[Supplementary material]

Dating Machu Picchu: results and implications for Inca chronology

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Previous radiocarbon measurements from Machu Picchu (Berger *et al.* 1988; Ziółkowski *et al.* 2020)

The first radiocarbon measurements (n=12) from Machu Picchu were published by Rainer Berger and colleagues (1988). This dating project was based on charcoal samples (n=7) recovered from a field project at Machu Picchu and human bone (n=5) from burials excavated by the 1912 Yale Peruvian Scientific Expedition then housed at the Yale Peabody Museum of Natural History.

Charcoal samples were obtained in 1983 by an archaeological project at Machu Picchu directed by the Peruvian National Institute of Culture (now the Ministry of Culture) and the University of California, Los Angeles (UCLA). These samples were recovered from a 1 × 1m excavation unit (Unit 1) undertaken in Room 6 of the Ingenuity Group or Sector V (Ziółkowski *et al.* 2020), a residential complex to the east of the central plaza (Bingham 1930: 82–5, fig. 219; Berger *et al*. 1988: fig.1). The stratigraphy was divided into arbitrary 10 cm levels to sterile bedrock. Dated charcoal samples were obtained from Levels 1, 4, 7, 10, 12, and 13. Problematically, only a few of the samples have clear associations with archaeological materials or features.

In the original publication (Berger *et al.* 1988), the measurements were calibrated following Stuiver (1982) and Suess (1979). Table S1 presents a recalibration of these measurements using SHCal20 (Hogg *et al.* 2020), IntCal20 (Reimer *et al.* 2020) and the Mixed calibration curves (Marsh *et al.* 2018; discussed below). As illustrated in this table and Figure S1, the calibrated radiocarbon dates do not correspond with the excavation stratigraphy. The only consistent dates

come from two charcoal samples from Level 7, which was a floor with associated Inca pottery. These samples (UCLA-2538E and UCLA-2538F) provided Late Horizon dates, which agree with the dates published in this study. Charcoal from Level 12 (UCLA-2538O) was associated with a hearth positioned at the base of the wall. Samples from below Level 12 were not associated with cultural materials or features "…and therefore cannot be used so far for the reconstruction of the history of the site" (Berger *et al.* 1988: 709).

Table S1. Recalibrated charcoal dates from the 1983 Machu Picchu dating project (Berger *et al.* 1988). Measurements are calibrated on OxCal v. 4.4 with the SHCal20 (Hogg *et al.* 2020), IntCal20 (Reimer *et al.* 2020) and Mixed curves (Marsh *et al.* 2018).

Lab (UCLA)	Context	Material	C14 date	68.2% (SHCal20)	95.4% (SHCal20)	68.2% (IntCal20)	95.4% (IntCal20)	68.2% (Mixed)	95.4% (Mixed)
2538A	Level 1 (0-10cm)	Charcoal	595±100	AD 1303(30.1%)1362 1380(38.2%)1448	AD 1129(1.2%)1250 1265(91.3%)1510 1584(3.0%)1622	AD 1298-1417	AD 1221-1490	AD 1298-1434	AD 1223(93.6%)1507 1591(1.8%)1618
2538B	Level 4 (31-40cm)	Charcoal	2775±160	1196(2.3%)1173 BC 1162(1.9%)1143 1131(64.1%)770	1378(1.2%)1174 BC 1305(93.9%)473 435(0.4%)422	1195(2.7%)1174 BC 1161(2.2%)1144 1130(63.4%)795	1404(88.9%)721 BC 707(1.9%)662 652(4.7%)544	1192(1.9%)1176 BC 1159(1.7%)1144 1128(64.7%)780	1392(2.2%)1334 BC 1324(93.2%)516
2538E	Level 7 (61-70cm); Floor I	Charcoal	380±40	AD 1484(17.7%)1514 1544(50.6%)1626	AD 1459-1634	AD 1454(47.1%)1516 1590(21.2%)1620	AD 1443(53.8%)1529 1542(41.6%)1635	AD 1459(36.6%)1515 1574(31.7%)1624	AD 1454-1632
2538F	Level 7 (61-70cm); Floor I	Charcoal	390±40	AD 1462(30.3%)1511 1549(7.4%)1562 1575(30.6)1623	AD 1457-1631	AD 1448(49.9%)1514 1591(18.4%)1620	AD 1437(59.5%)1529 1550(35.9%)1635	AD 1456(40.3%)1514 1578(28.0%)1623	AD 1450(49.0%)1530 1538(46.5%)1632
2538K	Level 10 (91-100cm)	Charcoal	2700±50	898(21.4%)866 BC 846(46.9%)792	976(1.4%)952 BC 936(94.0%)762	898(29.6%)862 BC 855(38.7%)809	977(3.1%)952 BC 936(92.3%)791	898(26.4%)864 BC 848(41.8%)802	966(0.6%)960 BC 931(94.8%)778
2538O	Level 12 (111-120cm); Floor II, wall base	Charcoal	1365±45	AD 658(26.7%)690 703(10.6%)720 736(30.9%)772	AD 640(91.7%)775 813(3.7%)843	AD 609(6.0%)620 639(50.4%)682 745(9.9%)760 768(2.0%)771	AD 600(74.6%)708 726(20.8%)774	AD 646(41.3%)689 740(27.0%)772	AD 604(2.7%)624 634(92.7%)774
2438P	Level 13 (121-130 cm)	Charcoal	2660±45	891(3.7%)881 BC 834(64.5%)770	907(85.4%)749 BC 686(2.8%)666 640(7.3%)568	895(14.5%)875 BC 837(53.7%)792	906-778 BC	890(4.4%)882 BC 834(63.9%)780	910-761 BC

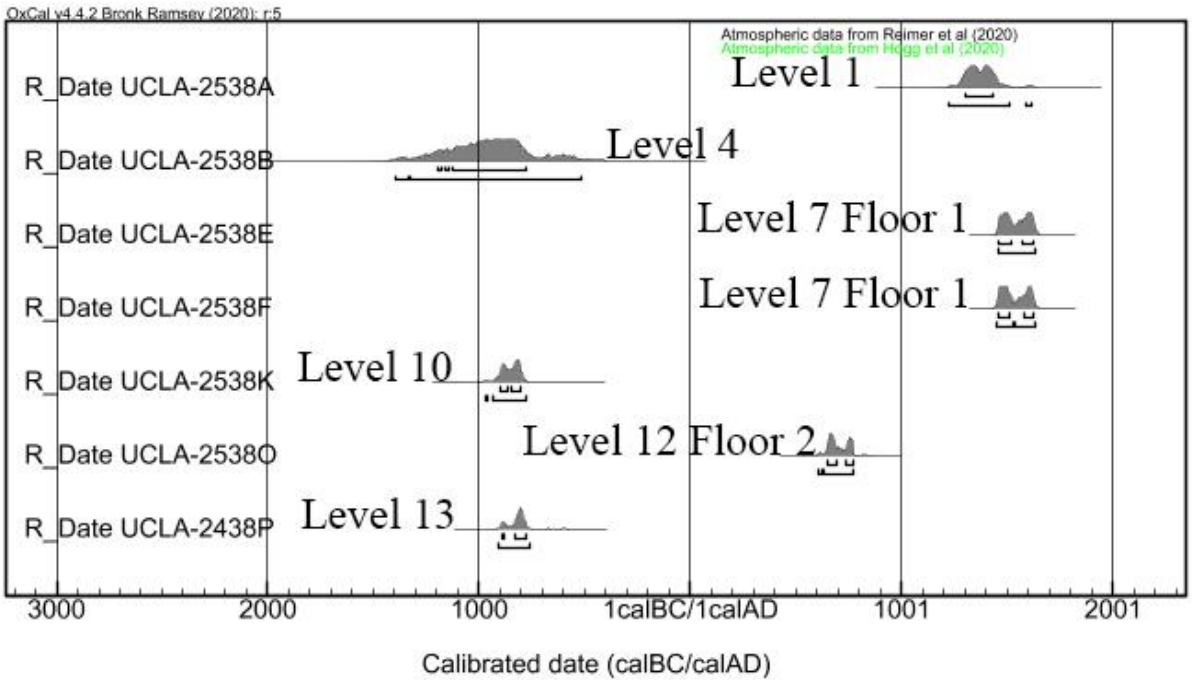

Figure S1. Recalibrated dates from charcoal samples from the 1983 Machu Picchu dating project in stratigraphic order. Dates calibrated with the mixed curve (Marsh et al*. 2018) on OxCal v4.4.*

Berger and colleagues (1988) also analysed seven bone samples (ribs and vertebrae) from different retainer burial contexts at Machu Picchu excavated by Hiram Bingham and his colleagues. Of these, five yielded a sufficient collagen fraction to produce radiocarbon measurements. Those samples that yielded dates had extremely wide error ranges (Table S2). The imprecision of these dates is likely the result of the numerous problems with radiocarbon dating bone in the 1980s (Hedges and Law 1989). In three different instances, human remains from Berger *et al.* (1988) and our study, were obtained from the same burial contexts. The differences in calibrated age ranges are compared in Figure S2. As can be seen in this illustration there is some overlap in dates at the 95.4% confidence interval, except for Burial Cave 3 in which there are significant differences.

Table S2. Recalibrated dates obtained from bone collagen from the 1983 Machu Picchu dating project (Berger *et al.* 1988). Dates are calibrated on OxCal v. 4.4 with SHCal20 (Hogg *et al.* 2020), IntCal20 (Reimer *et al*. 2020) and the Mixed curves (Marsh *et al.* 2018). * Indicates a radiocarbon date that may extend beyond the range of the calibration curve.

Lab (UCLA)	Context	Material	C14 date	68.2% (SHCal20)	95.4% (SHCal20)	68.2% (IntCal20)	95.4% (IntCal20)	68.2% (Mixed)	95.4% (Mixed)
2702A	Burial 3	Bone	2050±265	381(12.5%)242 BC 235 BC(54.3%)AD 252 AD 302(1.4%)320	756(2.4%)680 BC 671(1.9%)606 BC 596 BC(91.2%)AD 537	393 BC-AD 243	771 BC(94.3%)AD 243 AD 464(0.3%)476 AD 500(0.8%)531	389 BC-AD 249	755 BC (2.7%)678 BC 672 BC(91.7%) AD 480 AD 491(1.1%)529
2702B	Burial 26	Bone	855±365	AD 774(3.0%)816 841(65.2%)1453	AD 437(0.3%)455 467(92.1%)1708 1720(2.2%)1813 1836(0.3%)1852 1866(0.2%)1880 1926(0.3%)1943	AD 774-1426	AD 415(93.3%)1694 1726(1.6%)1811 1918(0.5%)…*	AD 774(3.0%)814 AD 826(65.2%)1440	AD 424(93.2%)1696 1724(1.0%)1810 1924(0.4%)…*
2702D	Burial 52	Bone	1485±185	AD 389(1.4%)401 409(65.8%)774 820(1.2%)830	AD 209-991	AD 364(63.7%)705 738(4.6%)772	AD 134(0.1%)138 162(0.7%)189 201(92.7%)902 915(1.9%)975	AD 388-772	AD 204-988
2702F	Burial 84	Bone	850±325	AD 778(0.3%)782 881(68.0%)1450	AD 540(94.0%)1690 1729(1.5%)1807	AD 777(0.7%)786 832(1.6%)851 875(65.9%)1421	AD 439(0.3%)460 478(0.3%)496 534(94.3%)1675 1743(0.1%)1750 1765(0.5%)1799	AD 776(0.8%)786 872(67.5%)1438	AD 532(94.2%)1686 1731(1.2%)1806
2702G	Burial 107	Bone	640±180	AD 1216-1497	AD 1026-1663	AD 1175-1457	AD 998(0.1%)1002 1020(95.3%)1647	AD 1183(1.5%)1194 1204(66.8%)1478	AD 1022-1654

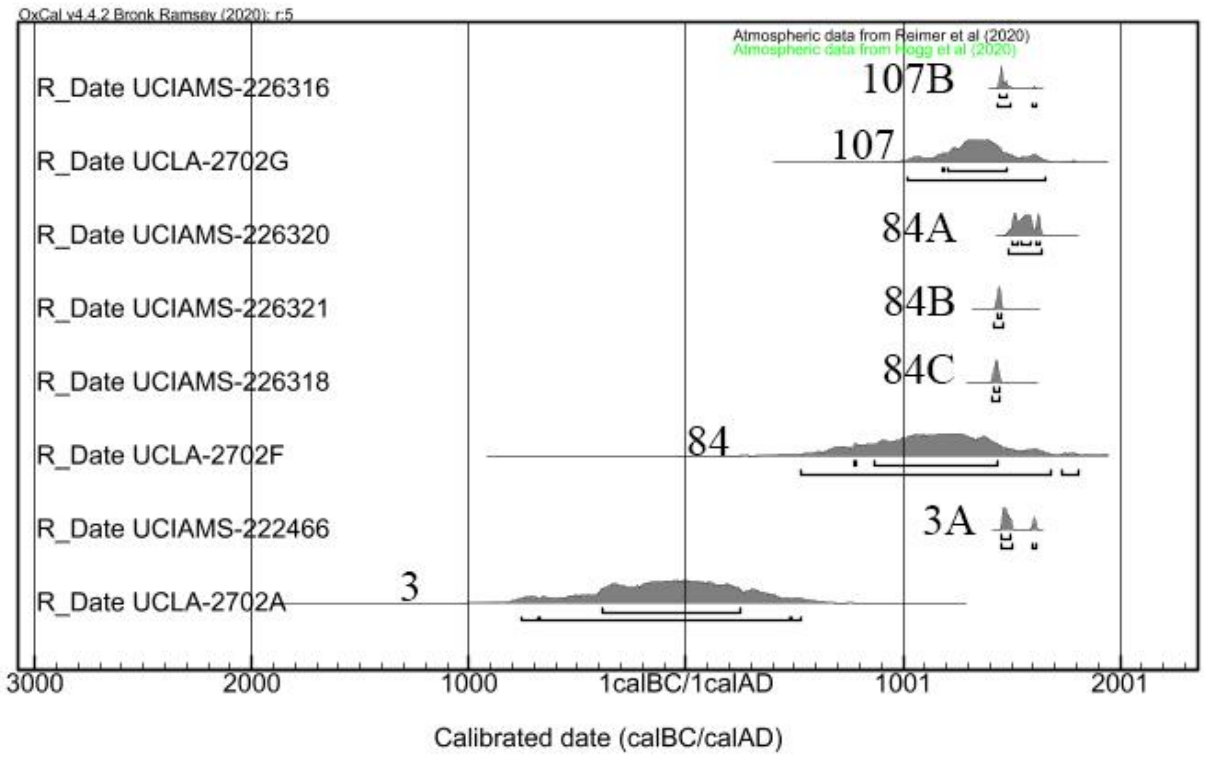

Figure S2. Comparison of radiocarbon dates from Berger et al. *(1988; UCLA) and this study (UCIAMS) of human burials from Machu Picchu. Dates calibrated with OxCal v 4.4 using the Mixed curve (Marsh* et al. *2018).*

Ziółkowski *et al.* (2020) recently published three new AMS dates obtained from charcoal samples from the same sector of Machu Picchu as reported by Berger *et al.* (1988; see Ziółkowski *et al.* 2020: figure 3 for excavation locations). Their excavations were located approximately 25 m from the UCLA test pit. Measurements range from 560±20 to 441±17 BP (Ziółkowski *et al.* 2020) and when calibrated (Table S3) conform to the early dates that we present for the retainer burials in this study, but as Ziólkowski *et al.* (2020) observes "Unfortunately, the wood-charcoal samples offering typically TPQ [terminus post quem] estimates were not identified to species, nor considered in terms of characterisation (whether heartwood, outer rings, roundwood, etc.) before dating. This limits our ability to comment on the likely scale of possible in-built age".

Table S3. Radiocarbon dates from Sector V of Machu Picchu (Ziółkowski *et al.* 2020). Measurements are calibrated with OxCal v. 4.4 with SHCal20 (Hogg *et al.* 2020), IntCal20 (Reimer *et al.* 2020) and the Mixed curve (Marsh *et al.* 2018).

Lab #	Context Description	Material	C14 date	68.2% (SHCal20)	95.4% (SHCal20)	68.2% (IntCal20)	95.4% (IntCal20)	68.2% (Mixed)	95.4% (Mixed)
Wk-48116	Unit 02-2017; Layer 3 (Floor of Patio)	Charcoal	560±20	1408-1430	1400-1440	1328(29.2%)1346 1395(39.1%)1412	1323(43.9%)1355 1392(51.5%)1422	1399-1423	1326(11.2%)1350 1392(84.2%)1435
Wk-46935	Unit 02-2017; Layer 4	Charcoal	490±18	1439-1454	1429-1459	1422-1439	1411-1445	1430-1447	1420-1454
Wk-46936	Unit 02-2017 extension; Layer 2 (sacrificial context)	Charcoal	441±17	1451-1487	1450(85.6%)1500 1600(9.8%)1612	1439-1455	1430-1466	1442-1464	1436-1494

Table S4. Contextual information of the burials that provided the osteological materials dated by AMS.

	Morphology (Verano 2003)				Strontium (Turner et al. 2009)		Grave Goods (Salazar 2001)
Burial	Sex	Age	Cranial Deformation (CD)	CD Regional Style Group	$^{87}Sr/^{86}Sr$	Isotope Geographic Cluster	
MP_33	M	25-33	No	not assigned	0.70713	not grouped	n.d.
MP_3A	F	30-40	No	not assigned	0.71098	Variable, spans multiple regions	Cuzco
MP_48A	M	15-18	Mild annular deformation	not assigned	n.d.	n.d.	Altiplano
MP_32	M	30-35	No	not assigned	n.d.	n.d.	n.d.
MP_23	M	16-18	Tumpline deformation	Central Highlands	0.71176	not grouped	n.d.
MP_45A	M	young adult	n.d.	n.d.	0.70744	Southwest highlands of Peru; N. Inland Chile, NW Bolivia	Altiplano
MP_4B	n.d.	n.d.	n.d.	n.d.	0.71991	not grouped	Altiplano
MP_4F	n.d.	n.d.	n.d.	n.d.	0.70901	Variable, spans multiple regions	Altiplano
MP_5B	M (?)	25-35	Possible tumpline (frontal flattening)	Central highlands	0.71072	Variable, spans multiple regions	Altiplano
MP_4i	M	Young adult	n.d.	n.d.	0.72053	Northwest Peru	n.d.
MP_31A	F	30-40	No	not assigned	0.70384	Variable, spans multiple regions	Altiplano
MP 107B	M	Young Adult	n.d.	n.d.	0.71824	Northwest Peru	n.d.
MP 51	n.d.	5-7	n.d.	n.d.	n.d.	n.d.	n.d.
MP 84C	M	35-45	No	not assigned	n.d.	n.d.	n.d.
MP 80	F	45-55	Occipital flattening	North coast	n.d.	n.d.	Altiplano
MP 84A	M	17-20	n.d.	n.d.	0.70764	not grouped	North Coast
MP 84B	M	35-45	n.d.	n.d.	n.d.	n.d.	n.d.
MP 61	F	30-40	n.d.	n.d.	0.71208	North coast?	Cuzco
MP 63	M	25-35	n.d.	North Coast	0.70528	Southern Peru; coast?	Altiplano
MP 55	n.d.	n.d.	n.d.	n.d.	0.72018	not grouped	Altiplano
MP 11	F	50-60	n.d.	North Coast	n.d.	n.d.	Altiplano
MP 78A	n.d.	13-18	n.d.	n.d.	n.d.	n.d.	Altiplano
MP 77A	F	40-50	n.d.	n.d.	0.70771	Variable, spans multiple regions	Altiplano
MP 42C	M	50+	Mild annular deformation/ circumferential	Central coast	0.71006	Southwest highlands of Peru; N. Inland Chile, NW Bolivia	n.d.
MP 65B	n.d.	8-9	n.d.	n.d.	0.71143	Southwest highlands of Peru; N. Inland Chile, NW Bolivia	Altiplano
MP 9B	F	18-24	Mild occipital flattening, asymmetrical	Central highlands	0.70438	not grouped	Altiplano

Table S5. Comparison of the SHCal20 (Hogg *et al.* 2020), IntCal20 (Reimer *et al.* 2013), and the Mixed curve (Marsh *et al.* 2018) dates of the retainer burials discussed in this study.

Lab (UCIAMS)	Burial number	Cemetery	Material	C14 date	del13C (‰)	68.2% (SHCal20)	95.4% (SHCal20)	68.2% (IntCal20)	95.4% (IntCal20)	68.2% (Mixed)	95.4% (Mixed)
222465	33	2	Molar	485±15	-11.3	1441-1455	1434-1459	1425-1438	1417-1446	1431-1449	1424-1454
222466	3A	1	Molar	405±15	-13.1	1462(45.8%)1503 1596(22.5%)1615	1456(59.4%)1510 1550(1.2%)1558 1581(34.8%)1623	1452-1474	1445(94.7%)1492 1604(0.8%)1607	1457-1493	1452(77.1%)1504 1594(18.3%)1616
222467	48A	1	Metatarsal	425±20	-12.9	1457(62.2%)1498 1603(6.1%)1608	1451(72.6%)1507 1591(22.8%)1619	1442-1465	1433-1482	1448-1484	1442(86.0%)1502 1597(9.5%)1614
222468	32	2	Molar	385±20	-9.8	1484(21.8%)1510 1550(6.9%)1560 1579(39.6%)1623	1460(33.6%)1519 1528(61.9%)1628	1456(56.4%)1498 1601(11.9%)1614	1449(72.6%)1518 1588(22.8%)1622	1464(43.3%)1504 1594(25.0%)1616	1455(53.2%)1518 1550(42.3%)1625
222469	23	3	Molar	395±20	-15.0	1463(8.3%)1473 1478(28.3%)1508 1588(31.7%)1620	1457(44.7%)1514 1543(50.7%)1626	1452-1490	1445(80.9%)1510 1592(14.5%)1620	1460(54.2%)1500 1600(14.1%)1612	1450(63.4%)1514 1554(0.6%)1559 1575(31.4%)1624
222470	45A	1	Molar	390±15	-12.8	1464(4.1%)1470 1481(26.5%)1509 1585(37.6%)1622	1460(39.7%)1514 1545(55.8%)1625	1455-1490	1450(82.8%)1506 1596(12.6%)1618	1464(51.5%)1500 1600(16.8%)1612	1455(62.2%)1510 1504(33.2%)1623
222471	4B	1	Molar	450±20	-12.3	1448-1484	1445(87.1%)1501 1599(8.4%)1613	1436-1453	1424-1460	1439-1460	1428-1490
222472	4F	1	Molar	540±20	-11.2	1415-1440	1407-1446	1401-1422	1327(12.1%)1350 1394(83.3%)1430	1406-1430	1398-1442
222473	5B	1	Molar	550±20	-18.3	1411-1435	1404-1443	1330(4.2%)1333 1397(64.1%)1421	1325(27.0%)1354 1392(68.5%)1425	1403-1425	1328(2.8%)1338 1395(92.6%)1440
222474	4I	1	Molar	540±15	-17.7	1419-1437	1410-1445	1404-1419	1328(3.0%)1337 1396(92.5%)1428	1409-1426	1401-1438
222475	31A	2	Molar	455±20	-11.0	1446-1483	1442(89.5%)1500 1600(6.0%)1612	1434-1450	1425-1458	1439-1458	1427-1482
226316	107B	outlier	Molar	440±20	-10.6	1452-1495	1447(81.6%)1503 1596(13.8%)1615	1439-1455	1430-1470	1442-1476	1435(92.6%)1498 1601(2.9%)1610
226317	51	3	Pars petrosa	420±20	-11.0	1459(58.4%)1499 1602(9.9%)1610	1451(69.4)1509 1587(26.0%)1621	1445-1467	1436-1490	1450-1490	1445(83.0%)1504 1596(12.5%)1616
226318	84C	4	Caninus	510±20	-11.6	1430-1450	1418-1455	1412-1431	1404-1440	1420-1442	1410-1449
226319	80	2	Molar	525±20	-13.4	1424-1445	1413-1450	1406-1426	1397-1437	1414-1435	1405-1445
226320	84A	4	Molar	345±20	-10.2	1510(39.3%)1550 1559(19.5%)1580 1623(9.4%)1633	1503(76.1%)1595 1615(19.3%)1645	1490(25.7%)1524 1572(42.6%)1630	1475(36.0%)1529 1540(59.5%)1635	1506(18.0%)1528 1544(39.6%)1592 1618(10.7%)1631	1490-1638
226321	84B	4	Metatarsal	475±20	-10.9	1442-1459	1429-1485	1426-1444	1419-1451	1434-1452	1424-1458
226322	61	2	Molar	415±25	-11.3	1459(54.4%)1501 1600(13.9%)1611	1451(60.3%)1512 1547(3.3%)1564 1572(31.8%)1624	1444-1476	1435(88.8%)1505 1596(6.7%)1617	1452(62.5%)1496 1602(5.8%)1608	1441(75.0%)1510 1586(20.5%)1622
226323	63	1	Molar	375±20	-11.5	1500(11.1%)1513 1545(45.2%)1601 1611(11.9%)1625	1464(1.7%)1470 1481(93.7%)1630	1460(50.2%)1500 1600(18.1%)1615	1453(62.8%)1523 1575(32.7%)1625	1475(31.9%)1512 1580(36.3%)1622	1458(43.9%)1523 1546(51.5%)1628
226324	55	3	Molar	400±20	-12.3	1462(41.0%)1506 1592(27.2%)1618	1456(50.0%)1513 1546(45.5%)1625	1450-1483	1444(85.2%)1506 1596(10.3%)1618	1458(56.4%)1498 1600(11.9%)1611	1450(68.5%)1510 1585(27.0%)1622
226325	11	3	Molar	415±20	-10.1	1460(55.7%)1500 1601(12.6%)1611	1452(65.4%)1510 1553(0.6%)1557 1582(29.5%)1623	1446-1473	1437(93.4%)1495 1601(2.1%)1610	1452-1490	1446(79.6%)1504 1593(15.9%)1617
226328	78A	3	Molar	415±20	-14.9	1460(55.7%)1500 1601(12.6%)1611	1452(65.4%)1510 1553(0.6%)1557 1582(29.5%)1623	1446-1473	1437(93.4%)1495 1601(2.1%)1610	1452-1490	1446(79.6%)1504 1593(15.9%)1617
226329	77A	3	Molar	470±20	-12.0	1441-1461	1433-1491	1428-1445	1420-1454	1435-1454	1422-1460
226330	42C	2	Molar	515±20	-18.9	1429-1448	1417-1453	1410-1428	1402-1439	1418-1440	1408-1446
226331	65B	1	Molar	425±20	-12.7	1457(62.2%)1498 1603(6.1%)1608	1451(72.6%)1507 1591(22.8%)1619	1442-1465	1433-1482	1448-1484	1442(86.0%)1502 1597(9.5%)1614
226332	9B	3	Pre-Molar	475±20	-13.5	1442-1459	1429-1485	1426-1444	1419-1451	1434-1452	1424-1458

Mixed Calibration Curve OxCal Input

Following Marsh *et al.* (2018), the following command was input into OxCal v4.4 to produce calibrated dates using the Mixed calibration curve:

```
Plot()
 {
  Curve("IntCal20","IntCal20.14c");
  Curve("SHCal20","SHCal20.14c");
  Mix_Curve("Mixed","IntCal20","SHCal20",U(0,100));
  R_Date("UCIAMS-222473", 550,20);
  R_Date("UCIAMS-222472", 540,20);
  R_Date("UCIAMS-222474", 540,15);
  R_Date("UCIAMS-226319", 525,20);
  R_Date("UCIAMS-226330", 515,20);
  R_Date("UCIAMS-226318", 510,20);
  R_Date("UCIAMS-222465", 485,15);
  R_Date("UCIAMS-226321", 475,20);
  R_Date("UCIAMS-226332", 475,20);
  R_Date("UCIAMS-226329", 470,20);
  R_Date("UCIAMS-222475", 455,20);
  R_Date("UCIAMS-222471", 450,20);
  R_Date("UCIAMS-226316", 440,20);
  R_Date("UCIAMS-222467", 425,20);
  R_Date("UCIAMS-226331", 425,20);
  R_Date("UCIAMS-226317", 420,20);
  R_Date("UCIAMS-226322", 415,25);
  R_Date("UCIAMS-226325", 415,20);
  R_Date("UCIAMS-226328", 415,20);
  R_Date("UCIAMS-222466", 405,15);
  R_Date("UCIAMS-226324", 400,20);
  R_Date("UCIAMS-222469", 395,20);
```

```
  R_Date("UCIAMS-222470", 390,15);
  R_Date("UCIAMS-222468", 385,20);
  R_Date("UCIAMS-226323", 375,20);
  R_Date("UCIAMS-226320", 345,20);
};
```

SHCal20, IntCal20 and Mixed calibrated dates of Machu Picchu compared

Challenges remain for selecting which calibration curve is most appropriate for dating the Inca heartland (Covey 2018). Following Ogburn (2012) we present the calibrated dates using SHCal20 and IntCal20 as a form of comparison with the mixed curve (Table S3) (Marsh et al. 2018; Nesbitt et al. 2020). Figures S3-S6 present multiplots comparing the different curves from different cemetery contexts at Machu Picchu. Comparative analysis suggests that IntCal20 dates for the Late Horizon are consistently 15-20 years earlier than SHCal20 (Ogburn 2012).

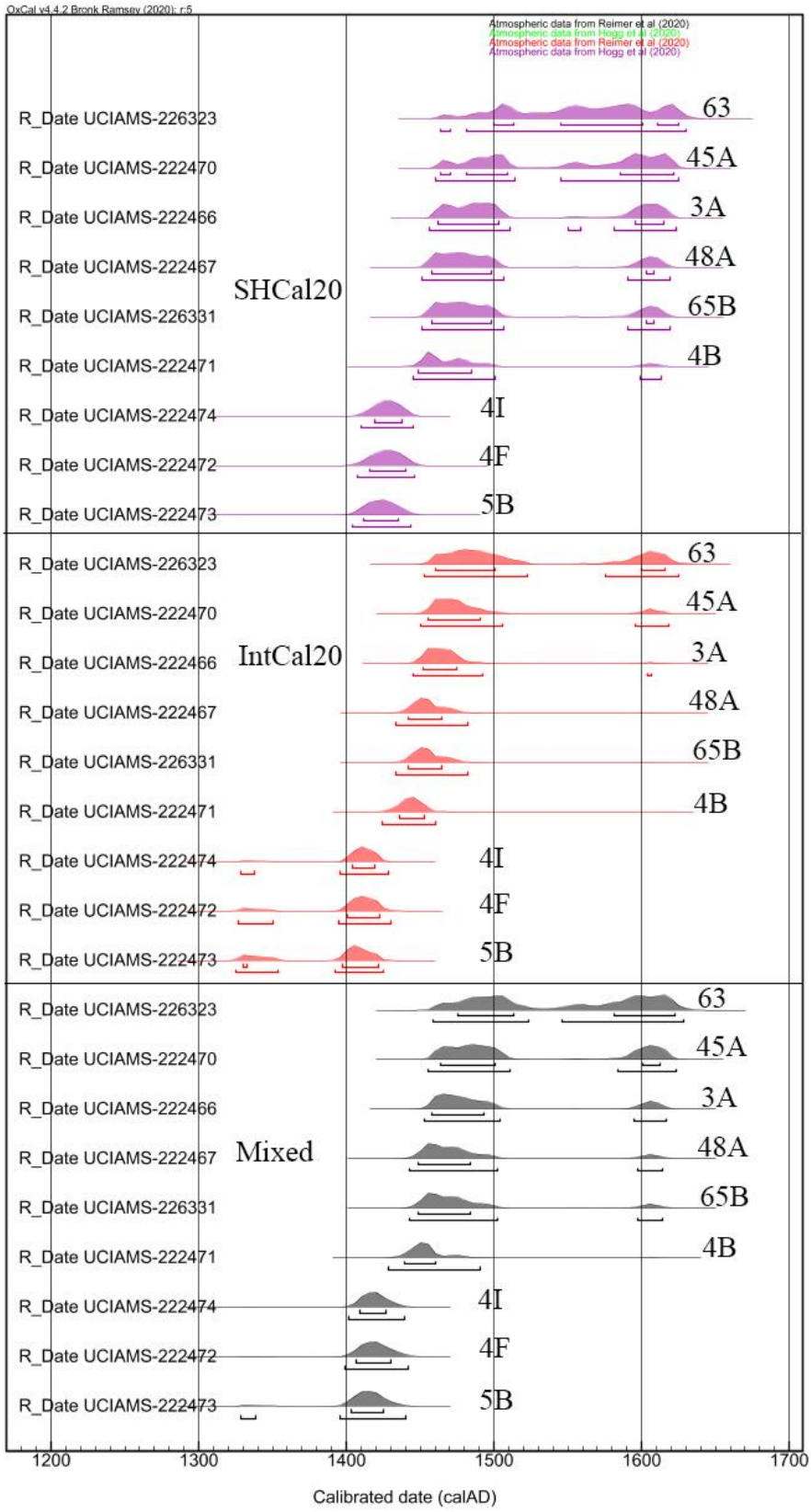

Figure S3. Comparing the different calibration curves for Cemetery 1 using OxCal v4.4.

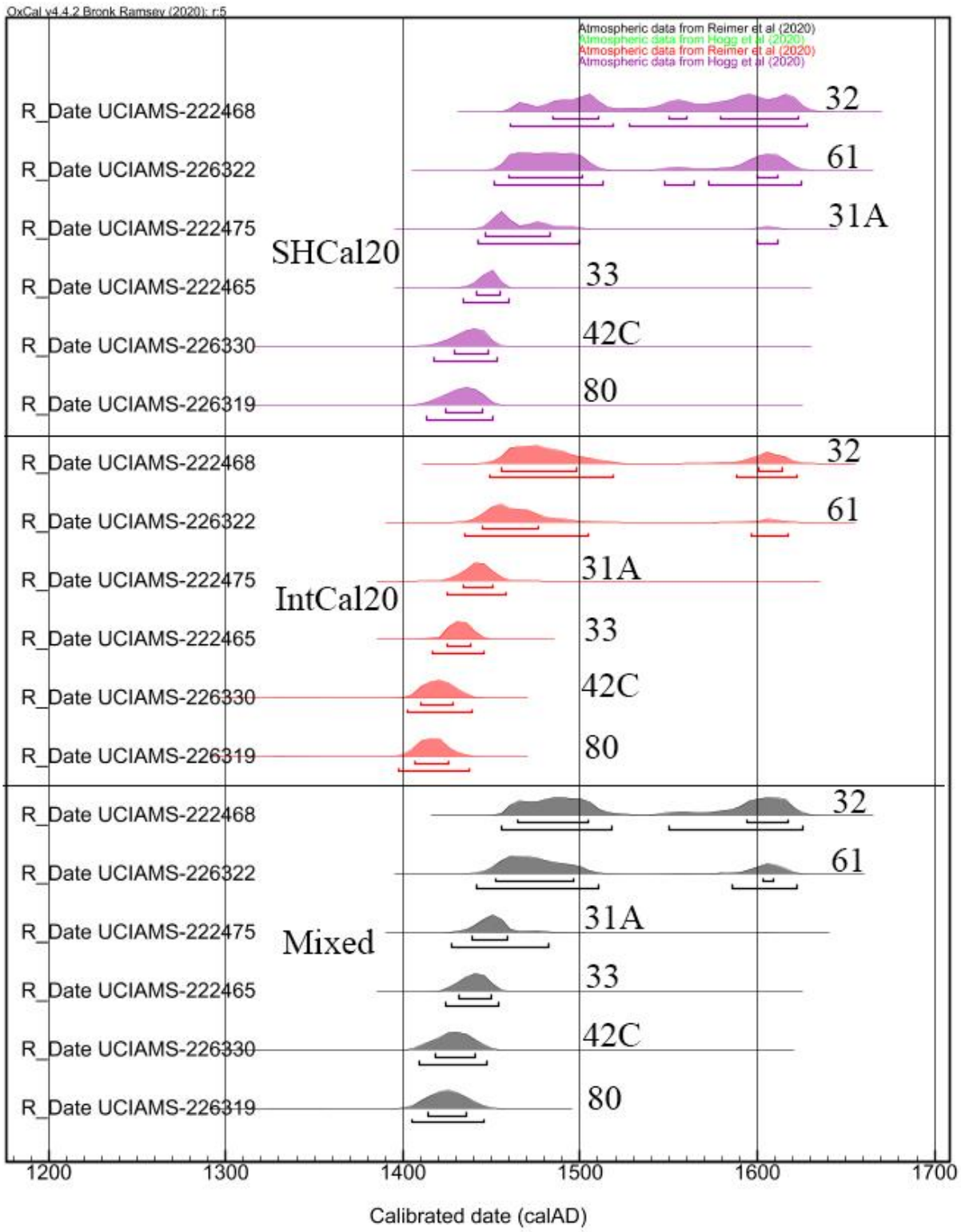

Figure S4. Comparing the calibration curves for Cemetery 2 using OxCal v.4.4.

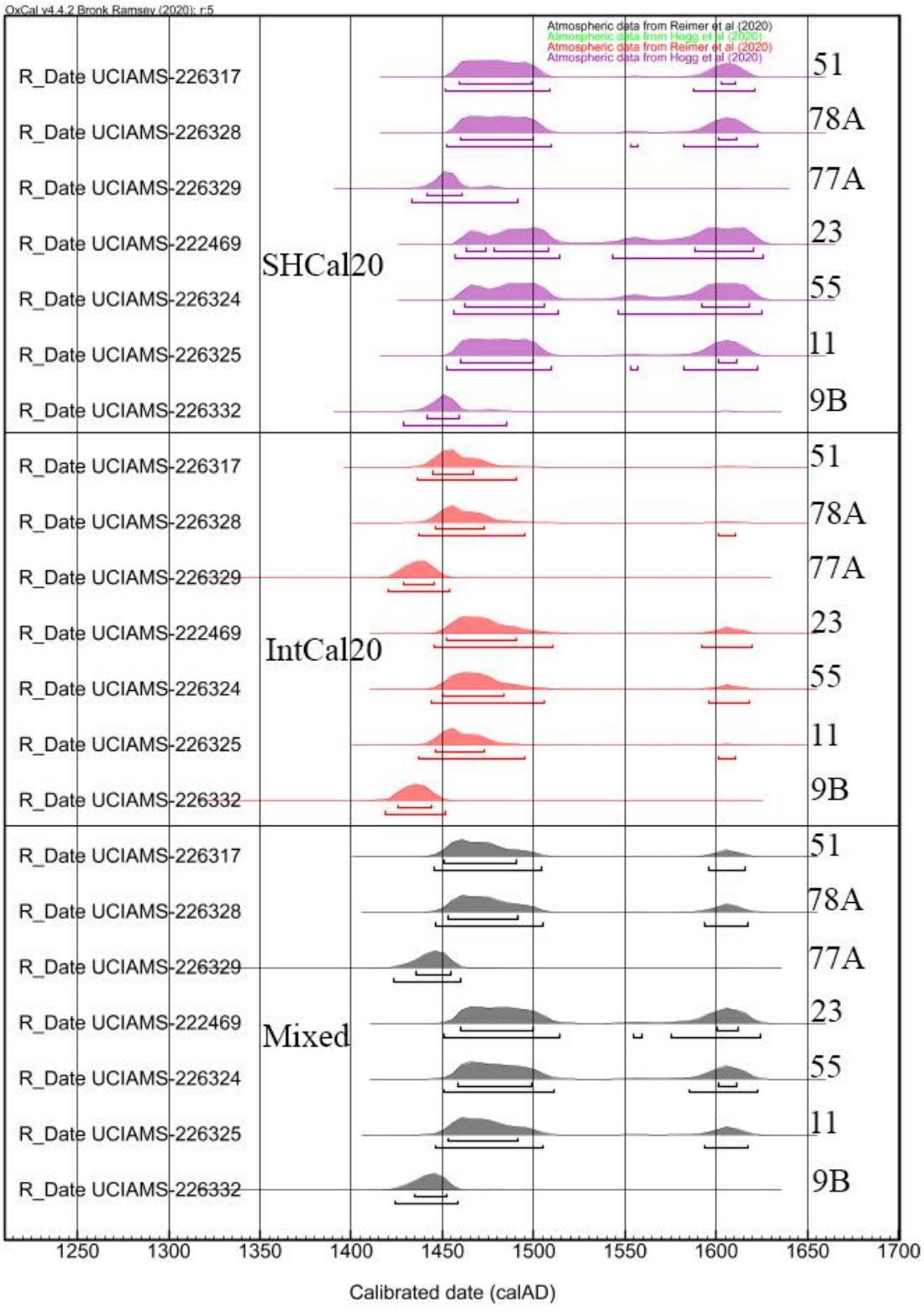

Figure S5. Comparing the calibration curves for Cemetery 3 using OxCal v4.4.

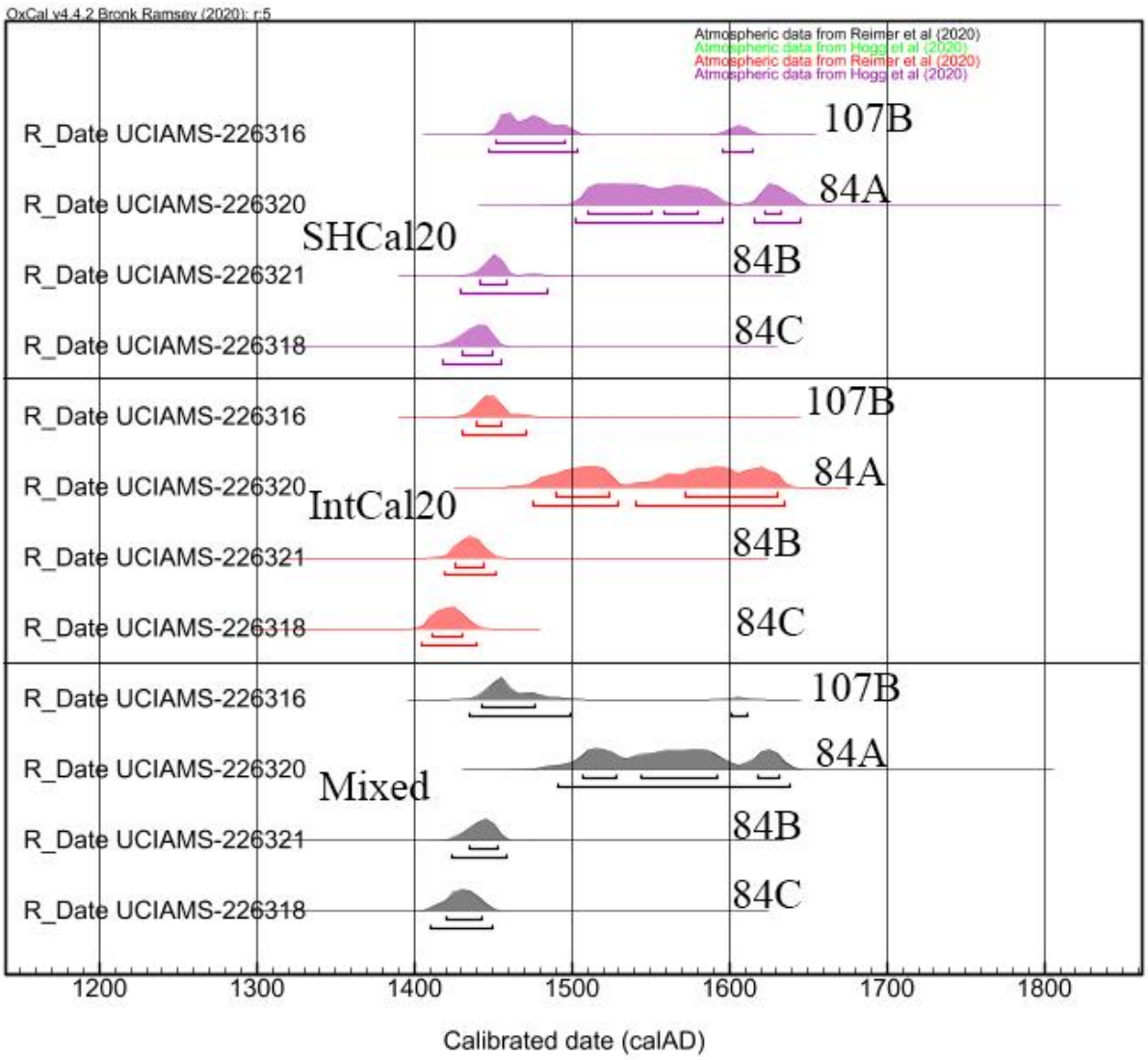

Figure S6. Comparing the calibration curves for Cemetery 4 and outlier (107B) using OxCal v4.4.

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