High-precision Bayesian chronological modeling on a calibration plateau: the Niedertiefenbach gallery grave

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# Supplementary information

## OxCal CQL code

The following OxCal CQL code (Bronk Ramsey 2009; Bronk Ramsey 2017) is required to recreate models shown in Figures 4-8 of the main text. For an explanation of each function, readers are referred to the OxCal online help manual, at <http://c14.arch.ox.ac.uk/oxcalhelp/hlp_contents.html>, and the references listed there.

### KDE\_Model of all 40 accepted dates (Figure 4)

Plot()

{

KDE\_Model("KDE\_Model of Niedertiefenbach dates", )

{

R\_Date("KH180045 KIA-52750", 4435, 25);

R\_Date("KH180044 KIA-52751", 4459, 24);

R\_Date("KH150641 KIA-52282", 4473, 28);

R\_Date("KH150640 KIA-53053", 4461, 25);

R\_Date("KH150639 GrM-14455", 4470, 20);

R\_Date("KH150637 KIA-52281", 4432, 28);

R\_Date("KH150636 KIA-53052", 4493, 26);

R\_Date("KH150635 KIA-52280", 4425, 28);

R\_Date("KH150634 KIA-53051", 4507, 25);

R\_Date("KH150633 KIA-52279", 4486, 29);

R\_Date("KH150631 GrM-14453", 4487, 19);

R\_Date("KH150630 KIA-53050", 4564, 25);

R\_Date("KH150629 GrM-14807", 4505, 20);

R\_Date("KH150628 KIA-53049", 4448, 26);

R\_Date("KH150627 KIA-52278", 4462, 27);

R\_Date("KH150626 GrM-14451", 4540, 20);

R\_Date("KH150625 KIA-52277", 4497, 27);

R\_Date("KH150624 KIA-53115", 4514, 24);

R\_Date("KH150623 GrM-14444", 4497, 18);

R\_Date("KH150622 KIA-53048", 4417, 19);

R\_Date("KH150621 GrM-14442", 4514, 18);

R\_Date("KH150620 KIA-53047", 4491, 25);

R\_Date("KH150619 KIA-52276", 4455, 24);

R\_Date("KH150618 KIA-52275", 4468, 25);

R\_Date("KH150617 GrM-14441", 4523, 18);

R\_Date("KH150616 KIA-52274", 4492, 24);

R\_Date("KH150615 KIA-53046", 4462, 24);

R\_Date("KH150613 KIA-53045", 4499, 26);

R\_Date("KH150612 GrM-14414", 4478, 18);

R\_Date("KH150611 KIA-53044", 4518, 25);

R\_Date("KH150610 KIA-52273", 4532, 25);

R\_Date("KH150422 KIA-52272", 4538, 24);

R\_Date("KH150289 weighted mean", 4495, 20);

R\_Date("KH150288 weighted mean", 4514, 22);

R\_Date("KH150287 KIA-52268", 4499, 25);

R\_Date("KH150206 KIA-52753", 4509, 25);

R\_Date("KH150203 weighted mean", 4489, 20);

R\_Date("117 weighted mean", 4474, 20);

R\_Date("82 KIA-52754", 4505, 25);

R\_Date("56 KIA-52755", 4446, 25);

};

};

### Simple bounded-phase model (Figures 5, 6)

Plot()

{

Sequence("simple bounded phase")

{

Boundary("start boundary");

Phase("Niedertiefenbach burials")

{

R\_Date("KH180045 KIA-52750", 4435, 25);

R\_Date("KH180044 KIA-52751", 4459, 24);

R\_Date("KH150641 KIA-52282", 4473, 28);

R\_Date("KH150640 KIA-53053", 4461, 25);

R\_Date("KH150639 GrM-14455", 4470, 20);

R\_Date("KH150637 KIA-52281", 4432, 28);

R\_Date("KH150636 KIA-53052", 4493, 26);

R\_Date("KH150635 KIA-52280", 4425, 28);

R\_Date("KH150634 KIA-53051", 4507, 25);

R\_Date("KH150633 KIA-52279", 4486, 29);

R\_Date("KH150631 GrM-14453", 4487, 19);

R\_Date("KH150630 KIA-53050", 4564, 25);

R\_Date("KH150629 GrM-14807", 4505, 20);

R\_Date("KH150628 KIA-53049", 4448, 26);

R\_Date("KH150627 KIA-52278", 4462, 27);

R\_Date("KH150626 GrM-14451", 4540, 20);

R\_Date("KH150625 KIA-52277", 4497, 27);

R\_Date("KH150624 KIA-53115", 4514, 24);

R\_Date("KH150623 GrM-14444", 4497, 18);

R\_Date("KH150622 KIA-53048", 4417, 19);

R\_Date("KH150621 GrM-14442", 4514, 18);

R\_Date("KH150620 KIA-53047", 4491, 25);

R\_Date("KH150619 KIA-52276", 4455, 24);

R\_Date("KH150618 KIA-52275", 4468, 25);

R\_Date("KH150617 GrM-14441", 4523, 18);

R\_Date("KH150616 KIA-52274", 4492, 24);

R\_Date("KH150615 KIA-53046", 4462, 24);

R\_Date("KH150613 KIA-53045", 4499, 26);

R\_Date("KH150612 GrM-14414", 4478, 18);

R\_Date("KH150611 KIA-53044", 4518, 25);

R\_Date("KH150610 KIA-52273", 4532, 25);

R\_Date("KH150422 KIA-52272", 4538, 24);

R\_Date("KH150289 weighted mean", 4495, 20);

R\_Date("KH150288 weighted mean", 4514, 22);

R\_Date("KH150287 KIA-52268", 4499, 25);

R\_Date("KH150206 KIA-52753", 4509, 25);

R\_Date("KH150203 weighted mean", 4489, 20);

R\_Date("117 weighted mean", 4474, 20);

R\_Date("82 KIA-52754", 4505, 25);

R\_Date("56 KIA-52755", 4446, 25);

Interval("duration of burial bounded phase model");

};

Boundary("end boundary");

};

};

### Preferred model (Figures 7, 8)

Plot()

{

Sequence("Niedertiefenbach")

{

Boundary("start burial");

Phase("all burials")

{

Phase("no layer")

{

Date("death of KH150613", R\_Date("KH150613 KIA-53045", 4499, 26)+N(25,7));

Date("death of KH150616", R\_Date("KH150616 KIA-52274", 4492, 24)+N(20,4));

Date("death of KH150617", R\_Date("KH150617 GrM-14441", 4523, 18)+N(25,7));

Date("death of KH150624", R\_Date("KH150624 KIA-53115", 4514, 25)+N(25,7));

Date("death of KH150628", R\_Date("KH150628 KIA-53049", 4448, 26)+N(25,7));

Date("death of KH150629", R\_Date("KH150629 GrM-14807", 4505, 20)+N(30,3));

Date("death of KH150630", R\_Date("KH150630 KIA-53050", 4564, 25)+N(10,5));

Date("death of KH150631", R\_Date("KH150631 GrM-14453", 4487, 19)+N(25,5));

Date("death of KH150633", R\_Date("KH150633 KIA-52279", 4486, 29)+N(25,7));

Date("death of KH150634", R\_Date("KH150634 KIA-53051", 4507, 25)+N(25,7));

Date("death of KH150636", R\_Date("KH150636 KIA-53052", 4493, 26)+N(25,7));

Date("death of KH150639", R\_Date("KH150639 GrM-14455", 4470, 20)+N(20,4));

Date("death of KH150640", R\_Date("KH150640 KIA-53053", 4461, 25)+N(25,7));

};

Page( );

Sequence("stratified")

{

Phase("below rubble layer")

{

Date("death of KH150615", R\_Date("KH150615 KIA-53046", 4462, 24)+N(0,1));

Date("death of KH150620", R\_Date("KH150620 KIA-53047", 4491, 25)+N(0,1));

Date("death of KH150622", R\_Date("KH150622 KIA-53048", 4417, 19)+N(1,1));

Date("death of KH150623", R\_Date("KH150623 GrM-14444", 4497, 18)+N(2,2));

Date("death of KH180045", R\_Date("KH180045 KIA-52750", 4435, 25)+N(5,2));

Date("death of KH180044", R\_Date("KH180044 KIA-52751", 4459, 24)+N(25,7));

Date("death of KH150635", R\_Date("KH150635 KIA-52280", 4425, 28)+N(25,7));

Date("death of KH150288", R\_Date("KH150288 weighted mean", 4514, 22)+N(15,7));

Date("death of KH150637", R\_Date("KH150637 KIA-52281", 4432, 28)+N(25,7));

Date("death of KH150289", R\_Date("KH150289 weighted mean", 4495, 20)+N(20,7));

Date("death of 117", R\_Date("117 weighted mean", 4474, 20)+N(20,7));

};

Boundary("rubble layer");

Phase("above rubble layer")

{

Date("death of KH150625", R\_Date("KH150625 KIA-52277", 4497, 27)+N(5,2));

Date("death of KH150626", R\_Date("KH150626 GrM-14451", 4540, 20)+N(25,5));

Date("death of KH150627", R\_Date("KH150627 KIA-52278", 4462, 27)+N(25,7));

Date("death of KH150641", R\_Date("KH150641 KIA-52282", 4473, 28)+N(25,7));

Date("death of 56", R\_Date("56 KIA-52755", 4446, 25)+N(15,7));

Date("death of 82", R\_Date("82 KIA-52754", 4505, 25)+N(15,7));

Date("death of 90", R\_Date("KH150206 KIA-52753", 4509, 25)+N(15,7));

Date("death of KH150422", R\_Date("KH150422 KIA-52272", 4538, 24)+N(25,7));

Date("death of KH150287", R\_Date("KH150287 KIA-52268", 4499, 25)+N(15,7));

Date("death of KH150203", R\_Date("KH150203 weighted mean", 4489, 20)+N(15,7));

Date("death of KH150618", R\_Date("KH150618 KIA-52275", 4468, 25)+N(20,4));

Date("death of KH150619", R\_Date("KH150619 KIA-52276", 4455, 24)+N(20,4));

Date("death of KH150621", R\_Date("KH150621 GrM-14442", 4514, 18)+N(25,5));

Date("death of KH150610", R\_Date("KH150610 KIA-52273", 4532, 25)+N(25,7));

Date("death of KH150611", R\_Date("KH150611 KIA-53044", 4518, 25)+N(5,3));

Date("death of KH150612", R\_Date("KH150612 GrM-14414", 4478, 18)+N(25,7));

};

};

Span("burial duration");

};

Boundary("end burial");

};

Page( );

Date("birth of KH180045", Date("=death of KH180045")-N(25,3));

Page( );

Phase("lcMLkin kinship information")

{

Phase("KH150620, KH150622 and KH150623 must be full siblings")

{

Date("=KH150620 KIA-53047");

Date("=KH150622 KIA-53048");

Date("=KH150623 GrM-14444");

Span("difference between KH150620, KH150622 and KH150623", U(0,15));

};

Phase("4th degree between KH150630 and KH150641")

{

Date("=KH150630 KIA-53050");

Date("=KH150641 KIA-52282");

Span("difference between KH150630 and KH150641", U(0,100));

};

Phase("5th degree between KH150630 and KH180045180045")

{

Date("=KH150630 KIA-53050");

Date("=birth of KH180045");

Span("difference between KH150630 and KH180045", U(0,120));

};

Phase("5th degree between KH150629 and KH180045")

{

Date("=KH150629 GrM-14807");

Date("=birth of KH180045");

Span("difference between KH150629 and KH180045", U(0,120));

};

Phase("3rd degree between KH150640 and KH180045")

{

Date("=KH150640 KIA-53053");

Date("=birth of KH180045");

Span("difference between KH150640 and KH180045", U(0,80));

};

Phase("5th degree between KH150640 and KH180044")

{

Date("=KH150640 KIA-53053");

Date("=KH180044 KIA-52751");

Span("difference between KH150640 and KH180044", U(0,120));

};

Phase("5th degree between KH150610 and KH180044")

{

Date("=KH150610 KIA-52273");

Date("=KH180044 KIA-52751");

Span("difference between KH150610 and KH180044", U(0,120));

};

Phase("5th degree between KH150612 and KH180044")

{

Date("=KH150612 GrM-14414");

Date("=KH180044 KIA-52751");

Span("difference between KH150612 and KH180044", U(0,120));

};

Phase("5th degree between KH150637 and KH180044")

{

Date("=KH150637 KIA-52281");

Date("=KH180044 KIA-52751");

Span("difference between KH150637 and KH180044", U(0,120));

};

Phase("5th degree between KH150637 and KH150627")

{

Date("=KH150637 KIA-52281");

Date("=KH150627 KIA-52278");

Span("difference between KH150637 and KH150627", U(0,120));

};

Phase("5th degree between KH150612 and KH150627")

{

Date("=KH150612 GrM-14414");

Date("=KH150627 KIA-52278");

Span("difference between KH150612 and KH150627", U(0,120));

};

Phase("5th degree between KH150619 and KH150627")

{

Date("=KH150619 KIA-52276");

Date("=KH150627 KIA-52278");

Span("difference between KH150619 and KH150627", U(0,120));

};

};

};

## Sensitivity testing

The following OxCal CQL code was used to check how sensitive the preferred model output is to different modeling decisions and the actual date range covered by the Niedertiefenbach sequence.

### Inclusion of non-replicated 2016 Poznan results

(results which are contradicted by new dates on the same individuals are still omitted, as in Appendix 1)

Plot()

{

Sequence("Niedertiefenbach")

{

Boundary("start burial");

Phase("all burials")

{

Phase("no layer")

{

Date("death of KH150613", R\_Date("KH150613 KIA-53045", 4499, 26)+N(25,7));

Date("death of KH150616", R\_Date("KH150616 KIA-52274", 4492, 24)+N(20,4));

Date("death of KH150617", R\_Date("KH150617 GrM-14441", 4523, 18)+N(25,7));

Date("death of KH150624", R\_Date("KH150624 KIA-53115", 4514, 25)+N(25,7));

Date("death of KH150628", R\_Date("KH150628 KIA-53049", 4448, 26)+N(25,7));

Date("death of KH150629", R\_Date("KH150629 GrM-14807", 4505, 20)+N(30,3));

Date("death of KH150630", R\_Date("KH150630 KIA-53050", 4564, 25)+N(10,5));

Date("death of KH150631", R\_Date("KH150631 GrM-14453", 4487, 19)+N(25,5));

Date("death of KH150633", R\_Date("KH150633 KIA-52279", 4486, 29)+N(25,7));

Date("death of KH150634", R\_Date("KH150634 KIA-53051", 4507, 25)+N(25,7));

Date("death of KH150636", R\_Date("KH150636 KIA-53052", 4493, 26)+N(25,7));

Date("death of KH150639", R\_Date("KH150639 GrM-14455", 4470, 20)+N(20,4));

Date("death of KH150640", R\_Date("KH150640 KIA-53053", 4461, 25)+N(25,7));

};

Page( );

Sequence("stratified")

{

Phase("below rubble layer")

{

Date("death of KH150615", R\_Date("KH150615 KIA-53046", 4462, 24)+N(0,1));

Date("death of KH150620", R\_Date("KH150620 KIA-53047", 4491, 25)+N(0,1));

Date("death of KH150622", R\_Date("KH150622 KIA-53048", 4417, 19)+N(1,1));

Date("death of KH150623", R\_Date("KH150623 GrM-14444", 4497, 18)+N(2,2));

Date("death of KH180045", R\_Date("KH180045 KIA-52750", 4435, 25)+N(5,2));

Date("death of KH180044", R\_Date("KH180044 KIA-52751", 4459, 24)+N(25,7));

Date("death of 142", R\_Date("142 Poz-62870", 4410, 35)+N(15,5)); //omitted from preferred model

Date("death of 133", R\_Date("133 Poz-67544", 4500, 35)+N(15,5)); //omitted from preferred model

Date("death of 136", R\_Date("136 Poz-67545", 4465, 35)+N(15,5)); //omitted from preferred model

Date("death of KH150635", R\_Date("KH150635 KIA-52280", 4425, 28)+N(25,7));

Date("death of KH150197", R\_Date("KH150197 Poz-65303", 4465, 35)+N(15,5)); //omitted from preferred model

Date("death of KH150288", R\_Date("KH150288 weighted mean", 4514, 22)+N(15,7));

Date("death of KH150637", R\_Date("KH150637 KIA-52281", 4432, 28)+N(25,7));

Date("death of KH150289", R\_Date("KH150289 weighted mean", 4495, 20)+N(20,7));

Date("death of 117", R\_Date("117 weighted mean", 4474, 20)+N(20,7));

Date("death of 103", R\_Date("103 Poz-62871", 4415, 40)+N(15,5));//omitted from preferred model

Date("death of 98", R\_Date("98 Poz-62872", 4465, 30)+N(15,5)); //omitted from preferred model

};

Boundary("rubble layer");

Phase("above rubble layer")

{

Date("death of KH150625", R\_Date("KH150625 KIA-52277", 4497, 27)+N(5,2));

Date("death of KH150626", R\_Date("KH150626 GrM-14451", 4540, 20)+N(25,5));

Date("death of KH150627", R\_Date("KH150627 KIA-52278", 4462, 27)+N(25,7));

Date("death of KH150641", R\_Date("KH150641 KIA-52282", 4473, 28)+N(25,7));

Date("death of 56", R\_Date("56 KIA-52755", 4446, 25)+N(15,7));

Date("death of 82", R\_Date("82 KIA-52754", 4505, 25)+N(15,7));

Date("death of 90", R\_Date("KH150206 KIA-52753", 4509, 25)+N(15,7));

Date("death of 77", R\_Date("77 Poz-62873", 4400, 35)+N(15,5)); //omitted from preferred model

Date("death of 67", R\_Date("67 Poz-62874", 4400, 35)+N(15,5)); //omitted from preferred model

Date("death of KH150422", R\_Date("KH150422 KIA-52272", 4538, 24)+N(25,7));

Date("death of KH150287", R\_Date("KH150287 KIA-52268", 4499, 25)+N(15,7));

Date("death of KH150203", R\_Date("KH150203 weighted mean", 4489, 20)+N(15,7));

Date("death of KH150618", R\_Date("KH150618 KIA-52275", 4468, 25)+N(20,4));

Date("death of KH150619", R\_Date("KH150619 KIA-52276", 4455, 24)+N(20,4));

Date("death of KH150621", R\_Date("KH150621 GrM-14442", 4514, 18)+N(25,5));

Date("death of 28", R\_Date("28 Poz-65258",4305,35)+N(15,7)); //omitted from preferred model

Date("death of KH150610", R\_Date("KH150610 KIA-52273", 4532, 25)+N(25,7));

Date("death of KH150611", R\_Date("KH150611 KIA-53044", 4518, 25)+N(5,3));

Date("death of KH150612", R\_Date("KH150612 GrM-14414", 4478, 18)+N(25,7));

Date("death of 2", R\_Date("2 Poz-62869", 4470, 30)+N(15,5)); //omitted from preferred model

};

};

Span("burial duration");

};

Boundary("end burial");

};

Page( );

Date("birth of KH180045", Date("=death of KH180045")-N(25,3));

Difference("burial", "start burial", "end burial");

Page( );

Phase("lcMLkin kinship")

{

Phase("KH150620, KH150622 and KH150623 must be full siblings")

{

Date("=KH150620 KIA-53047");

Date("=KH150622 KIA-53048");

Date("=KH150623 GrM-14444");

Span("difference between KH150620, KH150622 and KH150623", U(0,15));

};

Phase("4th degree between KH150630 and KH150641")

{

Date("=KH150630 KIA-53050");

Date("=KH150641 KIA-52282");

Span("difference between KH150630 and KH150641", U(0,100));

};

Phase("5th degree between KH150630 and KH180045")

{

Date("=KH150630 KIA-53050");

Date("=birth of KH180045");

Span("difference between KH150630 and KH180045", U(0,120));

};

Phase("5th degree between KH150629 and KH180045")

{

Date("=KH150629 GrM-14807");

Date("=birth of KH180045");

Span("difference between KH150629 and KH180045", U(0,120));

};

Phase("3rnd degree between KH150640 and KH180045")

{

Date("=KH150640 KIA-53053");

Date("=birth of KH180045");

Span("difference between KH150640 and KH180045", U(0,80));

};

Phase("5th degree between KH150640 and KH180044")

{

Date("=KH150640 KIA-53053");

Date("=KH180044 KIA-52751");

Span("difference between KH150640 and KH180044", U(0,120));

};

Phase("5th degree between KH150610 and KH180044")

{

Date("=KH150610 KIA-52273");

Date("=KH180044 KIA-52751");

Span("difference between KH150610 and KH180044", U(0,120));

};

Phase("5th degree between KH150612 and KH180044")

{

Date("=KH150612 GrM-14414");

Date("=KH180044 KIA-52751");

Span("difference between KH150612 and KH180044", U(0,120));

};

Phase("5th degree between KH150637 and KH180044")

{

Date("=KH150637 KIA-52281");

Date("=KH180044 KIA-52751");

Span("difference between KH150637 and KH180044", U(0,120));

};

Phase("5th degree between KH150637 and KH150627")

{

Date("=KH150637 KIA-52281");

Date("=KH150627 KIA-52278");

Span("difference between KH150637 and KH150627", U(0,120));

};

Phase("5th degree between KH150612 and KH150627")

{

Date("=KH150612 GrM-14414");

Date("=KH150627 KIA-52278");

Span("difference between KH150612 and KH150627", U(0,120));

};

Phase("5th degree between KH150619 and KH150627")

{

Date("=KH150619 KIA-52276");

Date("=KH150627 KIA-52278");

Span("difference between KH150619 and KH150627", U(0,120));

};

};

};

### Impact of small undetected dietary reservoir effects

This model adds a randomized individual reservoir-effect correction to each 14C age, of between 0 and ‘a’ 14C years, where the value of ‘a’ is set by the user.

Plot()

{

var(a); a=40; //maximum dietary reservoir effect permitted, defined by user

var(b); b=10; //uncertainty in DRE correction, defined by user

Sequence("Niedertiefenbach")

{

Boundary("start burial");

Phase("all burials")

{

Phase("no layer")

{

Delta\_R("KH150613 DRE", rand()\*a,b);

Date("death of KH150613", R\_Date("KH150613 KIA-53045", 4499, 26)+N(25,7));

Delta\_R("KH150616 DRE", rand()\*a,b);

Date("death of KH150616", R\_Date("KH150616 KIA-52274", 4492, 24)+N(20,4));

Delta\_R("KH150617 DRE", rand()\*a,b);

Date("death of KH150617", R\_Date("KH150617 GrM-14441", 4523, 18)+N(25,7));

Delta\_R("KH150624 DRE", rand()\*a,b);

Date("death of KH150624", R\_Date("KH150624 KIA-53115", 4514, 25)+N(25,7));

Delta\_R("KH150628 DRE", rand()\*a,b);

Date("death of KH150628", R\_Date("KH150628 KIA-53049", 4448, 26)+N(25,7));

Delta\_R("KH150629 DRE", rand()\*a,b);

Date("death of KH150629", R\_Date("KH150629 GrM-14807", 4505, 20)+N(30,3));

Delta\_R("KH150630 DRE", rand()\*a,b);

Date("death of KH150630", R\_Date("KH150630 KIA-53050", 4564, 25)+N(10,5));

Delta\_R("KH150631 DRE", rand()\*a,b);

Date("death of KH150631", R\_Date("KH150631 GrM-14453", 4487, 19)+N(25,5));

Delta\_R("KH150633 DRE", rand()\*a,b);

Date("death of KH150633", R\_Date("KH150633 KIA-52279", 4486, 29)+N(25,7));

Delta\_R("KH150634 DRE", rand()\*a,b);

Date("death of KH150634", R\_Date("KH150634 KIA-53051", 4507, 25)+N(25,7));

Delta\_R("KH150636 DRE", rand()\*a,b);

Date("death of KH150636", R\_Date("KH150636 KIA-53052", 4493, 26)+N(25,7));

Delta\_R("KH150639 DRE", rand()\*a,b);

Date("death of KH150639", R\_Date("KH150639 GrM-14455", 4470, 20)+N(20,4));

Delta\_R("KH150640 DRE", rand()\*a,b);

Date("death of KH150640", R\_Date("KH150640 KIA-53053", 4461, 25)+N(25,7));

};

Page( );

Sequence("stratified")

{

Phase("below rubble layer")

{

Delta\_R("KH150615 DRE", rand()\*a,b);

Date("death of KH150615", R\_Date("KH150615 KIA-53046", 4462, 24)+N(0,1));

Delta\_R("KH150620 DRE", rand()\*a,b);

Date("death of KH150620", R\_Date("KH150620 KIA-53047", 4491, 25)+N(0,1));

Delta\_R("KH150622 DRE", rand()\*a,b);

Date("death of KH150622", R\_Date("KH150622 KIA-53048", 4417, 19)+N(1,1));

Delta\_R("KH150623 DRE", rand()\*a,b);

Date("death of KH150623", R\_Date("KH150623 GrM-14444", 4497, 18)+N(2,2));

Delta\_R("KH180045 DRE", rand()\*a,b);

Date("death of KH180045", R\_Date("KH180045 KIA-52750", 4435, 25)+N(5,2));

Delta\_R("KH180044 DRE", rand()\*a,b);

Date("death of KH180044", R\_Date("KH180044 KIA-52751", 4459, 24)+N(25,7));

Delta\_R("KH150635 DRE", rand()\*a,b);

Date("death of KH150635", R\_Date("KH150635 KIA-52280", 4425, 28)+N(25,7));

Delta\_R("KH150288 DRE", rand()\*a,b);

Date("death of KH150288", R\_Date("KH150288 weighted mean", 4514, 22)+N(15,7));

Delta\_R("KH150637 DRE", rand()\*a,b);

Date("death of KH150637", R\_Date("KH150637 KIA-52281", 4432, 28)+N(25,7));

Delta\_R("KH150289 DRE", rand()\*a,b);

Date("death of KH150289", R\_Date("KH150289 weighted mean", 4495, 20)+N(20,7));

Delta\_R("117 DRE", rand()\*a,b);

Date("death of 117", R\_Date("117 weighted mean", 4474, 20)+N(20,7));

};

Boundary("rubble layer");

Phase("above rubble layer")

{

Delta\_R("KH150625 DRE", rand()\*a,b);

Date("death of KH150625", R\_Date("KH150625 KIA-52277", 4497, 27)+N(5,2));

Delta\_R("KH150626 DRE", rand()\*a,b);

Date("death of KH150626", R\_Date("KH150626 GrM-14451", 4540, 20)+N(25,5));

Delta\_R("KH150627 DRE", rand()\*a,b);

Date("death of KH150627", R\_Date("KH150627 KIA-52278", 4462, 27)+N(25,7));

Delta\_R("KH150641 DRE", rand()\*a,b);

Date("death of KH150641", R\_Date("KH150641 KIA-52282", 4473, 28)+N(25,7));

Delta\_R("56 DRE", rand()\*a,b);

Date("death of 56", R\_Date("56 KIA-52755", 4446, 25)+N(15,7));

Delta\_R("82 DRE", rand()\*a,b);

Date("death of 82", R\_Date("82 KIA-52754", 4505, 25)+N(15,7));

Delta\_R("90 DRE", rand()\*a,b);

Date("death of 90", R\_Date("KH150206 KIA-52753", 4509, 25)+N(15,7));

Delta\_R("KH150422 DRE", rand()\*a,b);

Date("death of KH150422", R\_Date("KH150422 KIA-52272", 4538, 24)+N(25,7));

Delta\_R("KH150287 DRE", rand()\*a,b);

Date("death of KH150287", R\_Date("KH150287 KIA-52268", 4499, 25)+N(15,7));

Delta\_R("KH150203 DRE", rand()\*a,b);

Date("death of KH150203", R\_Date("KH150203 weighted mean", 4489, 20)+N(15,7));

Delta\_R("KH150618 DRE", rand()\*a,b);

Date("death of KH150618", R\_Date("KH150618 KIA-52275", 4468, 25)+N(20,4));

Delta\_R("KH150619 DRE", rand()\*a,b);

Date("death of KH150619", R\_Date("KH150619 KIA-52276", 4455, 24)+N(20,4));

Delta\_R("KH150621 DRE", rand()\*a,b);

Date("death of KH150621", R\_Date("KH150621 GrM-14442", 4514, 18)+N(25,5));

Delta\_R("KH150610 DRE", rand()\*a,b);

Date("death of KH150610", R\_Date("KH150610 KIA-52273", 4532, 25)+N(25,7));

Delta\_R("KH150611 DRE", rand()\*a,b);

Date("death of KH150611", R\_Date("KH150611 KIA-53044", 4518, 25)+N(5,3));

Delta\_R("KH150612 DRE", rand()\*a,b);

Date("death of KH150612", R\_Date("KH150612 GrM-14414", 4478, 18)+N(25,7));

};

};

Span("burial duration");

};

Boundary("end burial");

};

Page( );

Date("birth of KH180045", Date("=death of KH180045")-N(25,3));

Page( );

Phase("lcMLkin kinship")

{

Phase("KH150620, KH150622 and KH150623 must be full siblings")

{

Date("=KH150620 KIA-53047");

Date("=KH150622 KIA-53048");

Date("=KH150623 GrM-14444");

Span("difference between KH150620, KH150622 and KH150623", U(0,15));

};

Phase("4th degree between KH150630 and KH150641")

{

Date("=KH150630 KIA-53050");

Date("=KH150641 KIA-52282");

Span("difference between KH150630 and KH150641", U(0,100));

};

Phase("5th degree between KH150630 and KH180045")

{

Date("=KH150630 KIA-53050");

Date("=birth of KH180045");

Span("difference between KH150630 and KH180045", U(0,120));

};

Phase("5th degree between KH150629 and KH180045")

{

Date("=KH150629 GrM-14807");

Date("=birth of KH180045");

Span("difference between KH150629 and KH180045", U(0,120));

};

Phase("3rd degree between KH150640 and KH180045")

{

Date("=KH150640 KIA-53053");

Date("=birth of KH180045");

Span("difference between KH150640 and KH180045", U(0,80));

};

Phase("5th degree between KH150640 and KH180044")

{

Date("=KH150640 KIA-53053");

Date("=KH180044 KIA-52751");

Span("difference between KH150640 and KH180044", U(0,120));

};

Phase("5th degree between KH150610 and KH180044")

{

Date("=KH150610 KIA-52273");

Date("=KH180044 KIA-52751");

Span("difference between KH150610 and KH180044", U(0,120));

};

Phase("5th degree between KH150612 and KH180044")

{

Date("=KH150612 GrM-14414");

Date("=KH180044 KIA-52751");

Span("difference between KH150612 and KH180044", U(0,120));

};

Phase("5th degree between KH150637 and KH180044")

{

Date("=KH150637 KIA-52281");

Date("=KH180044 KIA-52751");

Span("difference between KH150637 and KH180044", U(0,120));

};

Phase("5th degree between KH150637 and KH150627")

{

Date("=KH150637 KIA-52281");

Date("=KH150627 KIA-52278");

Span("difference between KH150637 and KH150627", U(0,120));

};

Phase("5th degree between KH150612 and KH150627")

{

Date("=KH150612 GrM-14414");

Date("=KH150627 KIA-52278");

Span("difference between KH150612 and KH150627", U(0,120));

};

Phase("5th degree between KH150619 and KH150627")

{

Date("=KH150619 KIA-52276");

Date("=KH150627 KIA-52278");

Span("difference between KH150619 and KH150627", U(0,120));

};

};

};

### Simulation of preferred model at different calendar dates

Calendar dates of samples shown below (Table S1, preferred model output simulation) are based on randomly sampling the 1-sigma range of the posterior distribution of each date of death given by the preferred model. Simply simulating a 14C age for the median posterior date of each sample would have generated too many burial dates towards the center of the overall date range, particularly for unstratified samples. This is intended to check the reproducibility of the model, after allowing for potential stochastic variation in 14C ages, i.e. to test whether enough samples have been dated for the model output to be robust, given the typical 14C measurement errors reported (here ±24) and the shape of the calibration curve around 3200 BC.

In other versions of the simulation, the same calendar dates were shifted 50 years earlier, and 50, 500 and 2000 years later, in order to simulate the same model both elsewhere on the late 4th millennium calibration plateau, and on apparently more favorable sections of the calibration curve.

To simulate a longer chronology, the 1-sigma range used to generate each randomized calendar date was shifted away from the median burial date in the preferred model (3212 BC) by the difference between 3212 BC and the mean of the posterior estimated date of that burial in the preferred model, so that the randomized calendar dates spanned a wider range (in this example 156 years, vs 101 years for simulated dates for the preferred model).

Table S1. Example of randomized calendar dates of samples used in simulation exercises. Negative values indicate years BC.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| sample | mean of posterior estimate in preferred model | 1-sigma | preferred model output simulation | preferred model shifted 50y earlier | preferred model shifted 50y later | preferred model output 500y later | preferred model output 2000y later | preferred model stretched |
| 56 | -3205 | 31 | -3178 | -3228 | -3128 | -2678 | -1178 | -3225 |
| 82 | -3194 | 27 | -3195 | -3245 | -3145 | -2695 | -1195 | -3155 |
| 90 | -3193 | 27 | -3178 | -3228 | -3128 | -2678 | -1178 | -3160 |
| KH150203 | -3198 | 29 | -3210 | -3260 | -3160 | -2710 | -1210 | -3185 |
| KH150287 | -3195 | 28 | -3222 | -3272 | -3172 | -2722 | -1222 | -3182 |
| KH150422 | -3186 | 24 | -3179 | -3229 | -3129 | -2679 | -1179 | -3177 |
| KH150610 | -3188 | 23 | -3179 | -3229 | -3129 | -2679 | -1179 | -3150 |
| KH150611 | -3194 | 26 | -3194 | -3244 | -3144 | -2694 | -1194 | -3151 |
| KH150612 | -3203 | 26 | -3222 | -3272 | -3172 | -2722 | -1222 | -3172 |
| KH150618 | -3202 | 29 | -3184 | -3234 | -3134 | -2684 | -1184 | -3204 |
| KH150619 | -3206 | 29 | -3232 | -3282 | -3182 | -2732 | -1232 | -3226 |
| KH150621 | -3189 | 25 | -3165 | -3215 | -3115 | -2665 | -1165 | -3162 |
| KH150625 | -3196 | 28 | -3174 | -3224 | -3124 | -2674 | -1174 | -3163 |
| KH150626 | -3183 | 22 | -3164 | -3214 | -3114 | -2664 | -1164 | -3168 |
| KH150627 | -3204 | 26 | -3208 | -3258 | -3158 | -2708 | -1208 | -3174 |
| KH150641 | -3200 | 28 | -3227 | -3277 | -3177 | -2727 | -1227 | -3178 |
| 117 | -3251 | 18 | -3251 | -3301 | -3201 | -2751 | -1251 | -3280 |
| KH150288 | -3252 | 19 | -3233 | -3283 | -3183 | -2733 | -1233 | -3297 |
| KH150289 | -3252 | 18 | -3265 | -3315 | -3215 | -2765 | -1265 | -3286 |
| KH150615 | -3252 | 17 | -3260 | -3310 | -3210 | -2760 | -1260 | -3278 |
| KH150620 | -3253 | 15 | -3257 | -3307 | -3207 | -2757 | -1257 | -3288 |
| KH150623 | -3251 | 16 | -3245 | -3295 | -3195 | -2745 | -1245 | -3306 |
| KH150635 | -3248 | 18 | -3260 | -3310 | -3210 | -2760 | -1260 | -3270 |
| KH150637 | -3248 | 18 | -3246 | -3296 | -3196 | -2746 | -1246 | -3290 |
| KH180044 | -3249 | 18 | -3240 | -3290 | -3190 | -2740 | -1240 | -3284 |
| KH180045 | -3248 | 16 | -3238 | -3288 | -3188 | -2738 | -1238 | -3281 |
| KH150613 | -3215 | 37 | -3229 | -3279 | -3179 | -2729 | -1229 | -3245 |
| KH150616 | -3218 | 37 | -3188 | -3238 | -3138 | -2688 | -1188 | -3242 |
| KH150617 | -3198 | 36 | -3206 | -3256 | -3156 | -2706 | -1206 | -3220 |
| KH150622 | -3253 | 12 | -3247 | -3297 | -3197 | -2747 | -1247 | -3301 |
| KH150624 | -3208 | 38 | -3208 | -3258 | -3158 | -2708 | -1208 | -3189 |
| KH150628 | -3228 | 30 | -3252 | -3302 | -3202 | -2752 | -1252 | -3244 |
| KH150629 | -3213 | 38 | -3220 | -3270 | -3170 | -2720 | -1220 | -3230 |
| KH150630 | -3195 | 22 | -3191 | -3241 | -3141 | -2691 | -1191 | -3164 |
| KH150631 | -3221 | 36 | -3242 | -3292 | -3192 | -2742 | -1242 | -3220 |
| KH150633 | -3219 | 37 | -3219 | -3269 | -3169 | -2719 | -1219 | -3227 |
| KH150634 | -3211 | 38 | -3238 | -3288 | -3188 | -2738 | -1238 | -3239 |
| KH150636 | -3217 | 37 | -3181 | -3231 | -3131 | -2681 | -1181 | -3243 |
| KH150639 | -3228 | 33 | -3215 | -3265 | -3165 | -2715 | -1215 | -3213 |
| KH150640 | -3232 | 26 | -3238 | -3288 | -3188 | -2738 | -1238 | -3230 |

Plot()

{

Sequence("Niedertiefenbach simulated chronology")

{

Boundary("start burial");

Phase("all burials")

{

Phase("no layer")

{

R\_Simulate("KH150613",-3229,24);

R\_Simulate("KH150616",-3188,24);

R\_Simulate("KH150617",-3206,24);

R\_Simulate("KH150624",-3208,24);

R\_Simulate("KH150628",-3252,24);

R\_Simulate("KH150629",-3220,24);

R\_Simulate("KH150630",-3191,24);

R\_Simulate("KH150631",-3242,24);

R\_Simulate("KH150633",-3219,24);

R\_Simulate("KH150634",-3238,24);

R\_Simulate("KH150636",-3181,24);

R\_Simulate("KH150639",-3215,24);

R\_Simulate("KH150640",-3238,24);

};

Sequence("stratified")

{

Phase("below rubble layer")

{

R\_Simulate("117",-3251,24);

R\_Simulate("KH150288",-3233,24);

R\_Simulate("KH150289",-3265,24);

R\_Simulate("KH150615",-3260,24);

R\_Simulate("KH150620",-3257,24);

R\_Simulate("KH150622",-3247,24);

R\_Simulate("KH150623",-3245,24);

R\_Simulate("KH150635",-3260,24);

R\_Simulate("KH150637",-3246,24);

R\_Simulate("KH180044",-3240,24);

R\_Simulate("KH180045",-3238,24);

};

Boundary("rubble layer");

Phase("above rubble layer")

{

R\_Simulate("56",-3178,24);

R\_Simulate("82",-3195,24);

R\_Simulate("90",-3178,24);

R\_Simulate("KH150203",-3210,24);

R\_Simulate("KH150287",-3222,24);

R\_Simulate("KH150422",-3179,24);

R\_Simulate("KH150610",-3179,24);

R\_Simulate("KH150611",-3194,24);

R\_Simulate("KH150612",-3222,24);

R\_Simulate("KH150618",-3184,24);

R\_Simulate("KH150619",-3232,24);

R\_Simulate("KH150621",-3165,24);

R\_Simulate("KH150625",-3174,24);

R\_Simulate("KH150626",-3164,24);

R\_Simulate("KH150627",-3208,24);

R\_Simulate("KH150641",-3227,24);

};

};

Span("burial duration");

};

Boundary("end burial");

};

Phase("lcMLkin kinship")

{

Phase("KH150620, KH150622 and KH150623 must be full siblings")

{

Date("=KH150620");

Date("=KH150622");

Date("=KH150623");

Span("difference between KH150620, KH150622 and KH150623", U(0,15));

};

Phase("4th degree between KH150630 and KH150641")

{

Date("=KH150630");

Date("=KH150641");

Span("difference between KH150630 and KH150641", U(0,100));

};

Phase("5th degree between KH150630 and KH180045")

{

Date("=KH150630");

Date("=KH180045");

Span("difference between KH150630 and KH180045", U(0,120));

};

Phase("5th degree between KH150629 and KH180045")

{

Date("=KH150629");

Date("=KH180045");

Span("difference between KH150629 and KH180045", U(0,120));

};

Phase("3rd degree between KH150640 and KH180045")

{

Date("=KH150640");

Date("=KH180045");

Span("difference between KH150640 and KH180045", U(0,80));

};

Phase("5th degree between KH150640 and KH180044")

{

Date("=KH150640");

Date("=KH180044");

Span("difference between KH150640 and KH180044", U(0,120));

};

Phase("5th degree between KH150610 and KH180044")

{

Date("=KH150610");

Date("=KH180044");

Span("difference between KH150610 and KH180044", U(0,120));

};

Phase("5th degree between KH150612 and KH180044")

{

Date("=KH150612");

Date("=KH180044");

Span("difference between KH150612 and KH180044", U(0,120));

};

Phase("5th degree between KH150637 and KH180044")

{

Date("=KH150637");

Date("=KH180044");

Span("difference between KH150637 and KH180044", U(0,120));

};

Phase("5th degree between KH150637 and KH150627")

{

Date("=KH150637");

Date("=KH150627");

Span("difference between KH150637 and KH150627", U(0,120));

};

Phase("5th degree between KH150612 and KH150627")

{

Date("=KH150612");

Date("=KH150627");

Span("difference between KH150612 and KH150627", U(0,120));

};

Phase("5th degree between KH150619 and KH150627")

{

Date("=KH150619");

Date("=KH150627");

Span("difference between KH150619 and KH150627", U(0,120));

};

};

};

# References

Bronk Ramsey C. 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51(1):337-60.

Bronk Ramsey C. 2017. Methods for summarizing radiocarbon datasets. Radiocarbon 59(6):1809-33.