APPENDIX B

A DEVILS HOLE PRIMER
by
J. M. Landwehr and I. J. Winograd

at
<http://water.usgs.gov/nrp/devils.html>

What is Devils Hole?
Devils Hole is a tectonic cave developed in the discharge zone of a regional aquifer in south-central Nevada. The walls of this predominantly subaqueous cavern are coated with dense vein calcite. The stable isotopic content of the calcite provides a 500,000-year record of variations in temperature and other paleoclimatic parameters.
(See Winograd, et al., 1992; and Riggs, et al., 1994.)

What do the stable isotopic records represent?
The Devils Hole δ18O record is an indicator of paleotemperature and corresponds in timing and magnitude to paleo-SST (sea surface temperature) recorded in Pacific Ocean sediments off the California and Oregon coasts. The record is also highly correlated with major variations in temperature in the Vostok ice core, from the East Antarctic plateau. The δ13C record is thought to reflect changes in global variations in the ratio of stable carbon isotopes of atmospheric CO2 and/or changes in the density of vegetation in the groundwater recharge areas tributary to Devils Hole.
(See Winograd et al., 1996; Herbert et al., 2001; Winograd, 2002; Winograd, et al., 1997; Landwehr and Winograd, 2001; Landwehr, 2002; and Coplen, et al., 1994.)

Are the Devils Hole ages accurate? How was the vein calcite dated?
As eminent a geochemist as W. Broecker has stated that "...the Devils Hole chronology is the best we have..." Since 1992, all core material has been uranium-series dated using thermal ionization mass spectrometric (TIMS) methodology. In 1997, the Devils Hole Thorium-230 dates were independently confirmed by non-USGS investigators using Protactinium-231.
(See Broecker, 1992; Ludwig, et al., 1992; Winograd, et al., 1997; and Edwards, et al., 1997.)

Is there still an inconsistency between the Devils Hole record and the Milankovitch hypothesis?

Yes. The Milankovitch hypothesis holds that the timing and duration of the Pleistocene ice ages are a direct consequence of variations in solar insolation occurring at the latitude of 65° North, in response to changes in the precession, obliquity and eccentricity of the Earth's orbit. The 500,000-year Devils Hole δ18O record presents four challenges to this theory with respect to:

1. the timing of the penultimate glacial-interglacial transition;
2. the duration of the interglacial climates ;
3. the apparent non-stationarity of paleoclimatic time series; and
4. the occurrence of a well-developed glacial-interglacial cycle at a time (450,000-350,000 years ago) when orbital theory indicates that none should occur.

Numerous discussions of the implications of the Devils Hole record to the Milankovitch hypothesis have been published since 1992, most addressing the first challenge listed above. However, uranium-series dating of corals that mark past sea level high stands has shown that the penultimate glacial-interglacial transition occurred by about 136,000 years ago, a finding irreconcilable with the Milankovitch hypothesis, even as modified by Crowley and Kim (1994). The three remaining challenges listed above have yet to receive detailed attention. A recent overview of this controversy appeared in the June 23, 2000 issue of Science.
(See Winograd, et al., 1992; Crowley and Kim, 1994; Winograd, et al., 1996; Winograd, et al., 1997; Henderson and Slowey, 2000; Gallup et al., 2002; Muhs et al., 2002; and Karner and Muller, 2000.)

How long can we expect the present interglaciation to last?
No one knows for sure. In the Devils Hole record, the last four interglaciations lasted over ~20,000 years with the warmest portion being a relatively stable period of 10,000- to 15,000-years duration. This is consistent with what is seen in the Vostok ice core from Antarctica and several records of sea level high stand, and would suggest that an equally long duration should be inferred for the current interglacial period as well. Work in progress on Devils Hole data for the period 60,000 to 5,000 years ago indicates that current interglacial temperature conditions may have already persisted for 17,000 years. Other workers have suggested that the current interglaciation might last tens of thousands of years. (See Winograd, et al., 1997; Muhs et al., 2002; and Paillard, 2001.)

Why should anyone but a scientist care about this topic?
In addition to providing information about the possible duration of our present interglacial climate (discussed above), research in Devils Hole has provided valuable information for water managers about recharge rates in the principal aquifer in south-central Nevada. Precise information about paleoclimates also provides information needed for evaluation of the potential suitability of Yucca Mountain, Nevada, for the disposal of nuclear wastes. (See Szabo, et al., 1994; Forester et al., 1999; and Thomas, Winograd and Coplen, 1996.)

Where can I see the records?
Records for the period ~560 to 60 ka are given in USGS Open-file report 97-792, "Data from Devils Hole Core DH-11". (See Landwehr, et al., 1997.)

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FOR ADDITIONAL INFORMATION:

See description of NRP project Interface of Paleoclimatology and Aquifer Geochemistry.

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APPENDIX C

Zeolites
by
Roberto Pabalan

The word zeolite has Greek roots and literally means ‘boiling stone,’ an allusion to the visible loss of water noted when natural zeolites are heated. The zeolite structure has tetrahedral SiO4 and AlO4 linked together to give three-dimensional anionic networks in which each oxygen is shared between two tetrahedra. Thus, there are no unshared oxygens in the framework. For every Si+4 that is replaced in the framework by Al+3, a negative charge is created which is neutralized by a charge equivalent of cations. The zeolite structure contains channels and cavities that are occupied by cations or water molecules. The cation has a high degree of mobility and ordinarily undergoes ion exchange while the water molecule is readily lost and regained without damage to the crystal structure.

Zeolite Occurrences at Yucca Mountain

Published information on industrial minerals, including zeolites, in the Yucca Mountain area was compiled and synthesized by Castor and Lock (1995). Figure B–1 is a 1:250,000 scale map showing the occurrences of industrial minerals in the Yucca Mountain vicinity based on information compiled by Castor and Lock (1995).

According to Castor and Lock (1995), clinoptilolite–heulandite group zeolites and mordenite are present in significant amounts in volcanic rocks of the Yucca Mountain area. Considerable literature is available on these occurrences because sorption and retardation of radionuclides by zeolites may be a factor in repository performance assessment and design (Bish and Vaniman, 1985). In addition, study of these minerals is important in understanding their potential reactivity in a repository environment. Age dates on zeolites have been used in attempts to date diagenetic or hydrothermal activity in the volcanic sequence at Yucca Mountain (WoldeGabriel, et al., 1993). The zeolite erionite occurs in small amounts in a single stratigraphic horizon at Yucca Mountain, along with rare phillipsite, chabazite, and stilbite (Bish and Chipera, 1991).

Quantitative data on zeolite mineral contents of borehole samples from Yucca Mountain are reported in Levy (1984) and Bish and Vaniman (1985) and provide some idea of zeolite mineral potential (Castor and Lock, 1995). Zeolite mineral deposits in the western U.S. that are being mined, or that have been investigated for economic potential, contain about 50 percent or more zeolite. Therefore, borehole intervals identified as containing 50 percent or more clinoptilolite plus mordenite have been compiled in order to estimate the size of the zeolite resource in the Yucca Mountain area (Castor and Lock, 1995).

Samples with 50 percent or more zeolite come from strongly zeolitized zones in ash flow tuff and bedded tuff in several stratigraphic units (Castor and Lock, 1995). The zeolitized tuff probably represents the overlap of an alteration zone defined by the presence of clinoptilolite and mordenite (diagenetic alteration zone II of Broxton, et al., 1987) with tuff that retained a large component of vitric material following the original cooling of the tuffs. The affected units include the basal part of the Topopah Spring Tuff of the Paintbrush Group, the tuff and lava of the Calico Hills, all three members of the Crater Flat Tuff, and bedded tuffs associated with these units.

Economic Resources of Zeolite at Yucca Mountain

A large subeconomic resource of zeolite is present at Yucca Mountain (Castor and Lock, 1995); however, the stratigraphic units that contain this estimated resource do not crop out within the Yucca Mountain Conceptual Controlled Area. Although zeolitized rock may reach the surface along the northeast border of the Yucca Mountain Conceptual Controlled Area, the zeolite is covered by considerable thicknesses of tuff containing little or no zeolite {about 500 m [1,640 ft] in borehole USW G-2) a short distance to the south. Because zeolite deposits are mined by open-pit methods, the amount of overburden is an important factor, and the zeolite subeconomic resource in the Yucca Mountain Conceptual Controlled Area occurs at depths that render commercial extraction unlikely. The deposit is economically unattractive when compared with the large amounts of readily extractable higher-grade zeolite elsewhere in the western United States. For instance, nearby deposits in the Ash Meadows and Beatty areas (Figure B–1) are of much higher grade and are more easily mineable. Many high-grade zeolite deposits in the western U.S. have been evaluated by mining companies, oil companies, and chemical companies, and their commercial potential has been known to industry for years; however, hundreds of millions of tons of zeolite have no commercial value as the total domestic market is only 35,000 to 45,000 tons per year.

As noted by Papke (1972), zeolite deposits of the type that is present in tuff at Yucca Mountain are extensive in Nevada and only have economic potential for uses that require only impure materials of relatively low unit value. Given their low commercial value, relatively low grades, and the poor mining situation, it is not likely that zeolites in the Yucca Mountain Conceptual Controlled Area will be commercially attractive in the foreseeable future (Castor and Lock, 1995).

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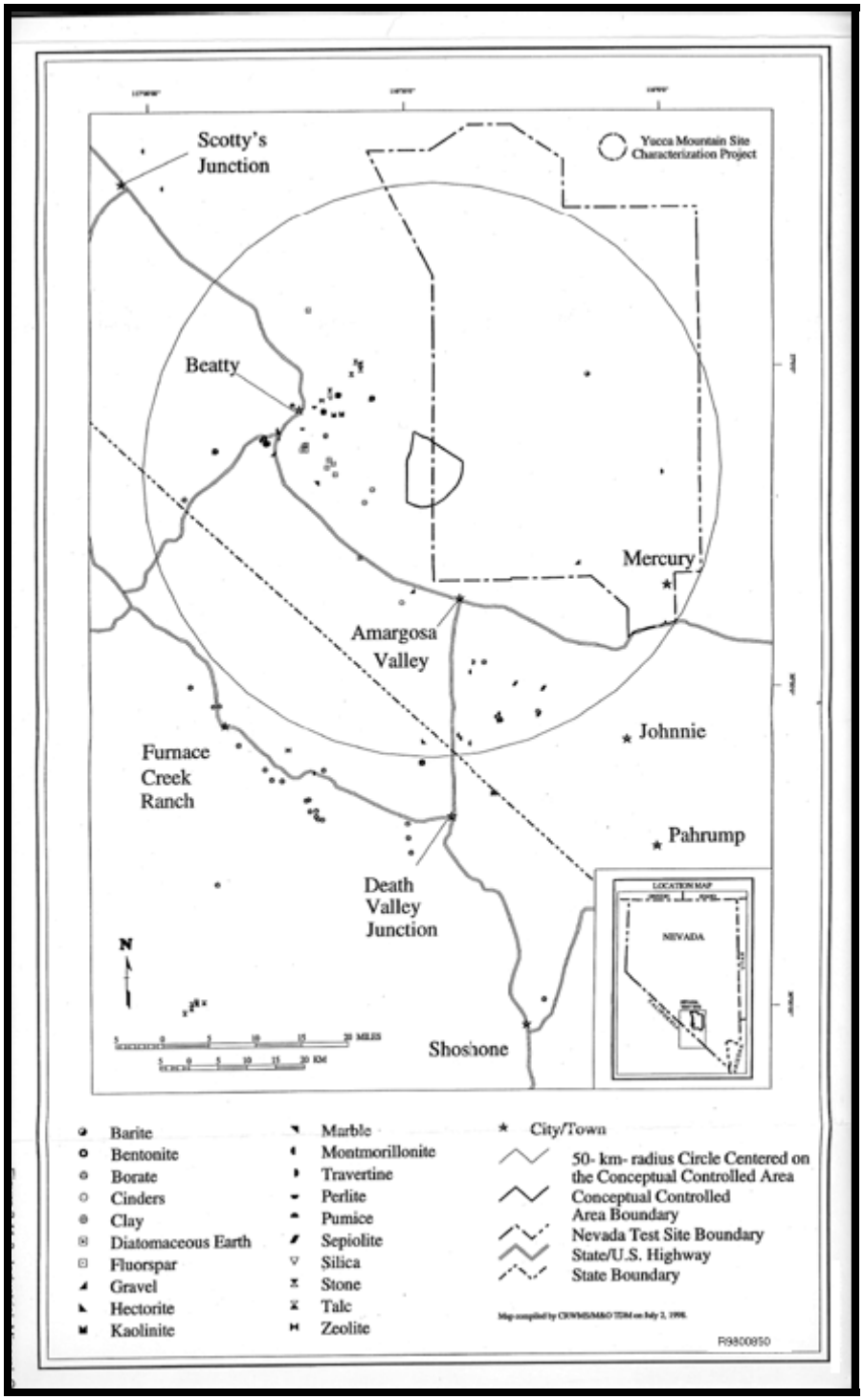
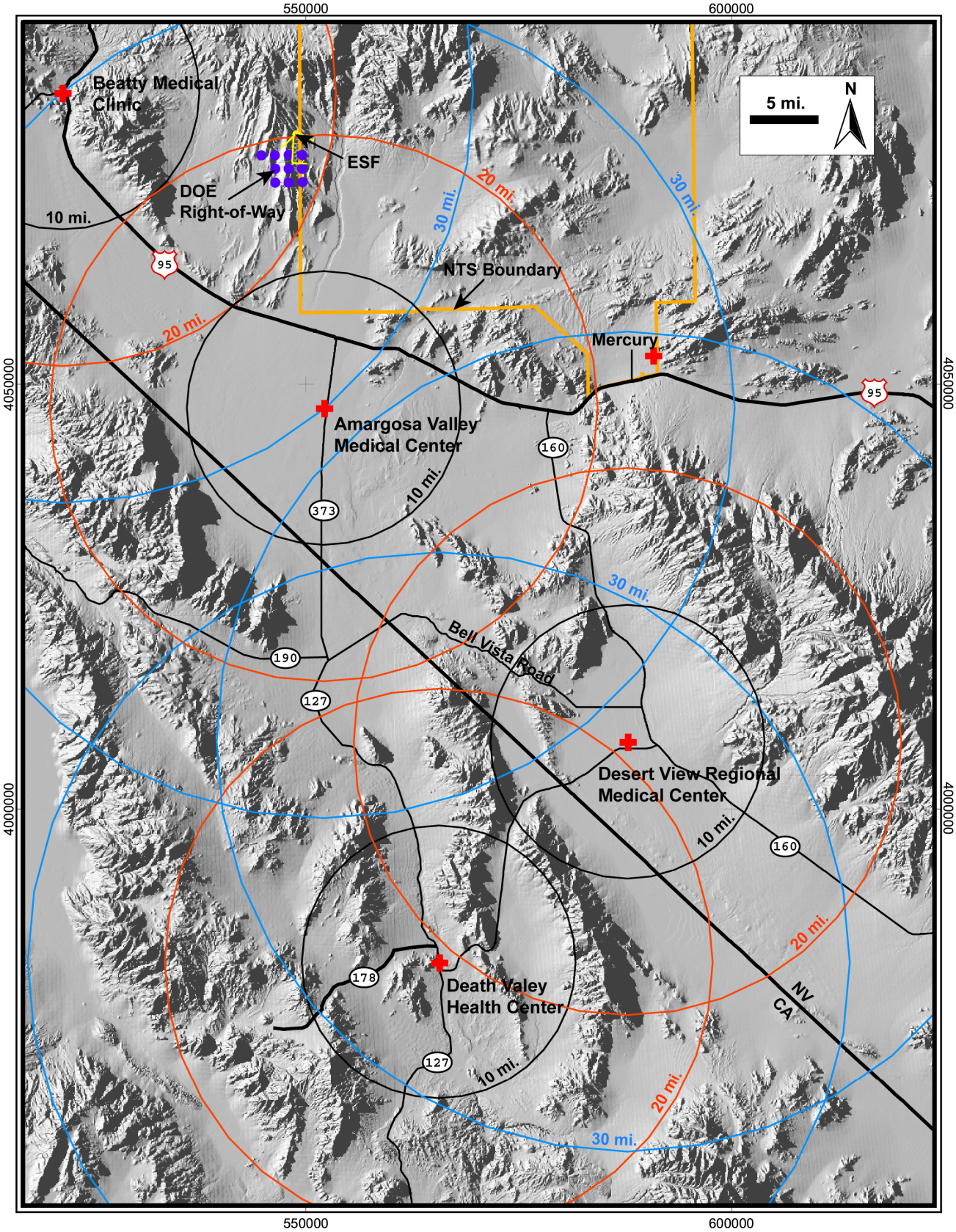


Figure C–1. Industrial mineral occurrences in the Great Basin vicinity of Yucca Mountain (DOE, 1999)

N O T E S

MEDICAL FACILITIES
IN SOUTHWESTERN NEVADA AND EASTERN CALIFORNIA

City	Location/Phone	Directions	Hours
Beatty, Nevada	Beatty Medical Clinic 702 Irving Street Beatty, Nevada (775) 553-2208	Irving Street crosses NV 374 three blocks southwest of the four-way stop light in the center of Beatty, Nevada. The clinic is located two blocks to the southeast of that intersection.	Monday to Friday; 8:00 am to 5:00 pm Primary Care
Amargosa Valley, Nevada	Amargosa Valley Medical Center 845 Farm Road Amargosa Valley, Nevada (775) 327-5432	The Amargosa Valley Medical Center is located on Farm Road 5 mi south of junction of highways US Highway 95 and NV 373 (approximately 11 mi north of the California–Nevada border on NV 373). Across the street from the clinic, the town is building a Flight for Life helicopter landing pad to facilitate more rapid response to emergencies.	Monday to Friday; 8:00 am to 5:00 pm Primary Care
Shoshone, California	Death Valley Health Center Old Highway 127 Shoshone, California (760) 852-4383 (800) 852-3842	Health Center is located north of junction CA 176 along Old State Route 127, which is parallel to and west of the new NV 127.	Monday to Friday; 7:00 am to 3:00 pm Primary Care– Limited Services
Pahrump, Nevada	Desert View Regional Medical Center 260 South Lola Lane Pahrump, Nevada (775) 751-7500	Medical Center at the intersection of S. Lola and W. Wilson. From **Shoshone, CA** – 5.6 mi. east of CA/NV state line on NV 372 to S. Lola, left 0.6 mi. From **Death Valley Junction, CA** via Bell Vista Rd: in Pahrump at start of E-W section of Bell Vista (See map) 2.9 mi to S. Leslie, right 3.6 mi. to W. Wilson, left 1.5 mi. to S. Lola, turn left. From **NV 160**, S to W. Wilson 1.9 mi. to S. Lola turn right.	24-Hour Emergency Services and Standard Hospital Services
Death Valley N.P., CA	Range Dispatch (760) 786-3200	Visitors Center at Furnace Creek Campground Area	First-Aid Only 8:00 am to 5:00 pm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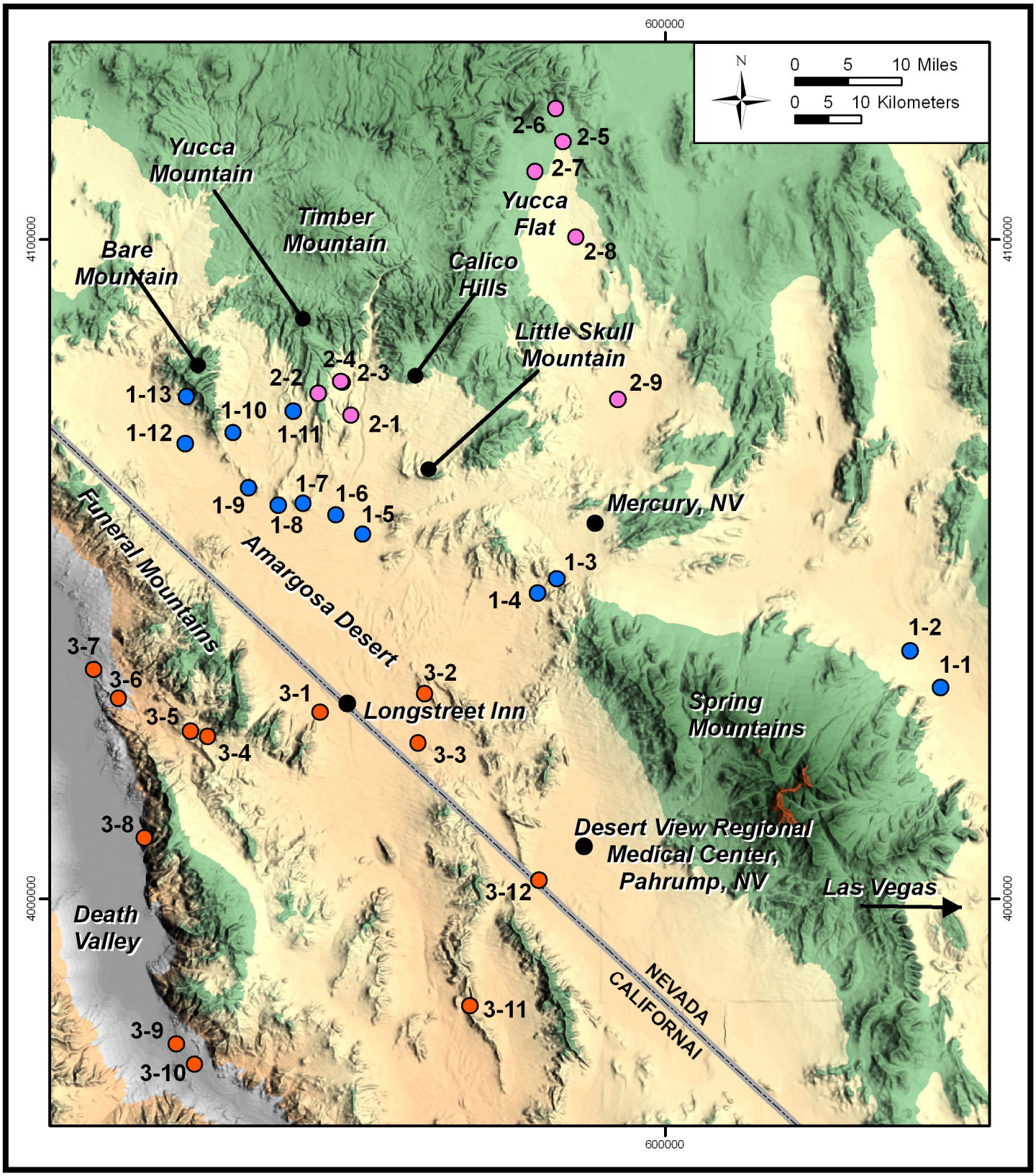
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