SUPPLEMENTARY MATERIAL

The Emerald Acropolis: elevating the moon and water in the rise of Cahokia

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In the mid eleventh century AD, Cahokia emerged as a substantial Mississippian urban centre. To the east, a shrine-complex known as the Emerald Acropolis, marking the beginning of a processional route to the city, also flourished. Excavations and geophysical survey of the monumental landscape around this site suggest that lunar cycles were important in the orientation of structures and settlement layout. They further indicate that water played a significant role in the ritual activities associated with the closure and abandonment of individual structures. The contemporary development of these sites suggests an intrinsic connection between them, and provides early evidence of the importance that the moon and water came to assume in Mississippian culture.

Keywords: Cahokia, Mississippian, eleventh century AD, lunar cycle, water ritual

Appendix S1. Procedure for calculating azimuths

Calculation of solar and lunar azimuths is done by first determining the distance to and angular elevation of the horizon (*h*) at various positions using topographic map viewing software (Terrain Navigator Pro, version 8.71). Given historic descriptions and soil types, we know that the site's eastern horizon and the glacial hills to its north and northwest were covered in prairie grass. The view to the west and southwest was likely tree covered, and the horizon angle calculations for the sun and moon sets in that direction were adjusted slightly to account for a 25-meter high forest canopy there. Each elevation is calculated by taking the inverse tangent of the vertical distance between the foresight (horizon) and the backsight location elevations divided by the horizontal distance between the two locations (foresight elevation – backsight elevation). The result is an uncorrected value that is then corrected to account for the effects of the earth's curvature, refraction, lower limb tangency, and parallax (for the moon only) using following equations:

Sun: corrected *h* = uncorrected *h* – refraction correction + 0.25 (lower limb tangency) – visible distance (km) x 0.0045.
Moon: corrected *h* = uncorrected *h* – refraction correction + 0.25 (lower limb tangency correction) + 0.95 (parallax correction) – visible distance (km) x 0.0045.

The following formula was then used to calculate the rising and setting positions of the sun and moon, where A is the rising or setting azimuth of the celestial body, *h* is the corrected angular elevation of the horizon, δ (delta) is the declination of the sun or moon, and ø (phi) is the latitude.

$$\cos A = \frac{\sin \delta - \sin \phi \sin h}{\cos \phi \cos h}$$

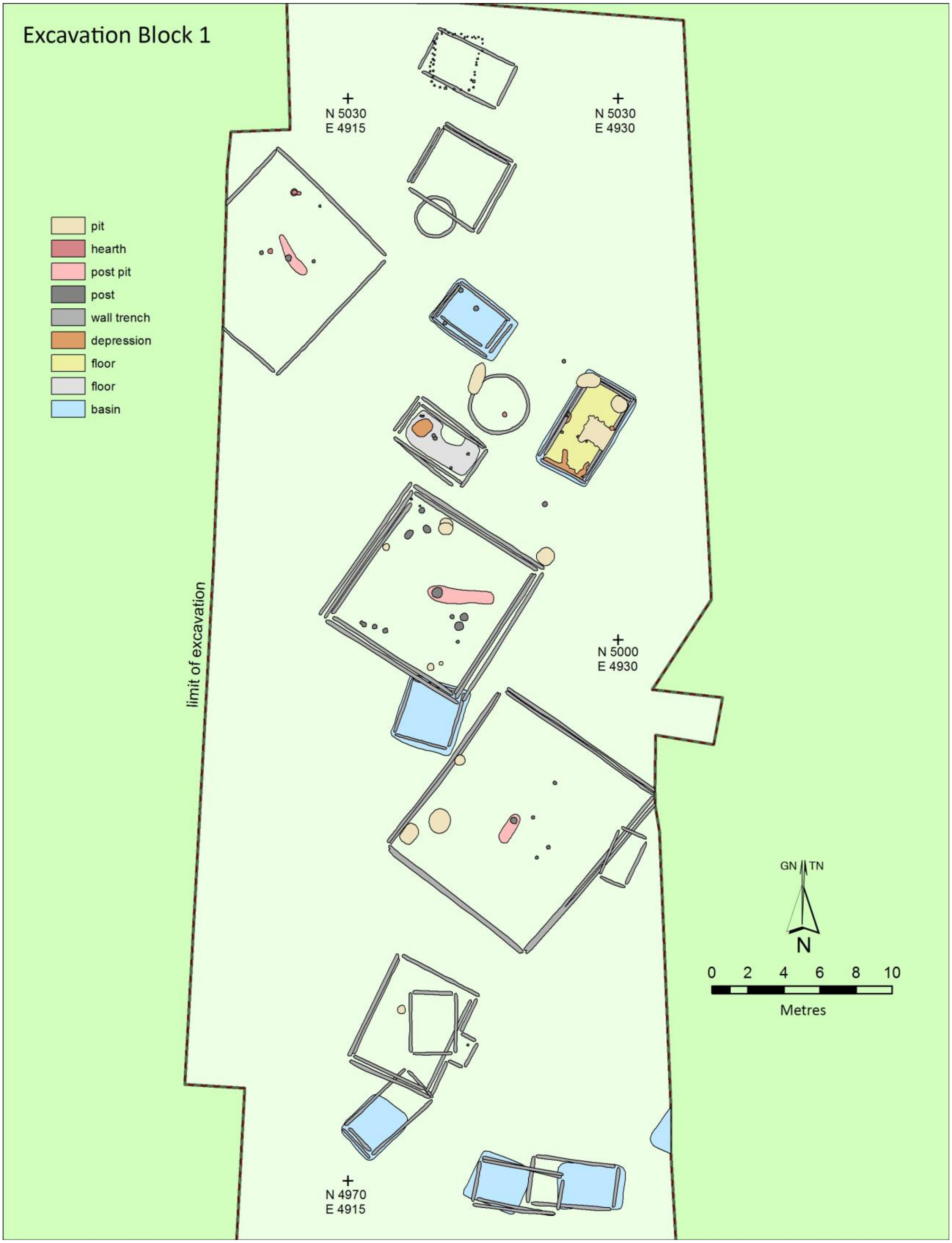
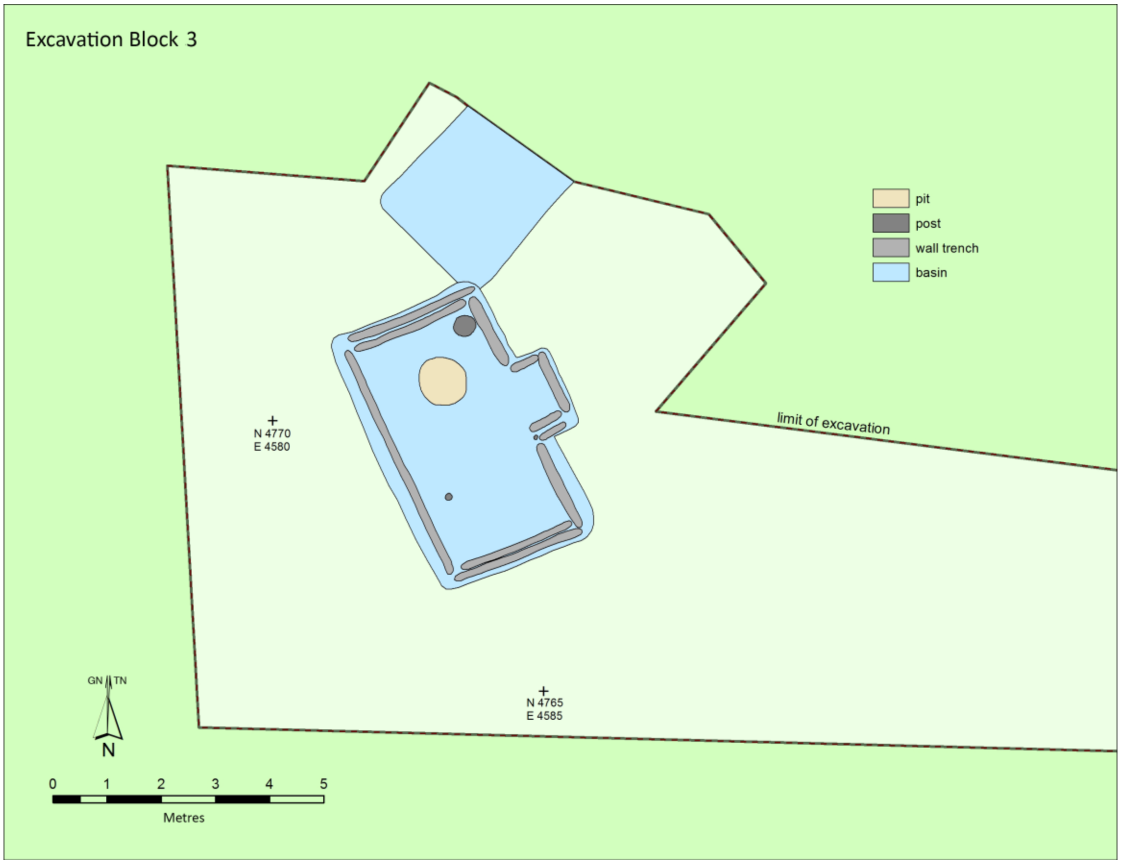


Figure S1. Plan views of Excavation Blocks 1, 3, 4 and 7 (continued on next page).



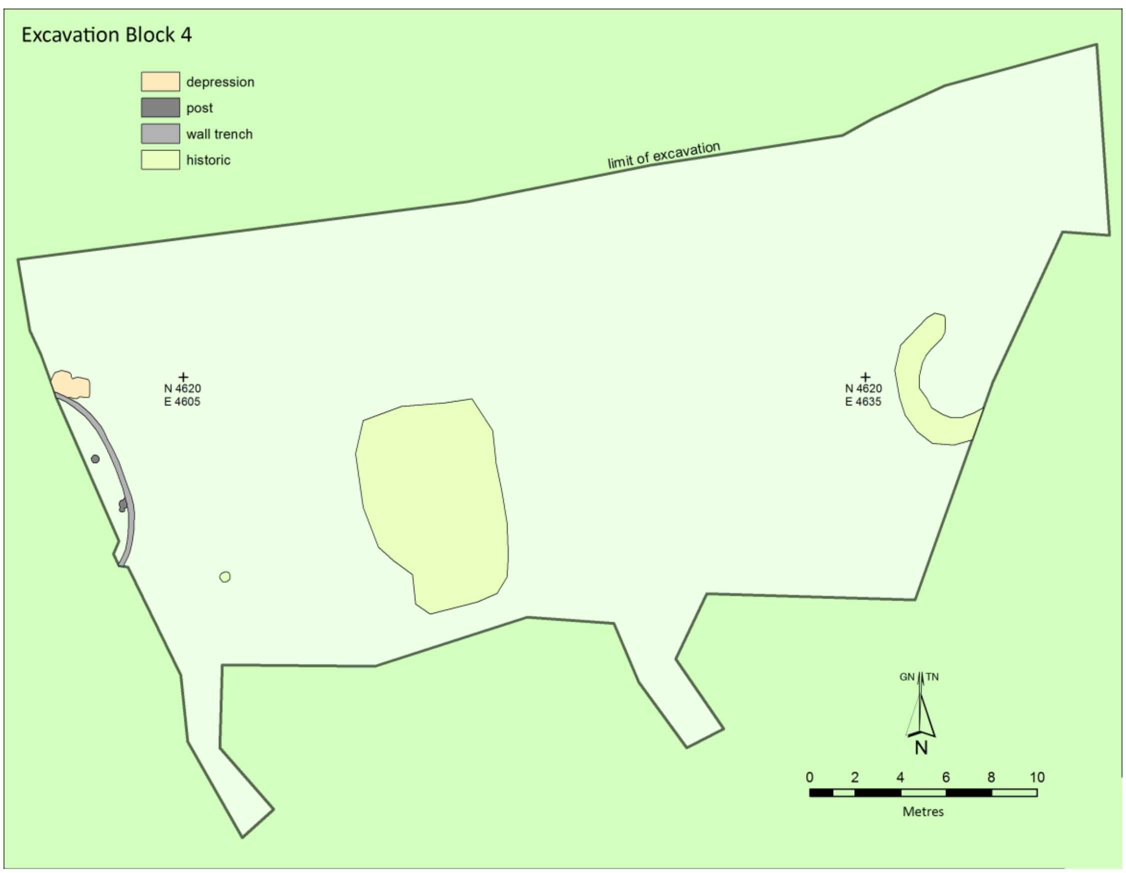


Figure S1. Plan views of Excavation Blocks 1, 3, 4 and 7 (continued on next page).

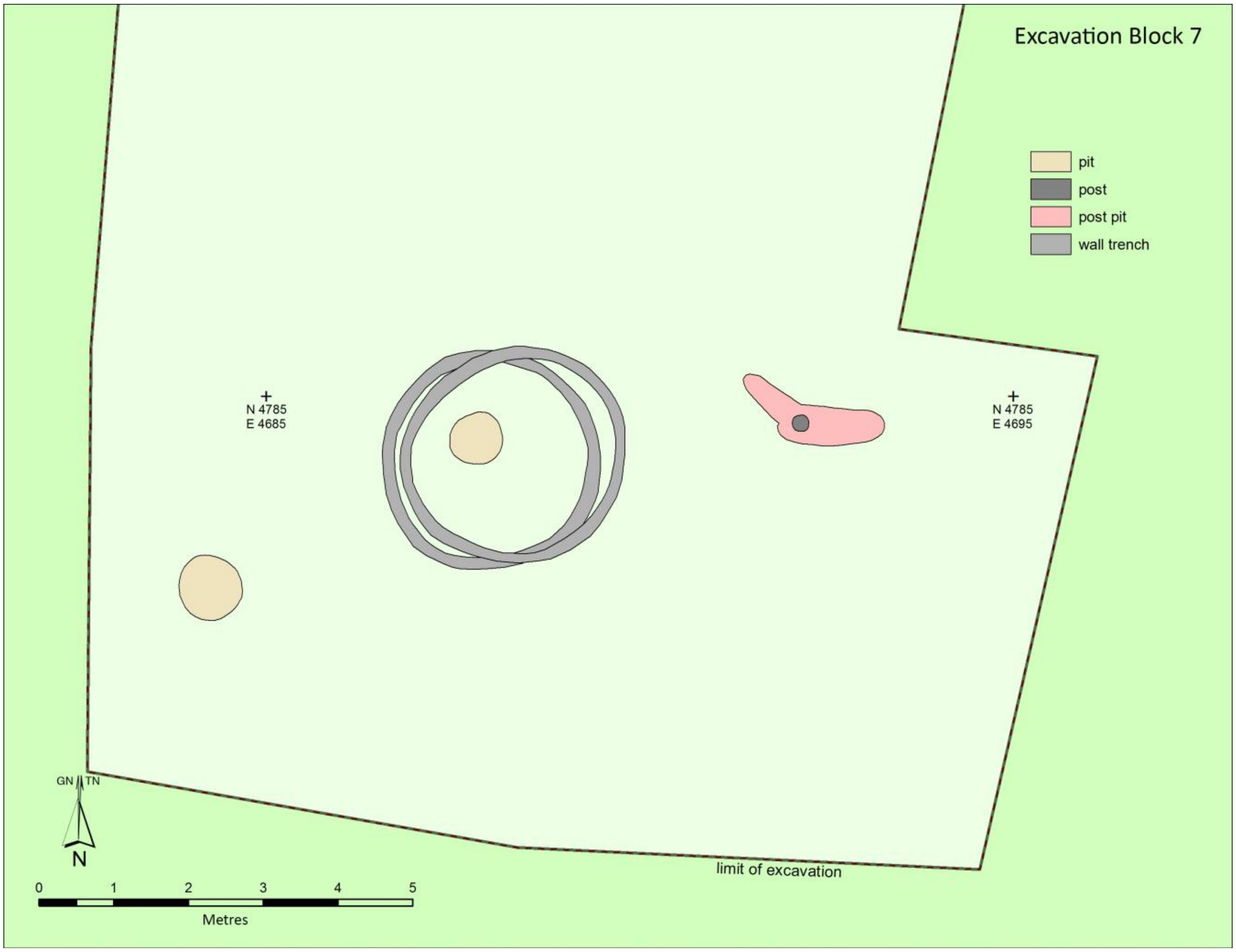


Figure S1. Plan views of Excavation Blocks 1, 3, 4 and 7.

Figure S2. Segment of 2014 excavation trench profile showing construction fill.

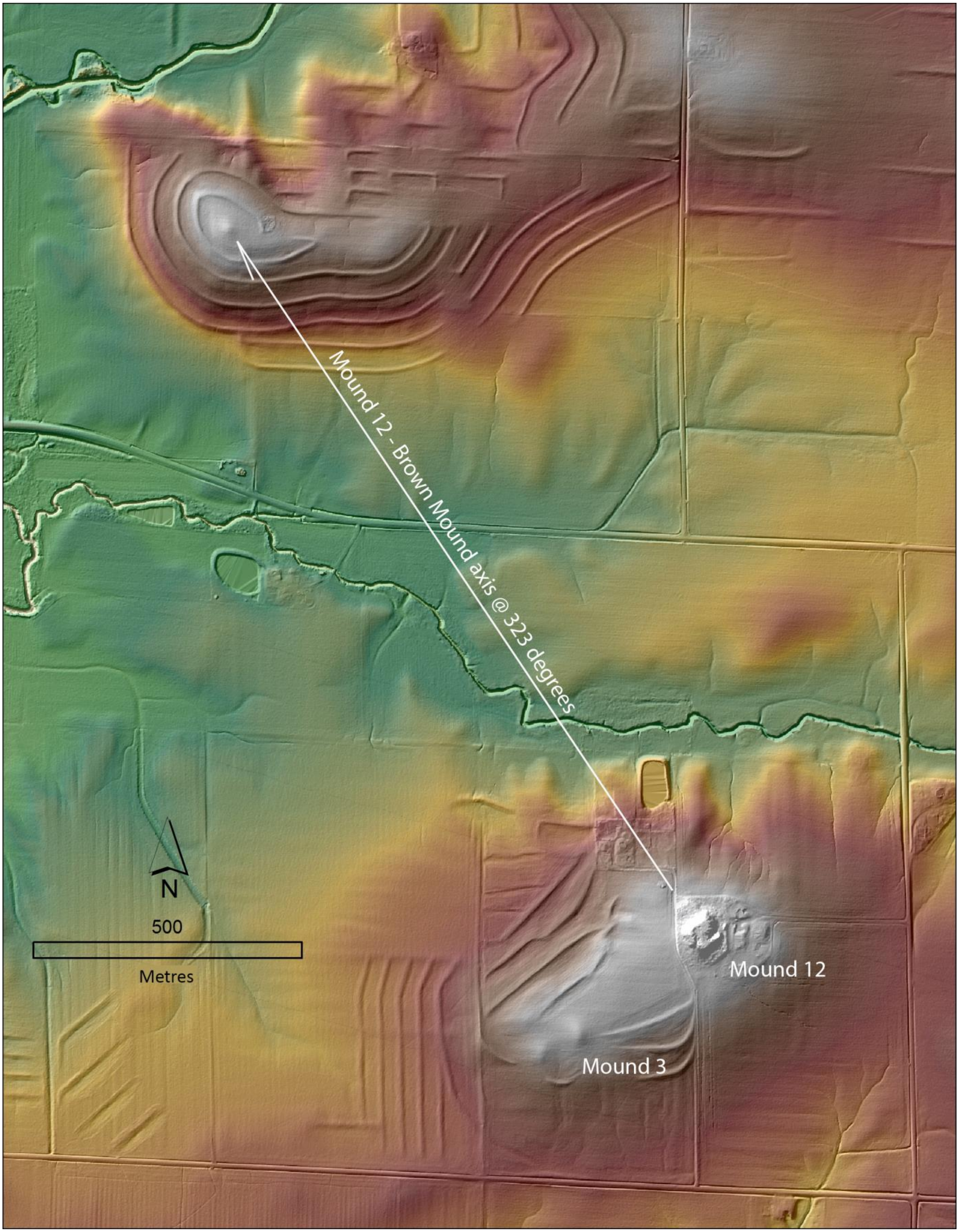


Figure S3. 2011 LiDAR plan map showing Brown Mound relative to Emerald Mound 12 (UTM north [true north correction = -1.75 degrees).

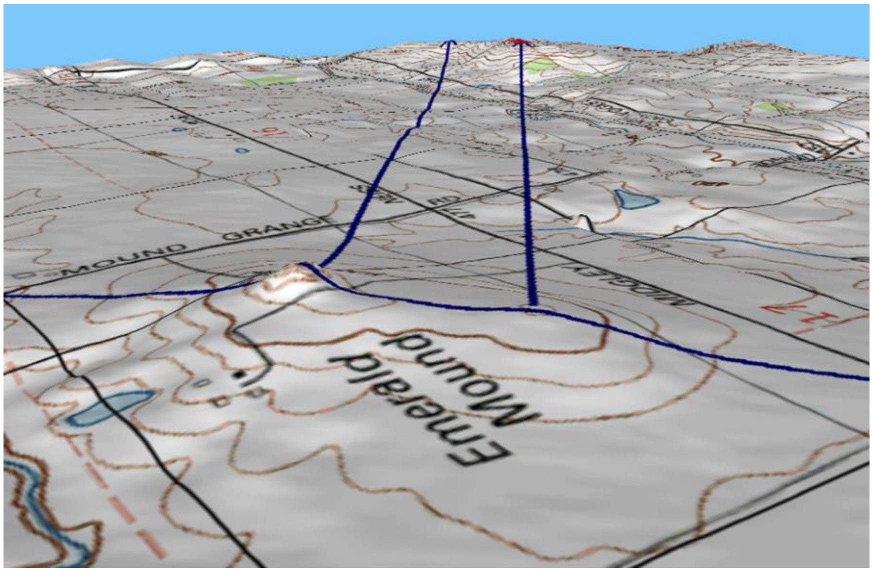


Figure S4. Oblique view to southeast of topography from Mounds 12 (left) and 2 (right) to Berger Hill along maximum south moonrise azimuth.

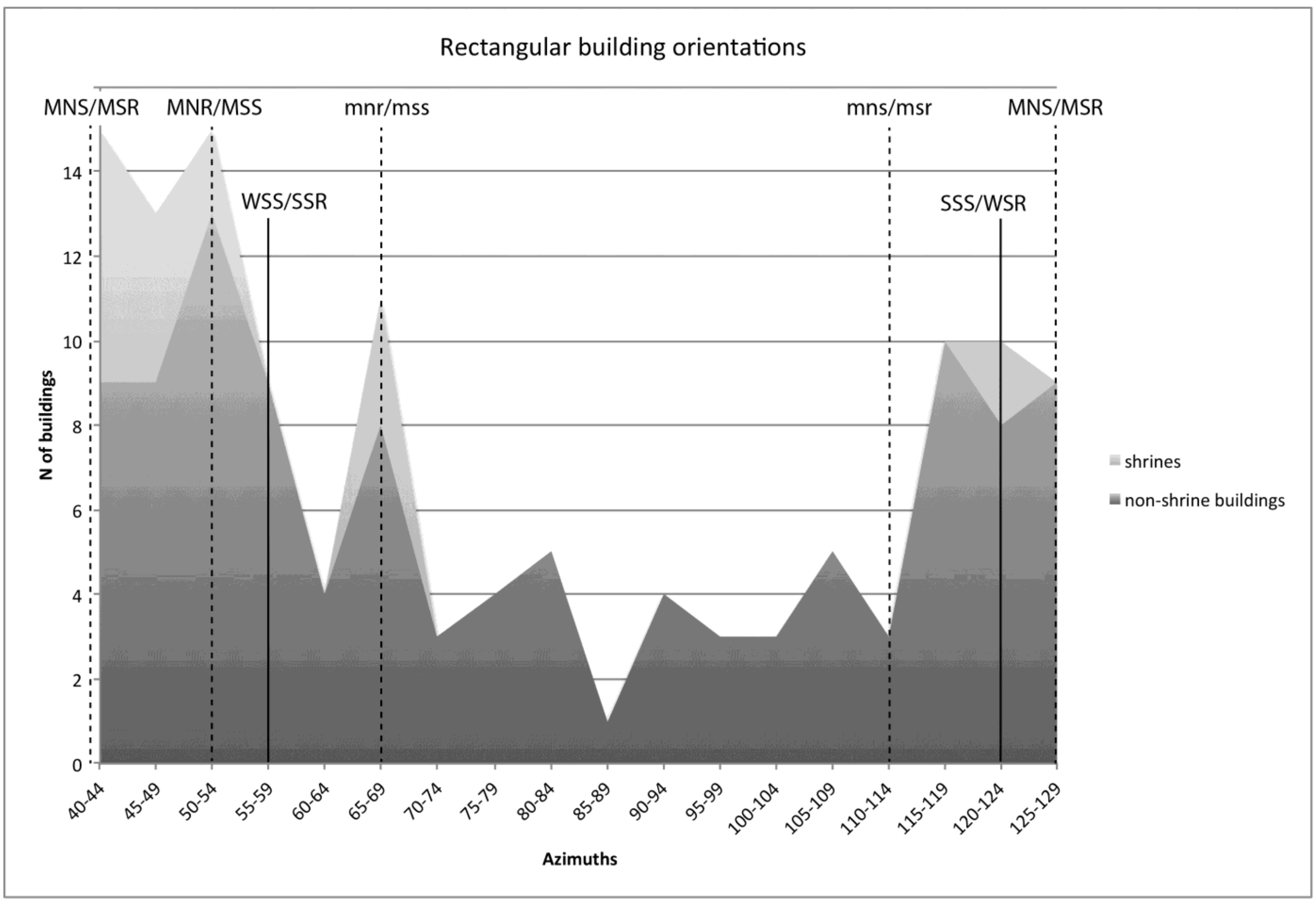


Figure S5. Histogram showing major orientations of measurable rectangular Emerald Acropolis buildings (for Solar positions: WSR, WSS, SSR, SSS = Winter Solstice Rise, Winter Solstice Set and Summer Solstice Rise, Summer Solstice Set; for Lunar positions: MNR, MNS, MSR, MSS and mnr, mns, msr, mss = Maximum Northern Rise, Maximum Northern Set, Maximum Southern Rise, Maximum Southern Set and minimum northern rise, minimum northern set, minimum southern rise, minimum southern set).

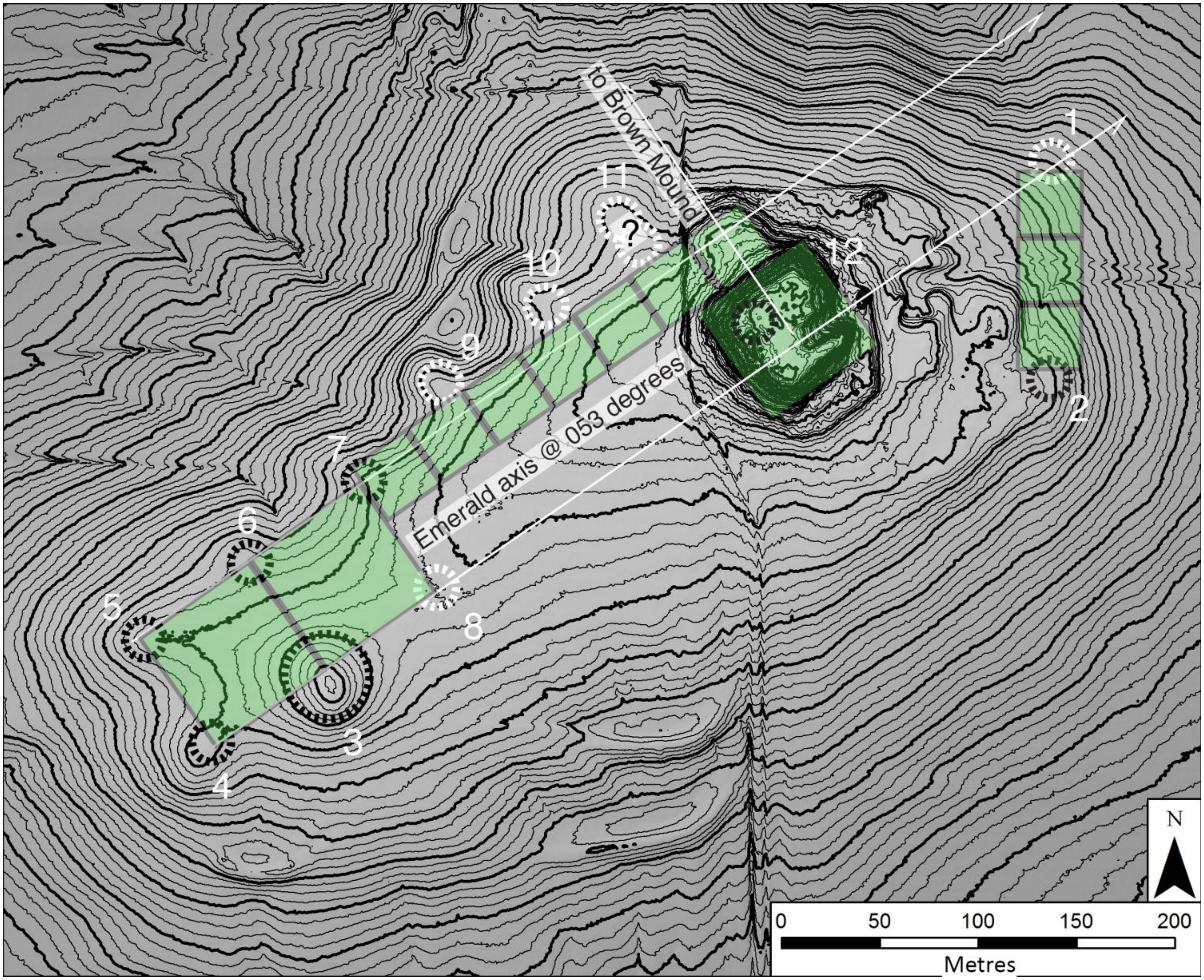


Figure S6. Plan view of Emerald Acropolis showing hypothetical construction plan: rectangles approximate the principal pyramid's first and second terrace basal dimensions.

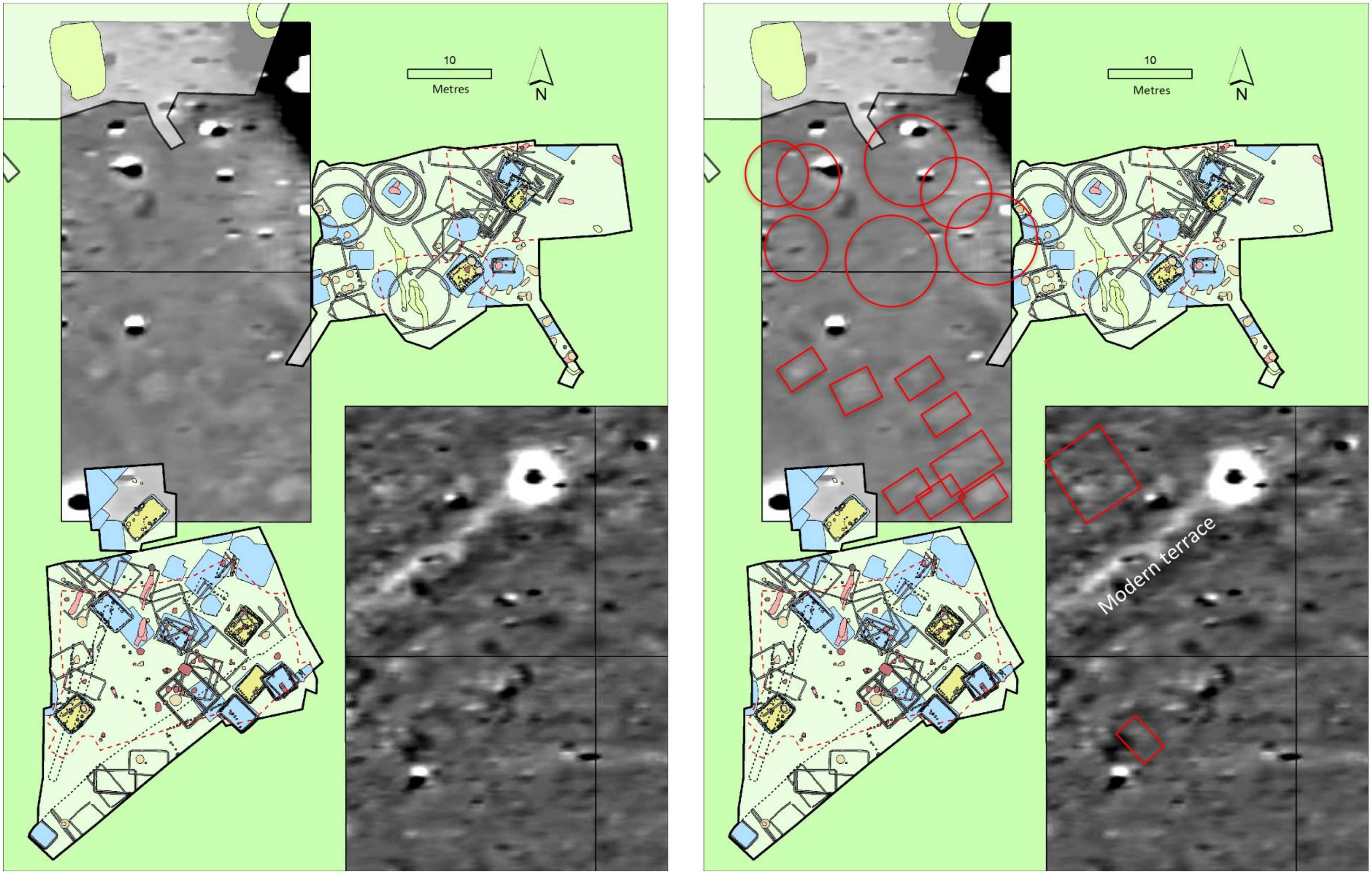


Figure S7. Gradiometer plots and EB plans (left) highlighting segregation of circular from rectangular buildings (right).

Figure S8. Artist's view of Mound 2 in 1881 (Anonymous 1881).

Table S1. Emerald Acropolis excavated building inventory and projections.

Building form	**N of wall-trench constructions**	**N of single-post constructions**	**Excavated sample totals**	**Projected numbers of buildings: N of construction pulses per century (100/9.3 years=10.8) multipled by factor of**	
				33 (17 ha/5183 sq m) for acropolis only	**121 (63 ha/5183 sq m) for entire site**
Shrine Houses	3	14	17	52	190
Council houses/temples	4	3	7	21	78
Rotundas/sweatlodges	11	0	11	34	123
T-shaped medicine lodge	2	0	2	6	22
Other rectangular buildings	100	3	103	315	1154
Totals	**120**	**20**	**140**	**428**	**1569**

Table S2. Emerald Acropolis radiocarbon dates.

Sample Number	Sample Type	Feature - Lot Number	Provenience	Carbonized material	ISGS Number	ISGS Date BP	+/-	BC/AD Date uncalibrated	Carbon 13 Ratio	Phase based on pottery	OxCal 4.2 calibrated range*	%
CI-661	AMS	104-2	burned house fill	hazelnut shell	3108	955	15	995	-25.3	Edelhardt	1022-1052	95.4
CI-662	AMS	104-49	burned house fill	oak wood	3109	990	15	960	-24.5	Edelhardt	1012-1044	95.4
CI-663	AMS	104-51	burned house fill	hickory wood	3110	990	20	960	-26.0	Edelhardt	997-1045	95.4
CI-664	AMS	111-5	burned house fill	hickory nutshell	3111	940	20	1010	-26.1	late Edelhardt	1038-1080	95.4
CI-665	AMS	111-9	burned house fill	hickory nutshell	3112	925	15	1025	-24.7	late Edelhardt	1040-1080	95.4
CI-669	AMS	157-59	bottom of house basin	ash wood	3116	935	15	1015	-24.1	late Edelhardt	1045-1085	95.4
CI-670	AMS	157-60	bottom of house basin	diffuse porous wood	3117	890	20	1060	-28.1	late Edelhardt	1046-1084	95.4
CI-672	AMS	157-65	bottom of house basin	hickory nutshell	3119	895	15	1055	-22.2	late Edelhardt	1046-1084	95.4
CI-666	AMS	157-2	upper zone of burned building	elm wood	3113	915	15	1035	-23.5	early Lohmann	1047-1091	95.4
CI-667	AMS	157-3	upper zone of burned building	walnut shell	3114	940	15	1010	-24.5	early Lohmann	1047-1094	95.4
CI-668	AMS	157-15	Zone 3 B burned structure	hickory nutshell	3115	910	20	1040	-27.0	early Lohmann	1047-1092	95.4
CI-671	AMS	157-100	ashy lens in house basin	hickory wood	3118	900	15	1050	-25.1	early Lohmann	1047-1090	95.4
CI-680	AMS	192-5	burned house fill	oak wood	3127	940	15	1010	-24.9	early Lohmann	1047-1094	95.4
CI-675	AMS	110-5	wall trench of structure	hickory nutshell	3122	900	20	1050	-24.6	Lohmann	1058-1207	95.4
CI-676	AMS	120-5	post pit	oak(?) wood	3123	965	15	985	-26.3	Lohmann	1085-1152	95.4
CI-677	AMS	120-11	post pit	hickory wood	3124	900	15	1050	-25.6	Lohmann	1056-1205	95.4
CI-678	AMS	124-26	structure basin floor	walnut shell	3125	875	15	1075	-26.7	Lohmann	1152-1217	95.4
CI-679	AMS	124-27	wall trench of structure	hickory wood	3126	930	15	1020	-25.7	Lohmann	1070-1159	95.4
CI-673	AMS	172-1	house basin fill	red oak wood	3120	805	15	1145	-26.2	late Lohmann	1215-1264	95.4
CI-674	AMS	172-6	house basin fill	hickory wood	3121	880	15	1070	-24.1	late Lohmann	1064-1216	95.4

*Note: Calibrated ranges based on OxCal 4.2, IntCal 13 curve, see Bronk, Ramsey, C. 2009, Bayesian Analysis of Radiocarbon Dates. Radiocarbon 51(1):337-360

Table S3. Rising and setting positions of the sun and moon from the Emerald Acropolis summit.

Emerald Acropolis summit	**Sunrise and moonrise calculations**						**Sunset and moonset calculations**					
Declination interpolations for AD 1000, derived from Hawkins 1966, table 3	**Max lunar north**	**Summer solstice**	**Min lunar north**	**Min lunar south**	**Winter solstice**	**Max lunar south**	**Max lunar north**	**Summer solstice**	**Min lunar north**	**Min lunar south**	**Winter solstice**	**Max lunar south**
1000 BC	28.966	23.816	18.666	18.666	23.816	28.966	28.966	23.816	18.666	18.666	23.816	28.966
500 BC	28.907	23.757	18.607	18.607	23.757	28.907	28.907	23.757	18.607	18.607	23.757	28.907
0 BC	28.846	23.696	18.546	18.546	23.696	28.846	28.846	23.696	18.546	18.546	23.696	28.846
AD 500	28.783	23.633	18.483	18.483	23.633	28.783	28.783	23.633	18.483	18.483	23.633	28.783
AD 1000	**28.718**	**23.568**	**18.418**	**18.418**	**23.568**	**28.718**	**28.718**	**23.568**	**18.418**	**18.418**	**23.568**	**28.718**
sin of AD 1000 declination	0.4805	0.3998	0.3159	-0.3159	-0.3998	-0.4805	0.4805	0.3998	0.3159	-0.3159	-0.3998	-0.4805
latitude of Emerald	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63
cos latitude	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812
sin latitude	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243
distance to bluffs/foresight (meters)	7249	5802	3598	7338	4293	3312	3017	4310	3935	3790	3482	3540
Elevation of distant hills/foresight + 25 m trees to setting positions	170	161	160	157	146	164	179	186	179	172	177	183
Elevation of Emerald ridge	156	156	156	156	156	156	156	156	156	156	156	156
Vertical / horizontal distances	0.0020	0.0009	0.0011	0.0001	-0.0023	0.0023	0.0078	0.0068	0.0057	0.0043	0.0060	0.0077
Angular elevation of Emerald, Inverse tan of vertical distance / horizontal distance	0.1146	0.0688	0.0516	0.0057	-0.1318	0.1318	0.4469	0.3896	0.3266	0.2464	0.3438	0.4412
corrected h for Emerald (refraction correction of 0.35, ala Wood fig. 4.5, and lower limb tangency of 0.25 + corrected for parallax 0.95	0.9646		0.9016	0.8557		0.9818	1.2969		1.1766	1.0964		1.2912
corrected h for Emerald (refraction correction of 0.35, plus .25 lower limb tangency, ala Wood fig. 4.5 for sun		-0.0313			-0.2318			0.2896			0.2438	
cos a.e.	0.9999	1.0000	0.9999	0.9999	1.0000	0.9999	0.9997	1.0000	0.9998	0.9998	1.0000	0.9997
sin a.e.	0.0168	-0.0005	0.0157	0.0149	-0.0040	0.0171	0.0226	0.0051	0.0205	0.0191	0.0043	0.0225
for Emerald:												
Cos A (Azimuth, see Wood p. 62)	0.6017	0.5122	0.3919	-0.4164	-0.5086	-0.6289	0.5971	0.5078	0.3881	-0.4197	-0.5152	-0.6332
inverse cos: Azimuths of AD 1000 positions	**53.01**	**59.19**	**66.93**	**114.61**	**120.57**	**128.97**	**306.66**	**300.51**	**292.84**	**245.18**	**238.98**	**230.71**
Selected azimuth orthogonals within 0-180 degree range	143.01	149.19	156.93	24.61	30.57	38.97	126.66	120.51	112.84	65.18	58.98	50.71

Table S4. Rising and setting positions of the sun and moon from Emerald's EB1 surface.

Emerald's EB1 surface	**Sunrise and moonrise calculations**						**Sunset and moonset calculations**					
Declination interpolations for AD 1000, derived from Hawkins 1966, table 3	**Max lunar north**	**Summer solstice**	**Min lunar north**	**Min lunar south**	**Winter solstice**	**Max lunar south**	**Max lunar north**	**Summer solstice**	**Min lunar north**	**Min lunar south**	**Winter solstice**	**Max lunar south**
1000 BC	28.966	23.816	18.666	18.666	23.816	28.966	28.966	23.816	18.666	18.666	23.816	28.966
500 BC	28.907	23.757	18.607	18.607	23.757	28.907	28.907	23.757	18.607	18.607	23.757	28.907
0 BC	28.846	23.696	18.546	18.546	23.696	28.846	28.846	23.696	18.546	18.546	23.696	28.846
AD 500	28.783	23.633	18.483	18.483	23.633	28.783	28.783	23.633	18.483	18.483	23.633	28.783
AD 1000	**28.718**	**23.568**	**18.418**	**18.418**	**23.568**	**28.718**	**28.718**	**23.568**	**18.418**	**18.418**	**23.568**	**28.718**
sin of AD 1000 declination	0.4805	0.3998	0.3159	-0.3159	-0.3998	-0.4805	0.4805	0.3998	0.3159	-0.3159	-0.3998	-0.4805
latitude of Emerald	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63	38.63
cos latitude	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812	0.7812
sin latitude	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243	0.6243
distance to bluffs/foresight (meters)	1344	1317	1242	1667	1667	1298	3571	3101	2849	414	336	335
Elevation of distant hills/foresight, plus 25 m high trees to the northwest only	149	150	150	152	152	150	196	190	186	152	152	152
Elevation of EB1	143	143	143	143	143	143	143	143	143	143	143	143
Vertical / horizontal distances	0.0047	0.0057	0.0053	0.0056	0.0056	0.0053	0.0149	0.0151	0.0149	0.0217	0.0268	0.0269
Angular elevation of EB1 Inverse tan of vertical distance / horizontal distance	0.2669	0.3254	0.3029	0.3199	0.3199	0.3034	0.8531	0.8640	0.8548	1.2443	1.5363	1.5392
corrected h for EB1 (refraction correction of 0.35, ala Wood fig. 4.5, and lower limb tangency of 0.25 + corrected for parallax 0.95	1.1169		1.1529	1.1699		1.1534	1.7031		1.7048	2.0943		2.3892
corrected h for EB1 (refraction correction of 0.35, plus .25 lower limb tangency, ala Wood fig. 4.5 for sun		0.2254			0.2199			0.7640			1.4363	
cos a.e.	0.9998	1.0000	0.9998	0.9998	1.0000	0.9998	0.9996	0.9999	0.9996	0.9993	0.9997	0.9991
sin a.e.	0.0195	0.0039	0.0201	0.0204	0.0038	0.0201	0.0297	0.0133	0.0298	0.0365	0.0251	0.0417
for EB1:												
Cos A (Azimuth, see Wood p. 62)	0.5996	0.5086	0.3884	-0.4208	-0.5148	-0.6313	0.5916	0.5012	0.3808	-0.4339	-0.5320	-0.6490
inverse cos (and hence azimuth of AD 1000 positions)	**53.16**	**59.43**	**67.15**	**114.88**	**120.99**	**129.15**	**306.30**	**300.08**	**292.38**	**244.29**	**237.86**	**229.53**
Selected azimuth orthogonals within 0-180 degree range	143.16	149.43	157.15	24.88	30.99	39.15	126.30	120.08	112.38	64.29	57.86	49.53