THE COSO - CASA DIABLO HYDRATION CONUNDRUM

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Archaeologists conducting research in the central coast region of California have identified a disturbing, possible inconsistency between hydration measurements from Casa Diablo and those from Coso specimens. Expectations are that hydration measurements from these obsidian sources should reflect their different hydration rates as seen elsewhere, particularly in the western Great Basin. Central coast archaeologists have speculated that temperatures depressed by the marine environment may differentially affect hydration development on specimens from these sources. We explore these observations through induced-hydration experiments and by examining archaeological data from contexts east of the Sierra Nevada crest westward to the shore of the Pacific Ocean.

Similarity in hydration band measurements between Casa Diablo and Coso obsidians has been observed at sites on and near California's central coastal area, from Santa Cruz, Monterey, and San Luis Obispo counties (Jones and Waugh 1995). This has lead to the conclusion that obsidian from these sources hydrates at roughly equal rates. However, when Coso hydration development is viewed from Inyo County, a problem arises, because observations there indicate that Coso obsidian hydrates at a significantly faster rate than does Casa Diablo glass. Based on physical and chemical laws, the relative rates between these two (and all) obsidians should remain constant when the sources being compared have been subjected to equal environmental conditions. The conundrum that presents itself is a possible hydration-rate change between eastern California and the central coast.

This leads to the hypothesis and null hypothesis:

- Casa Diablo and Coso obsidians hydrate at the same rate.
- Casa Diablo and Coso obsidians do not hydrate at the same rate.

These hypotheses typically can be tested under situations that include the following:

1. examination of obsidian specimens from dated contexts;
2. comparison of hydration band measurements obtained from temporally diagnostic artifacts (e.g., time-sensitive projectile points) and/or single-component sites, and;
3. comparison of induced-hydration band measurements.

Each of these avenues of investigation has merit, but each also has drawbacks. For example, discovery of datable features (e.g., hearths, house floors, caches) with associated obsidian specimens is a challenge. They are rare. Amassing several hundred time-sensitive obsidian projectile points from specific sources also can be difficult, especially in areas where they occur infrequently, such as along the central California coast. Single-component sites with appropriate numbers of obsidian specimens and sources are uncommon. Finally, induced-hydration studies have the potential to be fruitful, but how forced laboratory hydration behaves relative to natural hydration is open to debate.

INVESTIGATION PROCEDURES

Our study area includes two regions: the central California coast and near-coast counties of Monterey, San Benito, San Luis Obispo, and Santa Barbara; and the interior counties of Fresno, Inyo, Kern, Kings, Madera, and Tulare. The study area counties include the following environmental regimes: coastal; interior valley; mountains; and basin. Initially, we compiled hydration band measurements from 39 selected sites within the study area (Figure 1). These wide-ranging site locations are useful in examining the geographic distribution of the two obsidian sources considered here. Figure 1 shows the relative frequency of Coso and Casa Diablo obsidian specimens at these sites.

Temperature conditions are known to effect hydration development. The following discussion on temperature creates a context for how and why temperature is used in obsidian hydration studies.

EFFECTIVE HYDRATION TEMPERATURE

From the earliest days of obsidian hydration studies, it has been agreed that increased temperature will result in larger hydration bands. Effective Hydration Temperature (EHT) is the term used to describe the single temperature that best represents the compound effect of the varying temperatures to which an artifact has been subjected throughout its history. Recent studies suggested that the hydration measurement would be about 6% larger for every one degree Celsius. This means that, as an alternative to developing a rate that has EHT as a factor, one can adjust the measurement and use a common diffusion rate (a diffusion rate is one in which the age is calculated as a function of the square of the hydration rim.) For example, when applying a

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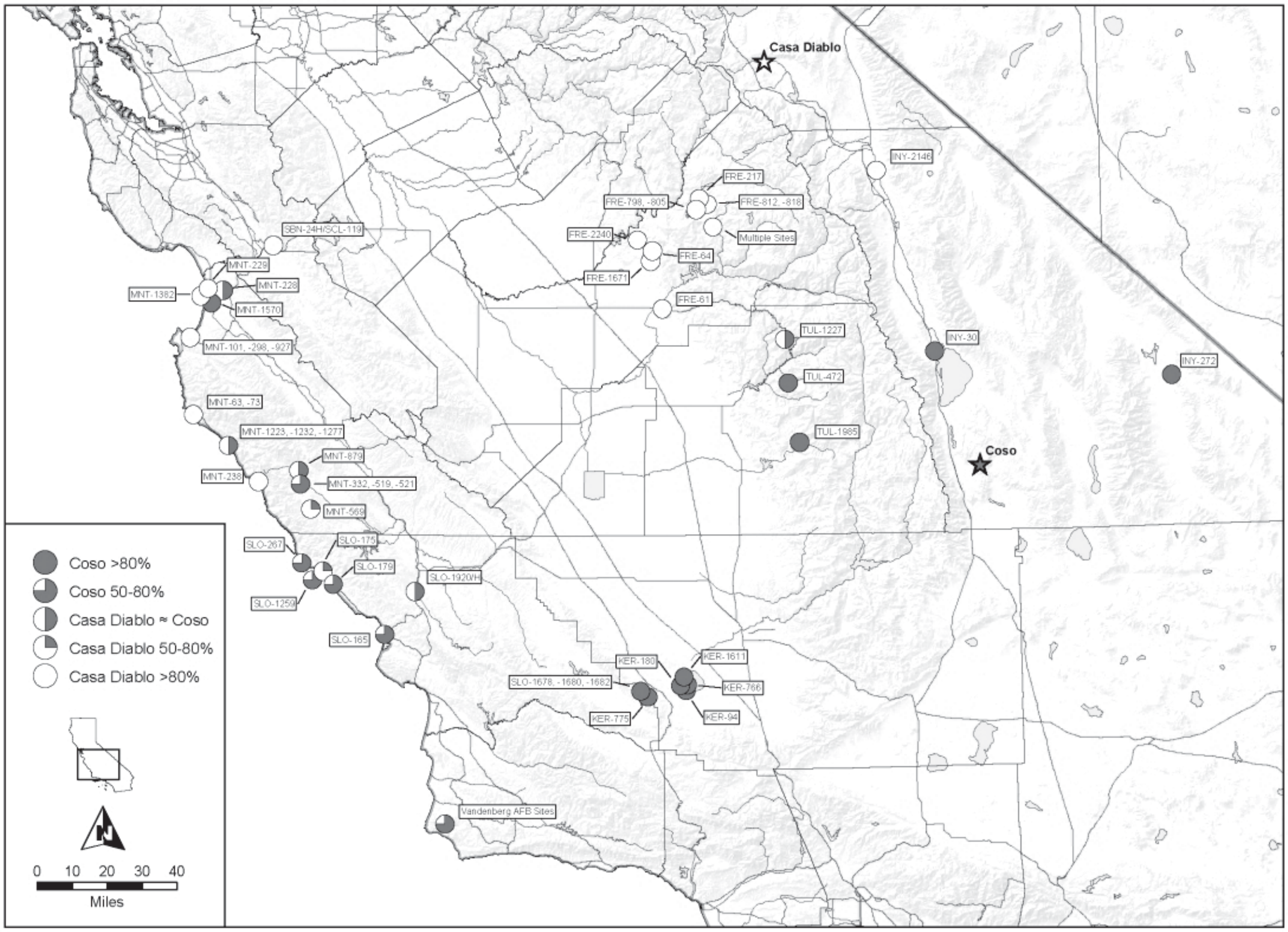


Figure 1: The study area showing the locations of the Coso and Casa Diablo obsidian sources and selected archaeological sites with hydration band measurements. Pie charts show the relative frequency of the two source materials.

diffusion rate developed for 16°C, in an environment with an EHT of 17°C, one can reduce the measurement by 6% and use the existing rate.

When the change in hydration rate is plotted against change in temperature, it follows an Arrhenius curve. This means that there is a straight-line relationship between one over the temperature in degrees Kelvin plotted against the natural log of the hydration rate. The temperature effect, therefore, is not linear. Each degree of additional heat has a compounding effect on the hydration rate. This effect varies over the full range of temperatures but can be simplified to the 6% adjustment in the ambient range.

Therefore, one of the factors needed to interpret a hydration measurement is the EHT of the site from which the artifact was recovered. If one is willing to assume that the temperature over the depositional history is similar to the current environment, one can either bury sensors at the site for a year or estimate the EHT using published weather-station data applied to Lee's Natural Effective Temperature equation.

In the *Journal of Applied Meteorology* (Lee 1969:423-430), Richard Lee discussed the collection of temperature data using a chemical device that converts sucrose to glucose and fructose over time as a function of temperature. He noted that since this reaction followed an Arrhenius equation, the temperature effect is exponential rather than linear and therefore cannot be used directly to determine the simple mean temperature. By sampling the relationship between mean and effective temperature, Lee provided regression factors using effective temperature (T_e) and range of temperatures (R_T) to approximate the mean temperature (T_a) from his chemical reaction:

$$T_a = -1.2316 + 1.0645\, T_e - 0.1607\, R_T$$

Because obsidian hydration also obeys an Arrhenius equation, these factors, used in the reverse direction (estimating effective temperature from mean temperature) and referred to as "Lee's formula," have been relied upon by archaeologists to estimate EHT for the interpretation of obsidian hydration dating.

EHT may be the single factor most responsible for error in obsidian hydration dating when good source-specific rates are available. Lee reports a standard error for his formula of 1.0^{0}C. This is a significant potential error when analyzing hydration dates. Added to this is the fact that the published weather-station data represent only recent temperature patterns and likely do not reflect the full history of the artifact.

We downloaded weather (temperature) data (http://www.wrcc.dri.edu/summary/climsmnca.html) which was used to calculate effective hydration temperatures from locations that span central California from the Pacific coast, across the Sierra Nevada to Owens Valley and beyond to Death Valley (Figure 2). Table 1 provides EHT values for weather stations throughout the study area. These EHTs are useful in our analysis of the effect that temperature should have had on the rate of development of hydration bands. Locations with lower EHTs should be marked by inhibited hydration development, while places with elevated EHTs should have experienced rapid hydration band growth. The EHT values across the landscape allow for standardizing hydration band measurements between locations of dissimilar temperature regimes. This allows for direct, meaningful comparison of the relative ages of archaeological phenomena found within our study area, which is marked by varied climatic conditions (e.g., coastal and near-coastal environment, San Joaquin Valley, Sierran foothills, high Sierra, and the western Great Basin).

Obviously, weather stations are not always located at places convenient to archaeological research. Clearly, Figure 2 reveals a paucity of coastal weather stations between Monterey and Santa Barbara. This dearth of weather-station data is being confronted by placement of temperature sensors at selected coastal and near-coastal sites. The temperature sensors are recording current surface and subsurface conditions on an hourly basis.

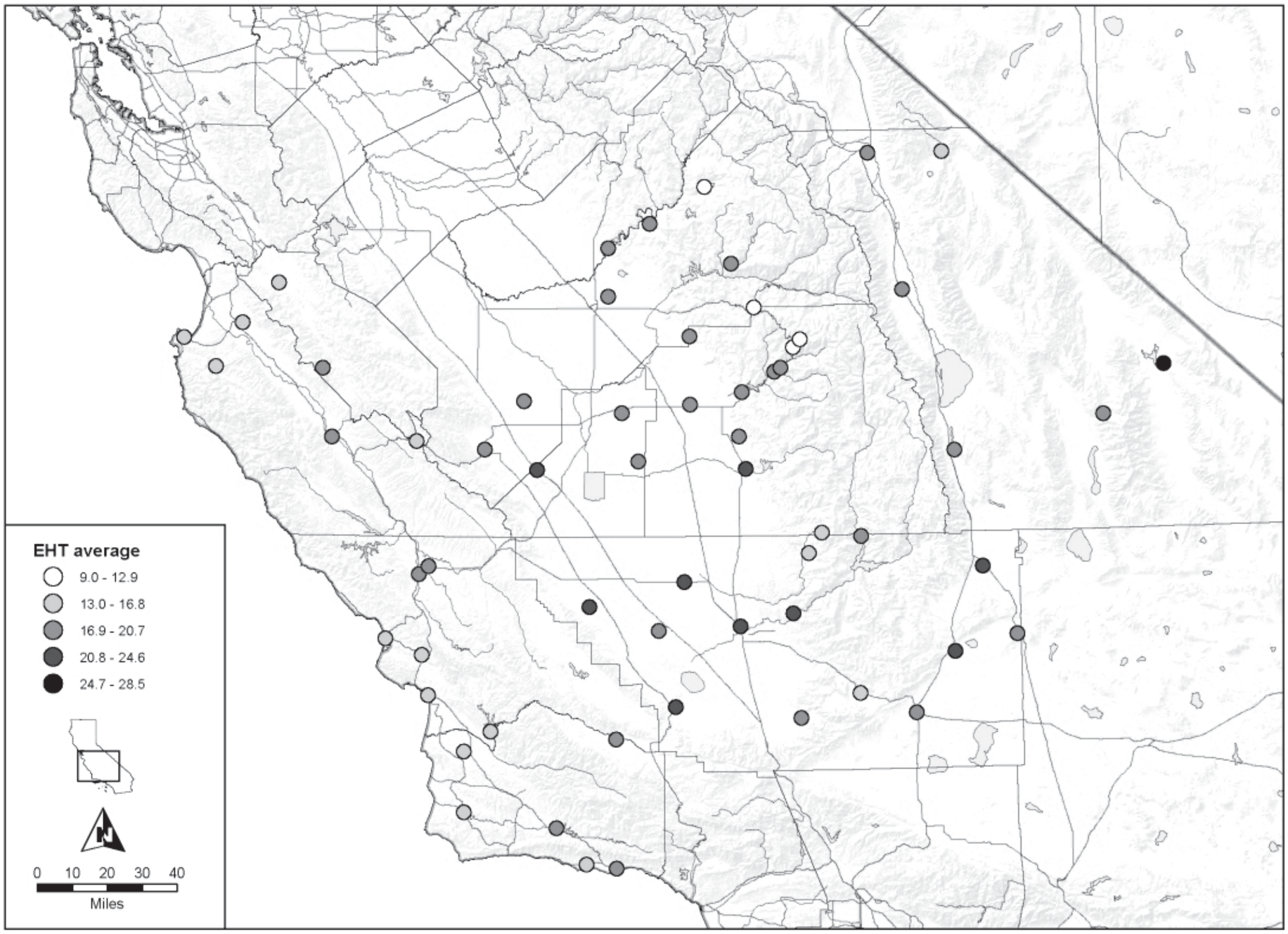
Naturally developed hydration proceeds too slowly for us to wait for it to achieve detectable, measurable widths. We would have to sit around for 100 or so years. This is clearly beyond the lifespan archaeologists enjoy. We therefore turn to inducing hydration under laboratory conditions.

INDUCED HYDRATION

Inducing obsidian hydration in the laboratory at high temperatures has been around since the 1960s when obsidian hydration dating was first introduced. The process capitalizes on the fact that the rate of hydration increases with increased temperature. This allows us to create measurable hydration bands under controlled conditions in weeks rather than centuries.

Researchers have attempted to calculate source-specific hydration rates using induced hydration by observing the change in hydration development over multiple temperatures in the range of 100 to 200 degrees Celsius. By extrapolating the resulting trend to ambient

Figure 2: Locations of weather stations used to calculate effective hydration temperatures in the study area. Temperature data adapted from http://www.wrcc.dri.edu/summary/climsmnca.html.



temperatures, they arrive at a rate for the ambient range. These rates have not yet proven reliable, in part because extended exposure to extreme temperatures in the liquid environment of the pressure reactor appears to cause some hydration band dissolution. The resulting smaller bands thus produce a slower rate and, in turn, dates calculated with this rate are too old to fit with archaeological expectations. However, induced-hydration experiments continue to be useful in understanding some aspects of the hydration process.

The experimental methods are relatively simple. We place multiple flakes of obsidian with water in a Parr pressure reactor with a sophisticated temperature controller. The water is buffered with silica gel to discourage dissolution. Additional experiments are underway to alter the environment further to attempt to eliminate dissolution entirely. When the flakes are removed from the reactor, thin sections are made of each flake and mounted on glass slides. Six measurements are made of each band, and these are averaged.

The three most common ways that induced hydration has been applied in the past are these:

1. To perform time-series studies (observing hydration growth for different amounts of time at a given temperature) to calculate the rate of growth;

2. To perform temperature-series studies (observing hydration growth for different temperatures for a given amount of time); and

3. To calculate comparison ratios to determine the relative hydration growth on two or more sources.

Kim Tremaine posited that two sources of obsidian could be subjected simultaneously to induced hydration to determine if they hydrate at the same rate or whether one hydrates faster or slower than the other (Tremaine 1989). She believed that the comparison ratio found at laboratory temperatures could be directly applied to artifacts that have hydrated at ambient temperatures. It is unclear how much the observed hydration band dissolution affects this practice. Improved induced-hydration procedures and equipment may allow us to resolve this issue more conclusively. We are convinced that if two sources hydrate similarly at high temperatures, they will do the same at ambient temperatures, and that if one source produces significantly larger bands under induced conditions, it can be assumed that it would hydrate faster under archaeological conditions.

To accelerate hydration development we make freshly flaked obsidian specimens from selected source material. These specimens are then placed into thermally-regulated reaction chambers and subjected under a controlled laboratory setting to identical environmental conditions of temperature, pressure, time, and moisture. Under controlled temperatures, usually set at 150 degrees centigrade, we can accelerate the hydration process to the point where useful hydration bands are produced in a few days or in a matter of weeks if we prefer larger bands.

Table 1: Weather Stations in Study Area with EHT.

Weather Station	County	Elev	EHT
Ash Mountain	Tulare	1,690	20.5
Auberry 1NW	Fresno	2,140	19.1
Bakersfield Airport	Kern	490	21.5
Balch Power House	Fresno	1,720	19.6
Bishop Airport	Inyo	4,110	17.0
Buttonwillow	Kern	270	20.5
Cachuma Lake	Santa Barbara	780	18.1
Cantil	Kern	2,010	21.4
Carmel Valley	Monterey	430	15.5
Coalinga	Fresno	670	20.6
Corcoran Irrig	Kings	200	20.3
Death Valley	Inyo	(190)	28.5
Deep Springs College	Inyo	5,230	15.5
Five Points 5 SSW	Fresno	290	20.1
Fresno Airport	Fresno	340	20.5
Friant Gov. Camp	Fresno	410	19.9
Giant Forest	Tulare	6,410	11.4
Glennville	Kern	3,140	15.3
Grant Grove	Fresno	6,600	11.0
Haiwee	Inyo	3,830	18.7
Hanford 1 S	Kings	250	19.9
Hollister	San Benito	280	16.5
Huntington Lake	Fresno	7,020	10.2
Independence	Inyo	3,950	19.1
Inyokem	Kern	2,440	21.1
Kern River PH1	Kern	970	23.1
Kern River PH3	Kern	2,700	19.7
Kettleman Station	Kings	510	21.7
King City	Monterey	320	16.9
Lemon Cove	Tulare	510	20.4
Lindsay	Tulare	420	19.9
Lodgepole	Tulare	6,730	9.0
Lompoc	Santa Barbara	90	15.9
Maricopa	Kern	670	21.6
Middlewater	Kern	800	21.2
Mojave	Kern	2,740	20.3
Monterey	Monterey	380	14.9
Morro Bay FD	San Luis Obispo	120	14.4
New Cuyama FS	Santa Barbara	2,160	17.5
Orange Cove	Fresno	430	19.9
Paso Robles	San Luis Obispo	700	17.4
Paso Robles Airport	San Luis Obispo	800	17.9
Pinacles NM	San Benito	1,310	17.5
Pismo Beach	San Luis Obispo	80	15.5
Porterville	Tulare	390	20.8
Posey 3 E	Tulare	4,960	13.2
Priest Valley	Monterey	2,300	16.0
Randsburg	Kern	3,570	20.4
Salinas 2 E	Monterey	80	15.8
Salinas Airport	Monterey	70	15.5
San Luis Obispo P	San Luis Obispo	310	16.6
Santa Barbara	Santa Barbara	-	17.3
Santa Barbara Airport	Santa Barbara	10	16.5
Santa Maria Airport	Santa Barbara	250	15.4
Tehachapi	Kern	4,020	15.5
Tejon Rancho	Kern	1,420	20.5
Three Rivers Ham	Tulare	1,140	20.4
Twitchell Dam	San Luis Obispo	580	16.8
Visalia	Tulare	330	20.5
Wasco	Kern	350	20.9
Wildrose RS	Inyo	4,100	18.4

For this research we induced hydration on obsidian from four locations/sources. Casa Diablo (Lookout Mountain) and two Coso locations (Colossal Quarry and generic West Sugarloaf) were analyzed, with Napa Valley as a control because its hydration rate is well understood. The reason for our analysis of obsidian from two Coso quarry locations will become apparent; however, for the moment, we point out that Colossal Quarry is depicted as a quarry locality within the larger geographic area known as West Sugarloaf.

The results of the induced hydration are shown on Table 2.

DISCUSSION

The induced hydration results shown on Table 2 reveal that West Sugarloaf (generic) obsidian clearly hydrates at a rate quite different from that for Colossal Quarry obsidian. West Sugarloaf bands are 20% larger than those of Colossal Quarry flakes hydrated under the same conditions.

But is it reasonable to believe that the Coso sub-source recovered from Inyo County, and that recovered from the central California coast, are distinct? Why would Colossal Quarry obsidian tend to travel to the coast and generic West Sugarloaf travel to the Owens Valley? Eerkens and Rosenthal (2004) suggest that they might. Although those authors did not distinguish Colossal Quarry from generic West Sugarloaf, they did observe that the use of Coso sub-sources varied geographically. "[C]ertain types of obsidians were thought of as being particularly poisonous' by Owens Valley inhabitants" (2004:25). If further research allows us to distinguish the Colossal Quarry sub-source, we may learn more about prehistoric commerce in central California.

Although these Coso quarries are not distinguished on the basis of trace elements during XRF analysis, it appears that they might be differentiated under microscopic examination. During a preliminary study, a limited number of West Sugarloaf hydration thin-sections were examined, and a potentially unique feature common to Colossal Quarry specimens was the presence of spider-like micro-structures.

Further research is warranted, and we anticipate pursuing some, if not all, of the following in the next few years:

1) Visit quarry and collect a wide range of specimens for intra-site studies;

2) Conduct more microscopic examination with CQ and other Coso glasses;

3) Check water content between glass "seams" and disbursed cobbles.

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Table 2: Induced Hydration Results.

Lab#	Submitter	Job#	Catalog#	Description	Remarks	Measurements	Mean
1	T. Origer	R-31	CD-LM-A	old	none	3.8 3.8 3.8 3.9 3.9 3.9	3.9
2	T. Origer	R-31	CD-LM-B	old	none	3.9 3.9 3.9 3.9 4.0 4.0	3.9
3	T. Origer	R-31	CD-LM-C	old	none	3.7 3.7 3.8 3.8 3.8 3.9	3.8
4	T. Origer	R-31	CD-LM-D	old	none	3.8 3.9 3.9 3.9 3.9 4.0	3.9
5	T. Origer	R-31	CD-LM-E	old	none	3.7 3.7 3.7 3.7 3.8 3.9	3.8
6	T. Origer	R-31	Coso-CQ-A	old	none	3.9 3.9 3.9 3.9 4.0 4.0	3.9
7	T. Origer	R-31	Coso-CQ-B	old	none	3.8 3.9 3.9 3.9 3.9 3.9	3.9
8	T. Origer	R-31	Coso-CQ-C	old	none	4.1 4.1 4.1 4.2 4.2 4.2	4.2
9	T. Origer	R-31	Coso-CQ-D	old	none	4.0 4.0 4.1 4.1 4.1 4.1	4.1
10	T. Origer	R-31	Coso-CQ-E	old	none	3.9 3.9 3.9 4.0 4.0 4.1	4.0
11	T. Origer	R-31	Coso-WS-A	old	none	4.8 4.8 4.8 4.8 4.9 4.9	4.8
12	T. Origer	R-31	Coso-WS-B	old	none	4.9 4.9 4.9 5.0 5.0 5.0	5.0
13	T. Origer	R-31	Coso-WS-C	old	none	4.8 4.8 4.8 4.8 4.8 4.8	4.8
14	T. Origer	R-31	Coso-WS-D	old	none	4.8 4.8 4.8 4.8 4.8 4.9	4.8
15	T. Origer	R-31	Coso-WS-E	old	none	4.8 4.9 4.9 4.9 4.9 5.0	4.9
16	T. Origer	R-31	NV-A	old	none	3.2 3.2 3.2 3.2 3.3 3.4	3.3
17	T. Origer	R-31	NV-B	old	none	3.3 3.3 3.4 3.4 3.5 3.5	3.4
18	T. Origer	R-31	NV-C	old	none	3.5 3.5 3.6 3.6 3.6 3.6	3.6
19	T. Origer	R-31	NV-D	old	none	3.2 3.3 3.3 3.3 3.3 3.4	3.3
20	T. Origer	R-31	NV-E	old	none	3.5 3.5 3.5 3.6 3.6 3.6	3.6
21	T. Origer	R-31	CD-LM-A	new	none	4.0 4.0 4.1 4.1 4.2 4.3	4.1
22	T. Origer	R-31	CD-LM-B	new	none	4.0 4.0 4.1 4.1 4.1 4.2	4.1
23	T. Origer	R-31	CD-LM-C	new	none	4.2 4.2 4.2 4.2 4.2 4.3	4.2
24	T. Origer	R-31	CD-LM-D	new	none	4.0 4.0 4.1 4.1 4.2 4.3	4.1
25	T. Origer	R-31	CD-LM-E	new	none	4.2 4.3 4.3 4.3 4.4 4.4	4.3
26	T. Origer	R-31	Coso-CQ-A	new	none	4.3 4.3 4.4 4.4 4.4 4.4	4.4
27	T. Origer	R-31	Coso-CQ-B	new	none	4.2 4.2 4.2 4.2 4.2 4.2	4.2
28	T. Origer	R-31	Coso-CQ-C	new	none	4.2 4.2 4.3 4.3 4.3 4.4	4.3
29	T. Origer	R-31	Coso-CQ-D	new	none	4.2 4.2 4.2 4.2 4.2 4.3	4.2
30	T. Origer	R-31	Coso-CQ-E	new	none	4.1 4.1 4.2 4.3 4.3 4.4	4.2
31	T. Origer	R-31	Coso-WS-A	new	none	4.8 4.8 4.9 5.0 5.0 5.1	4.9
32	T. Origer	R-31	Coso-WS-B	new	none	5.0 5.0 5.0 5.1 5.2 5.2	5.1
33	T. Origer	R-31	Coso-WS-C	new	none	5.2 5.2 5.2 5.2 5.2 5.3	5.2
34	T. Origer	R-31	Coso-WS-D	new	none	5.0 5.1 5.2 5.2 5.3 5.3	5.2
35	T. Origer	R-31	Coso-WS-E	new	none	5.2 5.2 5.2 5.2 5.3 5.4	5.3
36	T. Origer	R-31	NV-A	new	none	3.5 3.6 3.6 3.6 3.6 3.6	3.6
37	T. Origer	R-31	NV-B	new	none	3.7 3.7 3.7 3.8 3.8 3.9	3.8
38	T. Origer	R-31	NV-C	new	none	3.5 3.5 3.6 3.6 3.6 3.6	3.6
39	T. Origer	R-31	NV-D	new	none	3.5 3.5 3.5 3.5 3.6 3.6	3.5
40	T. Origer	R-31	NV-E	new	none	3.5 3.5 3.5 3.5 3.5 3.5	3.5

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