{array}$ |  |  |  |
| DEER CREEK \& KYLE CANYON PLATES |  | $\begin{aligned} & \text { L: } 1.5-2.0 \\ & \text { H: } 7.0,8.0 \\ & (1 \text { colln., KC }) \end{aligned}$ | $\begin{aligned} & \mathrm{L}: \sim 2.0 \\ & \mathrm{MC}: 3.0(\mathrm{KC}) \\ & \mathrm{H}: 4.5+\mathrm{gp} \\ & \text { (3 collns.) } \end{aligned}$ |  | $\begin{aligned} & \text { L: } 1.5-2.0+\text { hgp } \\ & \text { H: } 4.0 \\ & \text { (4 collns. }) \end{aligned}$ |  | $\mathrm{L}:$ 4.0 <br> $\mathrm{MC}:$ 4.5 <br> $\mathrm{H}:$ $5.0-5.5$ <br> (4 collns. $)$  |  | L: 3.5-4.0 <br> MC: 5.5 <br> H: 7.0 <br> (6 collns.) |  |
| ```DRY LAKE PLATE (east of LVVSZ )``` |  | $\begin{aligned} & \mathrm{MC}: 4.0,6.0 \\ & \text { (1 colln.) } \end{aligned}$ | $\begin{aligned} & \mathrm{MC}: 5.5,6.5 \\ & (1 \text { colln.) } \end{aligned}$ | $\begin{aligned} & \mathrm{MC}: 4.0,6.0 \\ & (1 \text { colln.) } \end{aligned}$ |  |  |  |  |  |  |
| KEYSTONE <br> PLATE | $\begin{aligned} & \mathrm{MC}: 2.5 \\ & (1 \text { colln. }) \end{aligned}$ | $\begin{array}{lc} \hline \mathrm{L}: & 1.5 \\ \mathrm{MC} & : 2.0 \\ \mathrm{H}: & 2.5 \\ (8 & \text { collns. }) \end{array}$ | L: 1.0 <br> MC : 2.0+ Igp <br> H: 3.5 <br> (4 collns.) | $\begin{aligned} & \mathrm{L}: 2.0 \\ & \mathrm{H}: 4.0,6.0 \\ & (2 \text { collns. }) \end{aligned}$ | $\begin{array}{lc} \mathrm{L}: & 1.5-2.0 \\ \mathrm{MC} & 2.5-3.0 \\ \mathrm{H}: & 6.0-6.5 \\ (22 & \text { collns. }) \end{array}$ | MC: 3.0 <br> (2 collns.) | L: 2.0-2.5 <br> MC : 2.5-3.0 <br> H: 3.5-4.0 <br> (18 collns.) | $\begin{aligned} & \mathrm{MC}: 3.5 \\ & (1 \text { colln. }) \end{aligned}$ | L: 3.0 <br> MC : 3.5-4.0 <br> H: 5.0, 6.0 <br> (14 collns.) | $\begin{aligned} & \text { MC : 2.5-3.0 } \\ & \text { (1 colln.) } \end{aligned}$ |
| $\underset{\text { PLATE }}{\text { BIRD SPRING }}$ | $\begin{aligned} & \mathrm{MC}: 1.0-1.5 \\ & \mathrm{H}: \\ & \text { (3 collns. }) \end{aligned}$ | $\begin{aligned} & \hline \text { L \& MC: } 1.0 \\ & \mathrm{H}: \\ & \text { (6 collns. }) \end{aligned}$ |  |  |  |  |  |  |  |  |
| PARAUTOCHTHON | MC: 1.0 <br> (1 colln.) | $\begin{aligned} & \text { L: } 1.0 \\ & \text { H: } 1.0-1.5 \\ & \text { (3 collns. }) \end{aligned}$ |  |  |  |  |  |  |  |  |

Figure 7. Distribution of CAI values by age and structural position in the major thrust plates of the Las Vegas $30^{\prime} X 60^{\prime}$ quadrangle. The Gass Peak plate correlates with the Wheeler Pass plate; the Valley plate with the Lee Canyon and Macks Canyon plates, and the Dry Lake plate with the Deer Creek and Kyle Canyon plates. LVVSZ, Las Vegas Valley shear zone; L, lowest CAI value; MC, most common CAI value; H, highest CAI value.
The complete distribution of CAI values is shown in figures 1-6.


[^0]:    ${ }^{1}$ U.S. Geological Survey, MS973, Box 25406, Denver Federal Center, Denver, CO 80225.
    ${ }^{2}$ U.S. Geological Survey, MS980, Box 25406, Denver Federal Center, Denver, CO 80225.
    ${ }^{3}$ Department of Geology and Geophysics and Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK 99775.
    ${ }^{4}$ U.S. Geological Survey, MS926A, Reston, VA 22092

