Automatic Matching of Scans from Hamby Sets

Friends, False Friends and Clones

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An Investigation …
- the statistical way

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Outline

- ★ Matching bullets - very brief overview of the algorithm: *getting RF scores*
- ★ Applications for quantifying identifications: *using RF scores*
- ★ Scores as a diagnostics tool: *mis(?)using RF scores*

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Hamby Sets

- ★ in collaboration with: St Louis PD, DCI Ankeny, Jim Hamby, Paul Murphy, NIST NBTRD
- ★ Hamby Sets 10, 36, 44, 173, 224, 252
- ★ Hamby Clones 159
- ★ Hamby Clone Test Set 224
- ★ each set consists of
  - ★ 20 known bullets (2 from each of ten consecutively manufactured P-85 barrels)
  - ★ 15 questioned bullets

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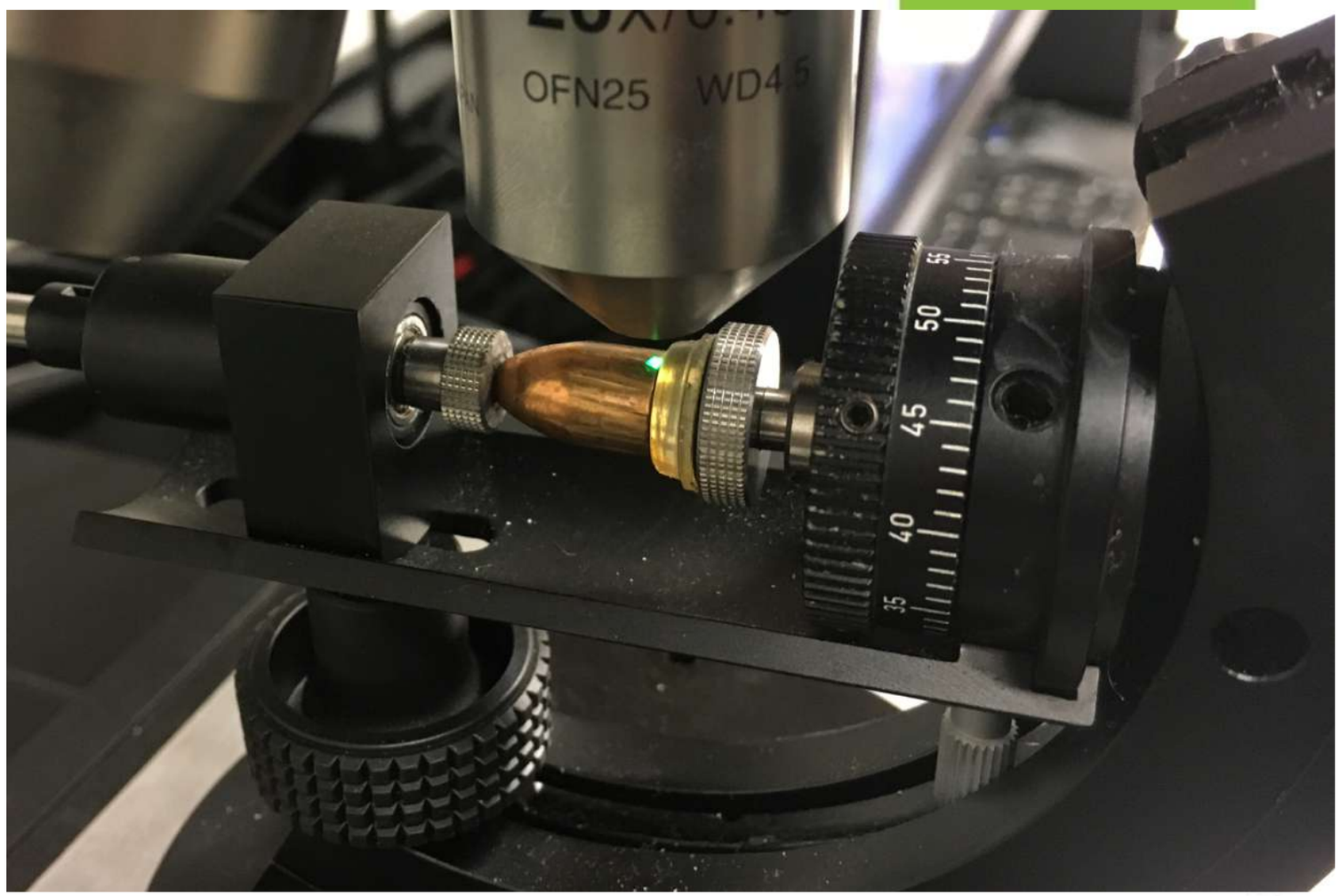
Data: Microscope Facility

Roy J. Carver High Resolution Microscopy Facility

Two Sensofar Confocal Light Microscopes

Six undergraduates scanning bullet lands

3d topographic images: height measurements on x-y grid



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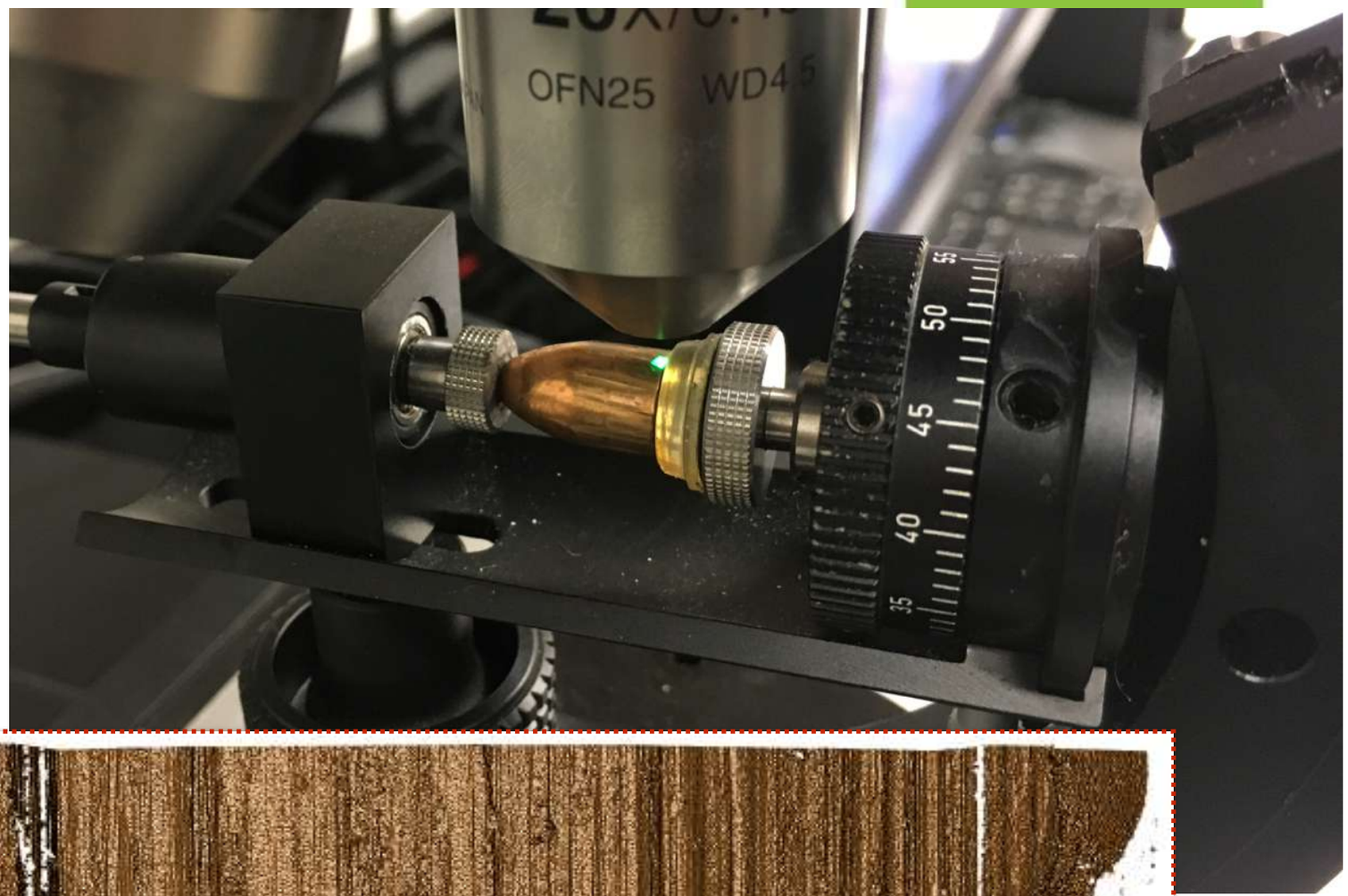

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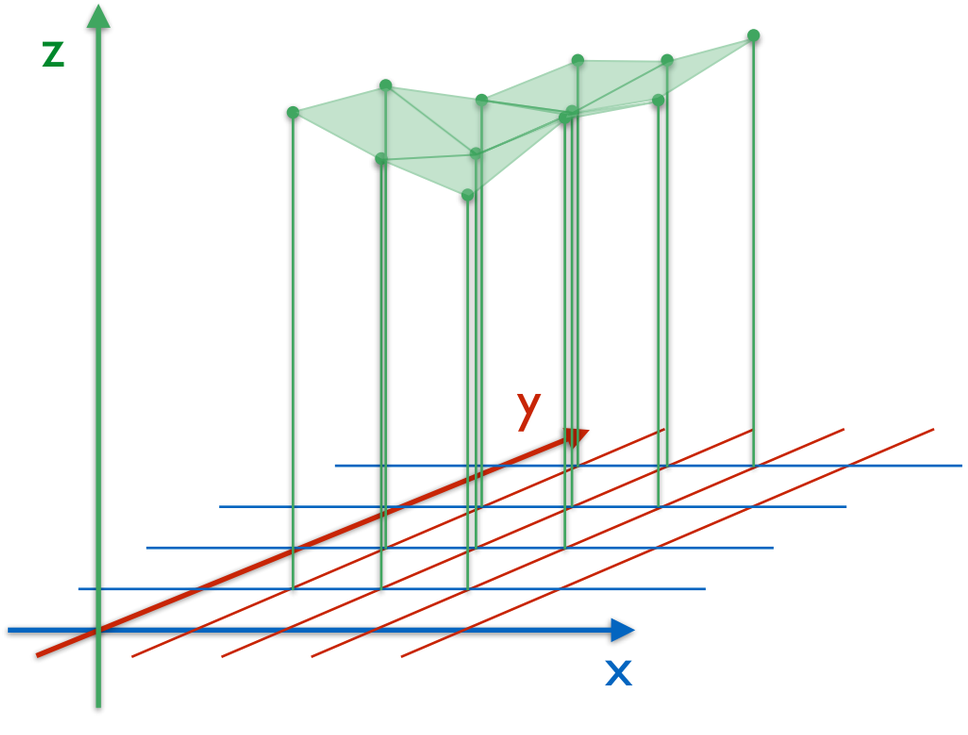
Data from CL Microscope

x-y-z files

Data captured on a regular grid of 0.645 *μm* x 0.645 *μm*

Total captured area for each land ~ *2.2 mm x 0.6 mm*



x - y - z file

x	y	z
18.705	0.000	-25.221138
19.350	0.000	-25.253155
19.995	0.000	-25.335022
20.640	0.000	-25.418171
21.285	0.000	-25.477917
21.930	0.000	-25.541687
22.575	0.000	-25.673903
23.220	0.000	-25.966341
23.865	0.000	-40.070286
24.510	0.000	-40.407612
25.155	0.000	-40.587063
25.800	0.000	-33.437973
26.445	0.000	-33.691895
27.090	0.000	-39.690674
27.735	0.000	-40.317741
.	.	.
.	.	.
.	.	.

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Automatic matching score

Step 1: identify region suitable for matching

land from bullet fired from Smith & Wesson

Region close to heel of bullet

Avoid break-off

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Automatic matching score

Step 1b: from scan to crosscut

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Automatic matching score

Step 1b: from scan to crosscut

Identify matching region

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Automatic matching score

Step 1b: from scan to crosscut

Identify matching region

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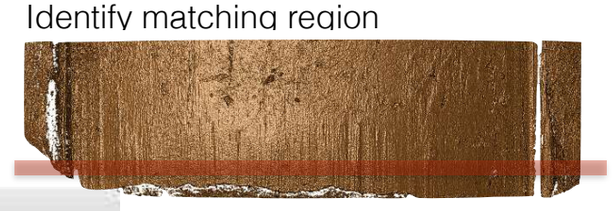
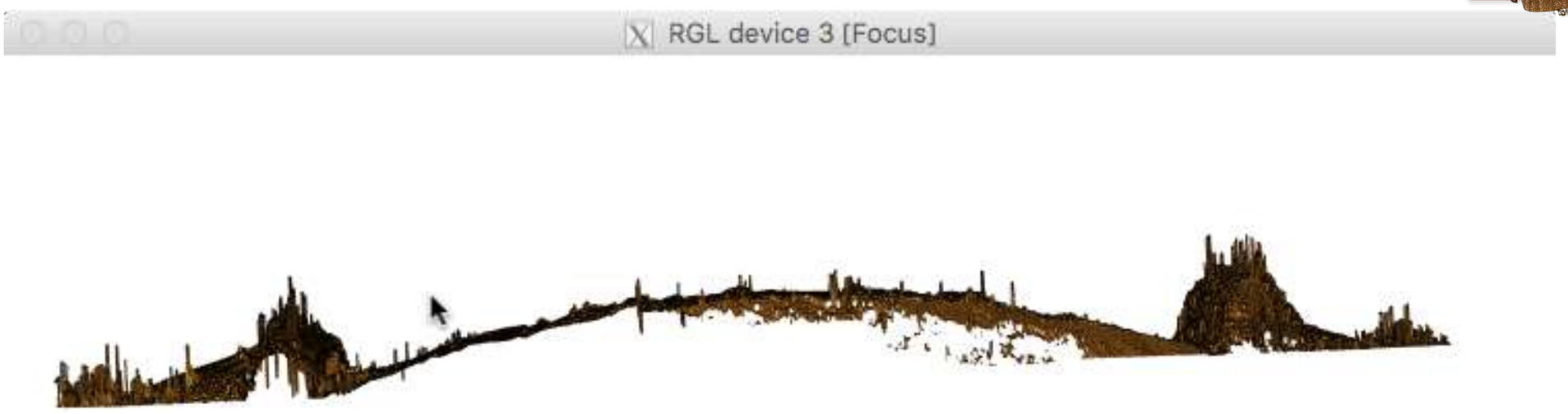
Automatic matching score

Step 1b: from scan to crosscut





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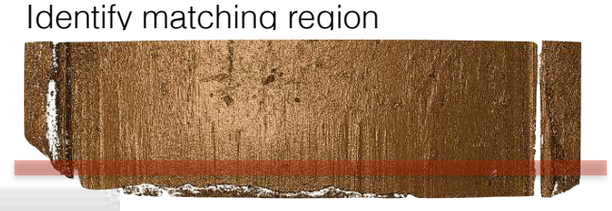
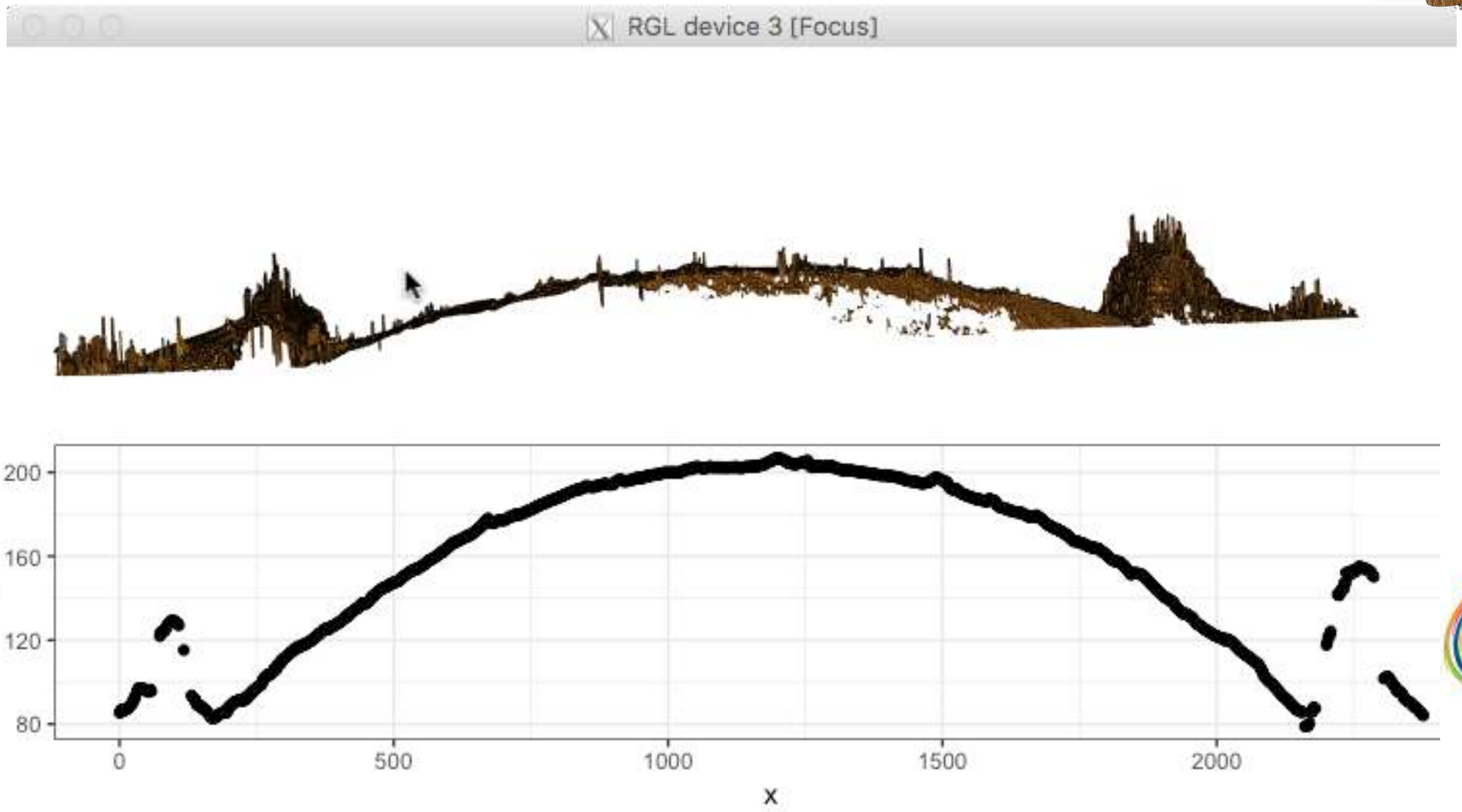
Automatic matching score

Step 1b: from scan to crosscut





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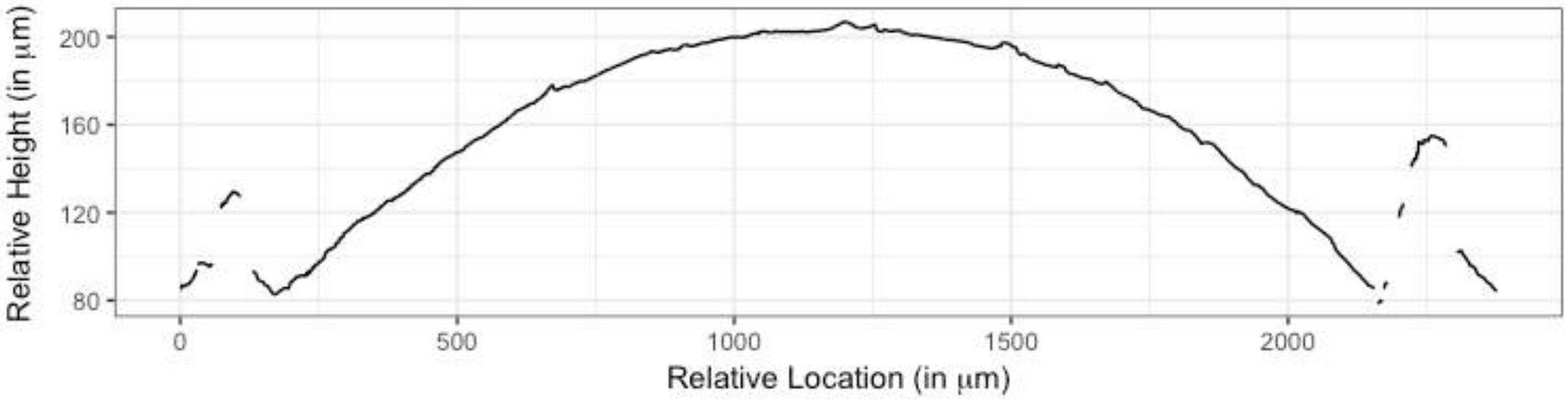
Automatic matching score

Step 2: Identify groove locations

Identify matching region



Shoulders (locations outside the grooves) are removed

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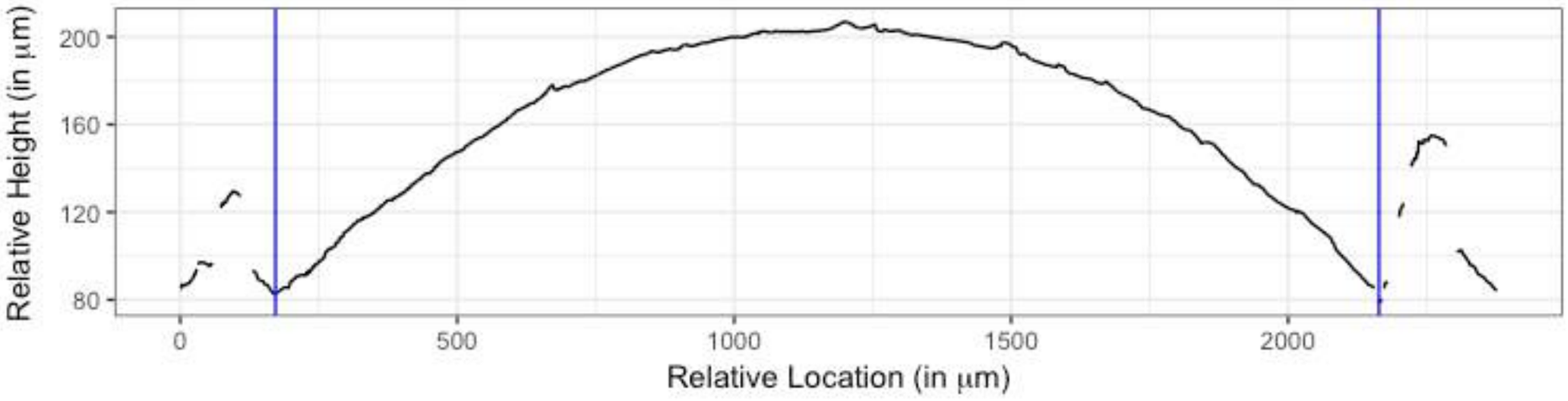
Automatic matching score

Step 2: Identify groove locations

Identify matching region



Shoulders (locations outside the grooves) are removed

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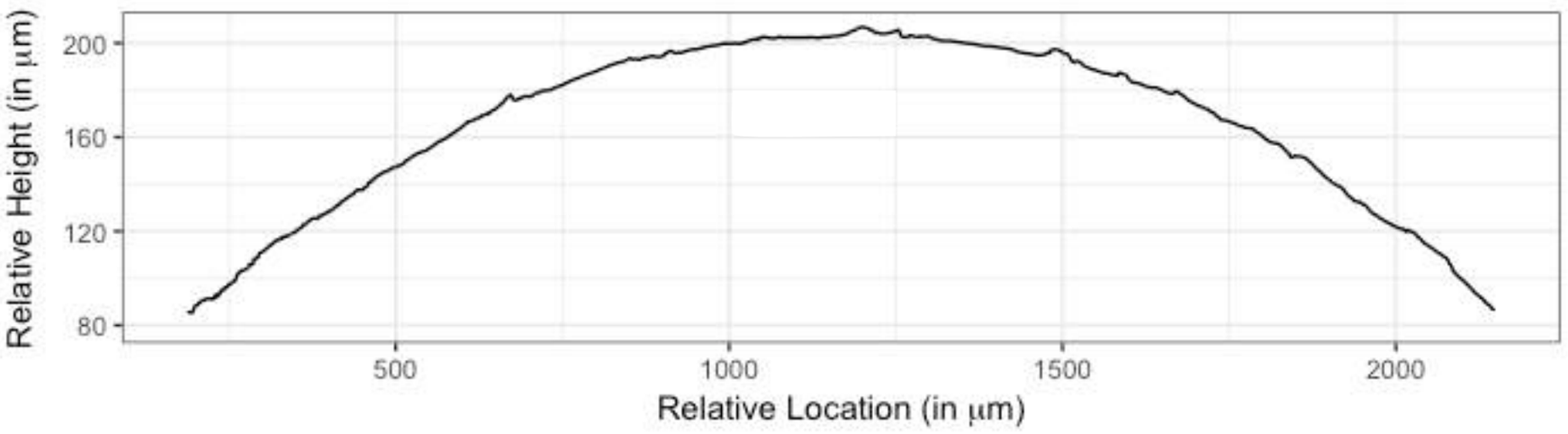
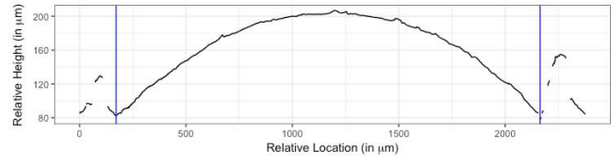
Automatic matching score

Step 3: Fit curvature



Identify matching region

Identify groove locations



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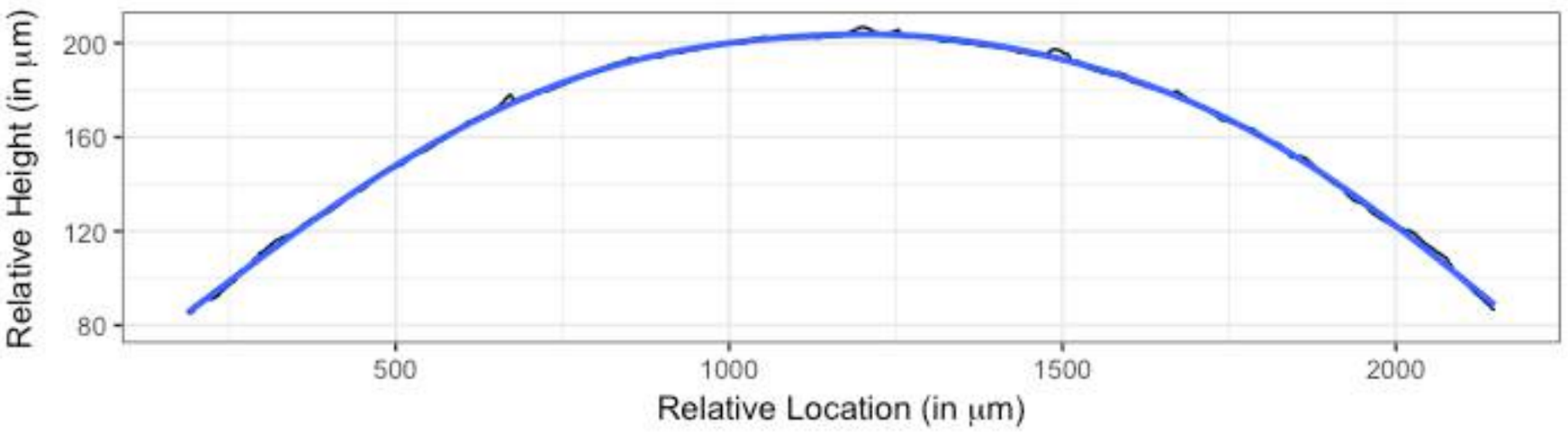
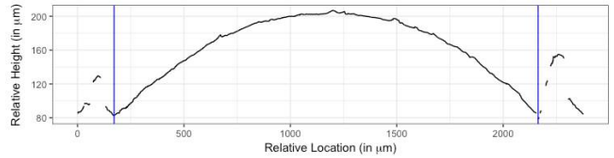
Automatic matching score

Step 3: Fit curvature



Identify matching region

Identify groove locations



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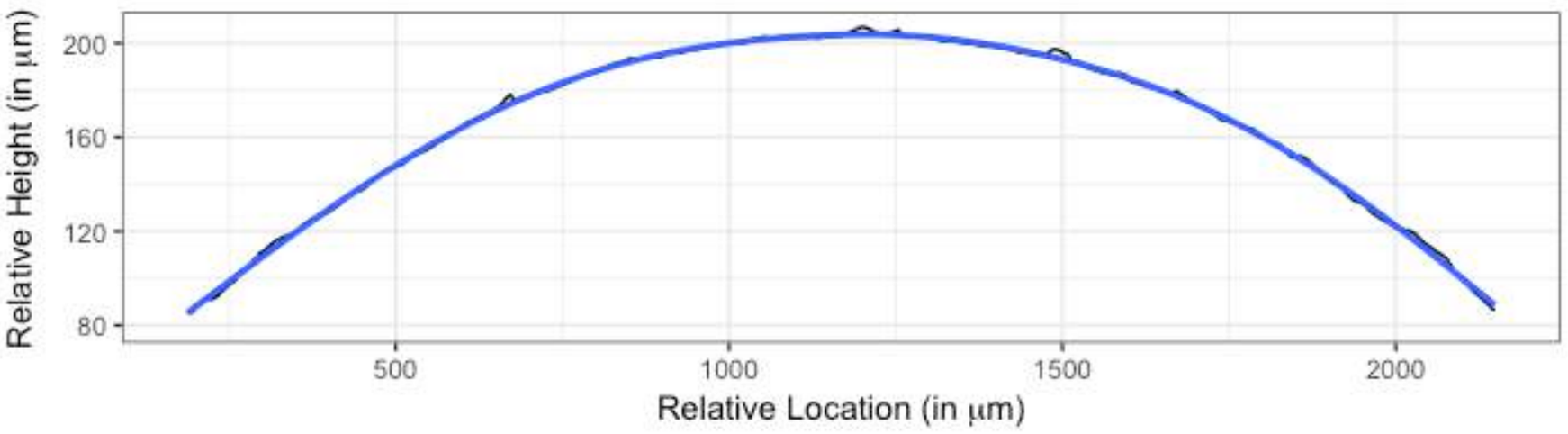
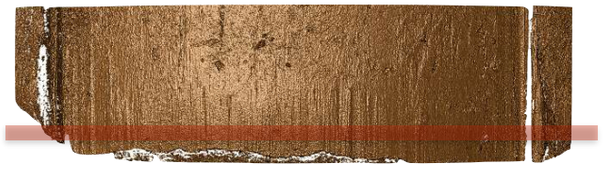
Automatic matching score

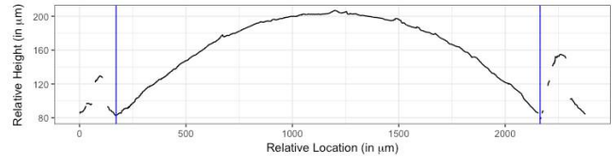
Step 3: Fit curvature & get signature



Identify matching region



Identify groove locations



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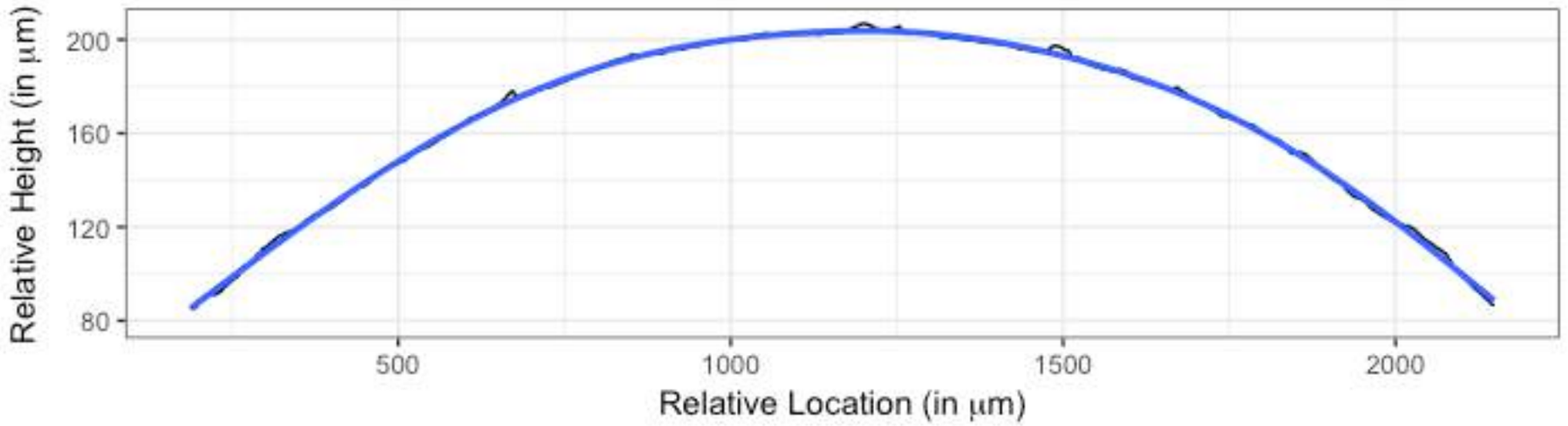
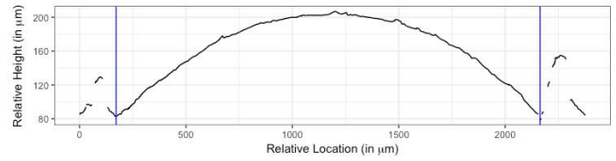
Automatic matching score

Step 3: Fit curvature & get signature



Identify matching region

Identify groove locations



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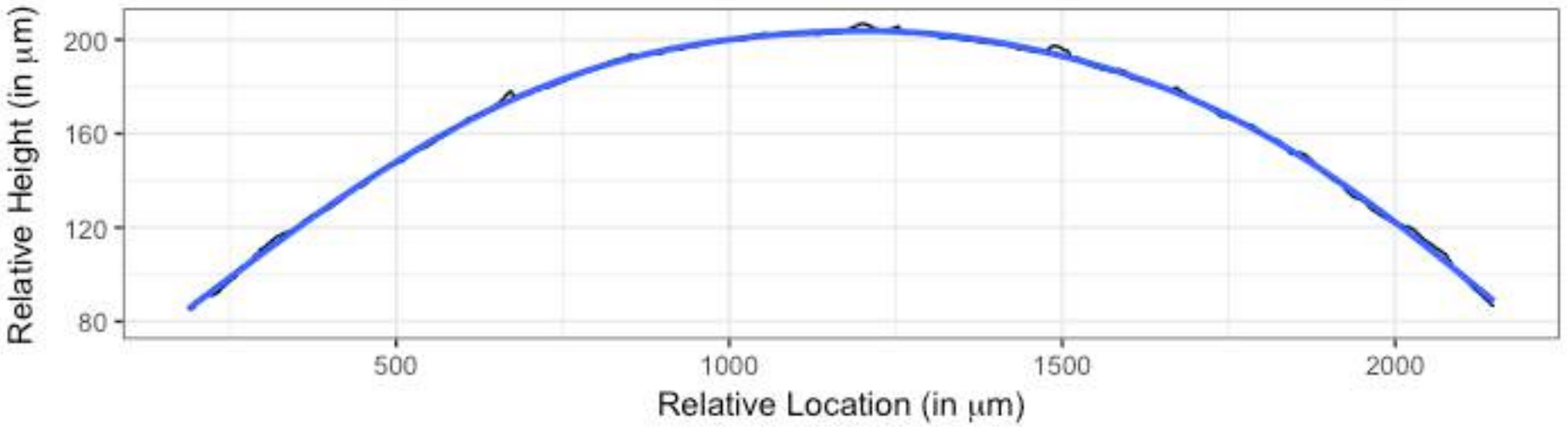
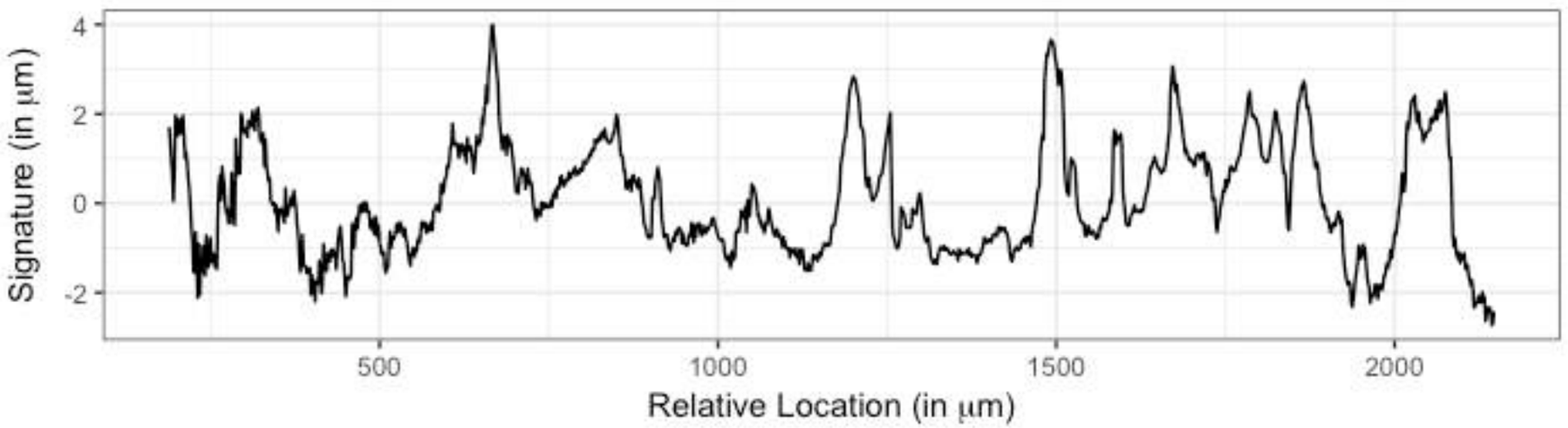
Automatic matching score

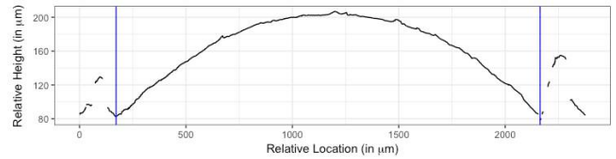
Step 3: Fit curvature & get signature





Identify matching region

Identify groove locations



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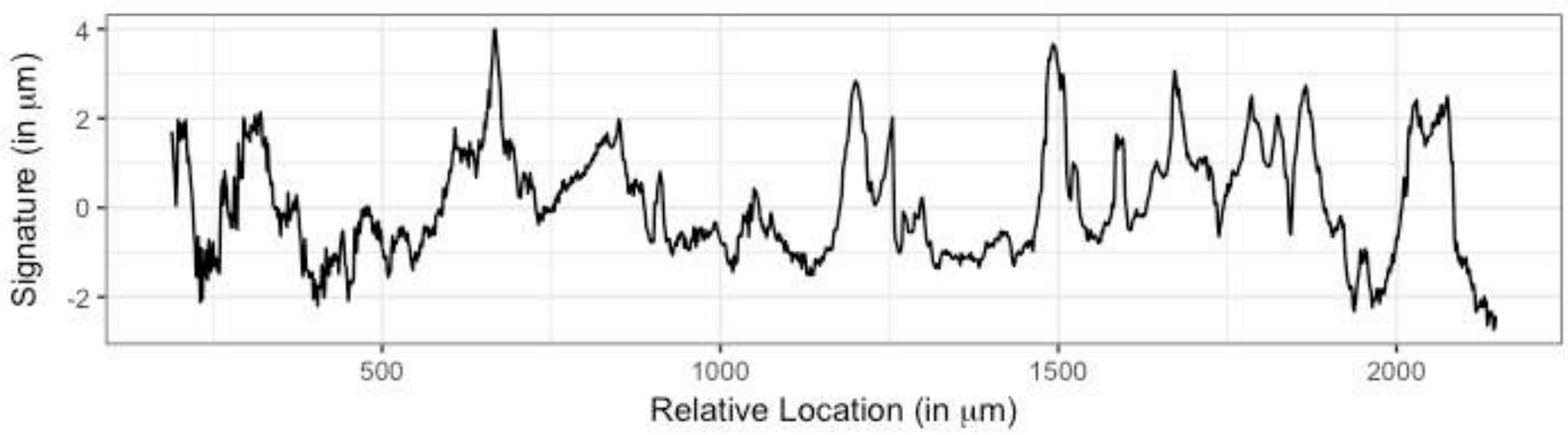
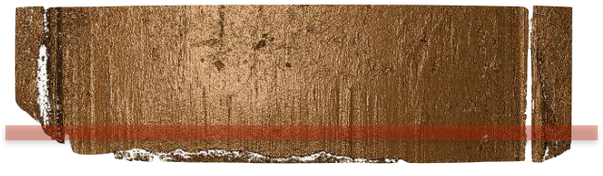
Automatic matching score

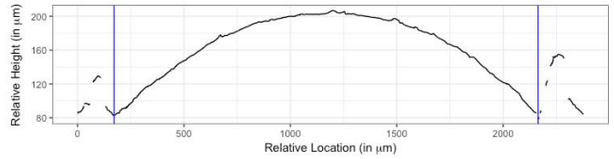
Step 4: Align signatures



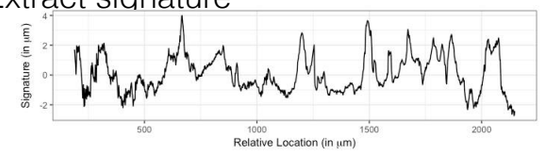
Identify matching region



Identify groove locations



Extract signature



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Automatic matching score

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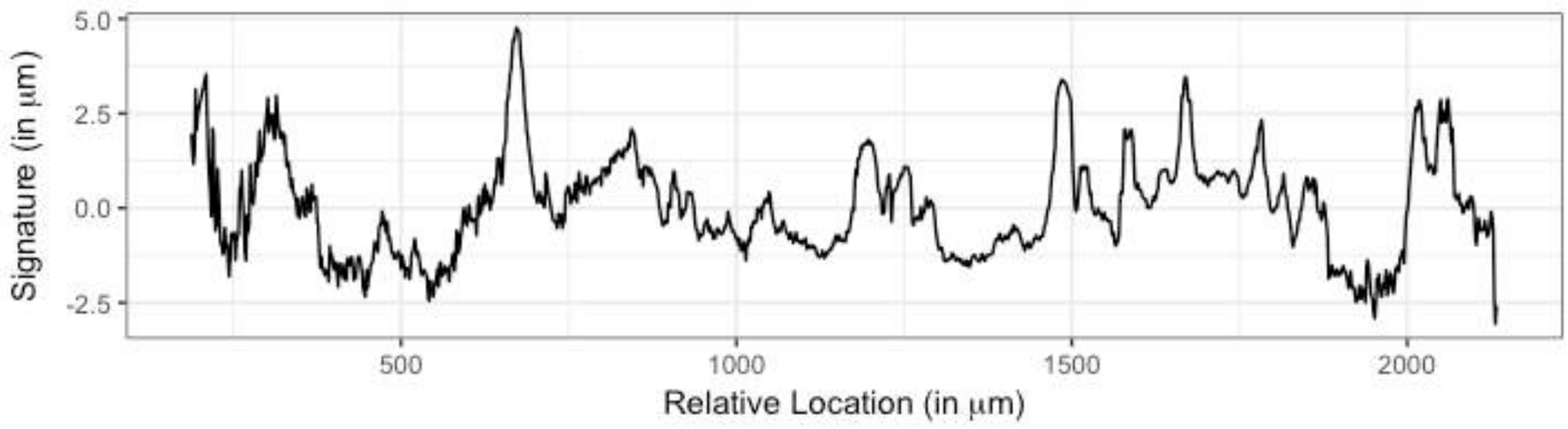
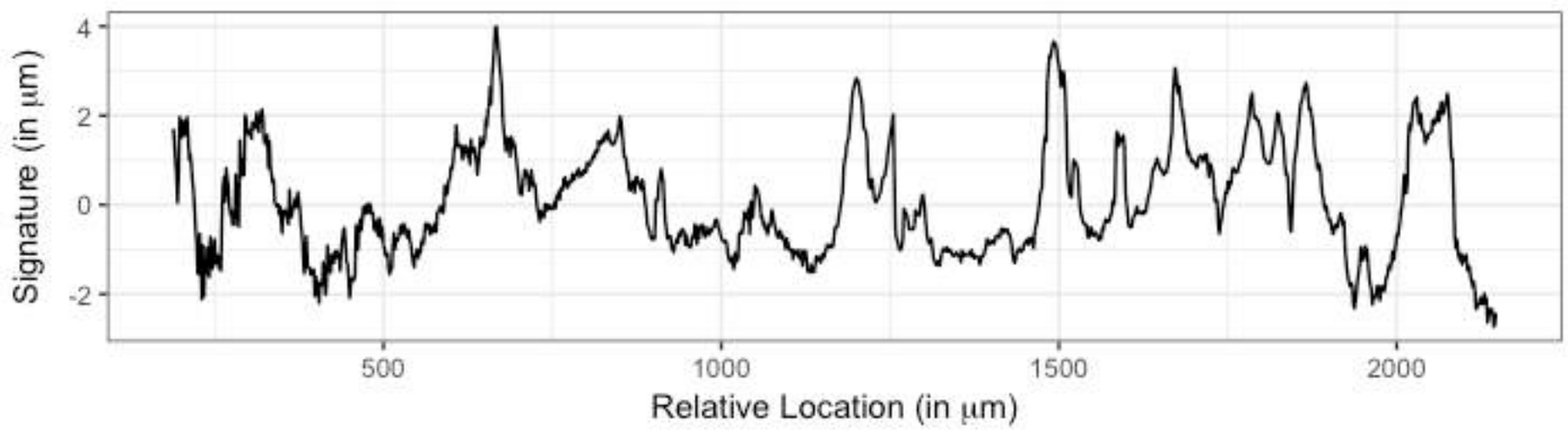
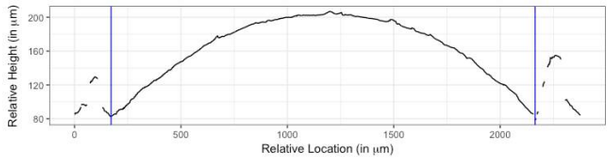


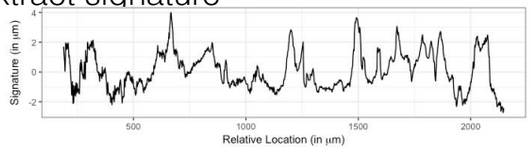


Identify matching region

Identify groove locations



Extract signature



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Automatic matching score

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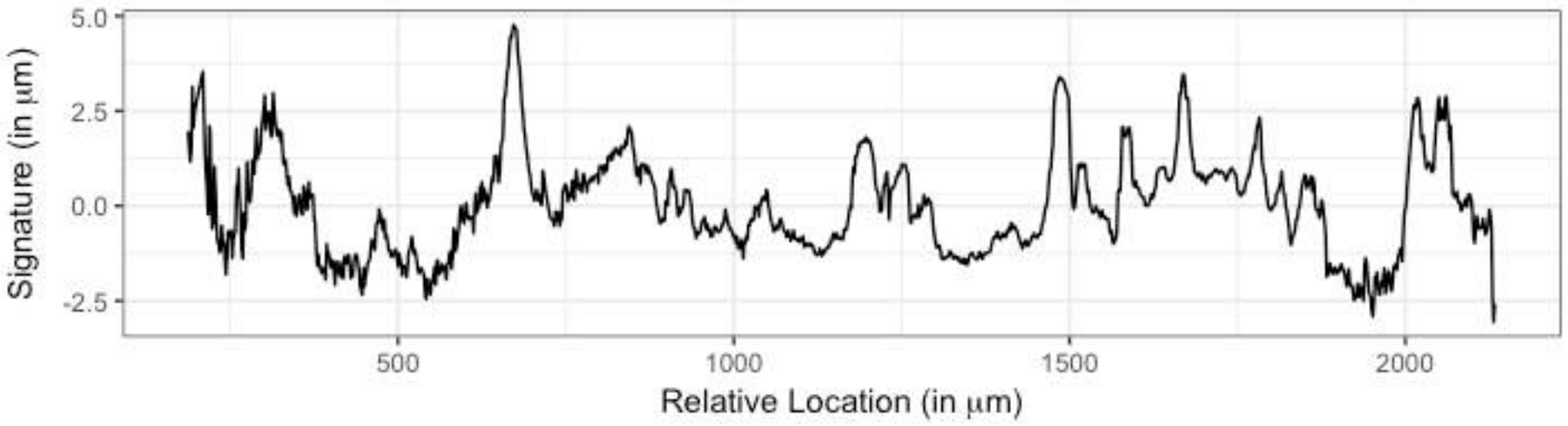
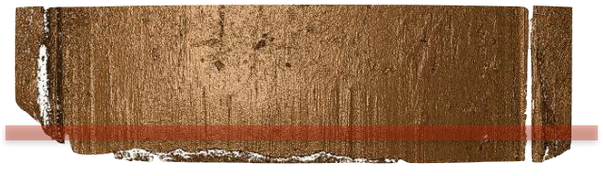
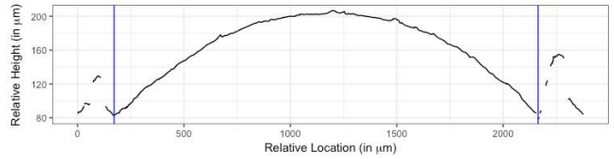


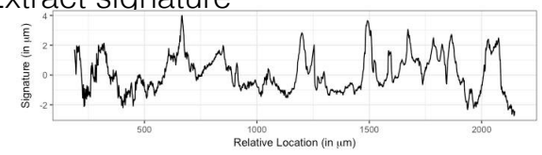
Identify matching region



Identify groove locations



Extract signature



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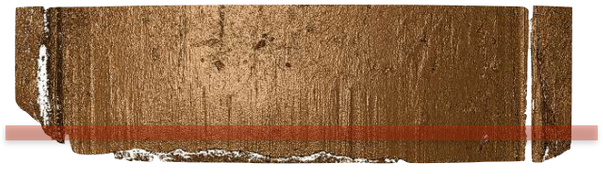
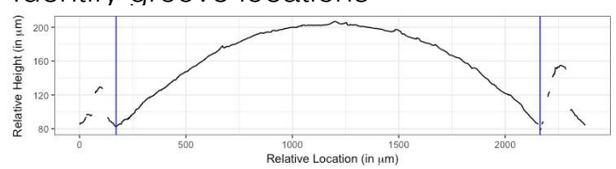
Automatic matching score

Step 4: Align signatures

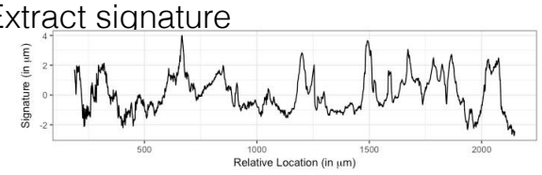
Identify matching region



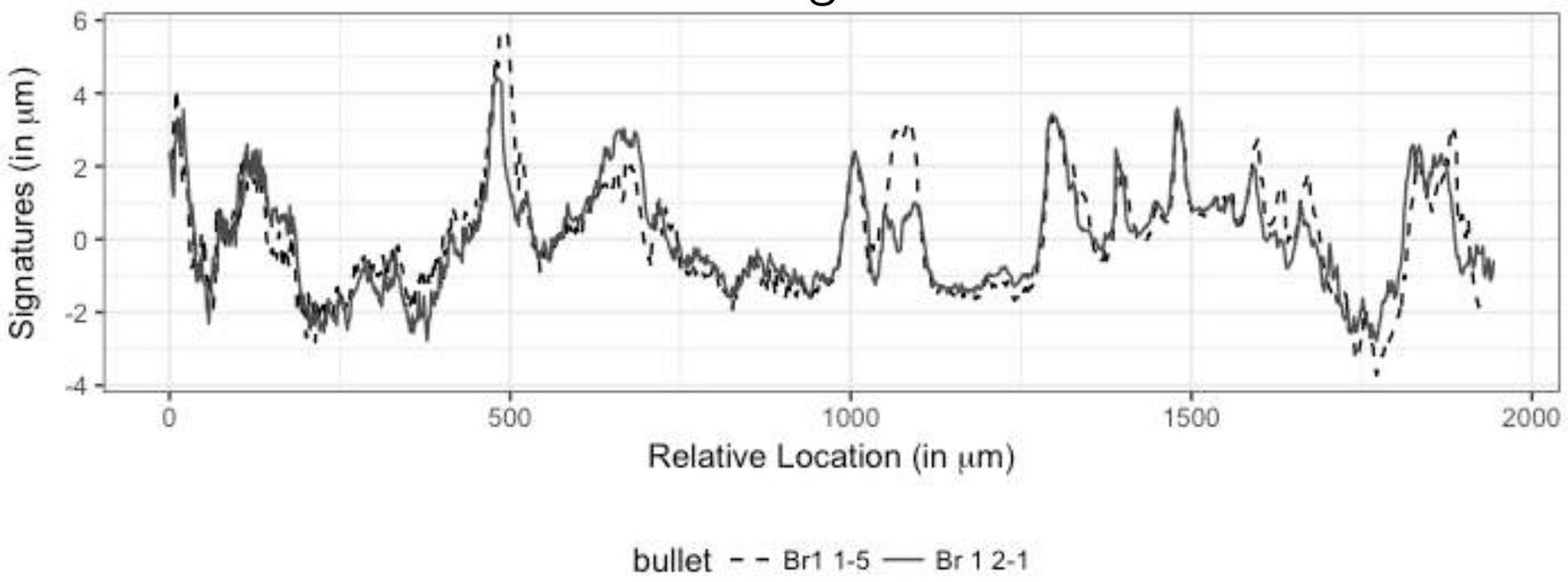
Identify groove locations



Extract signature



Horizontal shifts to find best alignment



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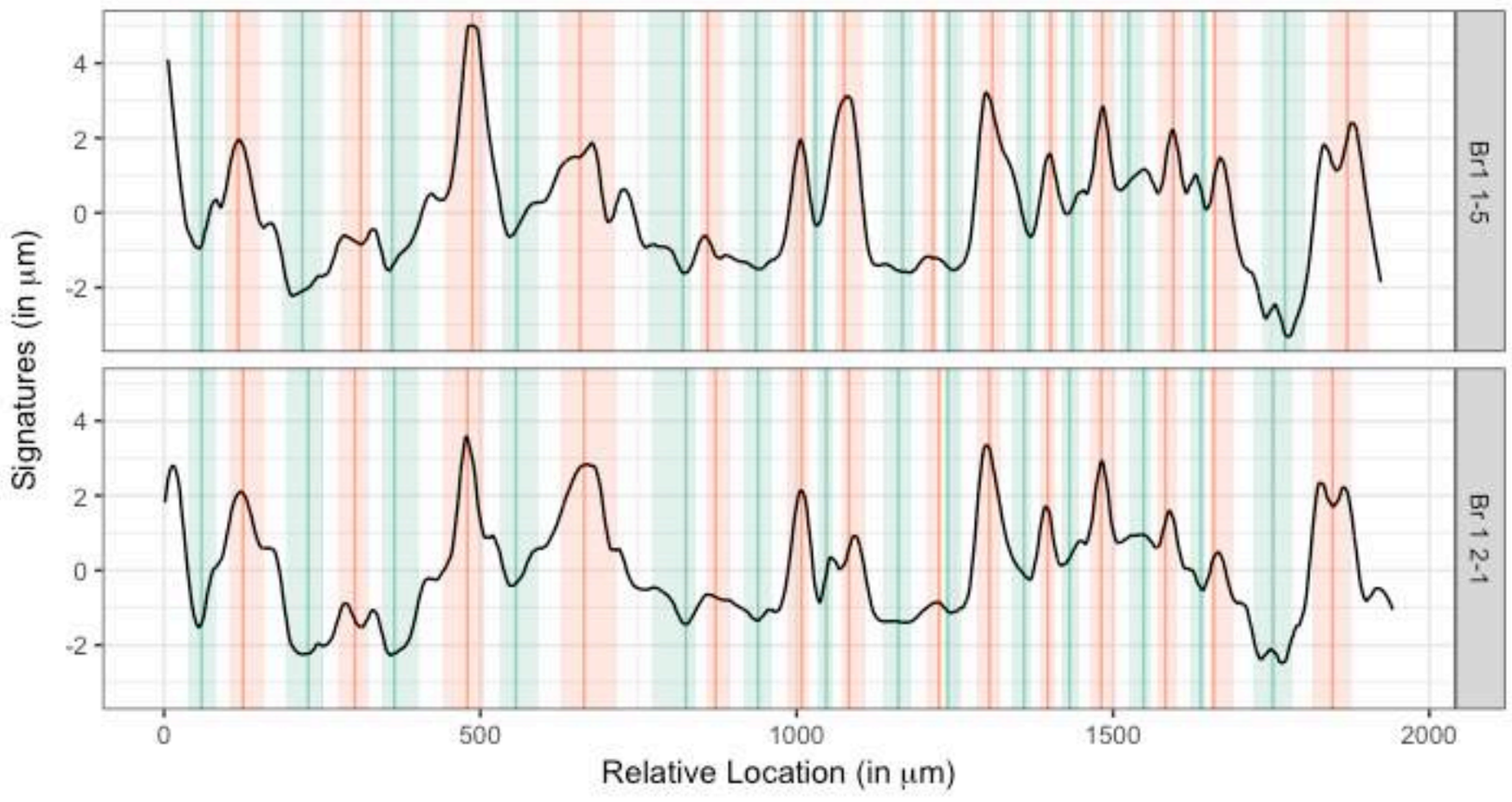
Automatic matching score

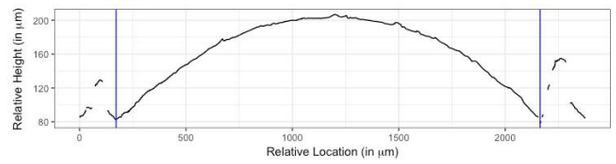
Step 5: Identify Peaks & Valleys

Peaks and valleys in the same locations of two lands are matching striae on the scans

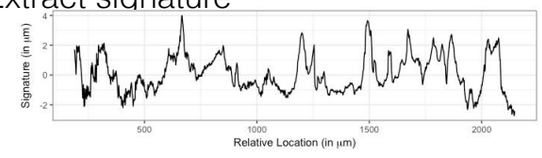


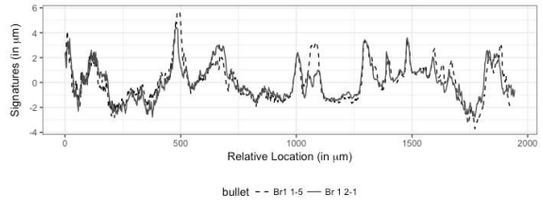
Identify matching region

Identify groove locations



Extract signature

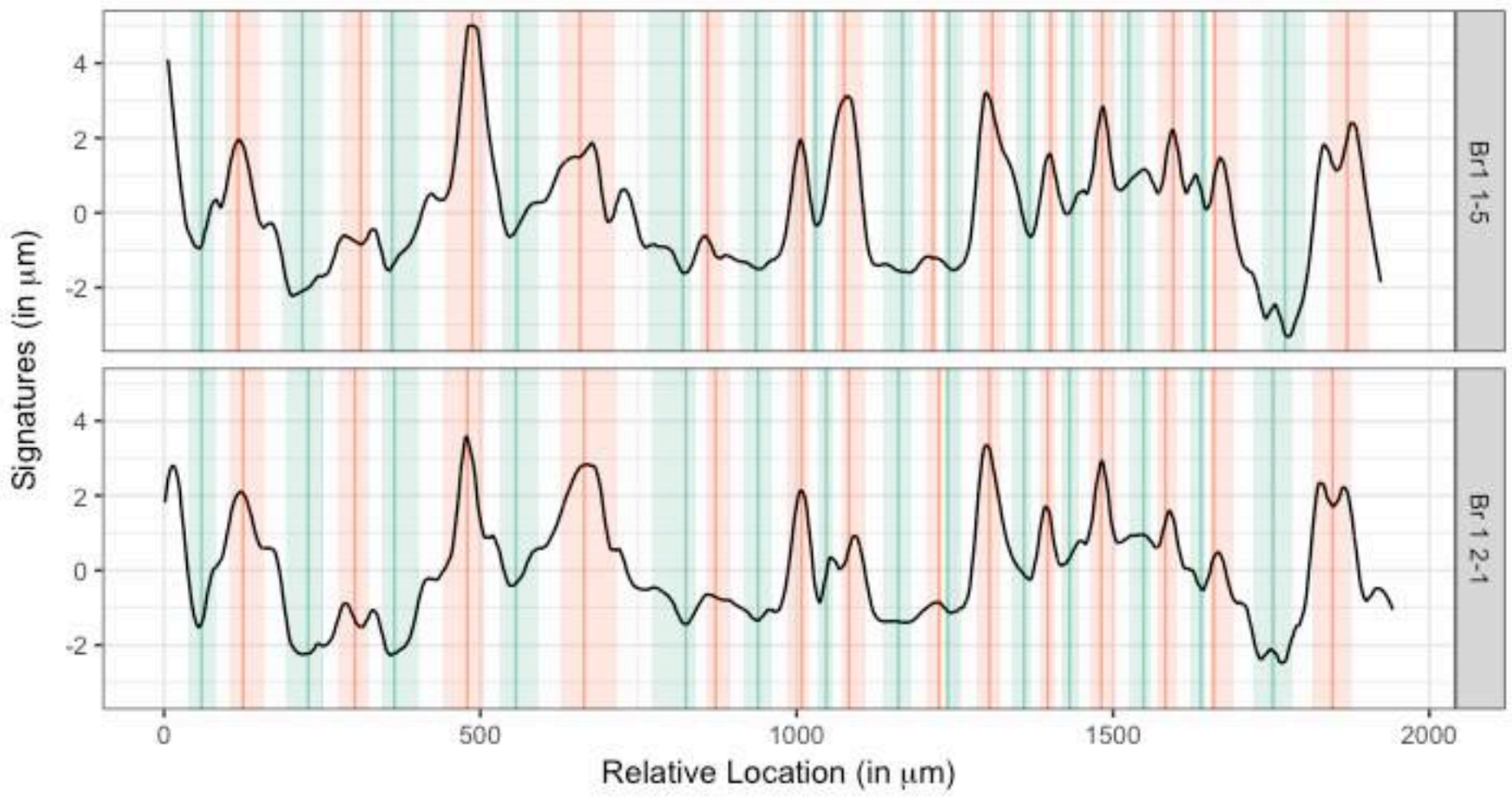




Automatic matching score

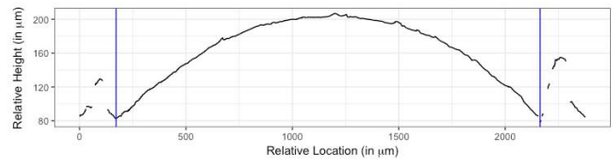
Step 6: Extract features

Feature should distinguish between a match and a non-match

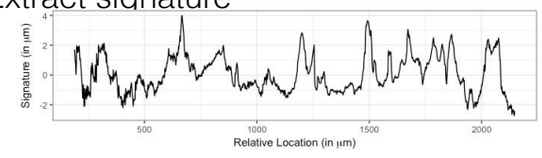


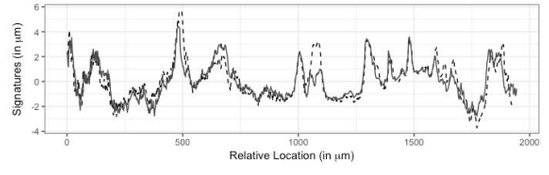
Identify matching region

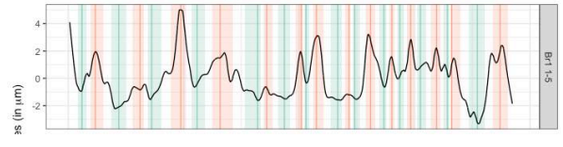
Identify groove locations



Extract signature





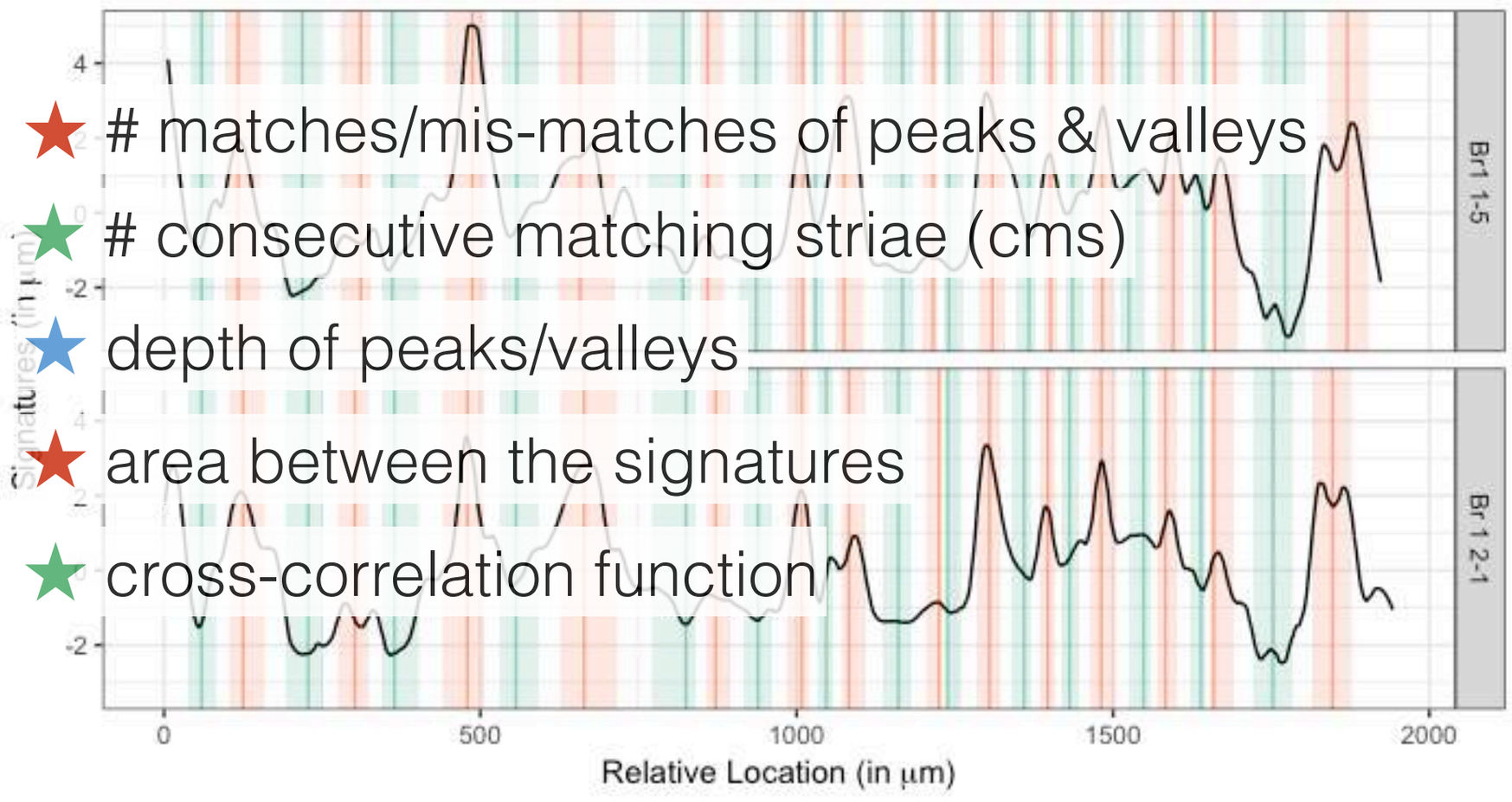


Automatic matching score

Step 6: Extract features

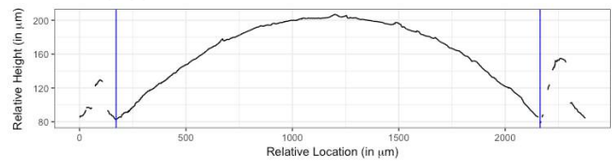
Feature should distinguish between a match and a non-match

- ★ # matches/mis-matches of peaks & valleys
- ★ # consecutive matching striae (cms)
- ★ depth of peaks/valleys
- ★ area between the signatures
- ★ cross-correlation function

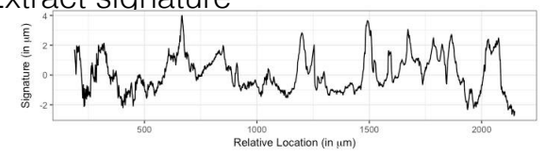


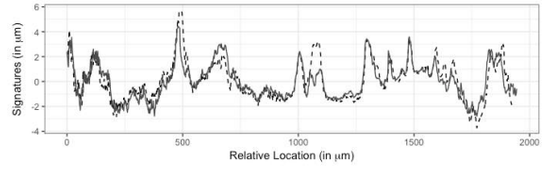
Identify matching region

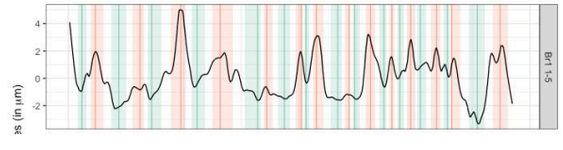
Identify groove locations



Extract signature





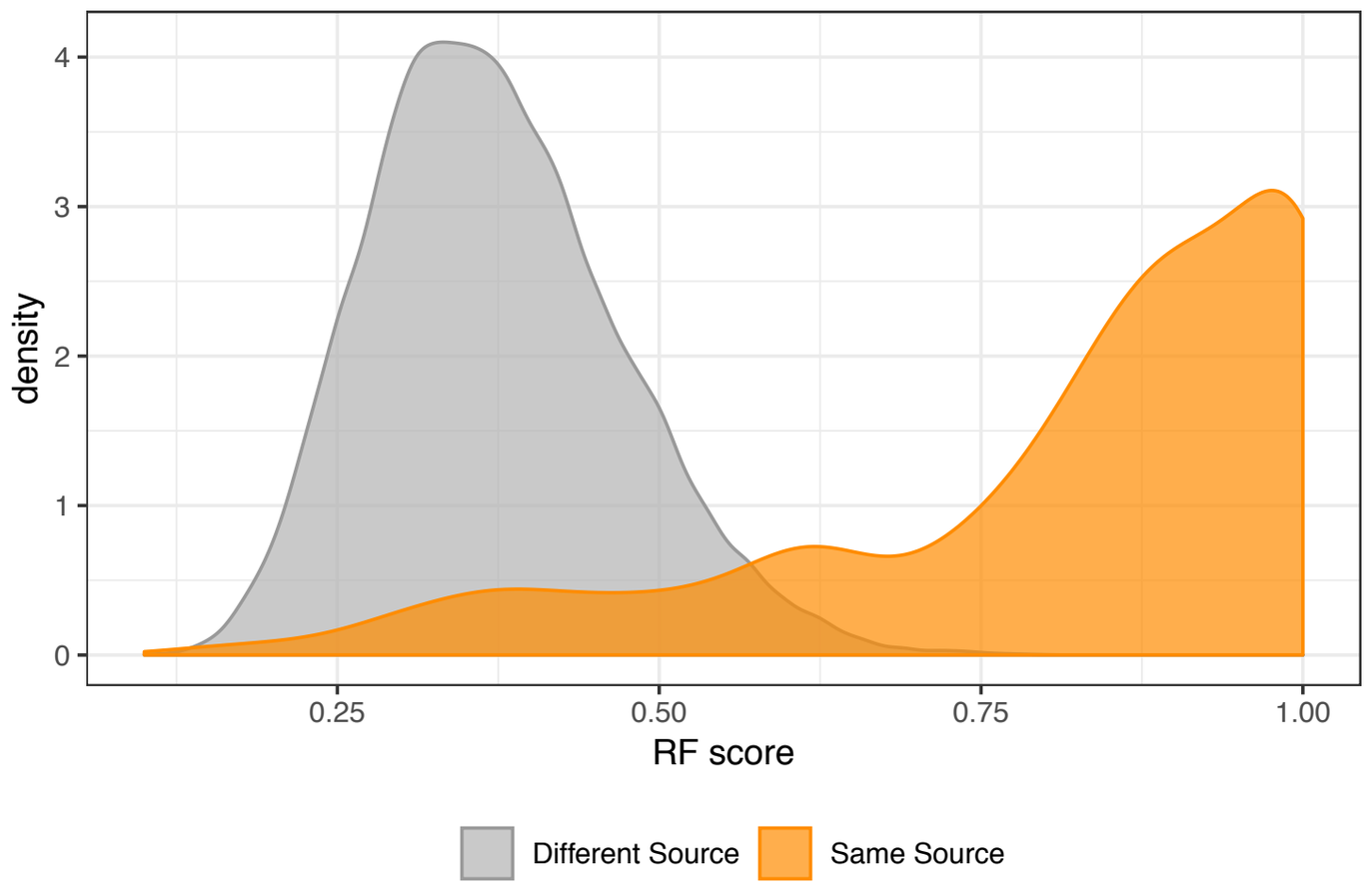


Automatic matching score

Step 7: Assign Score (Random Forest Model)

★ Matching score between 0 and 1

★ Higher score indicates more similarity between two lands



Automatic matching of bullet land impressions,
Annals of Applied Statistics,
Eric Riemer Hare, Heike Hofmann, and Alicia Carriquiry

Algorithmic approaches to match degraded land impressions
Eric Hare; Heike Hofmann; Alicia Carriquiry
Law, Probability and Risk, Volume 16, Issue 4, 1 December 2017, 203–221, https://doi.org/10.1093/lpr/mgx018

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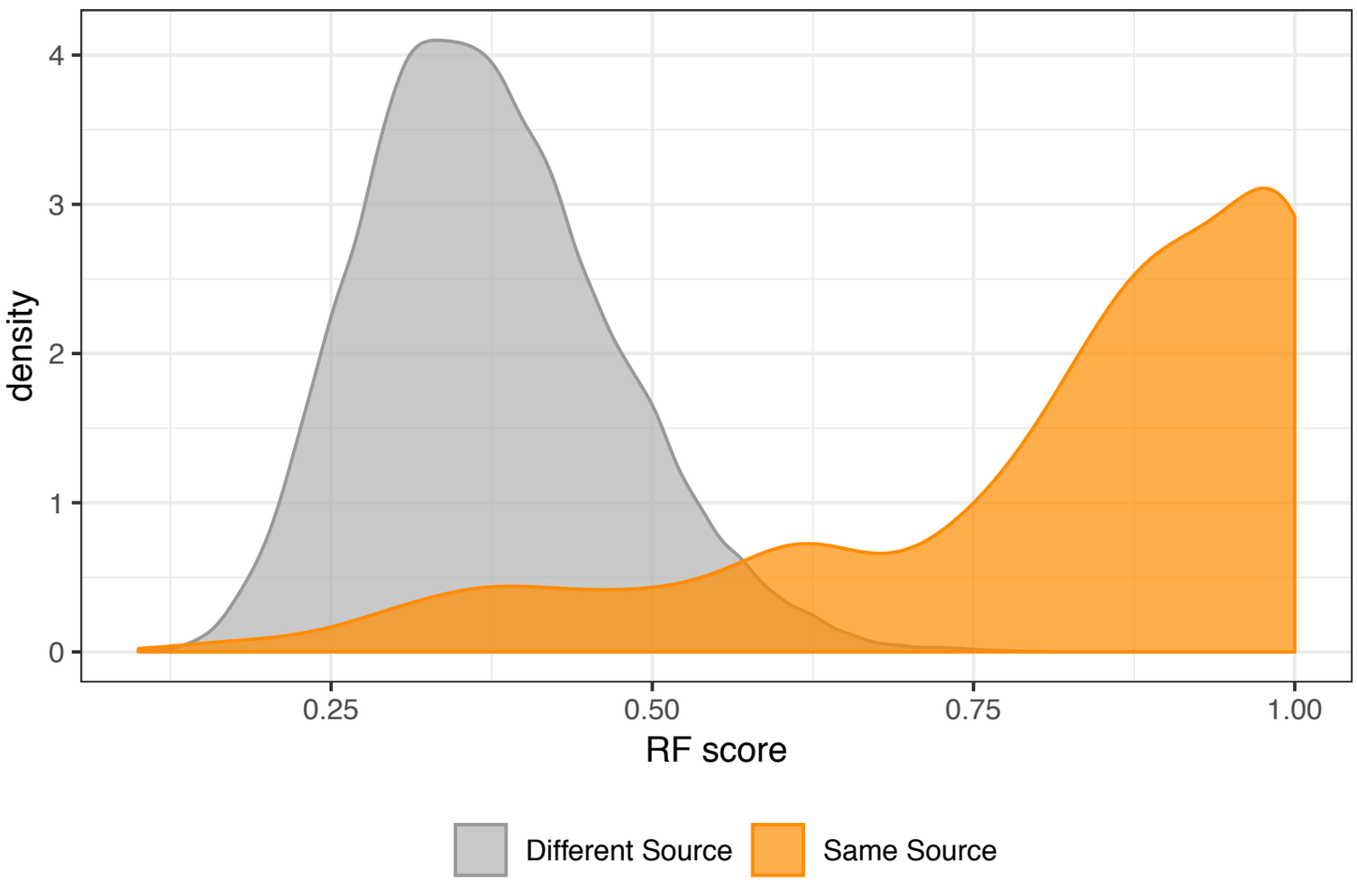
What does it mean?

★ let's assume that two bullet (land)s are compared, the model spits out a number …



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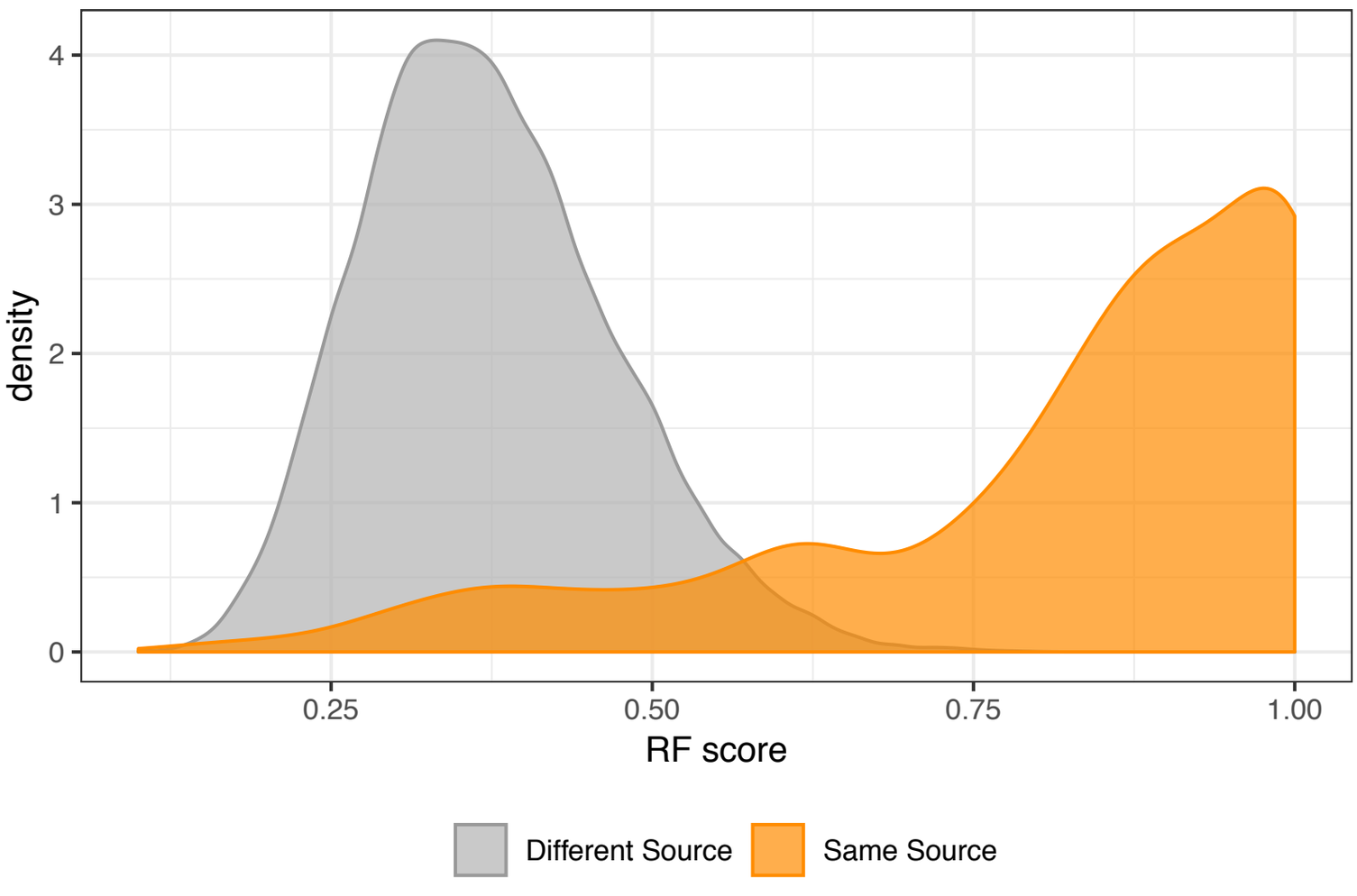
What does it mean?

★ let's assume that two bullet (land)s are compared, the model spits out a number …

○ 0.91



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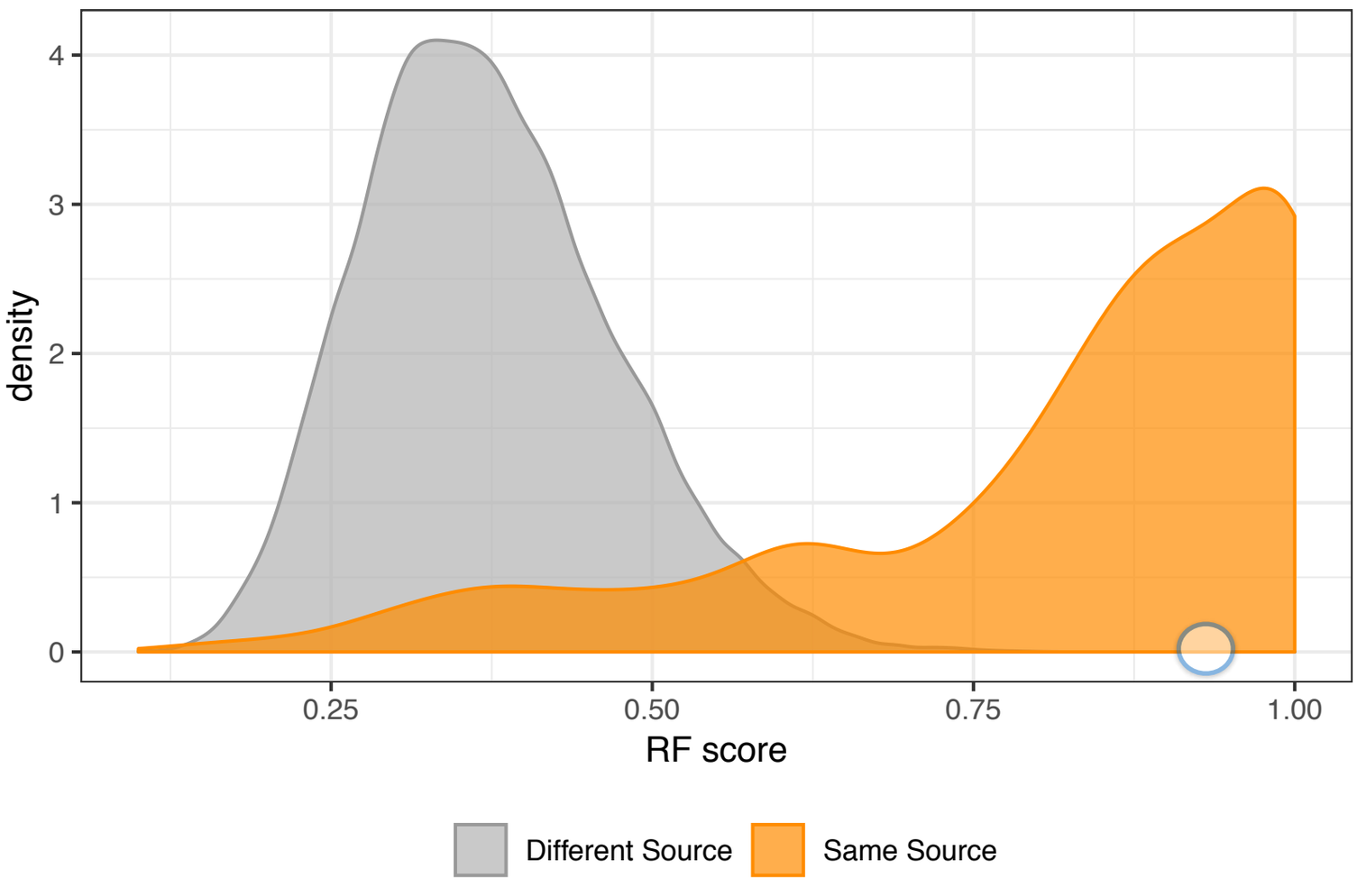

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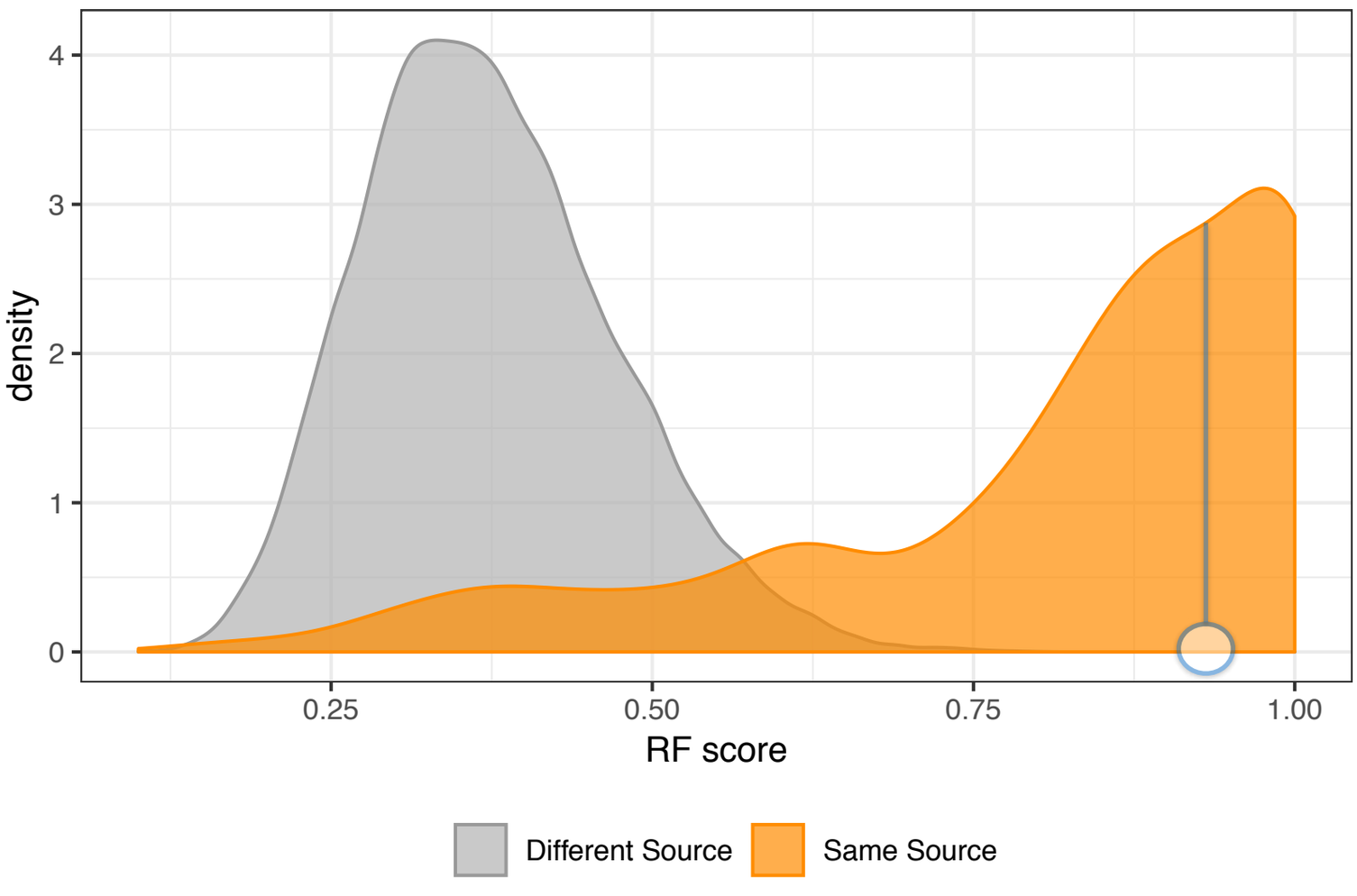

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What does it mean?

★ let's assume that two bullet (land)s are compared, the model spits out a number …

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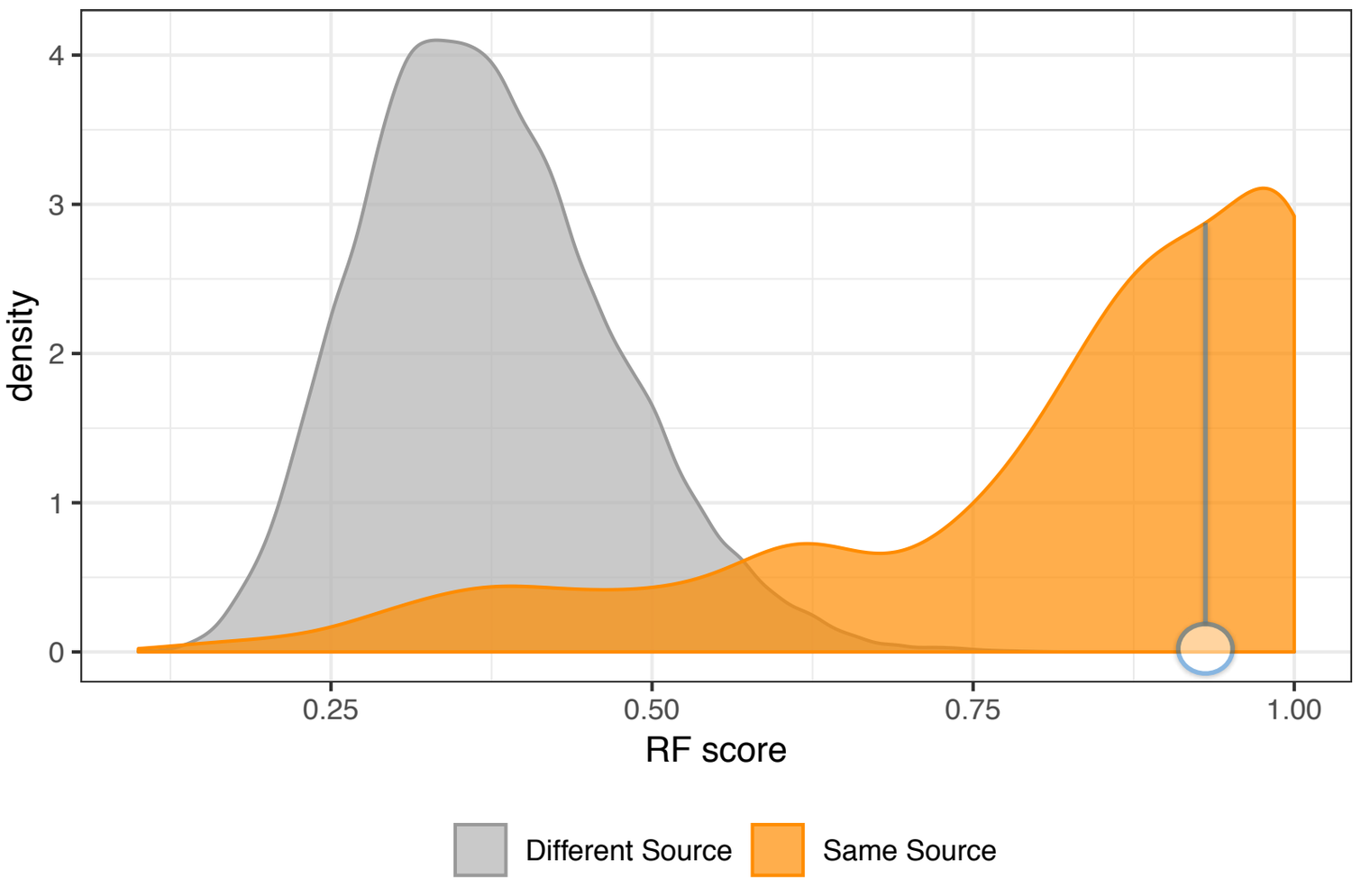
2.77



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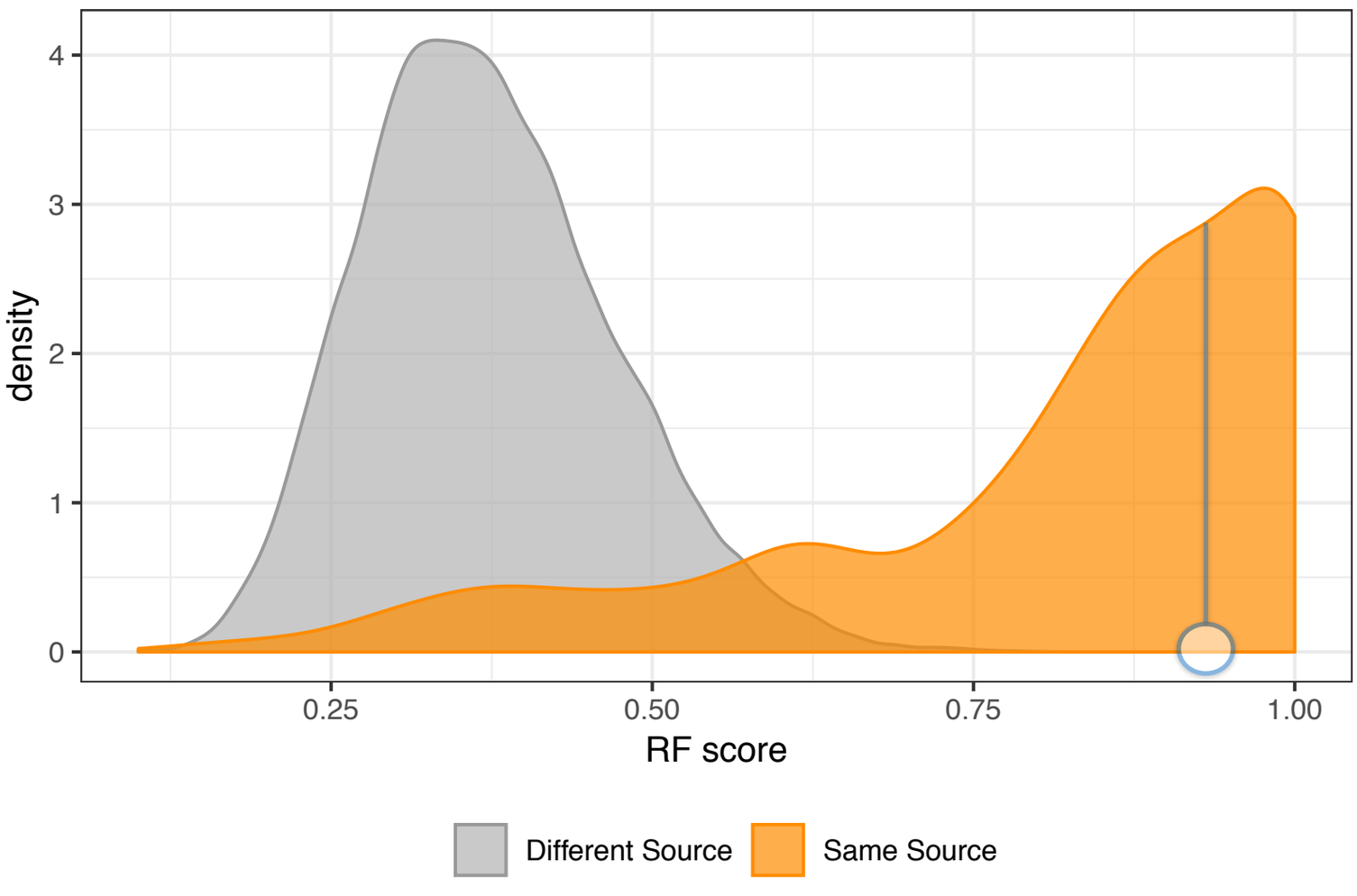
What does it mean?

★ let's assume that two bullet (land)s are compared, the model spits out a number …

○ 0.91

2.77 1.6×10^{-16}



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What does it mean?

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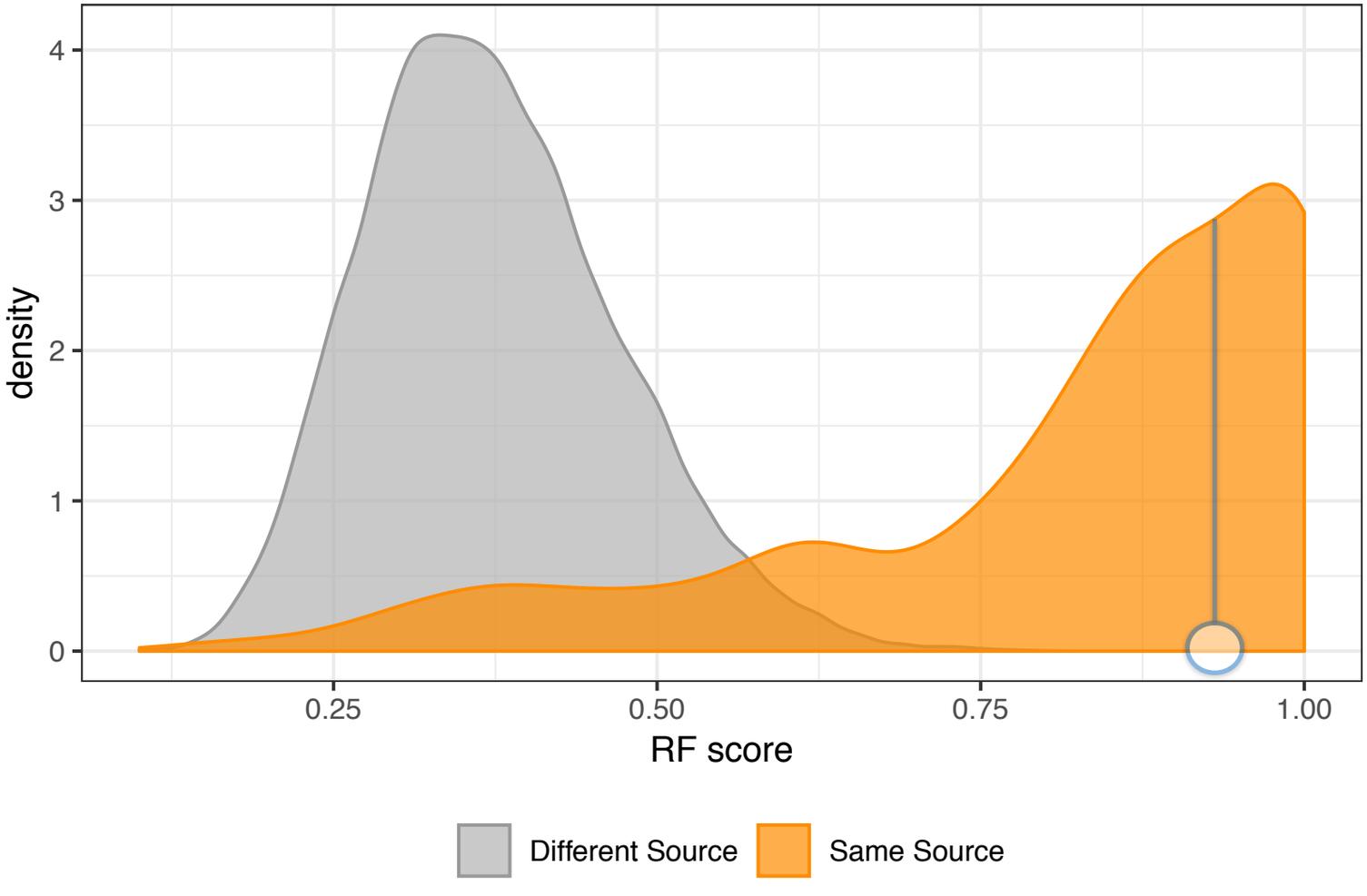
$2.77 / 1.6 \times 10^{-16} = 1.7 \times 10^{16}$



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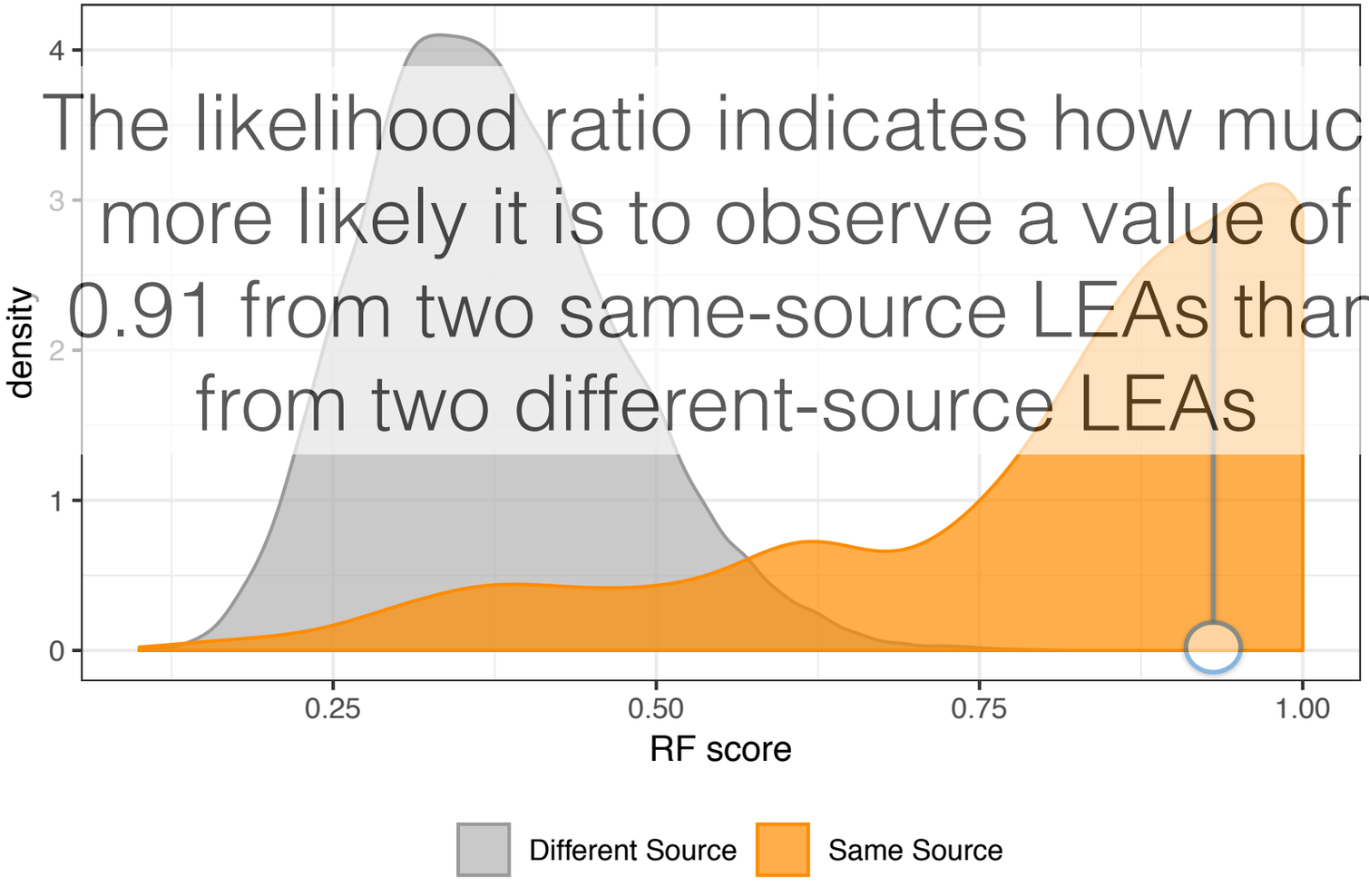
The likelihood ratio indicates how much more likely it is to observe a value of 0.91 from two same-source LEAs than from two different-source LEAs



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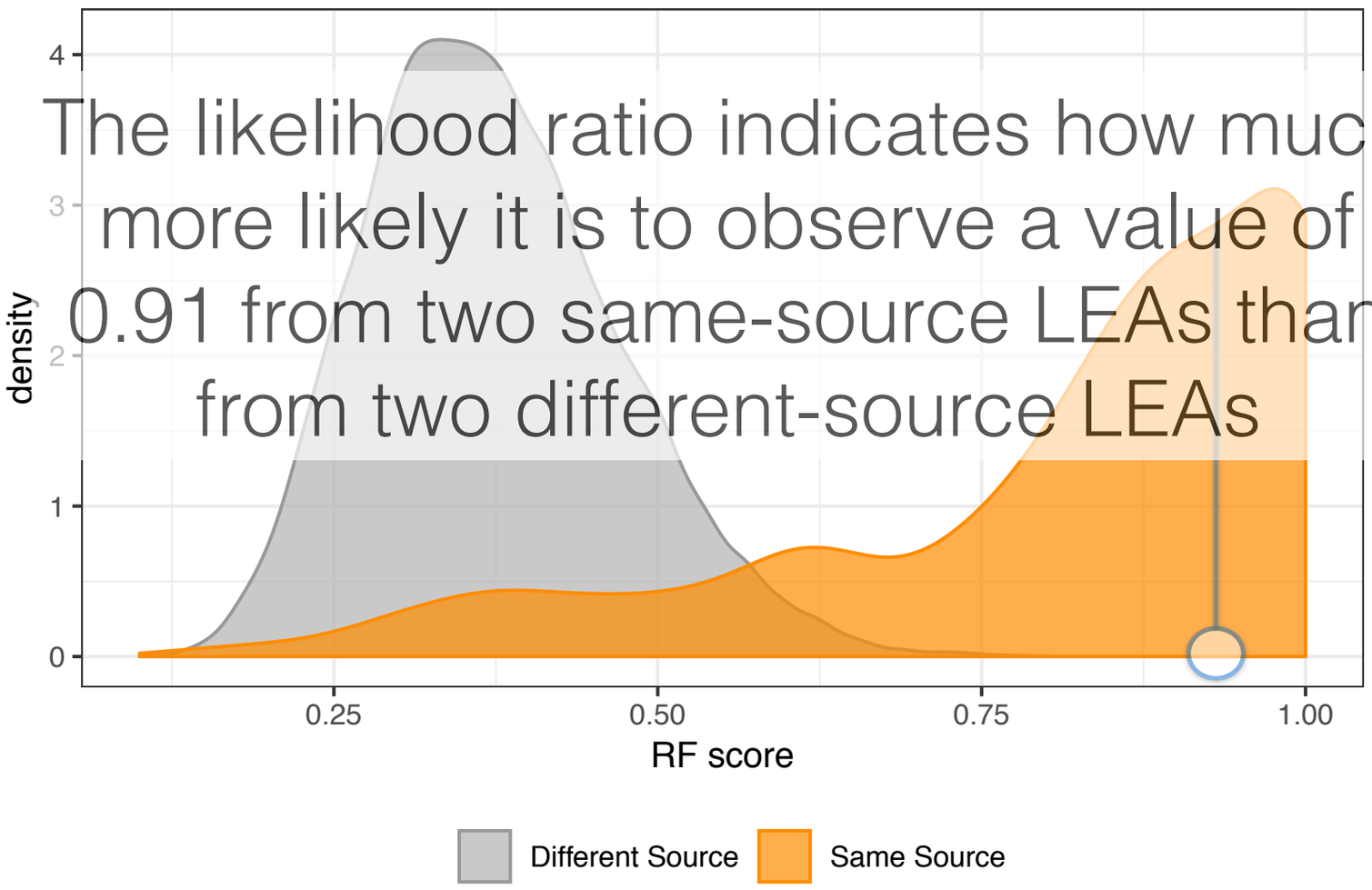
2.77 / 1.6x10^{-16} = 1.7x10^{16}

supports identification



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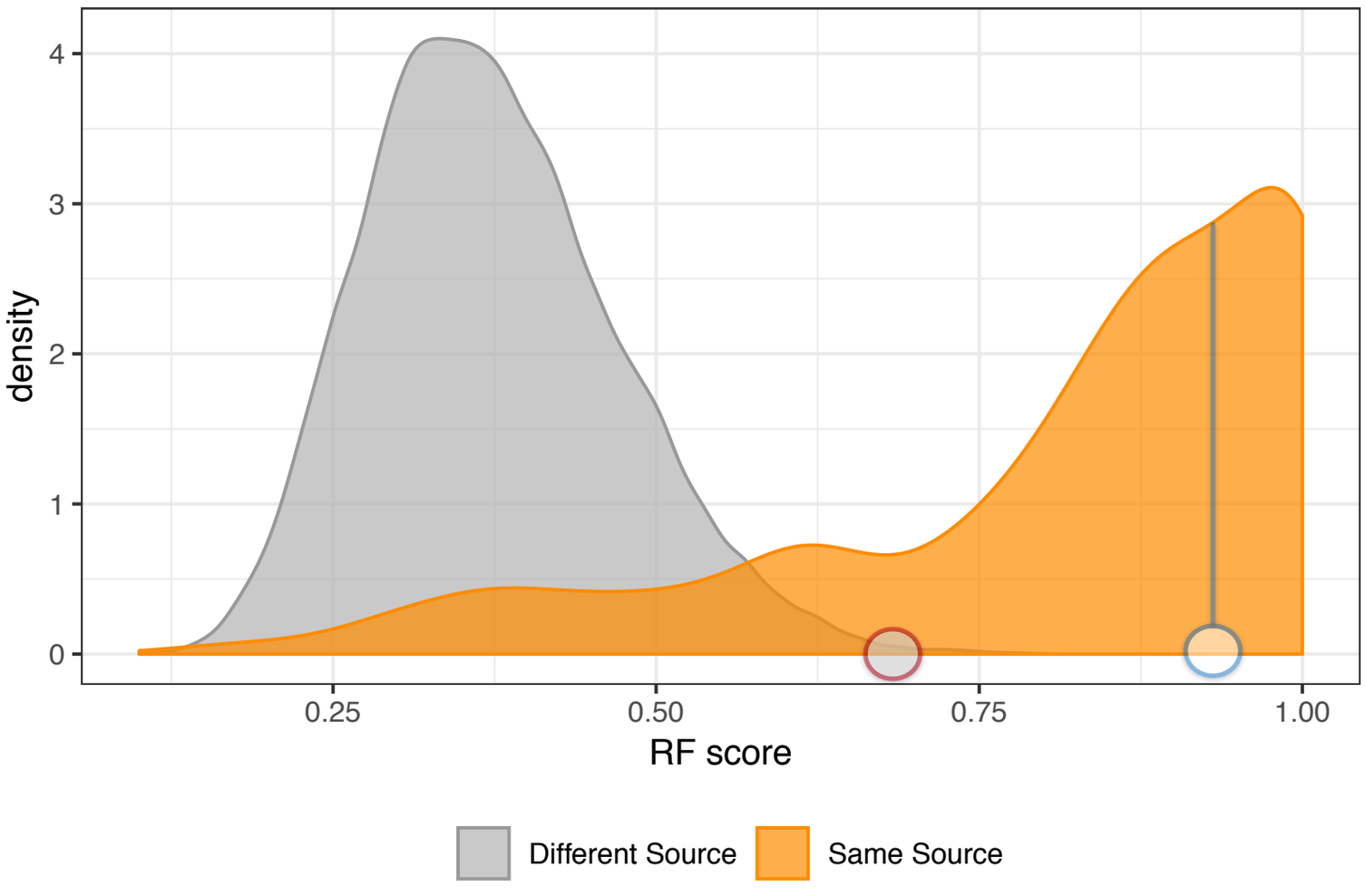

○ 0.91

$2.77 / 1.6 \times 10^{-16} = 1.7 \times 10^{16}$

supports identification

○ 0.69

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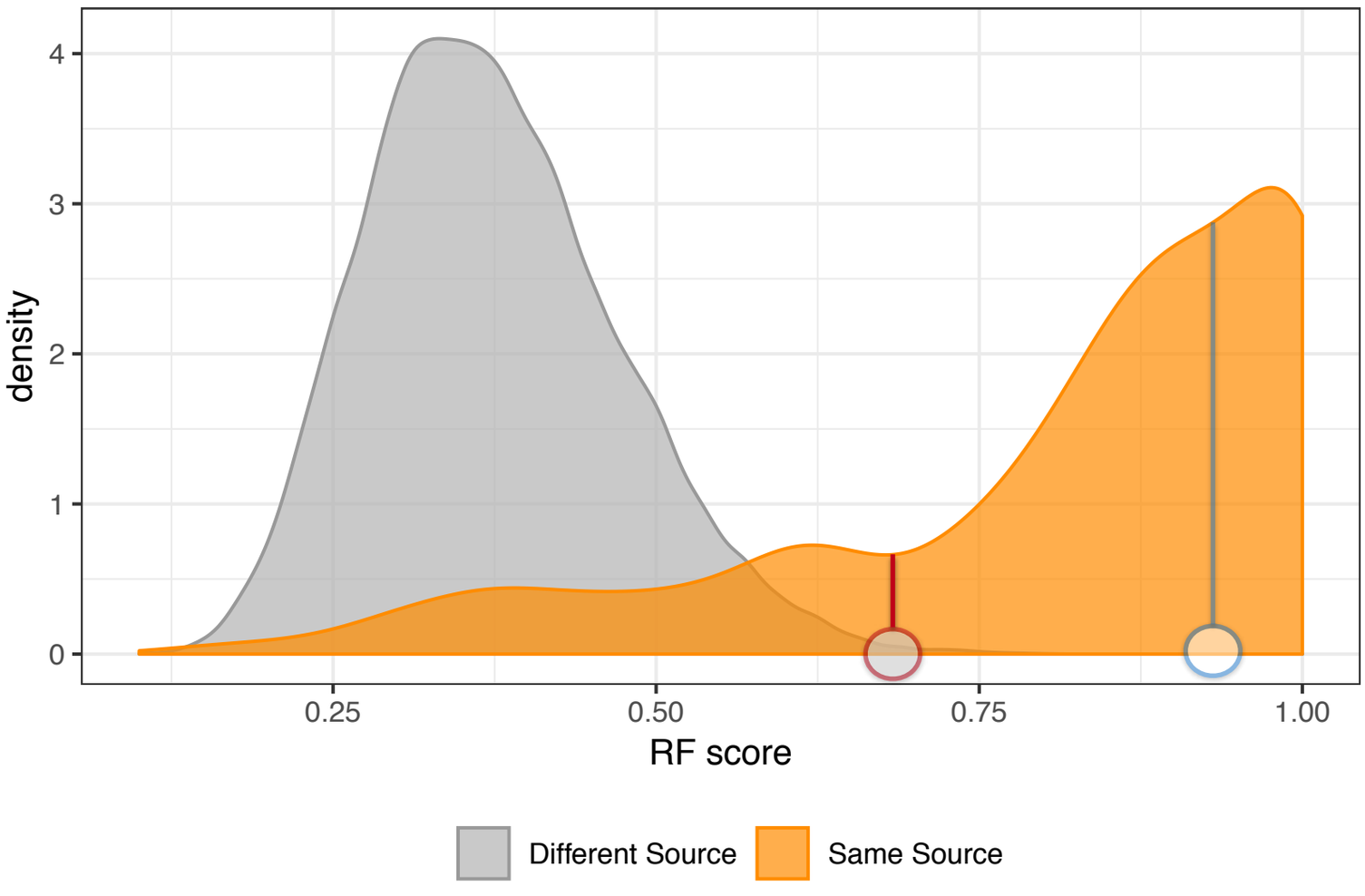

○ 0.91

2.77 / 1.6x10^{-16} = 1.7x10^{16}

supports identification

○ 0.69

0.67 / 0.05 = 13.4

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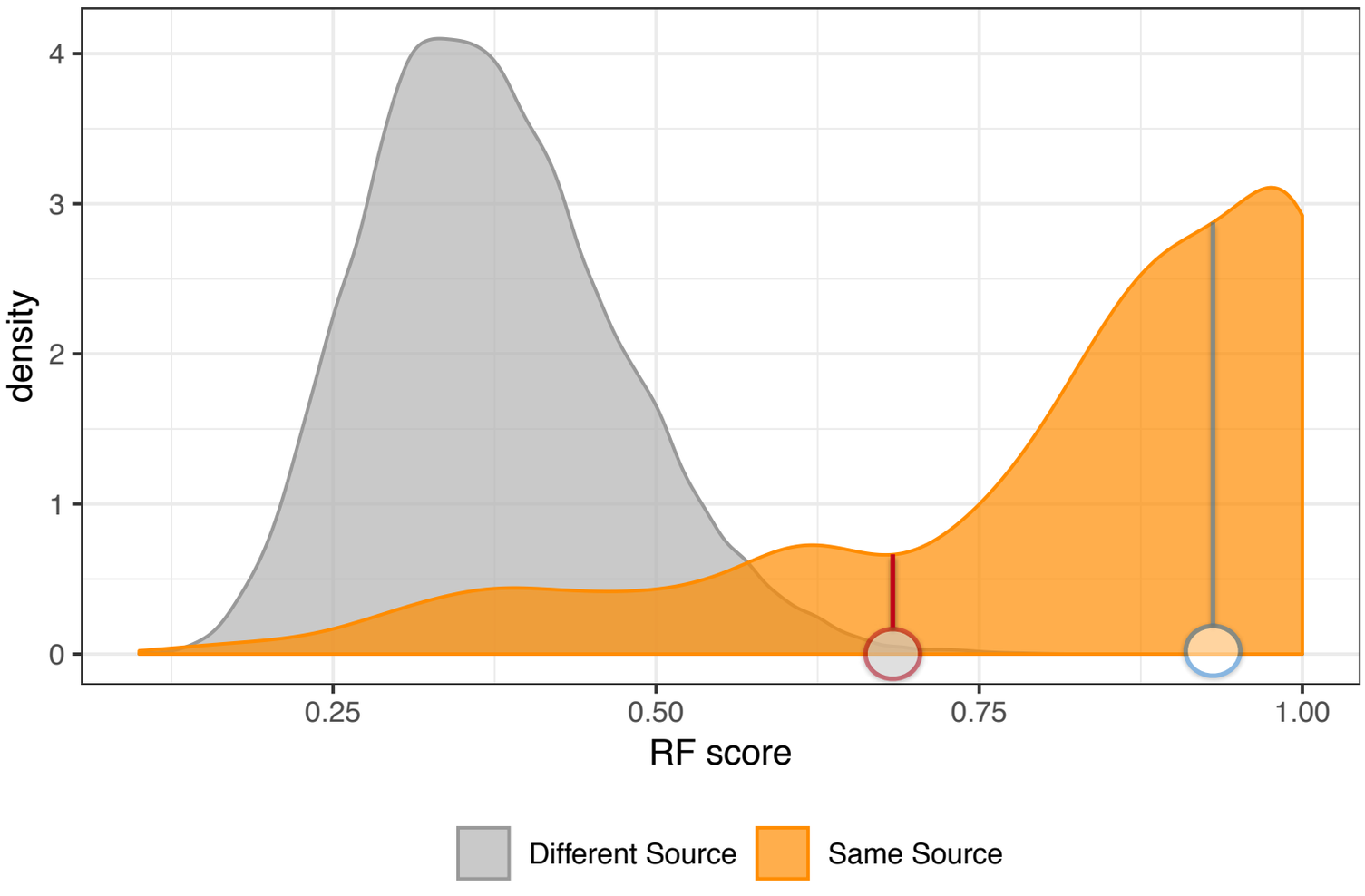

○ 0.91

2.77 / 1.6×10^{-16} = 1.7×10^{16}

supports identification

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0.67 / 0.05 = 13.4

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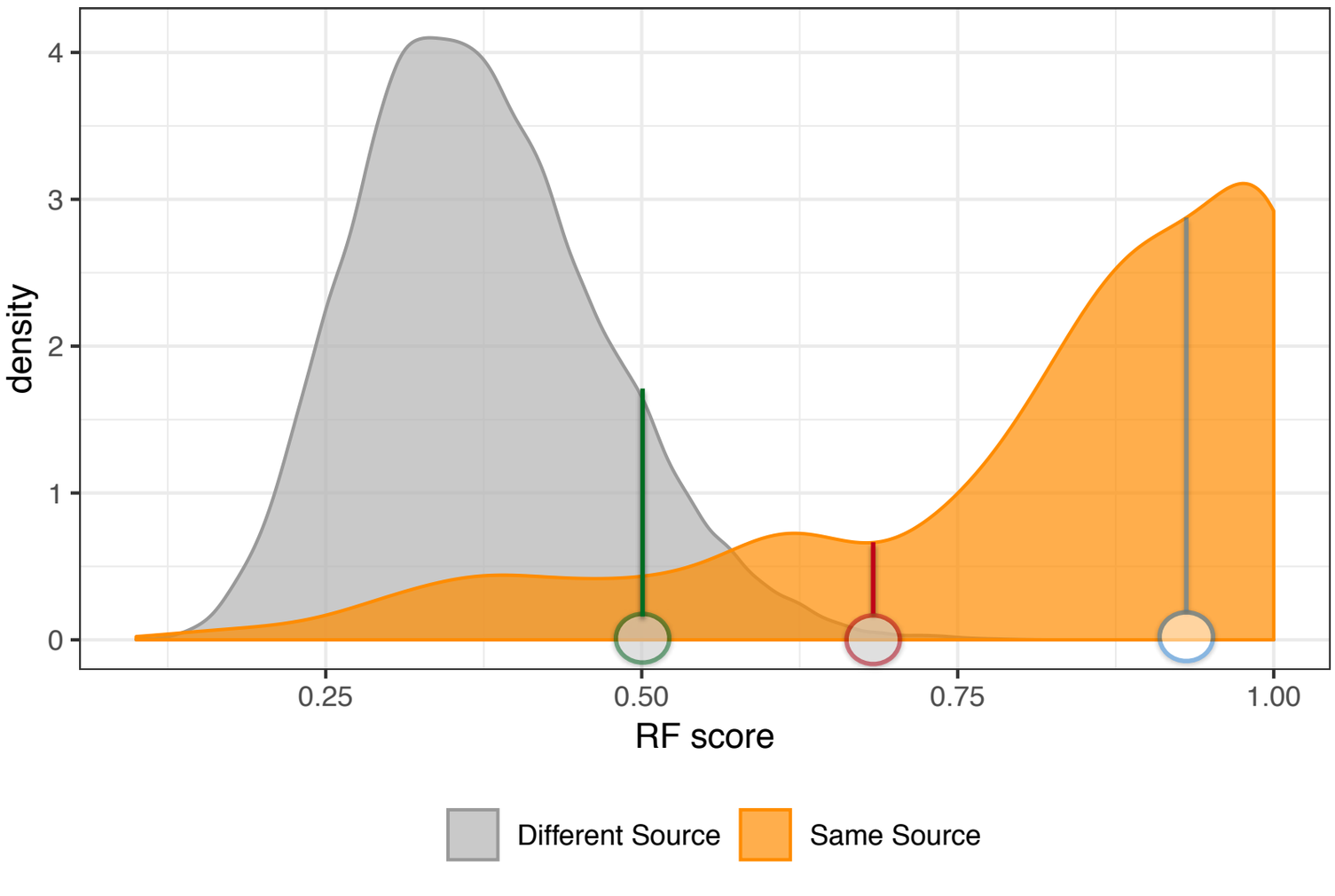

○ 0.91

2.77 / 1.6x10^{-16} = 1.7x10^{16}

supports identification

○ 0.69

0.67 / 0.05 = 13.4

supports identification

○ 0.50

0.43 / 1.65 = 0.26

inconclusive

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Shades of RF Scores

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HS 224 to Clone HS 224

Random Forest Scores

★ How well do LEAs match between a bullet and its clone?

HS 224 Br 1 - Bullet 1 - Land 1

HS 224 **Clone** Br 1 - Bullet 1 - Land 1

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HS 224 to Clone HS 224

Random Forest Scores

★ How well do LEAs match between a bullet and its clone?

HS 224 Br 1 - Bullet 1 - Land 1

HS 224 Barrel 1 - Bullet 1 - Land 2

HS 224 **Clone** Br 1 - Bullet 1 - Land 1

HS 224 **Clone** Br 1 - Bullet 1 - Land 2

HS 224 to Clone HS 224

Random Forest Scores

★ How well do LEAs match between a bullet and its clone?

Set	Bullet	Clone Bullet 1	Clone Bullet 2	Original Bullet 1	Original Bullet 2
Clone	**Bullet 1**	1.00	0.80		
	Bullet 2	0.80	0.83		
Original	**Bullet 1**			1.00	0.98
	Bullet 2			0.98	1.00

★ Original bullets match with higher RF score than clones

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HS 224 to Clone HS 224

Random Forest Scores

★ How well do LEAs match between a bullet and its clone?

Set	Bullet	Clone Bullet 1	Clone Bullet 2	Original Bullet 1	Original Bullet 2
Clone	Bullet 1	1.00	0.80	0.97	0.96
	Bullet 2	0.80	0.83	0.78	0.83
Original	Bullet 1			1.00	0.98
	Bullet 2			0.98	1.00

★ Original bullets match with higher RF score than clones

★ Original bullets match well to clones, almost as well as to each other

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HS 224 to Clone HS 224

Random Forest Scores

★ Some LEA scans of clones are showing artifacts:

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HS 224 to Clone HS 224

Random Forest Scores

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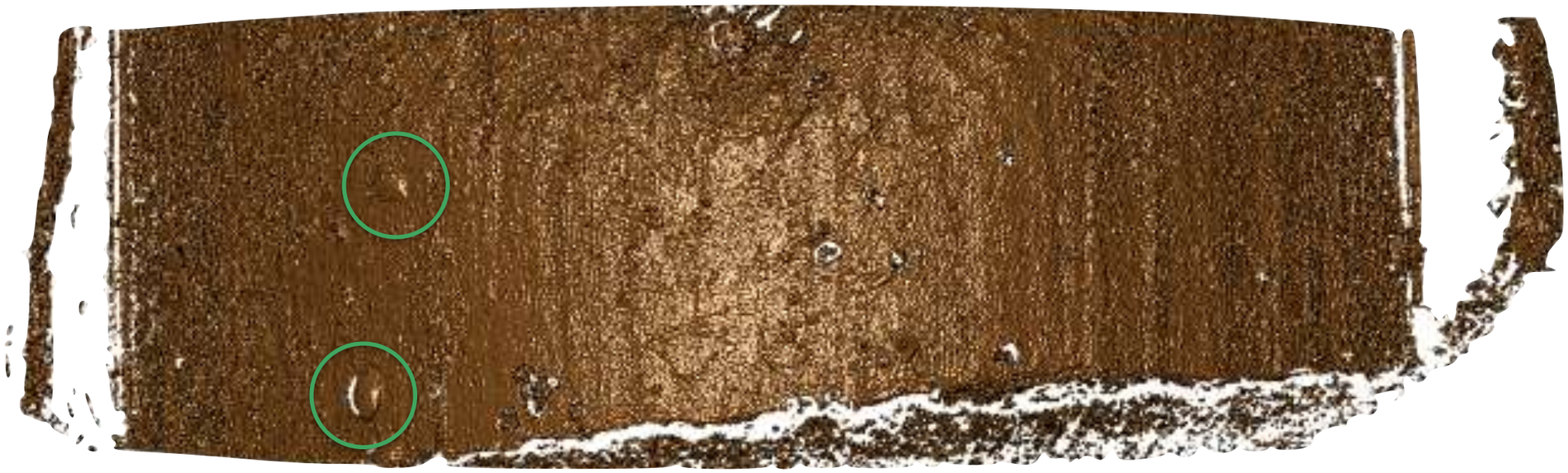

droplets

HS 224 to Clone HS 224

Random Forest Scores

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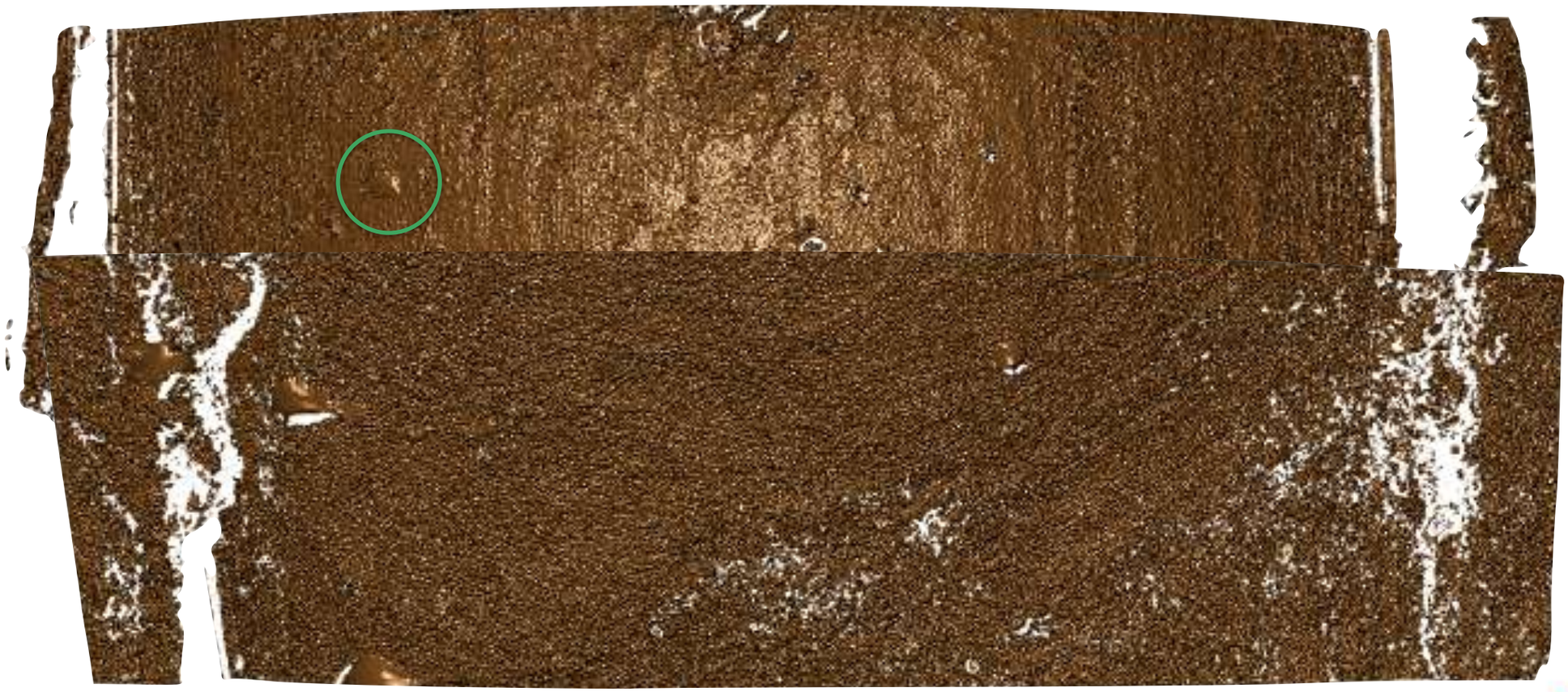

droplets

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HS 224 to Clone HS 224

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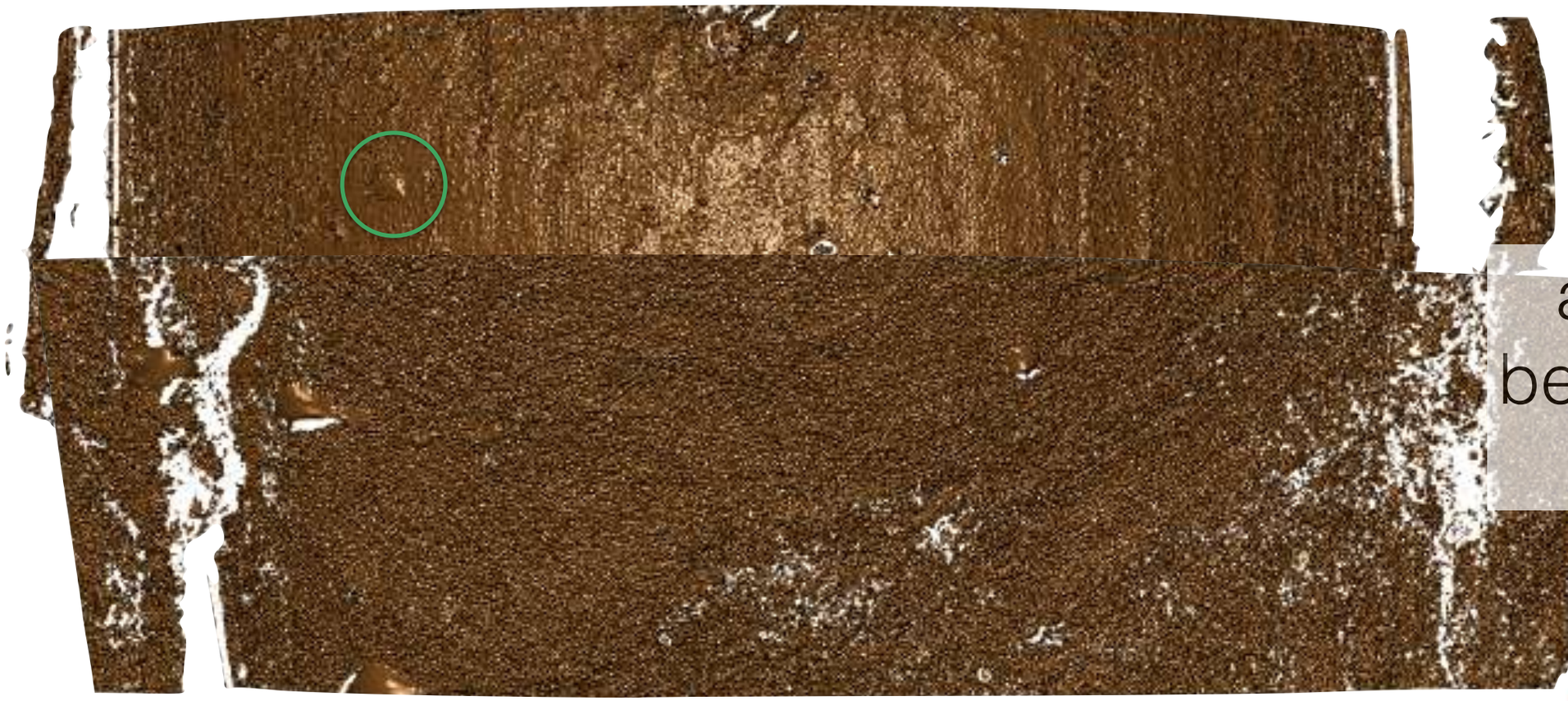

droplets

air pockets between clone and cast

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HS 224 to Clone HS 224

Random Forest Scores

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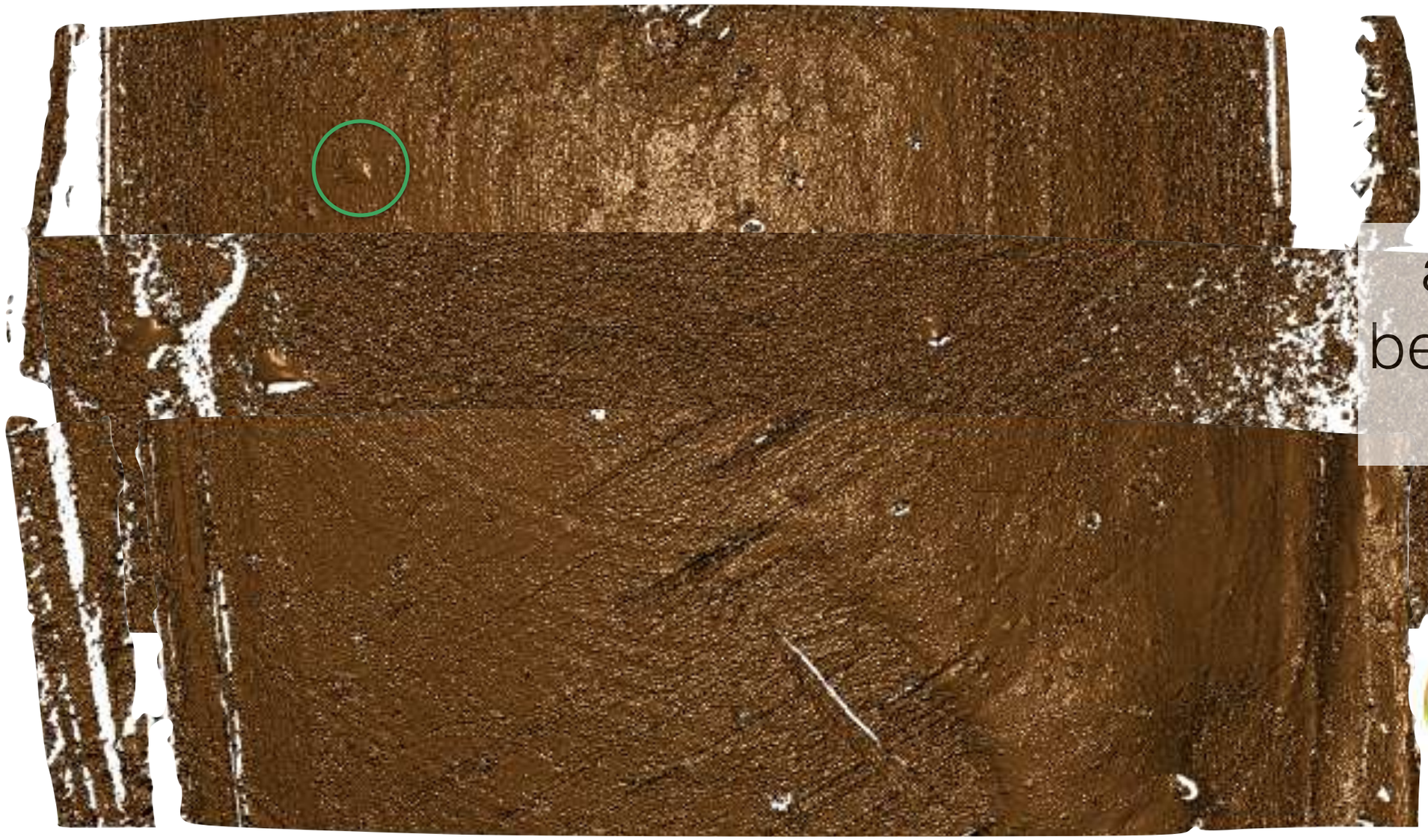

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HS 224 to Clone HS 224

Random Forest Scores

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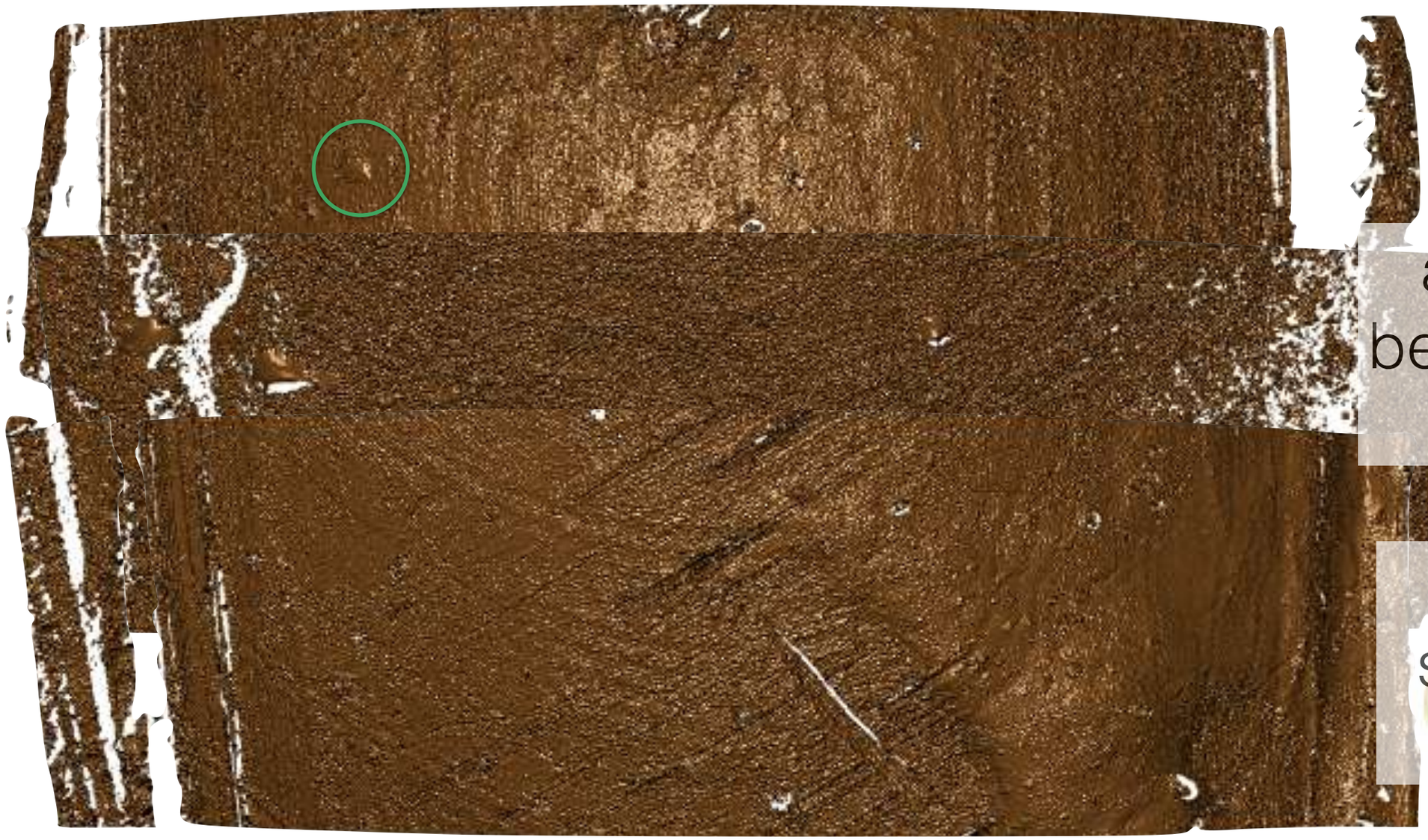


droplets

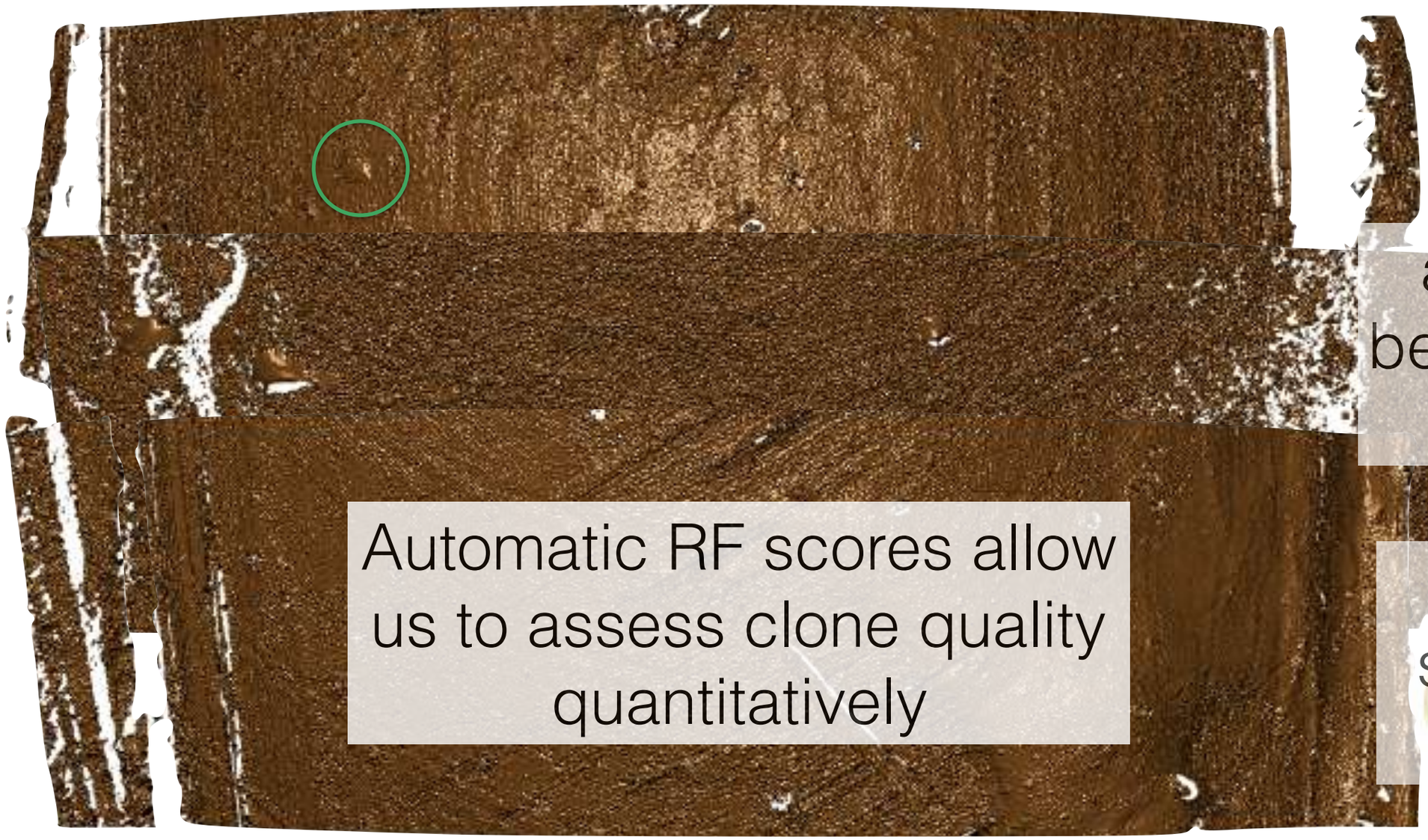
air pockets between clone and cast

some other structure but no striae

HS 224 to Clone HS 224

Random Forest Scores

★ Some LEA scans of clones are showing artifacts:



droplets

air pockets between clone and cast

some other structure but no striae

Automatic RF scores allow us to assess clone quality quantitatively

Hamby Set 10 and 44

Random Forest Scores

- ★ Hamby Set 10 and Set 44 are from the same 10 barrels of Ruger P-85s
- ★ Bullets from Hamby Set 44 are fired some time later (~ 240 shots in each barrel between the sets)
- ★ Two Goals:
  - ★ **check** identifications between the sets
  - ★ **quantify** identifications

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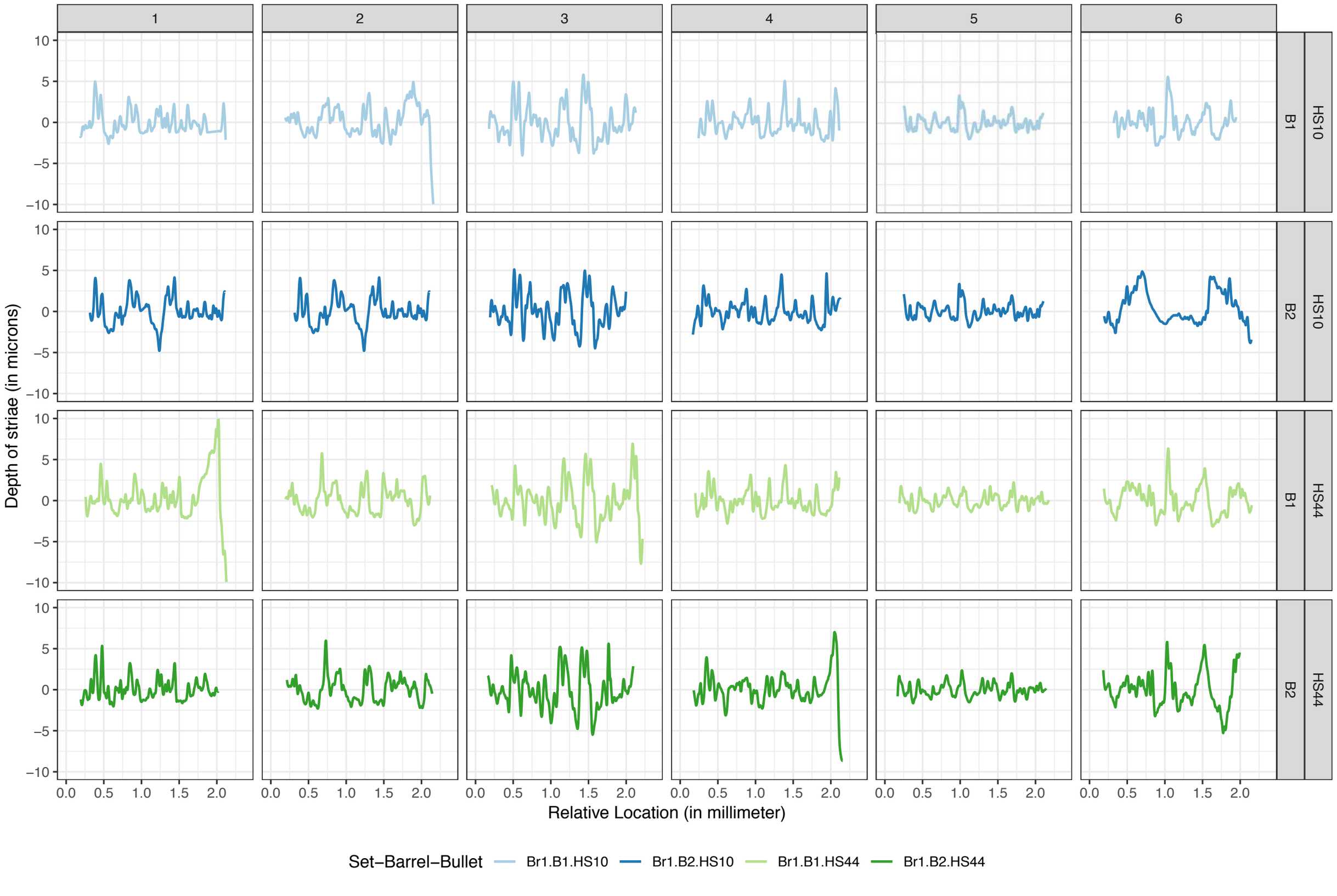
Hamby Set 10 and 44 Barrel 1



Hamby Set 10 and 44

Random Forest Scores

★ Identification between Sets 10 and 44 are possible

	HS10-B1	**HS10-B2**	**HS44-B1**	**HS44-B2**
HS10-B1	1.00	0.65		
HS10-B2	0.65	1.00		
HS44-B1			1.00	0.79
HS44-B2			0.79	1.00

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Hamby Set 10 and 44

Random Forest Scores

★ Identification between Sets 10 and 44 are possible

	HS10-B1	**HS10-B2**	**HS44-B1**	**HS44-B2**
HS10-B1	1.00	0.65	0.56	0.59
HS10-B2	0.65	1.00	0.57	0.57
HS44-B1			1.00	0.79
HS44-B2			0.79	1.00

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Hamby Set 10 and 44

Random Forest Scores

★ Identification between Sets 10 and 44 are possible

	HS10-B1	**HS10-B2**	**HS44-B1**	**HS44-B2**
HS10-B1	1.00	0.65	0.56	0.59
HS10-B2	0.65	1.00	0.57	0.57
HS44-B1			1.00	0.79
HS44-B2			0.79	1.00

★ RF scores between sets are not as high as within sets

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Hamby Set 10 and 44

Random Forest Scores

★ Identification between Sets 10 and 44 are possible

	HS10-B1	**HS10-B2**	**HS44-B1**	**HS44-B2**
HS10-B1	1.00	0.65	0.56	0.59
HS10-B2	0.65	1.00	0.57	0.57
HS44-B1			1.00	0.79
HS44-B2			0.79	1.00

★ RF scores between sets are not as high as within sets

★ RF scores can be used to quantify the strength of an identification

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RF Scores in context

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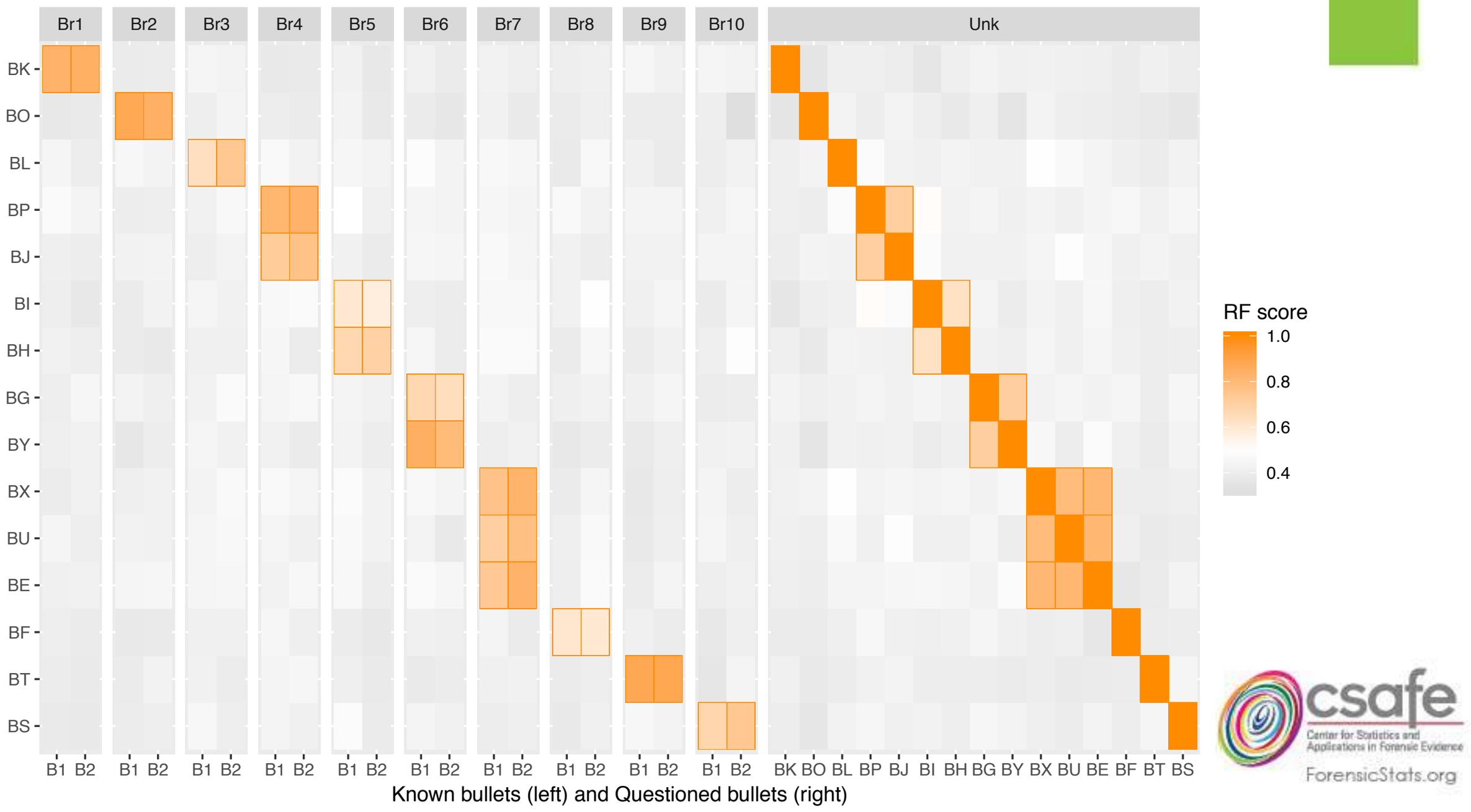
Hamby Set 44

RF Scores in context of a study



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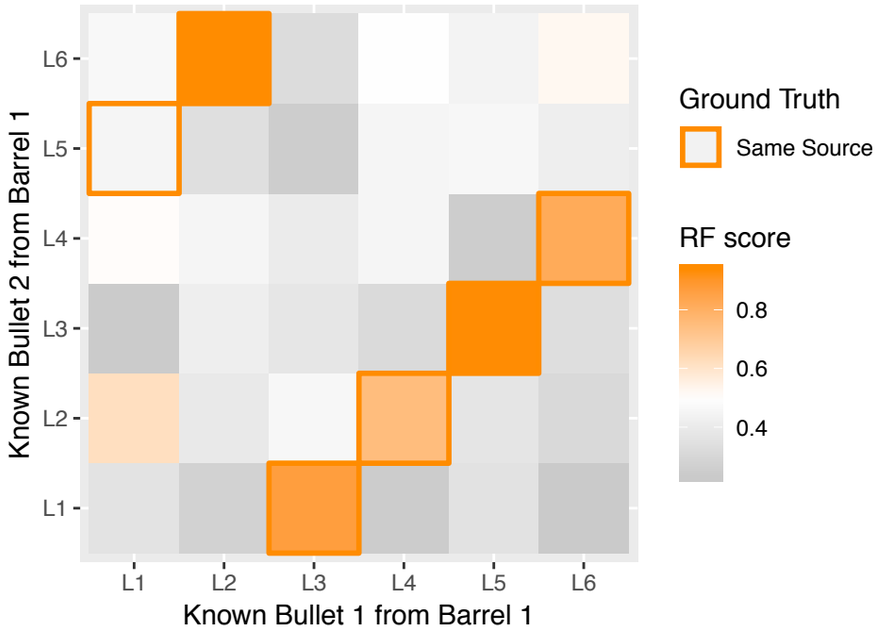
Hamby Set 44

Random Forest Scores

★ Land-to-land matches for bullets 1 and 2 from barrel 1



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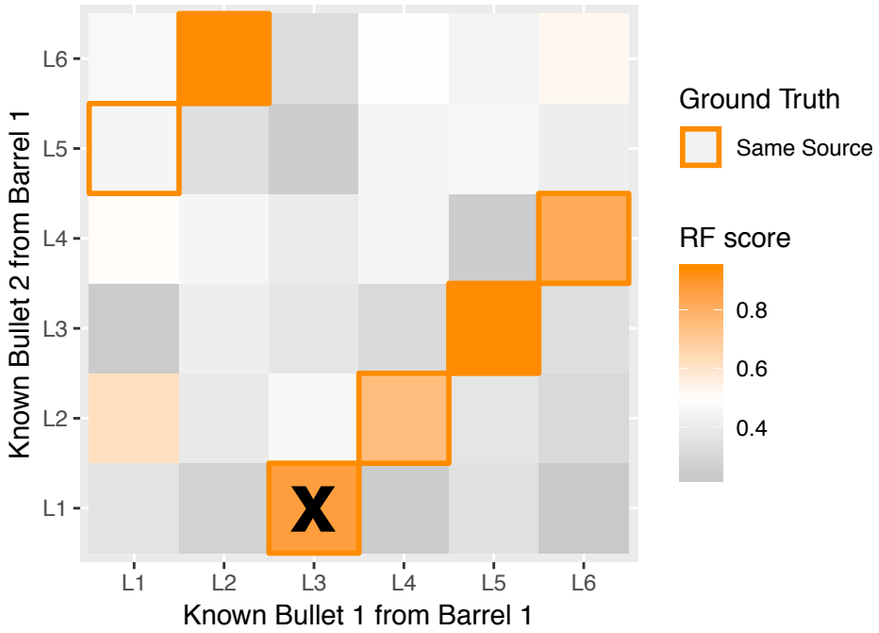

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Random Forest Scores

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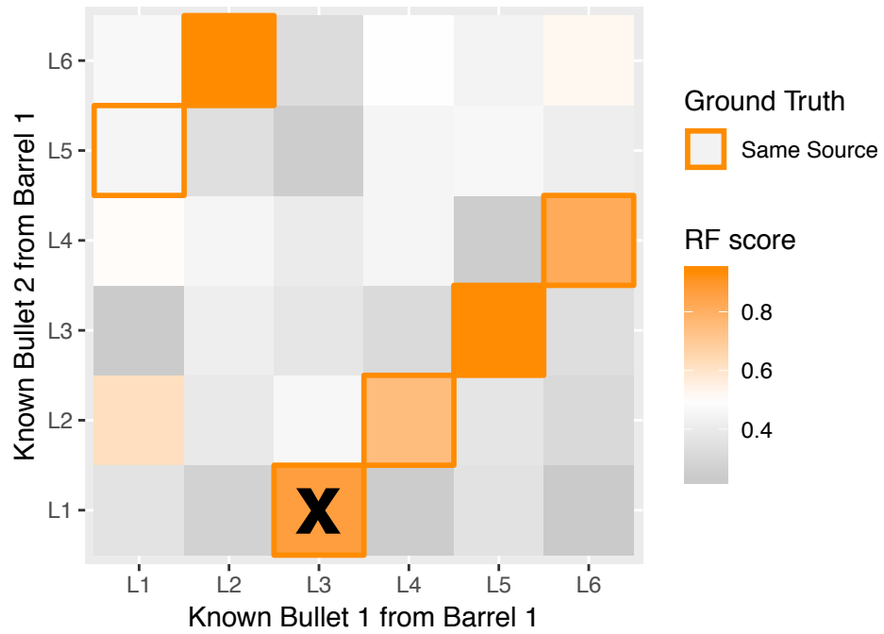

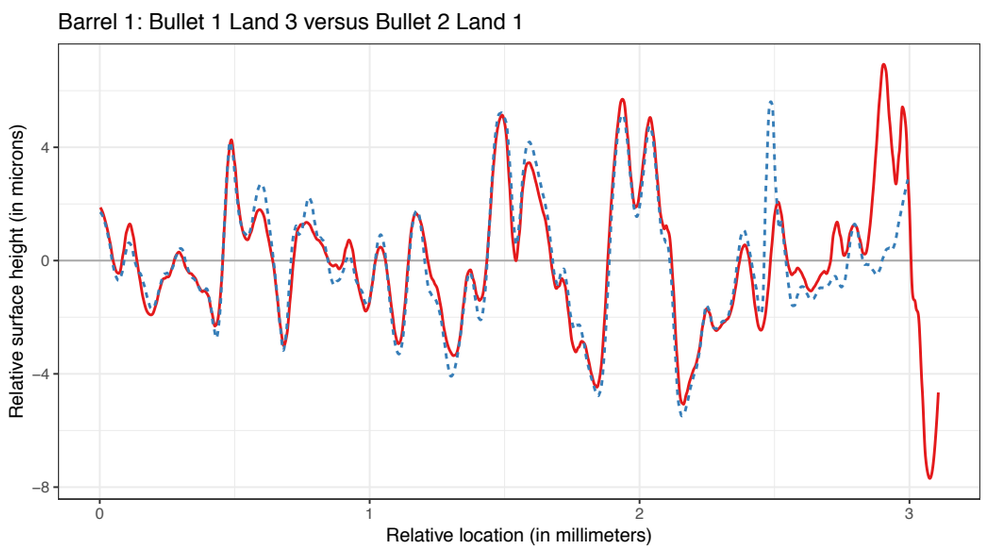

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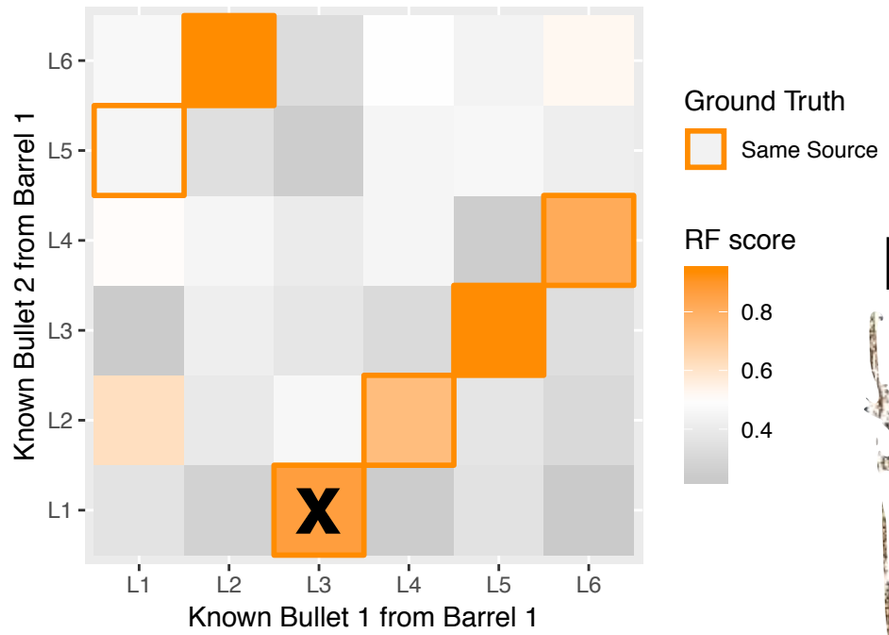
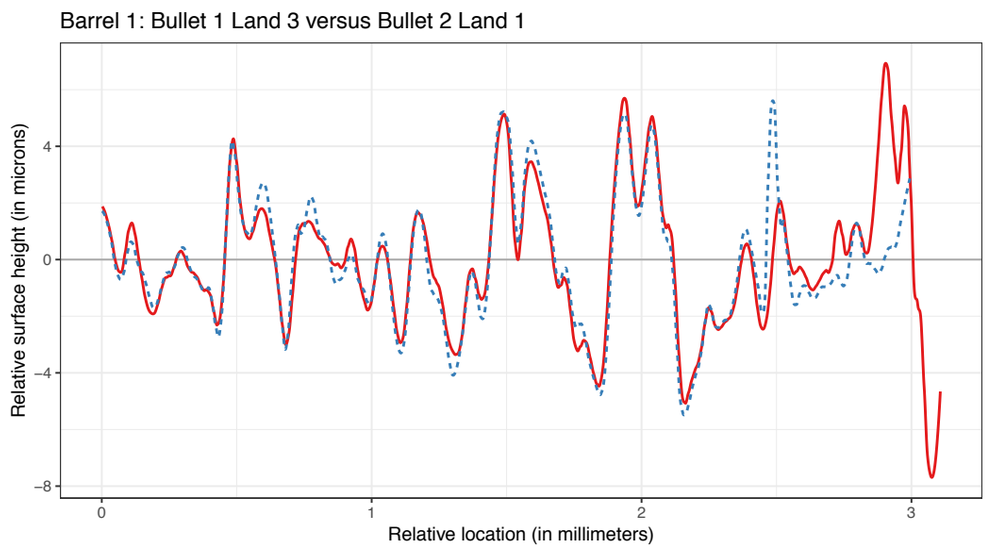




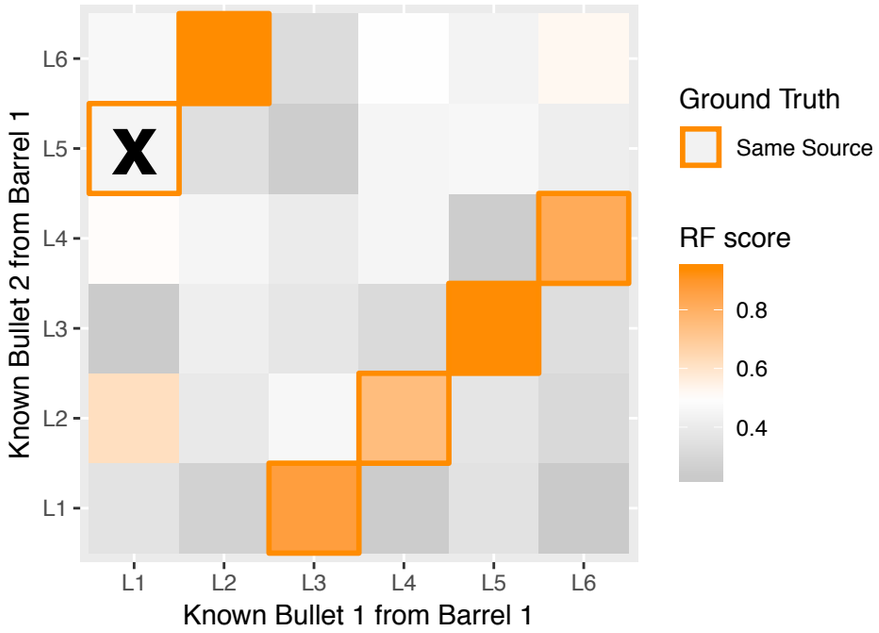
Barrel 1 - Bullet 1 - Land 3

Barrel 1 - Bullet 2 - Land 1

Hamby Set 44

Random Forest Scores

★ Land-to-land matches for bullets 1 and 2 from barrel 1



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Hamby Set 44

Random Forest Scores

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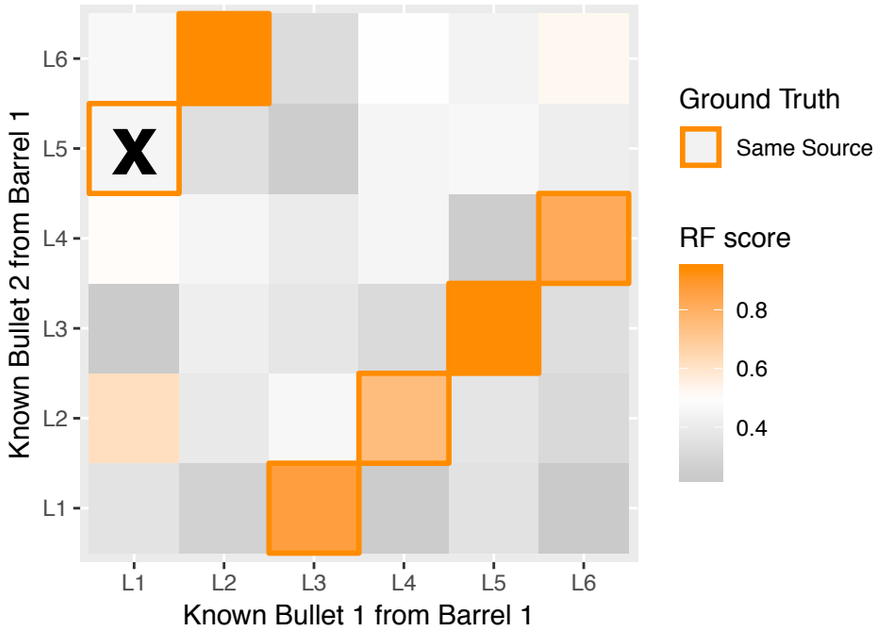

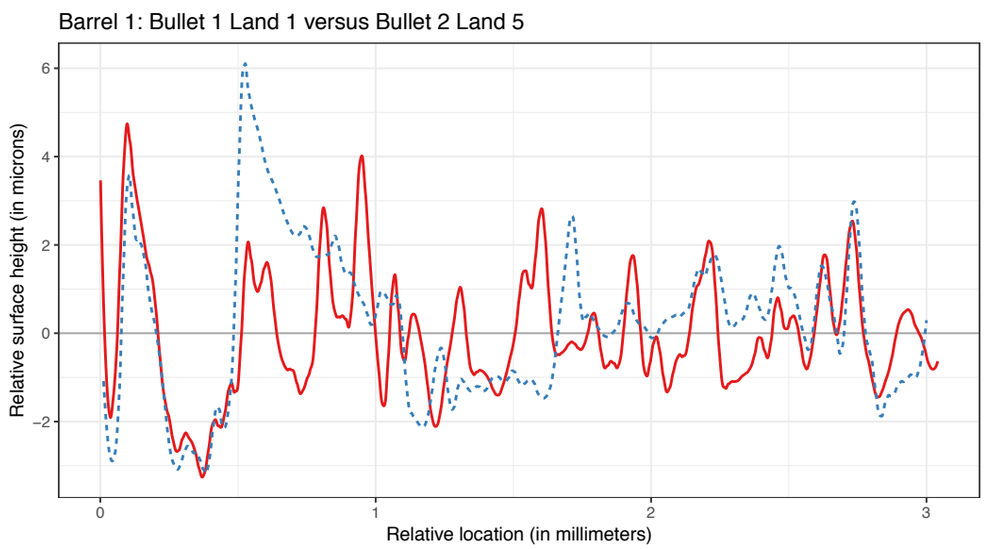

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Hamby Set 44

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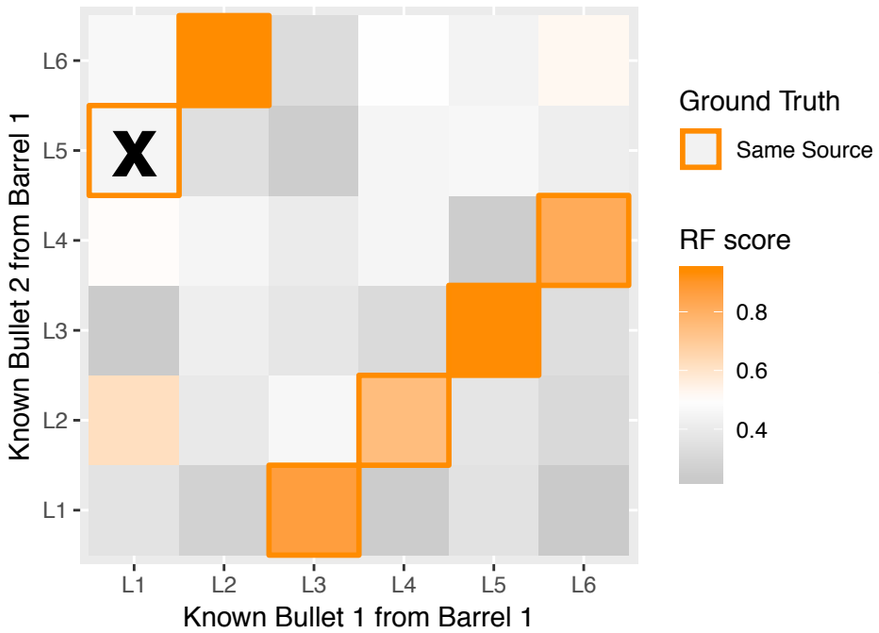
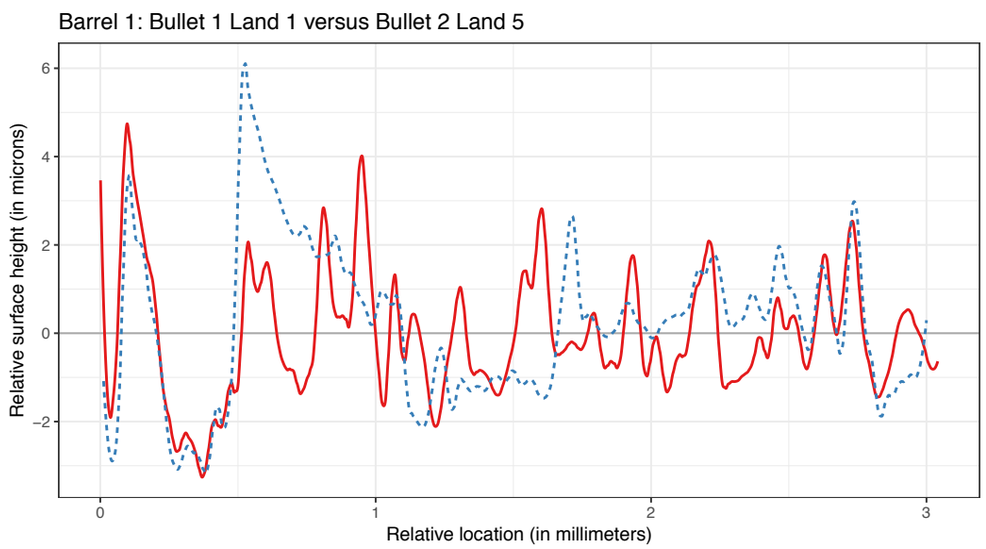
★ Land-to-land matches for bullets 1 and 2 from barrel 1



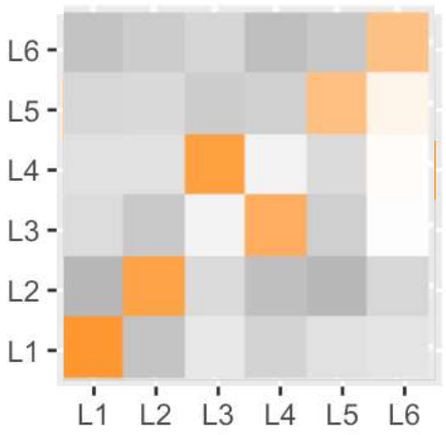


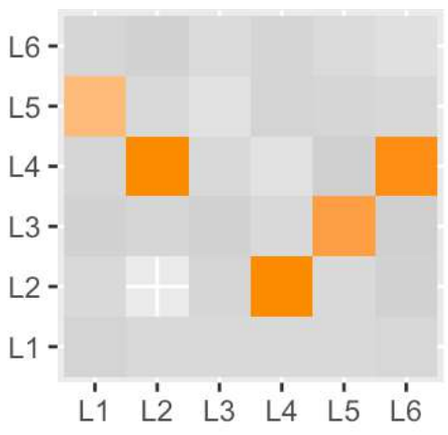
Barrel 1 - Bullet 1 - Land 1

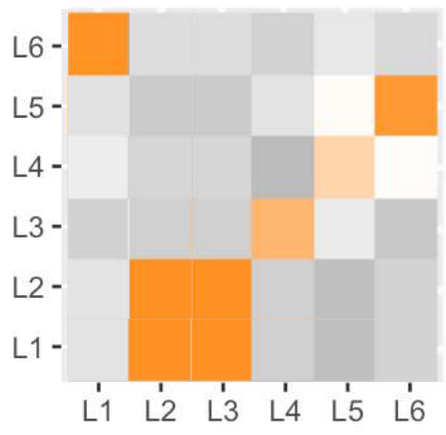
Barrel 1 - Bullet 2 - Land 5

Using the RF Score for diagnostics

★ Land-to-land matches for two bullets show oddities







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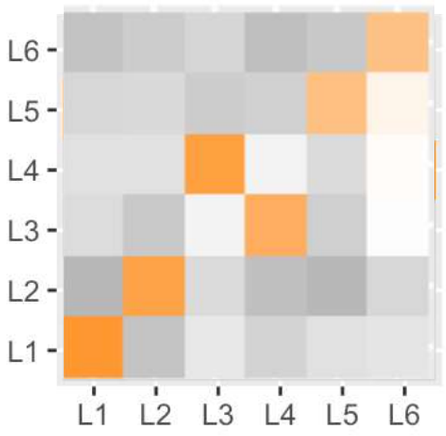
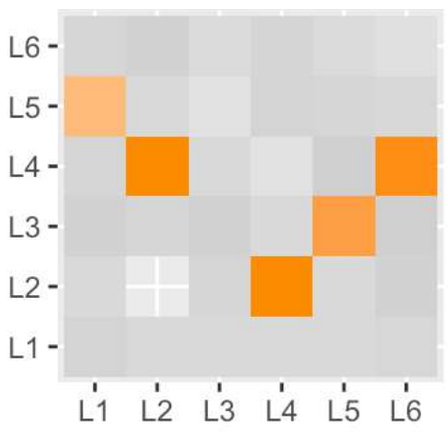
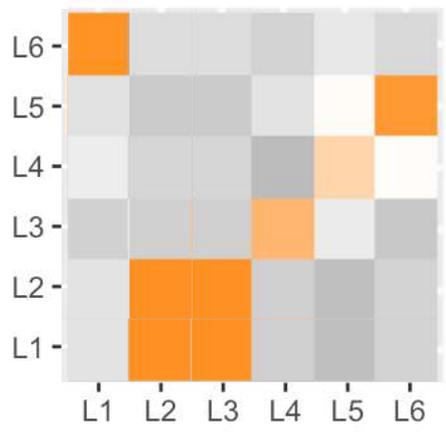
Using the RF Score for diagnostics

★ Land-to-land matches for two bullets show oddities







scans for lands 3 and 4 were mis-labelled for one bullet

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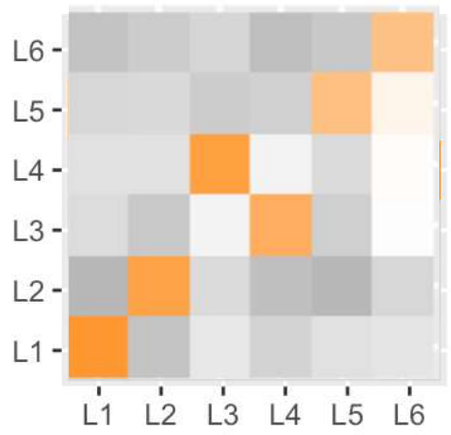

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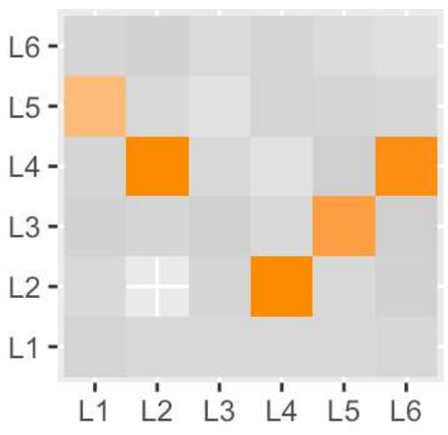
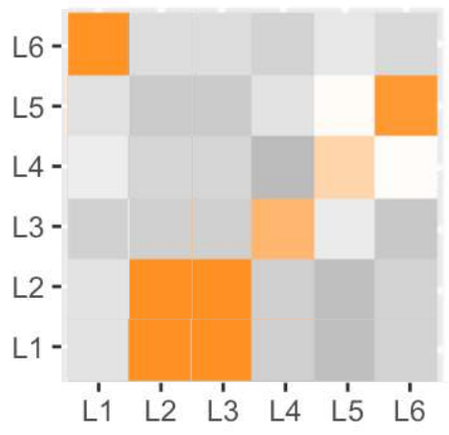


instead of turning right to scan land 6, scanner turned left and scanned land 4 again



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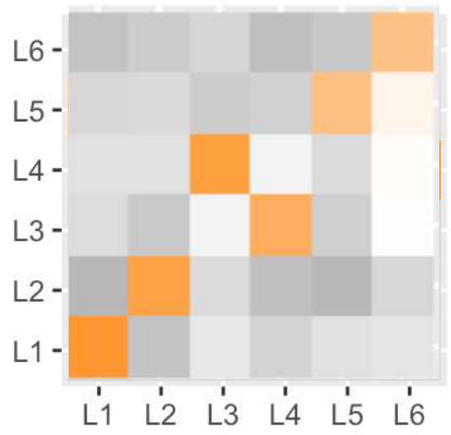

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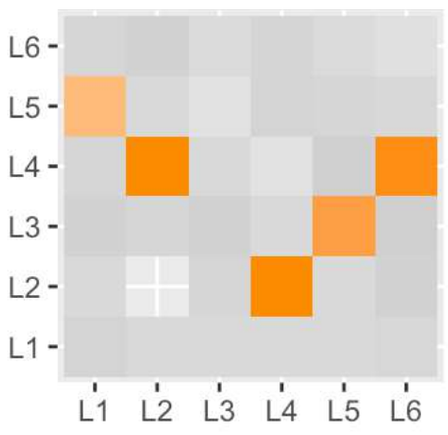

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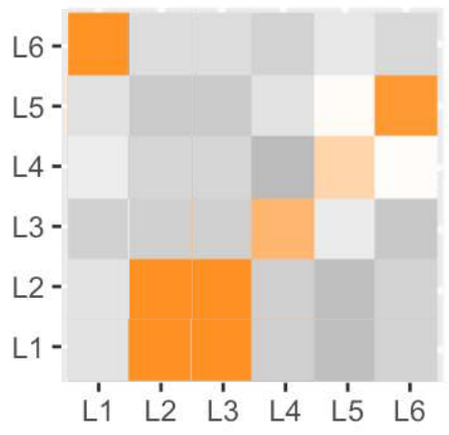

scans for land 2 and land 3 are identical

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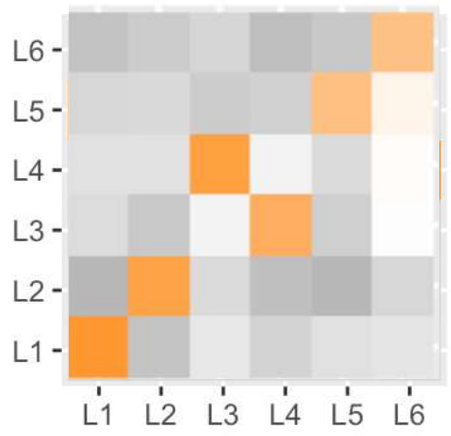
Using the RF Score for diagnostics

★ Land-to-land matches for two bullets show oddities



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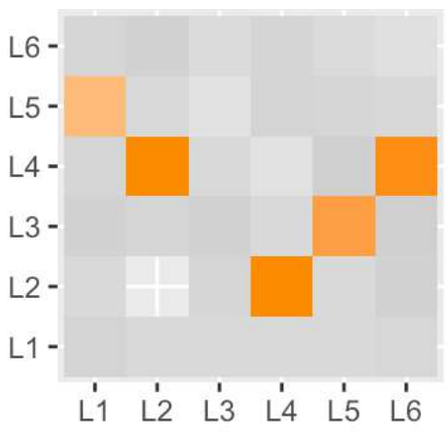

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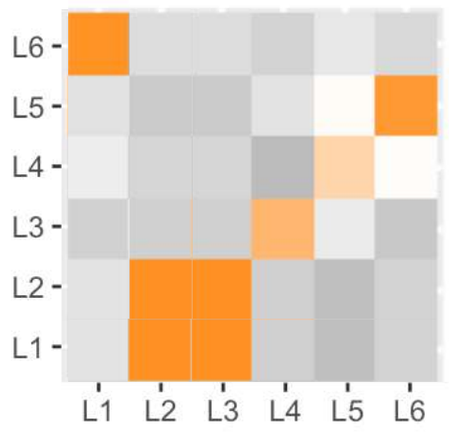

scans for land 2 and land 3 are identical

These things went wrong in our scanning lab

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Summary & further work

- ★ Random Forest Model provides interpretable and consistent scores for quantifying identifications
  - ★ matching clones to original bullets - assess clone quality
  - ★ matching bullets between Hamby sets
  - ★ quantification of bullet and scan deficiencies
- ★ Visualizations with increased context used for diagnostics
- ★ Limitations: traditional rifling only (LEAs are matched)

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Thank You!

Questions?

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ISU CSAFE bullet team

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