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Geochronologic and stratigraphic constraints on the Mesoproterozoic and Neoproterozoic Pahrump Group, Death Valley, California: A record of the assembly, stability and breakup of Rodinia

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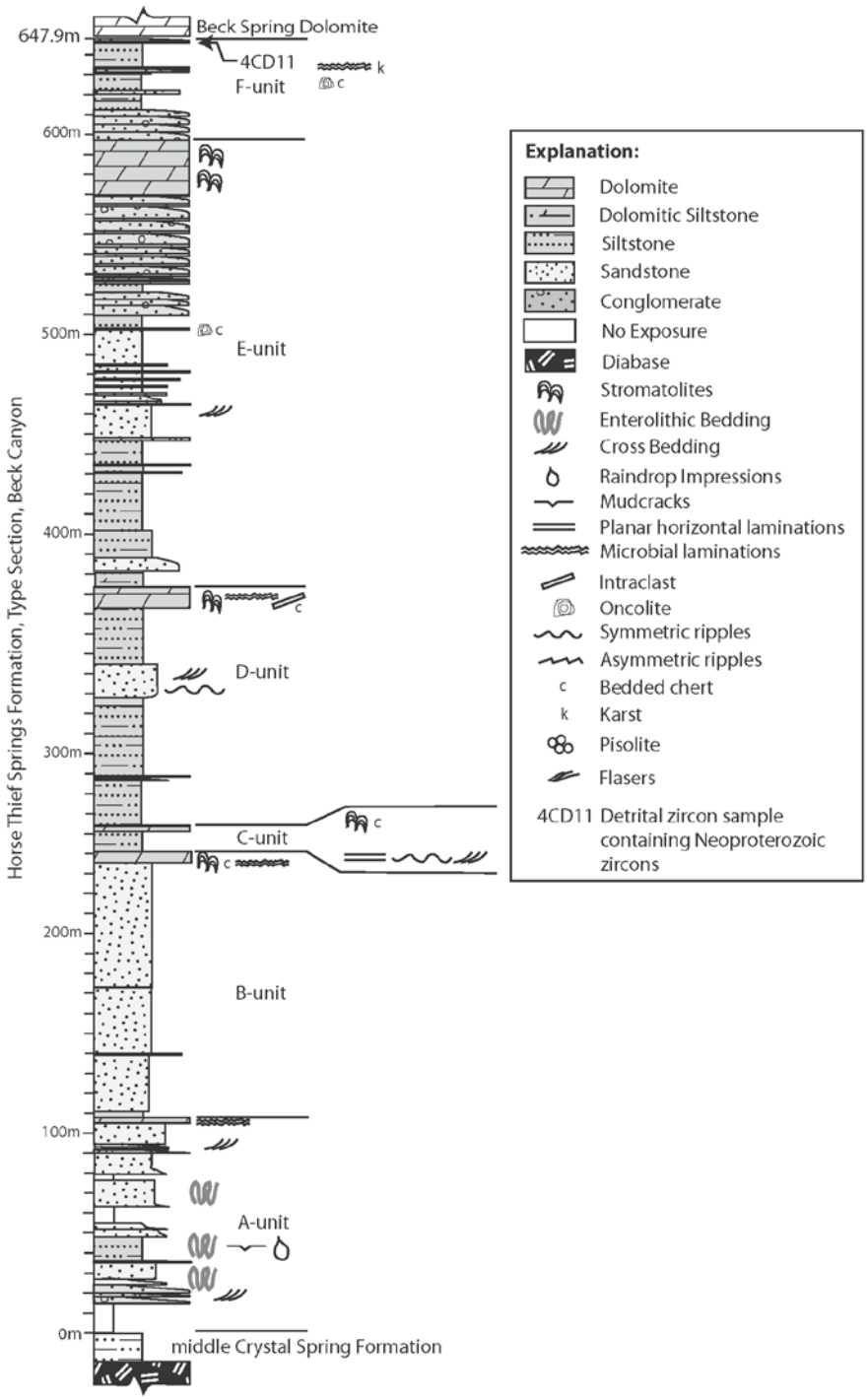

Figure DR1: Stratigraphic column showing the type section of the newly named Horse Thief Springs Formation in Beck Canyon in the Kingston Range. Note the poor exposure at the contact between the Horse Thief Springs Formation and the underlying Crystal Spring Formation.

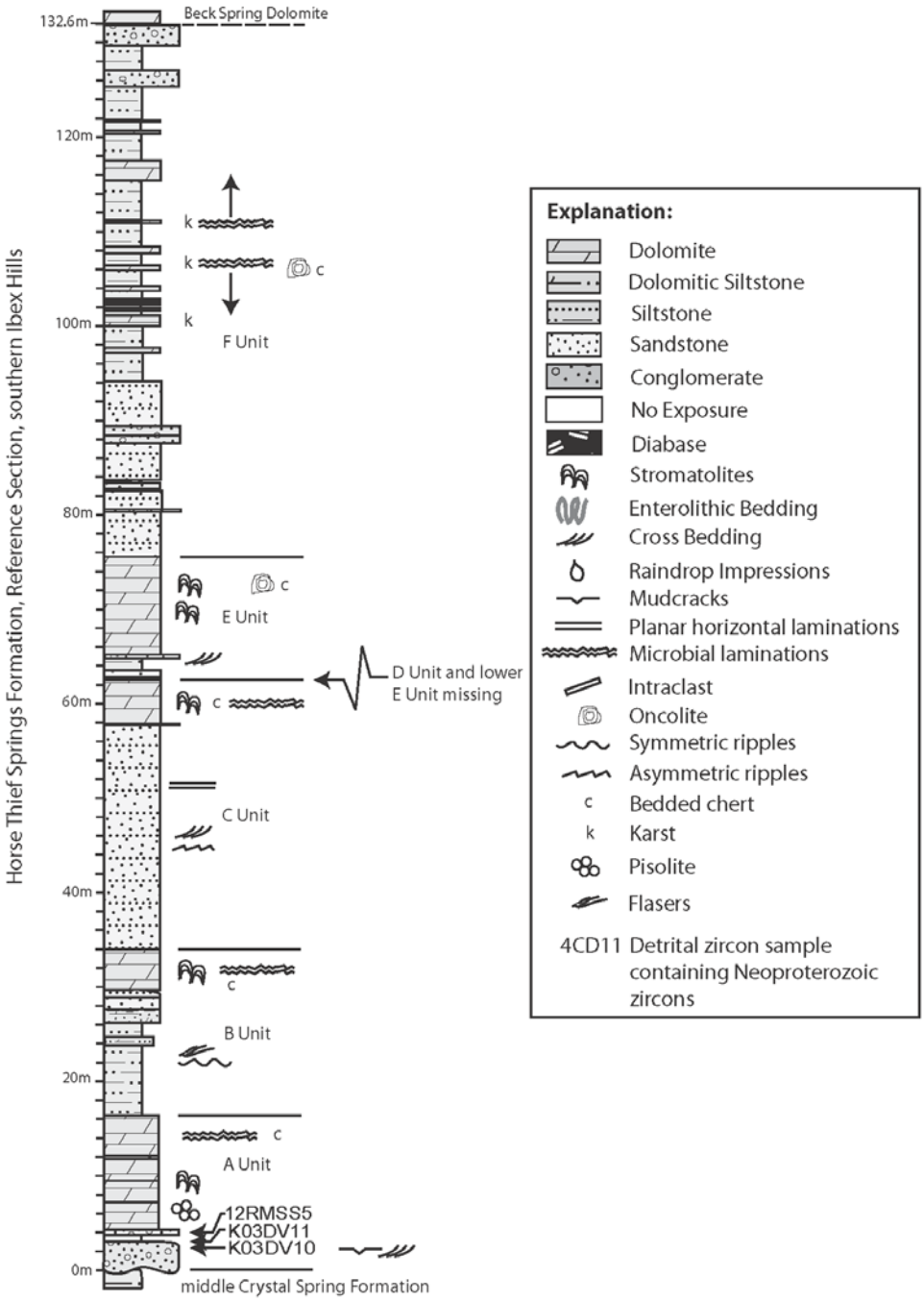

Figure DR1: Stratigraphic column showing the reference section of the newly named Horse Thief Springs Formation in the southern Ibex Hills. Note the unconformity and the locations of detrital zircon samples discussed in this paper. D-unit is absent at this locality.

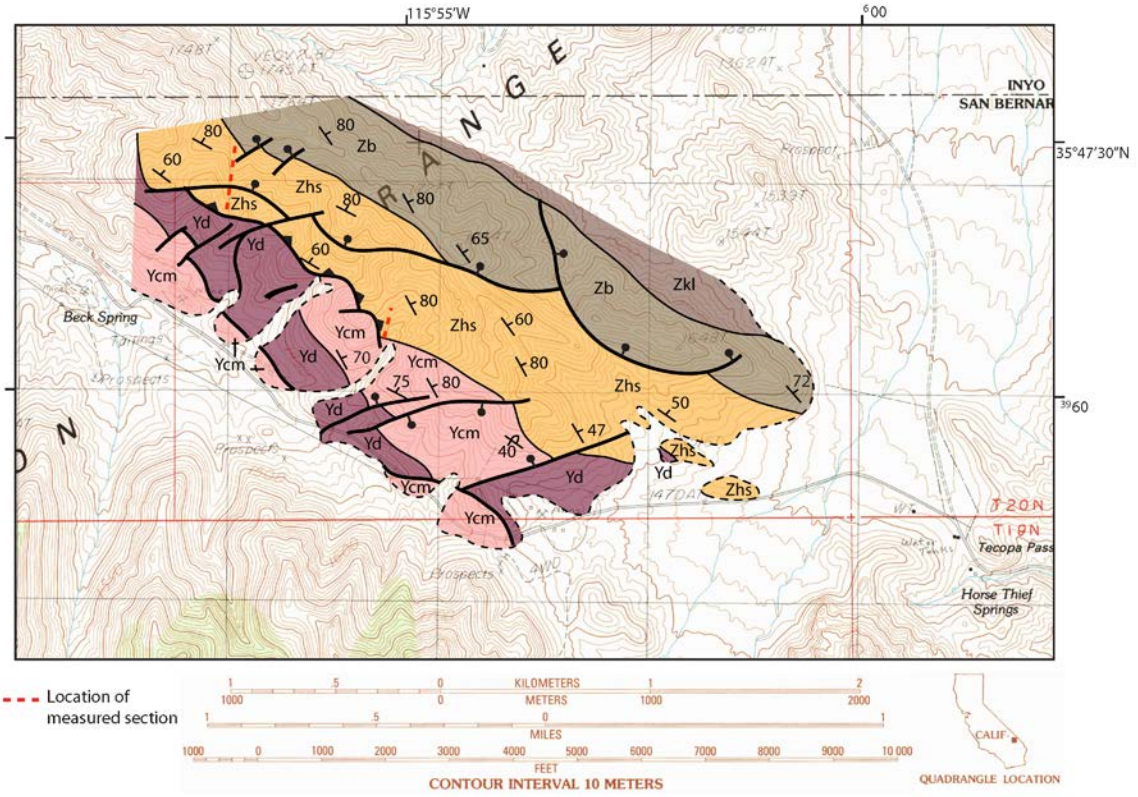

Figure DR3: Geologic map of the area surrounding the type section of the newly named Horse Thief Springs Formation. Base map is USGS Horse Thief Springs 7.5' quadrangle. Red dashed line represents type section as measured. Ycm – middle Crystal Spring Formation, Yd – diabase, Zhs – Horse Thief Springs Formation, Zb – Beck Spring Dolomite, Zkl – lower Kingston Peak Formation. Note multiple measured section lines required by structural complexity of type locality. Geology modified from Calzia et al. (1995).

Figure DR4: Photograph of the type section of the newly named Horse Thief Springs Formation, Beck Canyon, Kingston Range. View is to the southeast. Zhs – Horse Thief Springs Formation; Zb – Beck Spring Dolomite.

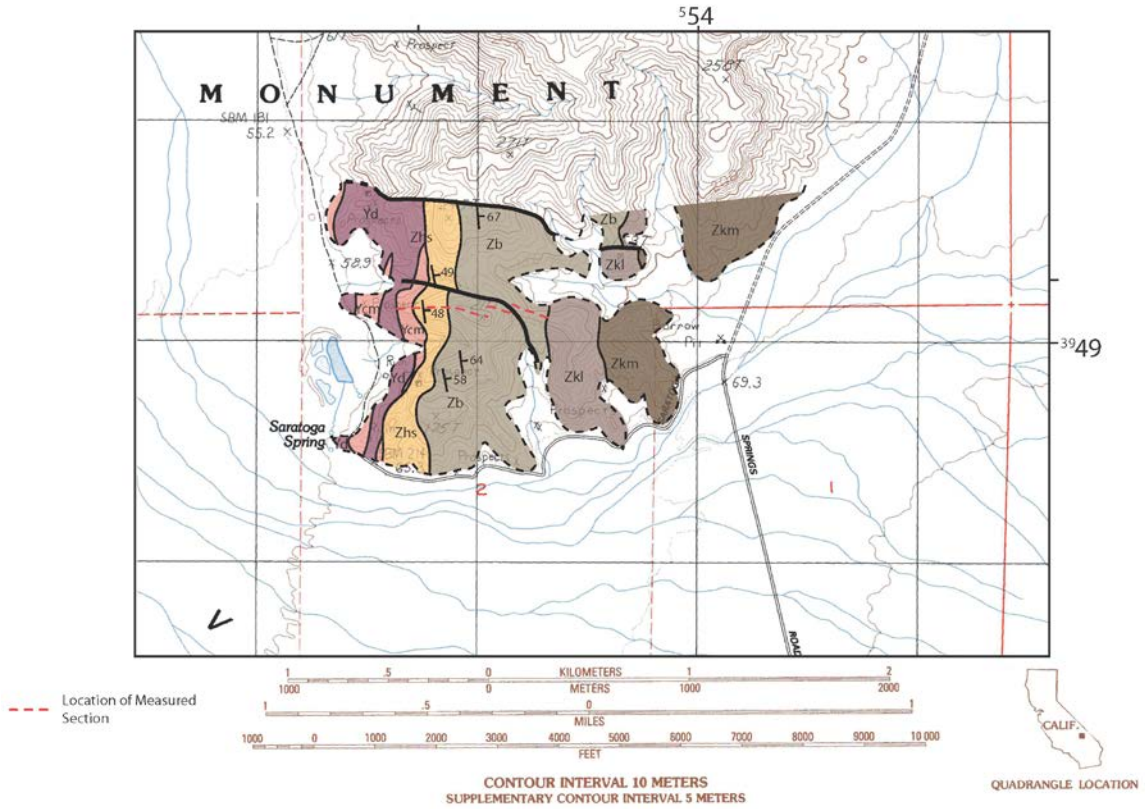

Figure DR5: Geologic map of the area surrounding the reference section of the newly named Horse Thief Springs Formation. Base map is USGS Old Ibex Pass 7.5' quadrangle. Red dashed line represents reference section as measured. Ycm – middle Crystal Spring Formation, Yd – diabase, Zhs – Horse Thief Springs Formation, Zb – Beck Spring Dolomite, Zkl – lower Kingston Peak Formation. Zkm – middle Kingston Peak Formation.

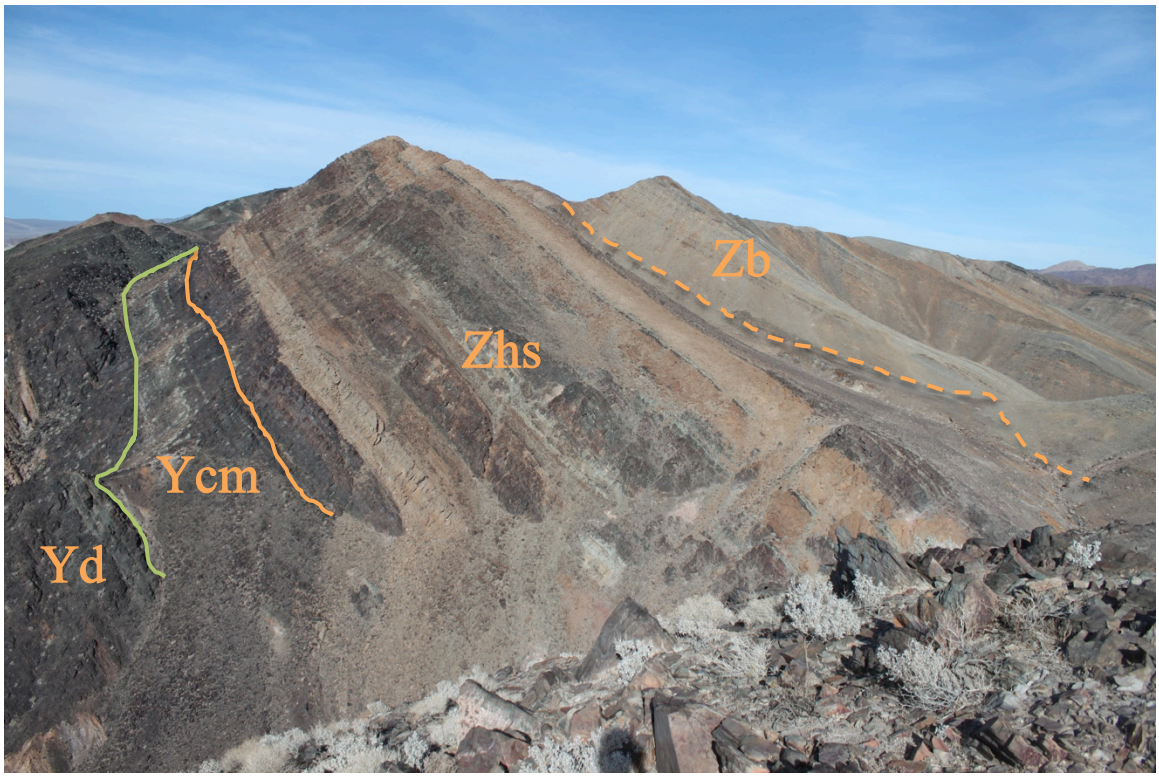

Figure DR6: Photograph of the reference section of the newly named Horse Thief Springs Formation, Saratoga Spring, southern Ibex Hills. View is to the north. Yd – Diabase; Ycm – middle Crystal Spring Formation; Zhs – Horse Thief Springs Formation; Zb – Beck Spring Dolomite. Dashed line indicates gradational contact. Distance between Ycm and Zb is approximately 150m for scale.

Table DR1: Detailed description of type section of Horse Thief Springs Formation

Stratigraphic section, Table A:

Horse Thief Spring Formation, lower portion	Start Loc.	11S_0597602	3960080
Beck Canyon, Kingston Range, Type Section Measured/Described by: Robert Mahon, Carol Dehler	End Loc.	11S_0598001	3960445

Description	**Bed Thickness (m)**	**Total Thickness (m)**
orange dolomite, correlated to upper section	X	X
dark green siltstone to fine sandstone	7.5	235.5
siltstone to fine sandstone, cm-scale medium sandstone beds	3	228
poor exposure, float as below	10.5	225
green laminated siltstone to fine sandstone	10.5	214.5
purple laminated fine sandstone to siltstone with dark green medium sandstone lenses	12	204
purple laminated fine sandstone to siltstone with dark green medium sandstone lenses	13.5	192
purple laminate fine sandstone to siltstone with dark green medium sandstone lenses	5.5	178.5
As below with pyrite cubes - sulfitic shales, greener, more fine sandstone	8	173
as below, disrupted laminae @150m	15	165
orange-green laminated siltstone to fine sandstone, poor exposure	10.2	150
white laminated coarse sandstone, cross bedded	0.6	139.8
orange laminated fine sandstone to siltstone, silicified	28.2	139.2
covered green siltstone as below	3	111
tan dolomite, poorly exposed (interbedded with green siltstone as above) - sample 12CDDV8 green siltstone	3	108
green medium sandstone grades to fine sandstone	1.5	105
as below, scoured base	2.5	103.5
as below, rip-ups at base	2	101
interbedded coarse to medium sandstone and purple siltstone, graded beds, dm-scale	4.5	99
white trough cross bedded coarse sandstone	1.5	94.5

as below	1	93
fine to medium sandstone to siltstone	0.5	92
coarse sandstone to granule conglomerate with chert cobbles	1.5	91.5
fine sandstone to siltstone	5	90
fine sandstone siltstone, fluid escape features/enterolithic bedding	2.5	85
fine to medium sandstone, trough cross bedded, convolute/enterolithic bedding	3.2	82.5
covered	2.8	79.3
as below, enterolithic folding	4.5	76.5
as below, fluid escape features, enterolithic folding	4.5	72
purple fine sandstone to siltstone, multiple cm-scale fining upward beds	3	67.5
coarse to medium sandstone, laminated to bedded, white to purple, 1m channelized coarse sandstone beds, convolute/enterolithic folding common	1.5	64.5
cover, float of fine sandstone	8	63
Trough cross bedded coarse to fine sand interbedded, lenses of coarse sand, fining upward	3	55
trough cross bedded fine to medium sandstone grading up into laminated siltstone to fine sandstone, disrupted/enterolithic bedding in cm-scale beds	4	52
Laminated siltstone to fine sandstone	3	48
massive siltstones grade into laminated siltstone to fine sandstone, convolute bedding common in laminated siltstones	3	45
as above	5	41
as below, grades into fine sandstone to siltstone	1	36
coarse sandstone siltstone 1-10 cm graded beds, enterolithic bedding, trough x-beds at 31.5m. sample 12CDDV9 at 31.5m	8	35
as below	2.9	27

as below, no pebbles at base	4.1	24.1
as below with horfels clasts	2	20
coarse sandstone to granule conglomerate at base, grades up to purple siltstone and fine sandstone, scoured base, clasts of hornfels, chert, siltstone	3.4	18
poor exposure - purple siltsstone, green fine sandstone, intraclasts of siltstone, beds fine upwards, some trough cross bedding, grit-sand-silt cycles, base not well exposed	14.6	14.6
green hornfelsic siltstone	9	0
Diabase	X	-9

Stratigraphic section, Table B:

Horse Thief Spring Formation, upper portion	Start Loc.	11S_0596817	3960923
Beck Canyon, Kingston Range, Type Section Measured/Described by: Robert Mahon, Paul Link	End Loc.	11S_0596984	3961346

Description	**Bed Thickness (m)**	**Total Thickness (m)**
thin bedded to laminated to stromatolitic dolomite - Beck Spring Dolomite	X	X
granule conglomerate to thin bedded sandstone, gray	1	522.3
granule conglomerate to sandstone to siltstone to orange dolomite and silty dolomite, meter-scale graded beds	10.5	521.3
green siltstone to coarse sandstone, ferruginous siltstone at 4.5m, coarse sandstone and siltstone above, cross laminated upwards	30	510.8
graded beds of granule conglomerate to fine sandstone, 0.5-1m thick	15	480.8
as below	5	465.8
gray cherty laminated and stromatolitic dolomite, loose sand interbeds	12	460.8
granule conglomerate beds in dolomite, interbeds coarsening upsection	7	448.8
cherty dolomite, weathers gray, sandy dolomite interbeds	2	441.8

orange dolomite with 1-2m siltstone to sandstone interbeds	24.5	439.8
0.5m granule conglomerate and coarse sandstone overlain by stromatolitic dolomite	5.5	415.3
tan dolomite interbedded with granule conglomerate, dolomite laminated at base, stromatolitic upward, interbeds fine upward	11	409.8
granule conglomerate, grades up into coarse quartzite	1.8	398.8
pebble conglomerate fines up into sandstone to siltstone	0.6	397
pebble to granule conglomerate, fines up into sandstone to siltstone	0.8	396.4
pebble to granule conglomerate, grades up into purple siltstone	2	395.6
orange dolomite, flat laminated with some disrupted beds and microbial laminations, sandy in part	1.8	393.6
green to purple laminated siltstone, mud cracks	4.4	391.8
orange weathering purple dolomite, microbially laminated	20	387.4
quartzose granule conglomerate to sandstone, white, grades up into white feldspathic granule conglomerate and quartzite, climbing ripples, cross beds	11.5	367.4
laminated purple siltstone and fine sandstone, some green laminations	6	355.9
orange dolomite, small stromatolites, microbial laminations, sandy/silty, no chert	1	349.9
Purple fine to medium sandstone with granule and pebble conglomerate beds, graded beds, stringers of white quartzite, overall sequence coarsens upward, sandstone beds rippled, mud drapes	76.5	348.9
fine sandstone, green with reduction spots	9	272.4
purple siltstone, enterolithic bedding, laminated, ripples, with interbedded fine sandstone with loads, scour; several beds of granule conglomerate and coarse sandstone; granule conglomerate beds thicken and coarsen upwards	21	263.4

red siltstone, bright red - visible on adjacent ridges, thin bedded to laminated	24	242.4
fine sandstone to siltstone, light green to tan	13.5	218.4
white medium grained quartzite, flat laminations, trough cross bedded, fines up to fine sandstone with shale partings, ripple thin laminations	6.8	204.9
brown dolomitic siltstone, laminated	1	198.1
green dolomitic siltstone in graded thin beds	7	197.1
tan dolomite, cherty, laminated, microbial laminations	10.4	190.1
laminated green and red siltstone, thin beddded, sandy at base, with symmetric ripples, small load casts	28	179.7
fine grained quartzite, siltstone laminations, symmetric ripples, thin bedded to laminated	1.7	151.7
green siltstone, coarsens up to fine sandstone	3.9	150
purple and green laminated siltstone, convolute bedding, reduction spots	3.5	146.1
green siltstone, laminated, trough cross laminations, becomes purple and green upward	19.5	142.6
dolomitic green siltstone, laminated dolomite, soft sediment deformation	0.6	123.1
green siltstone	0.8	122.5
fine to medium quartzite, tan, soft sediment deformation	1	121.7
laminated green siltstone, fine sand lenses	22.5	120.7
dolomite, silty to sandy, laminated, stromatolitic, chert beds, weathers brown	2.9	98.2
green siltstone and fine sandstone interbedded, thin bedded	10.4	95.3
dolomitic sandstone	1	84.9
dolomitic sandstone, gray, medium to coarse grained, grades to gray dolomite	1.3	83.9
orange dolomite, thin chert beds, thin bedded to laminated	3	82.6
white medium to coarse quartzite, rip-up clasts, 0.5m bed of rip-up clasts at 76m	9.6	79.6

purple siltstone and fine sandtone, reduction spots, coarse sandstone interbeds, 60cm bed of rip-up clasts at 57m, enterolithic bedding	18	70
purple to white quartzite, no rip-up clasts	10	52
medium sand quartzite, 1-10cm beds	4.5	42
purple to white quartzite with rip-up clasts up to 10cm, laminated to thick bedded, trough x-beds, enterolithic bedding	9	37.5
purple siltstone and fine sandstone, laminated, small (1-5cm) trough cross beds, convolute bedding	10.5	28.5
green to purple siltstone, phyllitic, laminated, epidote alteration in fractures, faulted base	18	18

Table DR2: Detailed description of reference section of the Horse Thief Springs Formation

Horse Thief Spring Formation	Start Loc.	11S_0552543	3949341
Saratoga Spring, southern Ibex Hills Measured/Described by: Robert Mahon, Paul Link			

Description	**Bed Thickness (m)**	**Total Thickness (m)**
Thin Bedded laminated-stromatolitic dol - Beck Spring Dolomite - contact gradational	X	X
silty orange laminated dolomite, pinches out to north	0.7	132.6
granule conglomerate bed, graded	2.2	131.9
laminated siltstone and medium to coarse sandstone interbeds	2.6	129.7
granule to pebble conglomerate, quartz, chert and dolomite pebbles	1.8	127.1
siltstone, poorly exposed	3.5	125.3
orange dolomite	0.2	121.8
siltstone	0.9	121.6
orange dolomite	0.4	120.7
gray siltstone, poorly exposed	2.8	120.3
orange dolomite, laminated with dolomite intraclasts, loaded base, pyrite cubes	2.1	117.5
laminated platy dolomite and siltstone interbeds, all silt above 112.4m	4.2	115.4
dolomite	0.3	111.2
siltstone, laterally continuous with 10-40cm dolomite lenses	2.5	110.9
orange dolomite, thin silt interbeds, pinches out lateraly	0.7	108.4
siltstone, grades to dolomite	1.3	107.7
orange dolomite, dolomite intraclasts at base	0.5	106.4
bedded to laminated siltstone	1.7	105.9
laminated dolomite, platy cleavage	0.5	104.2
siltstone	0.8	103.7

dolomite, karst at top	0.2	102.9
siltstone lens	0.2	102.7
dolomite, karst at top	0.2	102.5
siltstone	0.4	102.3
orange dolomite, karst at top filled with sandstone	0.3	101.9
siltstone	0.5	101.6
dolomite, orange weathering, stromatolitic at top, karst at top filled with silicified sandstone	1.1	101.1
fine sand to silt, thick bedded at base, laminated at top where interbedded with fine laminated silty dolomite	2.3	100
dolomite, gray, weathers orange, laminated at base, microbial laminations at top	0.5	97.7
siltstone, gray	3.1	97.2
interbedded grit and sandstone, grade up into silt and fine sand, mud cracks on silt beds, fine upwards to all silt	6.5	94.1
quartzite, red to pink, medium sand to granule, thin bedded, poorly developed cross bedding, complex trough cross beds upwards, 30cm thick pebble horizons at 81.1m, siltstone interbeds at 83.1m, generally fining upward overall	12	87.6
dolomite, stromatolitic, stromatolites up to 15cm diameter, 18cm high, tan to light gray, lenses of silty dolomite between mounds, some branching stromatolites	10.4	75.6
granule conglomerate, quartz clasts	0.4	65.2
green laminated siltstone to fine sandstone	1.3	64.8
medium to coarse sandstone with chert clasts up to 1.5cm (sample 12RMSS6)	0.7	63.5
chert bed, green, rolled up stromatolites or oncolites 8cm diameter, quartz stringers (sample 11RMSS10)	0.3	62.8
gray dolomite weathers brown, microbial laminations, contains fine sand	4.6	62.5
green granule to pebble conglomerate, green matrix, chert pebbles, mainly quartz clasts	0.2	57.9

gray to green fine sand to siltstone, laminated, thin discontinuous dolomite lenses, some beds of fine sandstone upwards, dolomite disappears upwards, mud cracks	23.7	57.7
laminated dolomite, gray, weathers dark brown, 3-5cm chert beds and lenses	4.3	34
coarse sandstone, fines up to siltstone, purple weathering, green fresh	0.8	29.7
scoured base, dolomitic medium sand, silty dolomite rip-ups	1.3	28.9
sandstone, sitlstone, laminated quartzite in 5cm thick beds	1.4	27.6
siltstone to fine sandstone, green fresh, weathers pink-purple-orange	1.5	26.2
orange siltstone to dolomitic siltstone, thin bedded to laminated, mm-scale graded beds of fine sand to silt	0.9	24.7
green siltstone, weathers red to pink, thin bedded to laminated (12CDDV4, 12CDDV7)	7.4	23.8
orange silty laminated dolomite, pink-green interbedded siltstone at top, sand below grades into dolomite	4.3	16.4
orange dolomitic sandstone, fine-medium grained	0.3	12.1
dolomite, orange-gray, sandy at base with dolomite nodules in trough cross beds	2.3	11.8
dolomite, orange to tan, thick bedded to massive, oncolites or giant ooliths(?) up to 8mm in coarse sandy dolomite matrix	2.3	9.5
dolomite, tan, sucrosic, sandy, crinkled texture	2.9	7.2
scoured base, conglomerate, coarse white quartzose matrix, clasts of siltstone, hornfels, chert, clasts up to 10cm, laterally heterogeneous	0.6	4.3
Siltstone, purple, drapes irregular surface, underlying clasts protrude into siltstone	0.7	3.7

erosional contact, 20cm of scour locally, purple to green pebble to cobble conglomerate, clasts of siltstone, chert, quartzite, clasts up to 7cm, interbedded with medium sand to silt, mud crack intervals, rip-ups. unit is laterally variable, lenses of siltstone, conglomerate lenses pinch out laterally, overall fines upward, Sample 11RMSS9, K03DV09 (near road)	3	3
purple-green siltstone with 10cm uneven zones of carbonate lenses	4.9	0
silicified dolomite layers in siltstone, thin bedded, hornfelsic	3.5	-4.9
purple siltstone	1.9	-8.4
stringers of altered dolomite in purple siltstone	1	-10.3
purple flat laminated siltstone and fine sandstone, becomes massive upward	6.5	-11.3
fine sandstone, 10cm interbeds of brown dolomite	1.2	-17.8
purple siltstone and fine sandstone, flat laminated to thick bedded	4.3	-19
float of purple siltstone and fine sandstone	1.4	-23.3
green siltstone and fine sandstone, 20cm thick sandstone interbeds, coarsens upward to green sandstone and purple siltstone	5	-24.7
silicified dolomite, gray to green, sandy at top	4	-29.7
laminated purple siltstone-brown dolomitic siltstone, brown dolomite, 0.5cm interbedded	0.45	-33.7
purple siltstone, altered, pitted, hornfels	6.1	-34.15
diabase, olive green, medium-coarse crystalline	X	-40.25

Table DR3: Detrital zircon analysis table notes.

Notes:
Analyses with >10% uncertainty (1-sigma) in 206Pb/238U age are not included.
Analyses with >10% uncertainty (1-sigma) in 206Pb/207Pb age are not included.
Best age is determined from 206Pb/238U age for analyses with 206Pb/238U age < ~1000 Ma and from 206Pb/207Pb age for analyses with 206Pb/238Uage > ~1000 Ma.
Actual cutoff used is different for each sample, selected to avoid dividing clusters of ages.
Concordance (Conc) is based on 206Pb/238U age / 206Pb/207Pb age, with 100% = concordant.
Analyses with >20% discordance (<80% concordance) are not considered further.
Analyses with between 20% and 30% discordance (70%-80% concordance) are highlighted, but not considered further.
Analyses with >5% reverse discordance (>105% concordance) are not included.
All uncertainties are reported at the 1-sigma level, and include only internal (measurement) errors.
External (systematic) errors are 1-2% for both 206Pb/238U and 206Pb/207Pb ages (2-sigma level).
U concentration and U/Th are calibrated relative to Sri Lanka zircon and are accurate to ~20%.
Common Pb correction is from 204Pb, with composition interpreted from Stacey and Kramers (1975).
Uncertainties of 1.5 for 206Pb/204Pb, 0.3 for 207Pb/ 204Pb, and 2.0 for 208Pb/ 204Pb are applied to common Pb composition.
U/Pb and 206Pb/207Pb fractionation is calibrated relative to fragments of a large Sri Lanka zircon of 563.5 ± 3.2 Ma (2-sigma).
U decay constants and composition as follows: 238U = 9.8485 x 10-10, 235U = 1.55125 x 10-10, 238U/235U = 137.88
Analytical methods as described by Gehrels et al. (2008).
Concordia and age-probability plots made with Isoplot (Ludwig, 2008).

Gehrels, G.E., Valencia, V., Ruiz, J., 2008, Enhanced precision, accuracy, efficiency, and spatial resolution of U-Pb ages by laser ablation-multicollector-inductively coupled plasma-mass spectrometry: Geochemistry, Geophysics, Geosystems, v. 9, Q03017, doi:10.1029/2007GC001805.
Ludwig, K.R., 2008, Isoplot 3.6: Berkeley Geochronology Center Special Publication No. 4, 77 p.