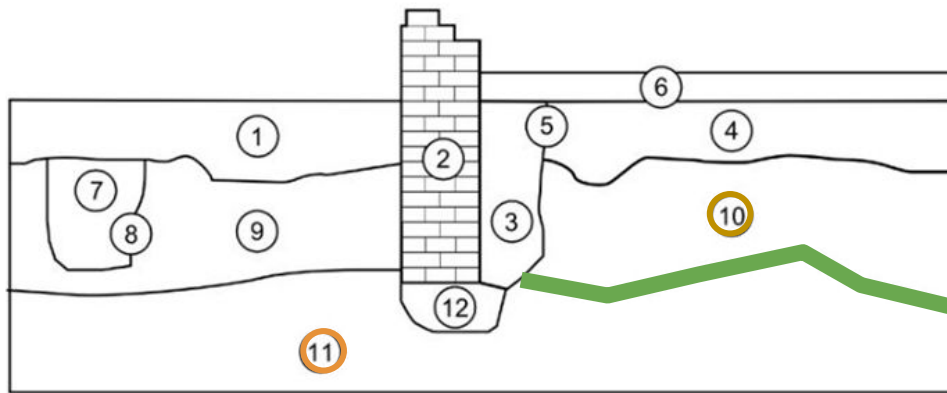
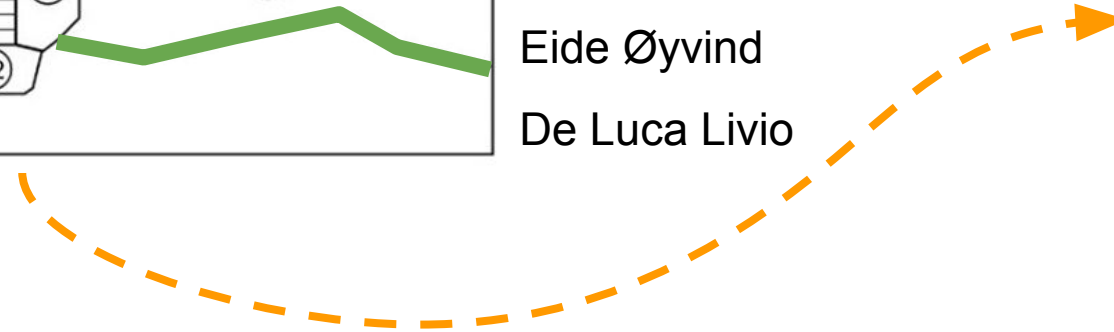
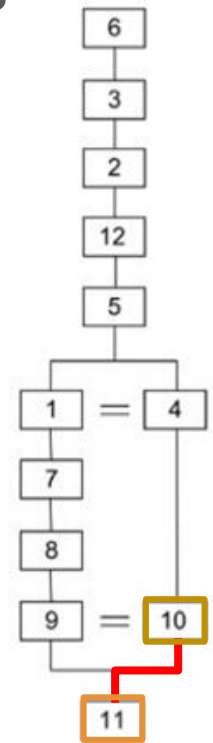


# Spatio-Temporal Reasoning on Stratigraphic Data in Archaeology: Formalization of the Harris Laws as Inferences Using CIDOC CRM



Guillem Anaïs  
Van Ruymbeke Muriel  
Eide Øyvind  
De Luca Livio



30-31 October 2024

SWODCH'24:

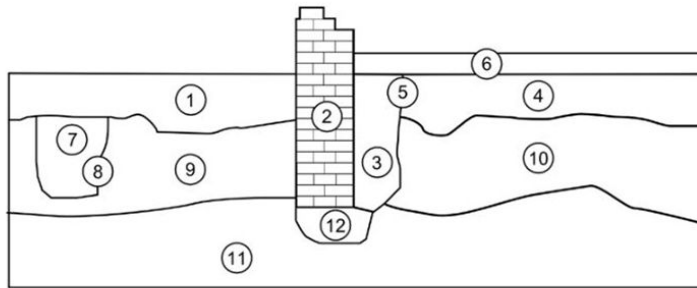
International Workshop on Semantic Web and Ontology Design for Cultural Heritage 2024,  
Maison des Sciences de l'Homme Val de Loire, Tours, France





© Hervé Paillet, Inrap

[3]



[1]

**Parks Canada Ontario Service Centre  
Archaeological Services**

**LOT SUMMARY**

Date Began: 29.7.04	Crew: H. Cary	Site: 15114 Fort Henley
Date Ended: 29.7.04		Lot No.: 15114 L29

**Nature of Lot:**

<input type="checkbox"/> Present Soil	<input type="checkbox"/> Bulked Soil	<input type="checkbox"/> Invasion	<input type="checkbox"/> Sample
<input type="checkbox"/> Deposition Level	<input type="checkbox"/> Interface	<input type="checkbox"/> Feature	<input type="checkbox"/> Lot Extension/Link
<input checked="" type="checkbox"/> Fills	<input type="checkbox"/> Artificial Cluster	<input type="checkbox"/> Natural Shale	<input type="checkbox"/> Other

Soil Description: CHIRONOM, CLAY AND SAND OCCUPATIONAL FILL

**Soil Type:**

Color: DARK GREYISH BROWN (10YR4/5), YELLOWISH BROWN (10YR5/6) AND GREY (10YR6/1)

Composition: FRAGILE CLAY AND 10% GREY SAND

Consistency: MEDIUM

Rock Particle Size (%): 10% AQUEOUS LIMESTONE SPALL AVERAGING 17 x 5 cm

**Spatial Characteristics:**

Dimensions/Shape and Extent: RECTANGULAR 1.05m x 0.8m.

Block Topography: GRADUAL SLOPE TO SOUTHWEST WITH HIGHLY UNDULATING TOP SURFACE

Thickness and Range: 6-15cm. THINNEST IN SOUTH AND THICK TO NORTH. AVERAGES 12cm THICK

**Excavation Method:**

<input checked="" type="checkbox"/> Hand Trowel	<input type="checkbox"/> Shovel	<input checked="" type="checkbox"/> Screened - 4mm	<input type="checkbox"/> Pinned
<input type="checkbox"/> Not Excavated	<input type="checkbox"/> Backhoe	<input type="checkbox"/> Over	

**Mode of Deposition:**

MODE: <input type="checkbox"/> Natural	<input type="checkbox"/> Primary	<input checked="" type="checkbox"/> Deposition	<input type="checkbox"/> Multiple Deposition	<input type="checkbox"/> Unknown	COUP D'UNGE: <input checked="" type="checkbox"/> H	<input type="checkbox"/> M	<input type="checkbox"/> L
DURATION: <input checked="" type="checkbox"/> Single Event	<input type="checkbox"/> Accum. Over Time	<input type="checkbox"/> Unknown			<input type="checkbox"/> H	<input checked="" type="checkbox"/> M	<input type="checkbox"/> L
ARTIFACTS: <input type="checkbox"/> De Facto	<input checked="" type="checkbox"/> Primary	<input type="checkbox"/> Secondary	<input type="checkbox"/> Unknown		<input checked="" type="checkbox"/> H	<input type="checkbox"/> M	<input type="checkbox"/> L

**Interpretive Notes:** MATURED CLAY, CHIRONOM AND SAND DEPOSIT PROBABLY DATING TO OFFICERS' BARRACKS OCCUPYING C. 1820-61. HIGH NUMBER OF ARTIFACTS IN GOOD CONDITION SUGGESTS DEPOSIT WAS NOT DISTURBED BY DEMOLITION. MANY HIGH END ITEMS, PERHAPS CLEAN-UP ITEMS UNIDENTIFIED. VERY SIMILAR TO MATERIAL UNCOVERED OVER BURDEN IN 151116F.

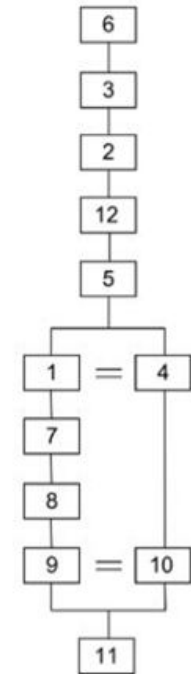
Continued on additional page

**Lot Relation:**

Above: 33	28	26			
Below: 28, 26					
Flank: 24					
Core: 33					

**Diagnostic Important Finds:** NEAR COMPLETE STEW GRILL, TIMBER BASE, CERAMIC CHAMBER POT RIM, WEARABLE ITEMS, HIGH NUMBER OF FISH AND ANIMAL BONES (SOME QUANTIFIED)

[2]



[1]

[1]

Mantegari, Glauco, Alessandro Mosca, and Maurizio Cattani. 2007. Formal Knowledge Representation and Automated Reasoning for the Study of Archaeological Stratigraphy.

[2]

Cary, Henry C, and Joseph H Last. "For the Record: The What, How and When of Stratigraphy." For the Record, no. 83 (2007).

[3]

[https://www.images-archeologie.fr/Accueil/Recherche/p-3-lg0-notice-IMAGE-Deux-archeologues-relevant-une-coupe-stratigraphique-du-fosse-de-l-enceinte..htm?&notice\\_id=3906](https://www.images-archeologie.fr/Accueil/Recherche/p-3-lg0-notice-IMAGE-Deux-archeologues-relevant-une-coupe-stratigraphique-du-fosse-de-l-enceinte..htm?&notice_id=3906)

# Onsite excavation documentation of a stratigraphic unit: example of stratigraphic unit form

## Pros:

- A long tradition of documentation practice in the field
- Methodology
- Normalized documentation

## Cons:

- semantic modeling and data sharing are not yet common place in archaeology
- granularity of documentation

Cary, Henry C, and Joseph H Last. "For the Record: The What, How and When of Stratigraphy." For the Record, no. 83 (2007).

Parks Canada Ontario Service Centre  
Archaeological Services

LOT SUMMARY

Date Began: 29.7.04	Crew: H. Cary	Site: 1314 FORT HENRY
Date Ended: 29.7.04		Lot No.: 131416 L29

Nature of Lot:

<input type="checkbox"/> Recent Soil	<input type="checkbox"/> Rutted Soil	<input type="checkbox"/> Intrusion	<input type="checkbox"/> Sample
<input type="checkbox"/> Occupation Level	<input type="checkbox"/> Interface	<input type="checkbox"/> Feature	<input type="checkbox"/> Lot Extension/Back
<input type="checkbox"/> Fill	<input type="checkbox"/> Artifact Cluster	<input type="checkbox"/> Natural Strata	<input type="checkbox"/> Other

Brief Description: CHARCOAL, CLAY AND SAND OCCUPATION FILL

Soil Type:

Colour: DARK GREYISH BROWN (10YR4/2), YELLOWISH BROWN (10YR5/6) AND GREY (10YR6/1)

Composition: FRAGILE CLAY AND 10% GREY SAND

Consistency: MODERATE

Rock Particle Size (%): 10% ANGULAR LIMESTONE SPALL AVERAGE 17 x 5 x 5 cm

Spatial Characteristics:

Dimension/Shape and Extent: RECTANGULAR 1.05m x 0.8m.

Slope/Terrain: GRADUAL SLOPE TO SOUTHWEST WITH SLIGHTLY UNDULATING TOP ELEVATION

Thickness and Range: 6-13cm. THICKEST IN SOUTH AND THINS TO NORTH. AVERAGE 12cm THICK

Excavation Method:

<input checked="" type="checkbox"/> Hand Trowel	<input type="checkbox"/> Shovel	<input checked="" type="checkbox"/> Screened - 4mm	<input type="checkbox"/> Flashed
<input type="checkbox"/> Not Excavated	<input type="checkbox"/> Backhoe	<input type="checkbox"/> Other	

Mode of Deposition:

MODE: <input type="checkbox"/> Natural	<input type="checkbox"/> Primary	<input checked="" type="checkbox"/> Displaced	<input type="checkbox"/> Multiple Displaced	<input type="checkbox"/> Unknown	CONFIDENCE: <input checked="" type="checkbox"/> H	<input type="checkbox"/> M	<input type="checkbox"/> L
DURATION: <input checked="" type="checkbox"/> Discrete Event	<input type="checkbox"/> Accum. Over Time	<input type="checkbox"/> Unknown			<input type="checkbox"/> H	<input checked="" type="checkbox"/> M	<input type="checkbox"/> L
ARTIFACTS: <input type="checkbox"/> De facto	<input checked="" type="checkbox"/> Primary	<input type="checkbox"/> Secondary	<input type="checkbox"/> Unknown		<input checked="" type="checkbox"/> H	<input type="checkbox"/> M	<input type="checkbox"/> L

Interpretive Notes: MOTTLED CLAY, CHARCOAL AND SAND DEPOSIT PROBABLY DATING TO OFFICERS' BARRACKS OCCUPATION C. 1820-41. HIGH NUMBER OF ARTIFACTS IN GOOD CONDITION SUGGESTS DEPOSIT WAS NOT DISTURBED BY DEMOLITION. MANY HIGH END ITEMS, PERHAPS CLEAN-UP DURING INHABITATION. VERY SIMILAR TO MATERIAL UNCOVERED OVER BEDROCK IN 131416F.

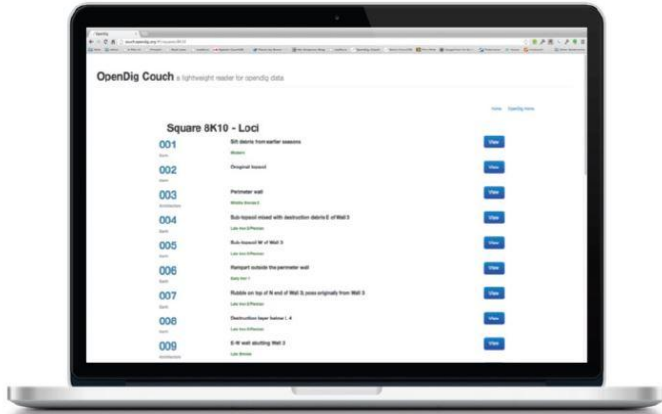
Continued on additional page

Lot Relation:

Above: 33	28	26				
Below: 20, 26	29					
Out: 33						
Out by:						

Diagnostic/Important Finds: NEAR COMPLETE STEEL GLASS, TUMBLER BASE, CROWNGLASS CIGARETTE PPT PAN, WROUGHT NAILS, HIGH NUMBER OF FISH AND ANIMAL BONES (SOME COLLECTED)

# Recording excavation data: OpenDig [1], Syslat [2], AIR [3]...



Portable OpenDig Field Server



OpenDig field-recording application for iOS

[1] Vincent, Matthew L., Falko Kuester, and Thomas E. Levy. 2013. "OpenDig: In-Field Data Recording for Archaeology and Cultural Heritage." In 2013 Digital Heritage International Congress (DigitalHeritage), 2:539–42. IEEE.  
[https://ieeexplore.ieee.org/abstract/document/6744823/?casa\\_token=pXxjxJqTga4AAAAA:DAWIGdisIdVKOETmQQ2USAJ4VMSsGXbEVsvUOj7Croepgd1\\_E2Ze7UI-U0B7sao61HnxK90OpHs](https://ieeexplore.ieee.org/abstract/document/6744823/?casa_token=pXxjxJqTga4AAAAA:DAWIGdisIdVKOETmQQ2USAJ4VMSsGXbEVsvUOj7Croepgd1_E2Ze7UI-U0B7sao61HnxK90OpHs).

[2] Roure, Réjane, Sébastien Munos, Hakima Manseri, and Michel Py. 2021. "Towards an Archaeological Information System: The Evolution of Syslat, an Archaeological Data Management Software." In Big Data and Archaeology. Proceedings of the XVIII UISPP World Congress (4–9 June 2018, Paris, France), edited by François Djindjian and Paola Moscati, 15:62–70. Archaeopress. <https://hal.science/hal-04228247>.

[3] Derudas, P., Nurra, F., & Svensson, A. (2023). New AIR for the Archaeological Process? The use of 3D web Semantic for Publishing Archaeological Reports. ACM Journal on Computing and Cultural Heritage, 16(3), 1-23.

# Archiving excavation data: example of OpenContext:

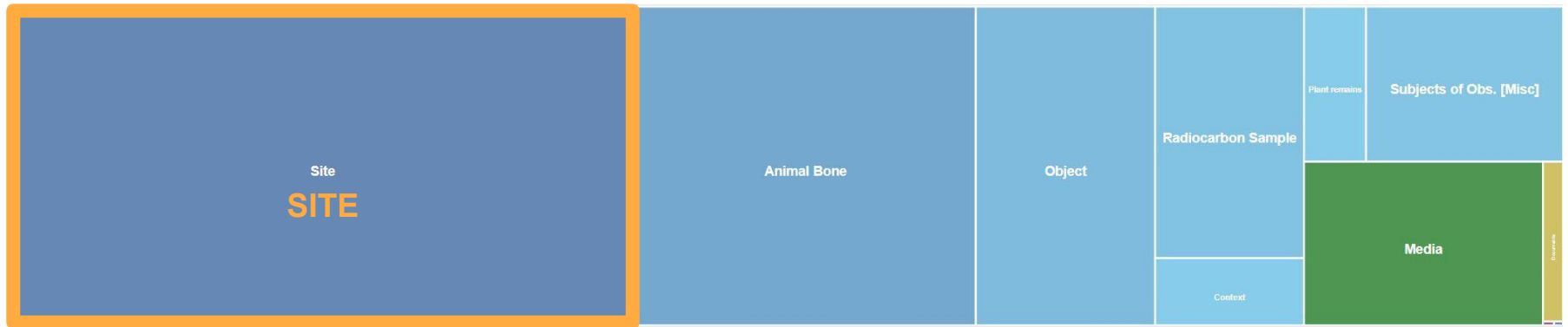


Fig.: relative proportion of different types of content published by Open Context.

Example of Ariadne: <https://portal.ariadne-infrastructure.eu/search?q=stratigraphy%20site>

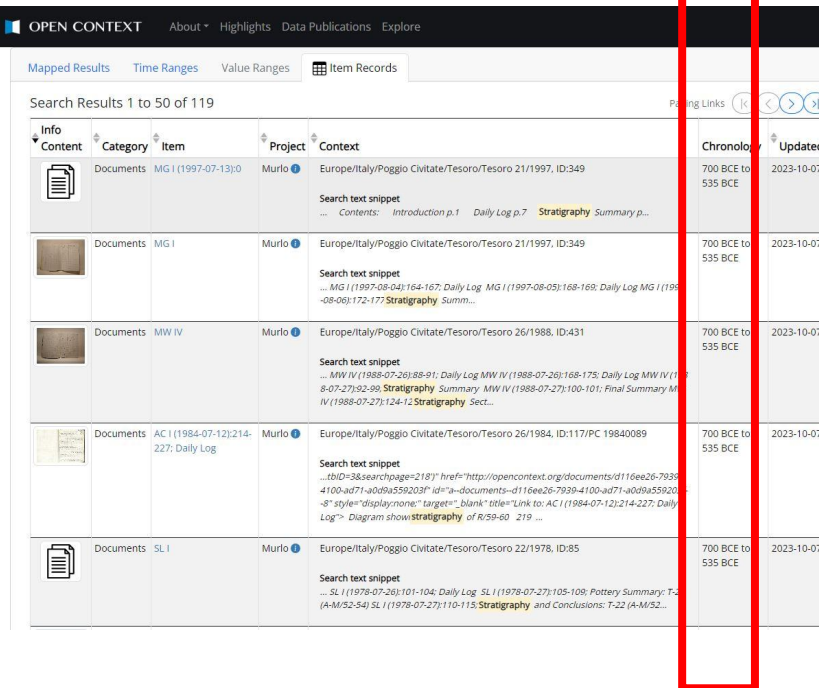
Example of OpenArcheo:

[Talk on SPARNATURAL, a knowledge graph visual query system, and its use in OpenArcheo, a portal of archaeological knowledge graphs by Thomas FRANCAERT (SPARNA) and Florian HIVERT (Université de Tours/MSH), 30/10/2324, SWODCH'24]

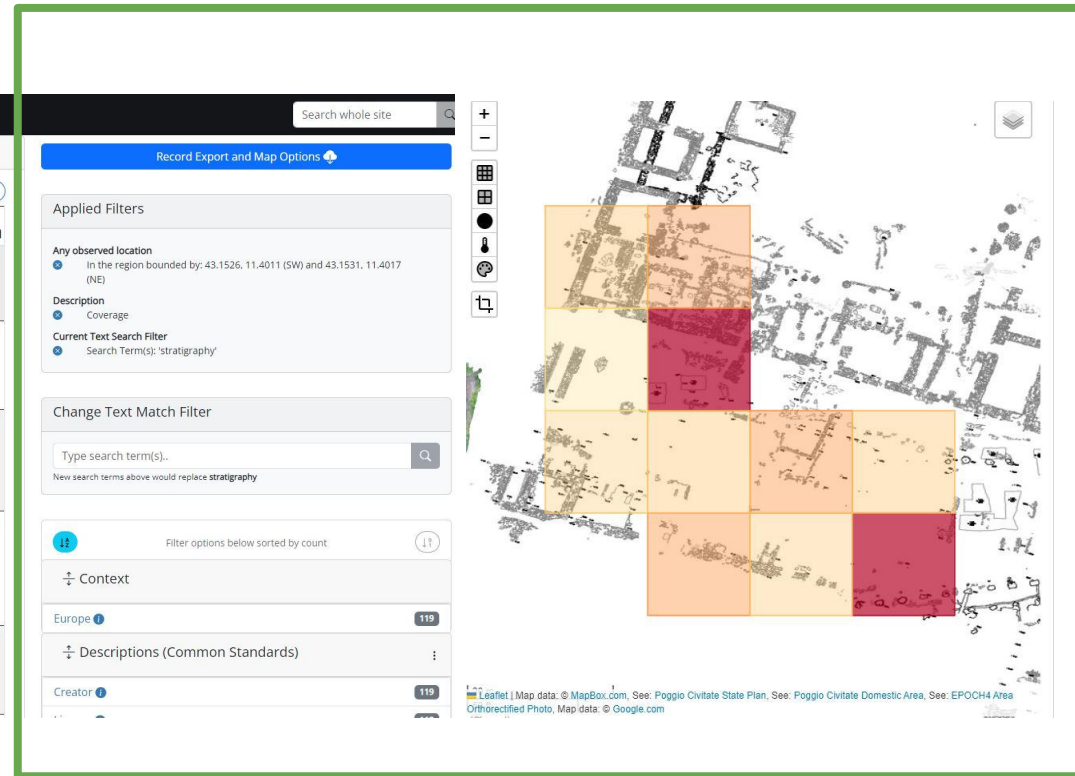
# Identified problem: uncorrelated temporal and spatial information

temporal  
information

place and spatial information



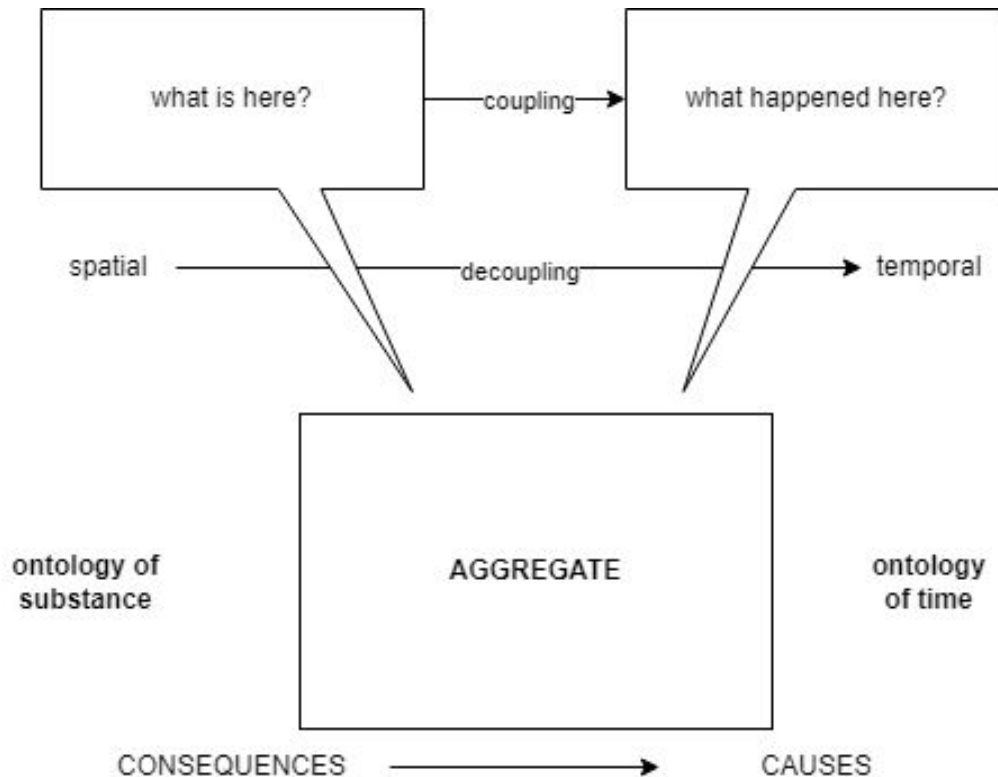
Info	Content	Category	Item	Project	Context	Chronology	Updated
	Documents	MG I (1997-07-13):0	Murlo	Europe/Italy/Poggio Civitate/Tesoro/Tesoro 21/1997, ID:349	Search text snippet ... Contents: Introduction p.1 Daily Log p.7 Stratigraphy Summary p...	700 BCE to 535 BCE	2023-10-07
	Documents	MG I	Murlo	Europe/Italy/Poggio Civitate/Tesoro/Tesoro 21/1997, ID:349	Search text snippet ... MG I (1997-08-04):164-167; Daily Log MG I (1997-08-05):168-169; Daily Log MG I (1997-08-06):172-177 Stratigraphy Summ...	700 BCE to 535 BCE	2023-10-07
	Documents	MW IV	Murlo	Europe/Italy/Poggio Civitate/Tesoro/Tesoro 26/1988, ID:431	Search text snippet ... MW IV (1988-07-26):88-91; Daily Log MW IV (1988-07-26):168-175; Daily Log MW IV (1988-07-27):92-99; Stratigraphy Summary MW IV (1988-07-27):100-101; Final Summary MW IV (1988-07-27):124-12 Stratigraphy Sect...	700 BCE to 535 BCE	2023-10-07
	Documents	AC I (1984-07-12):214-227; Daily Log	Murlo	Europe/Italy/Poggio Civitate/Tesoro/Tesoro 26/1984, ID:117/PC 19840089	Search text snippet ... (ID=3&searchpage=218)" href="http://opencontext.org/documents/d116ea26-7939-4100-ad71-a0d9a559203f" id="a-documents-d116ea26-7939-4100-ad71-a0d9a559203f" style="display:none; target="; blank" title="Link to: AC I (1984-07-12):214-227; Daily Log"> Diagram shows Stratigraphy of R/59-60 219 ...	700 BCE to 535 BCE	2023-10-07
	Documents	SL I	Murlo	Europe/Italy/Poggio Civitate/Tesoro/Tesoro 22/1978, ID:85	Search text snippet ... SL I (1978-07-26):101-104; Daily Log SL I (1978-07-27):105-108; Pottery Summary: T-2 (A-M/52-54) SL I (1978-07-27):110-115; Stratigraphy and Conclusions: T-22 (A-M/52...	700 BCE to 535 BCE	2023-10-07



<https://opencontext.org/query/?allevent-geotile=1202320222213033100&prop=dc-terms-coverage&q=stratigraphy#tab=3/ovgrd=oc/zm=20/lat=43.15285/long=11.40141/ov=sq>



# Archaeological theory of aggregate: Reasoning about space and time



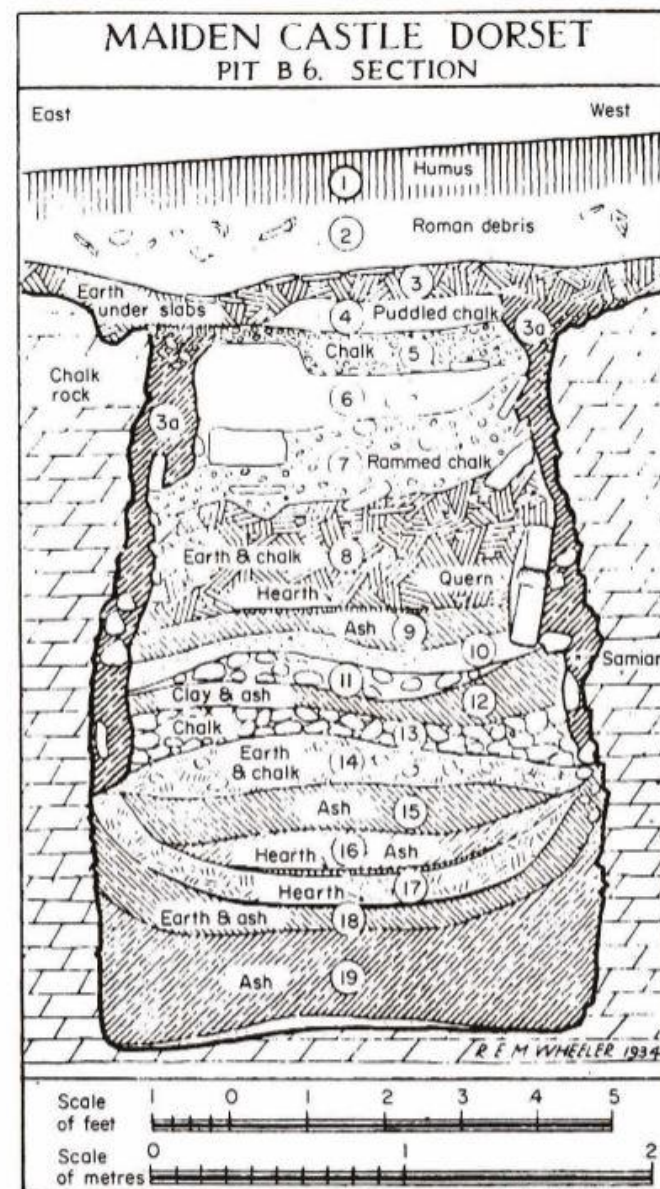
How to apply a consistent modeling and reasoning to the decoupling spatial/temporal?

[Boissinot, Philippe. 2015. Qu'est-ce qu'un fait archéologique? Éditions EHESS.  
translation authors]

# Archaeological stratigraphy

- Archaeological stratigraphy is the study of layered deposits or strata for understanding the chronological sequence of past human activity.
- A Harris Matrix is a stratification diagram used in archaeology to express the sequence of deposition of contexts, reflecting relative chronology rather than absolute time, and aiding in the interpretation of site development and material culture analysis.

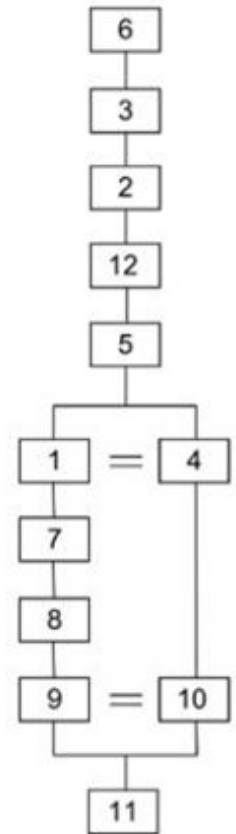
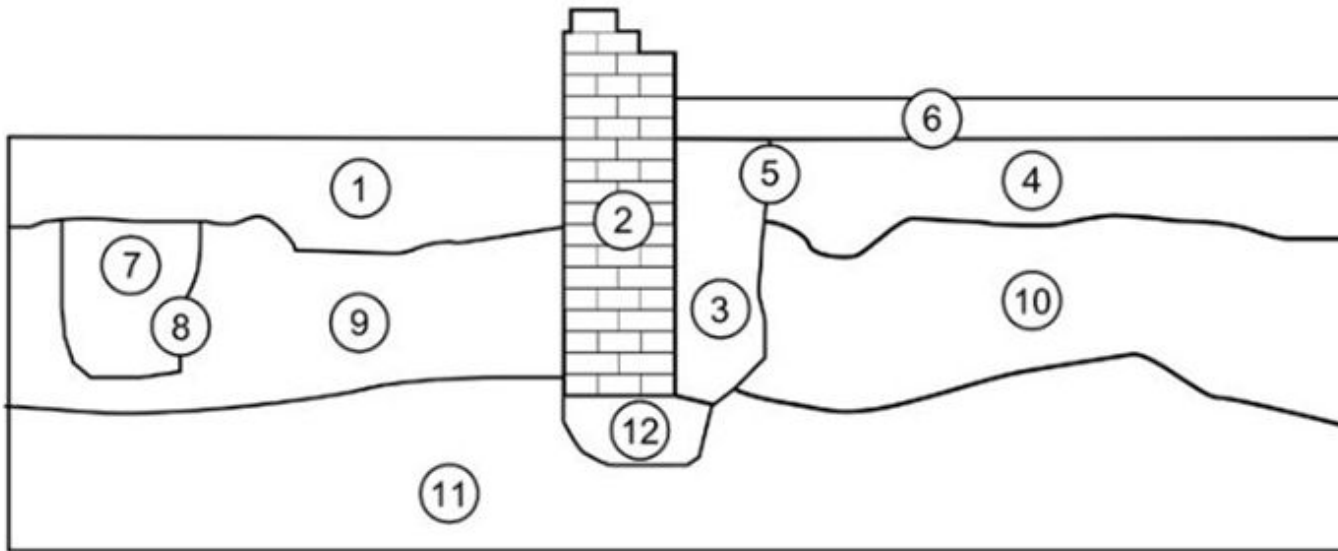
[Harris, *The Principles of Archaeological Stratigraphy*, 1979, fig.2, p.12]



**Fig. 2** This section drawing, made by Mortimer Wheeler in 1934, is one of the earliest to contain 'layer numbers' (from Wheeler 1943: fig. 10; courtesy of the Society of Antiquaries of London).



# Theoretical example of stratigraphy analysis and Harris matrix



#a: hypothetical excavation section drawing

#b: resulting Harris matrix

#a

#b

[Mantegari, Glauco, Alessandro Mosca, and Maurizio Cattani. 2007. Formal Knowledge Representation and Automated Reasoning for the Study of Archaeological Stratigraphy.]

# State-of-the-art: Mantegari et al. [17]

Modelling of stratigraphy using knowledge representation and performing automated reasoning on spatial and temporal aspects of archaeological data.

AnsProlog to define prolog rules

- Description of primitive spatial relations: cover, cut, fill, leanOn, attachTo, equalTo (covered, cutBy, filledBy, isLeanedOn).
- A second set of rules is defined for the primitive temporal relations: directly posterior to (dirPostTo), directly anterior to (dirAntTo), posteriorTo, anteriorTo, contemporary(X,Y).

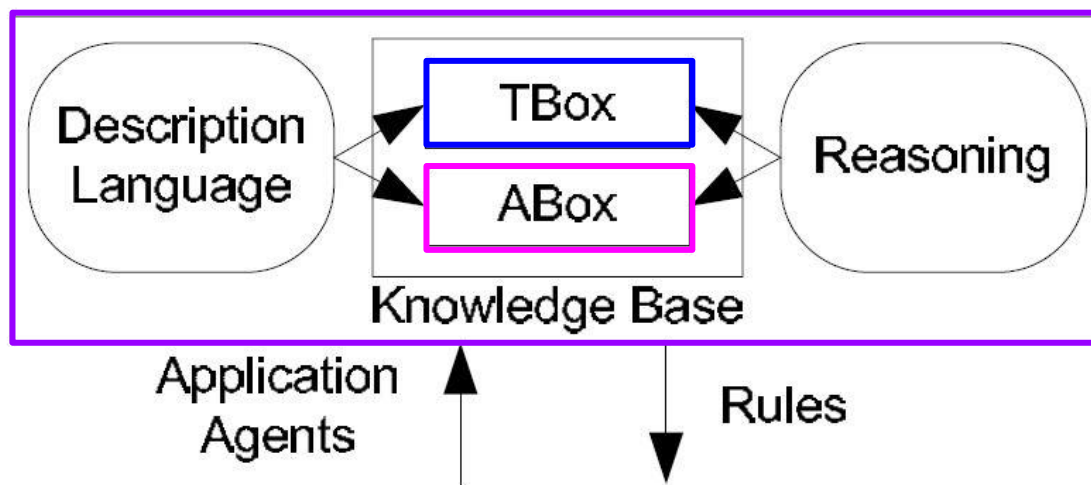
The approach proposes to map the first set with the second, using a third set of rules to translate the topological relationship into a temporal one.

This preliminary work concludes with the need to represent the rules defined by Harris in a formal way to compute the models accordingly, and to test the approach on large datasets.

[Mantegari, Glauco, Alessandro Mosca, and Maurizio Cattani. 2007. Formal Knowledge Representation and Automated Reasoning for the Study of Archaeological Stratigraphy.]

# Ontologies and knowledge domain

- general domain knowledge: **TBox** (ontology) made of a finite set of axioms
- factual knowledge about particular individuals: **ABox** (data) made of a finite set of assertions  $C(a), r(a, b)$  ( $C$  concept,  $r$  role,  $a, b$  inds)
- **DL Knowledge Base (KB)** = **TBox** (ontology) + **ABox** (data)



[Patrón, Pedro, Emilio Miguelañez, and Yvan R. Petillot. 2011. Embedded Knowledge and Autonomous Planning: The Path towards Permanent Presence of Underwater Networks. INTECH Open Access Publisher. p.205, fig.4: Knowledge Base representation system including the TBox, ABox, the description language and the reasoning components. Its interface is made of orientation rules and agent queries. (figure modified by the authors)]

# State-of-the-art: CRMarchaeo, v2.1.1, p.18

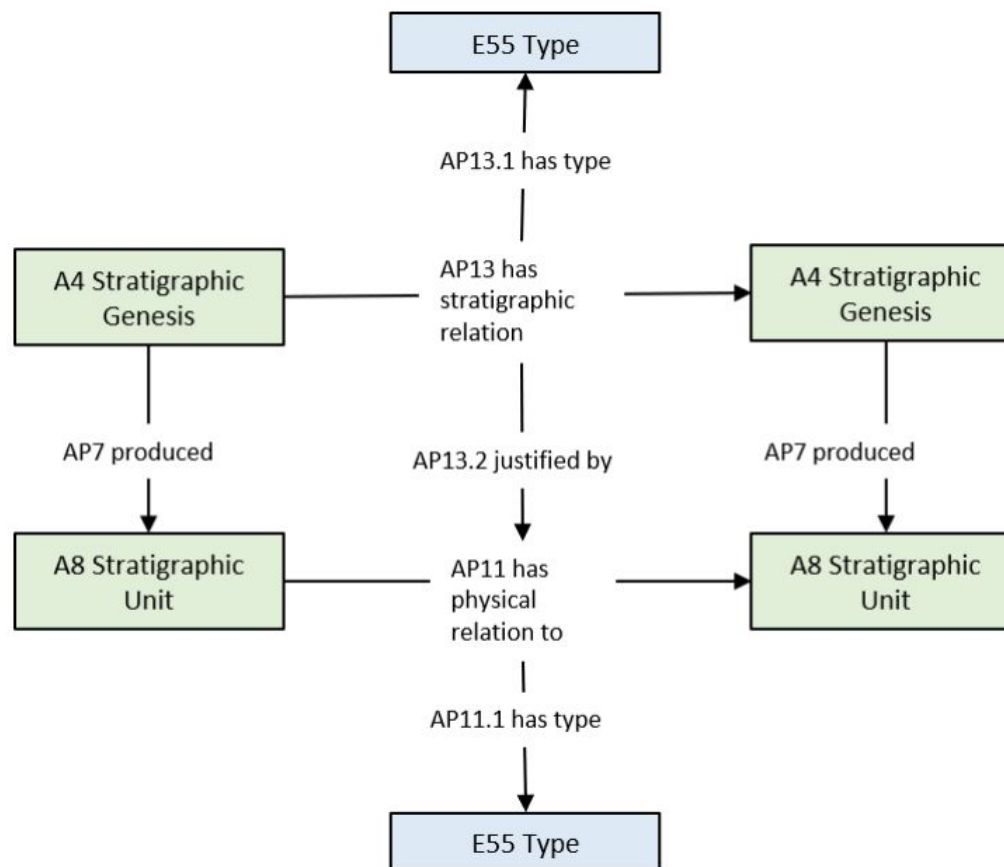


Figure 5: CRMarchaeo conceptualisation to represent stratigraphic relationships contained in Harris Matrix, being justified by physical relationships.

# State-of-the-art: Documenting time periods with CRM, SKOS, owl-time

**Table 1** relationships between time periods, with their associated inverse property

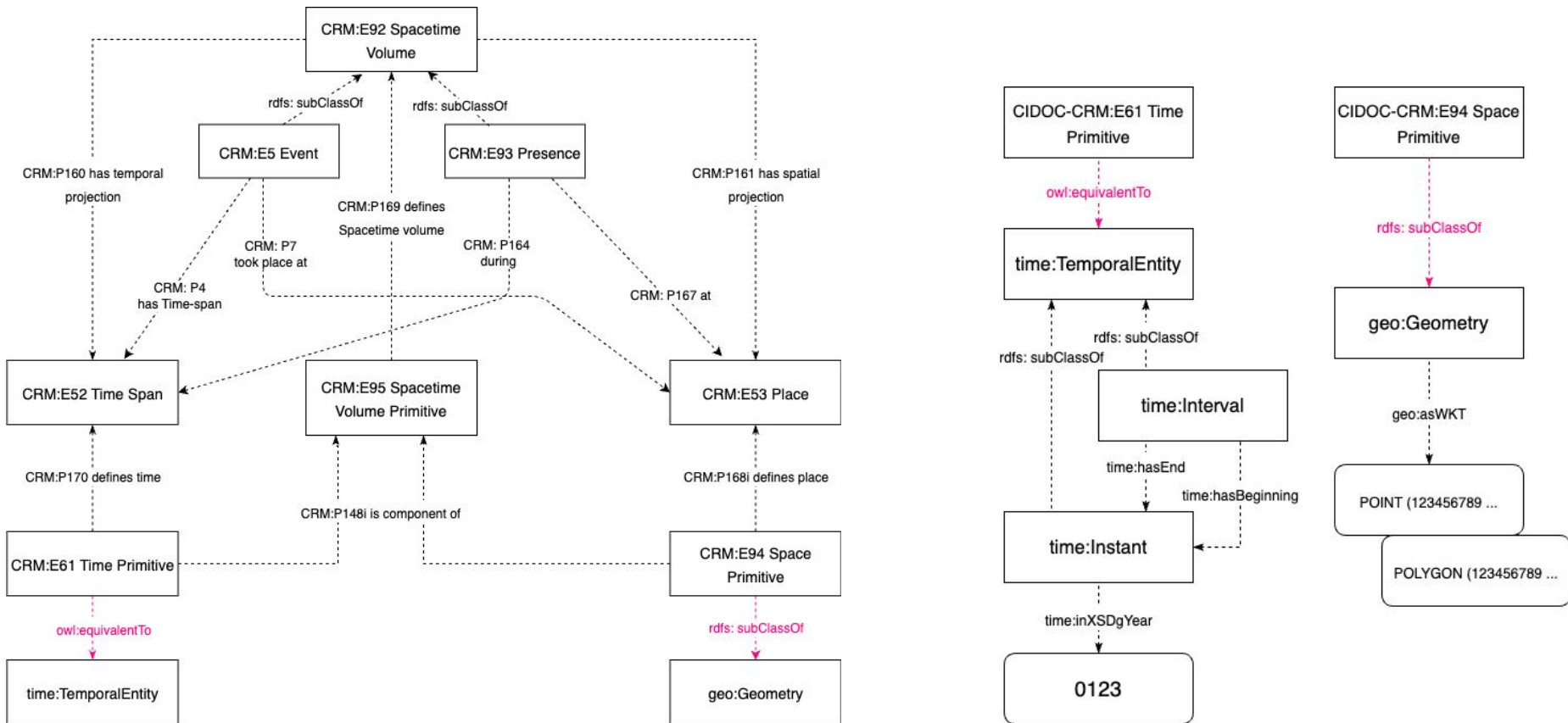
CIDOC CRM Property	OWL-Time Property	Transitive?
P114F.is_equal_in_time_to	intervalEquals	✓
P115F.finishes	intervalFinishes	✓
P115B.is_finished_by	intervalFinishedBy	
P116F.starts	intervalStarts	✓
P116B.is_started_by	intervalStartedBy	
P117F.occurs_during	intervalDuring	✓
P117B.includes	intervalContains	
P118F.overlaps_in_time_with	intervalOverlaps	
P118B.is_overlapped_in_time_by	intervalOverlappedBy	×
P119F.meets_in_time_with	intervalMeets	×
P119B.is_met_in_time_by	intervalMetBy	
P120F.occurs_before	intervalBefore	✓
P120B.occurs_after	intervalAfter	

Note: *transitive*<sup>1</sup> in Table 1 refers to relationships that are logically transitive; transitivity is not formally stated for the interval relations in the RDF implementations of CIDOC CRM and OWL-Time (the latter does however include separate transitive versions of the *before* and *after* properties). Fig. 2 shows how each of these formal relationships between periods can be deduced based on start/end dates.

[Binding, Ceri. 2010. "Implementing Archaeological Time Periods Using CIDOC CRM and SKOS." In , 273–87.  
<https://doi.org/10.1007/978-3-642-13486-9>.]

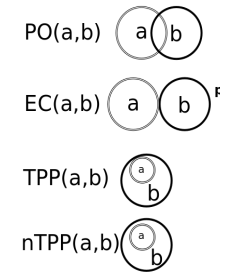
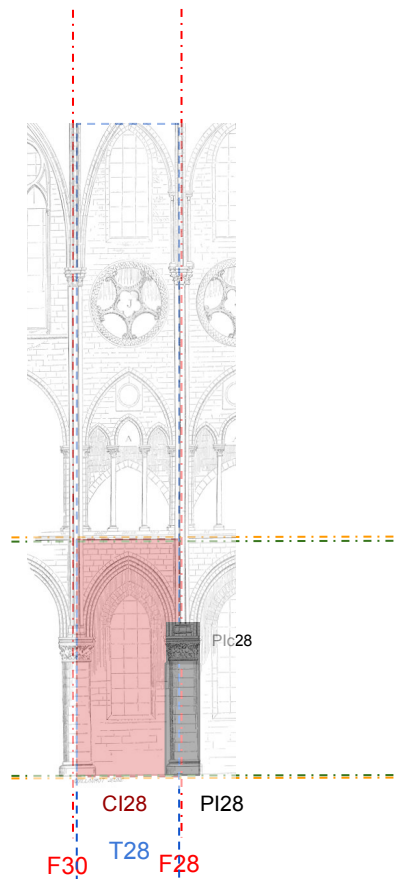
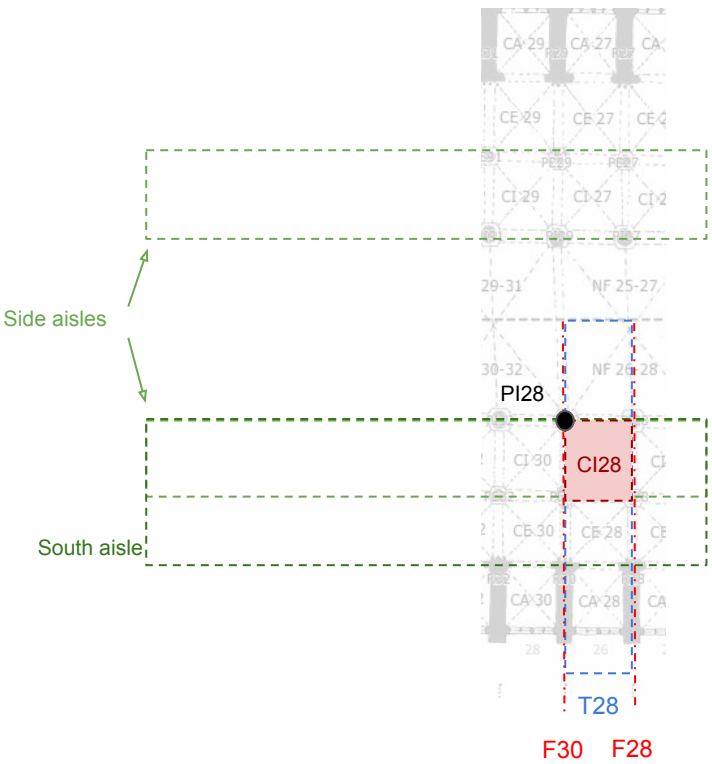


# State-of-the-art: Nys et al., 2018 / Van Ruymbeke, 2021



[Van Ruymbeke, 2021]

# State-of-the-art: documenting and reasoning about heterogeneous topological relations: Place - Object/Spatial Primitive



Implementation of RCC8 in Geosparql:  
<http://www.opengis.net/def/function/geosparql>

[Guillem et al., 2023] RCC8 for CIDOC CRM: semantic modeling of mereological and topological spatial relations in Notre-Dame de Paris, A.Guillem, A.Gros, K.Reby ; V.Abergel, L.De Luca, SWODCH 2023]



# Competency questions (1)

CQ#0.1 What is the excavation and stratigraphy documentation accessible (section drawings, SU inventory)?

CQ#0.2: Is there a Harris matrix for the considered excavation?

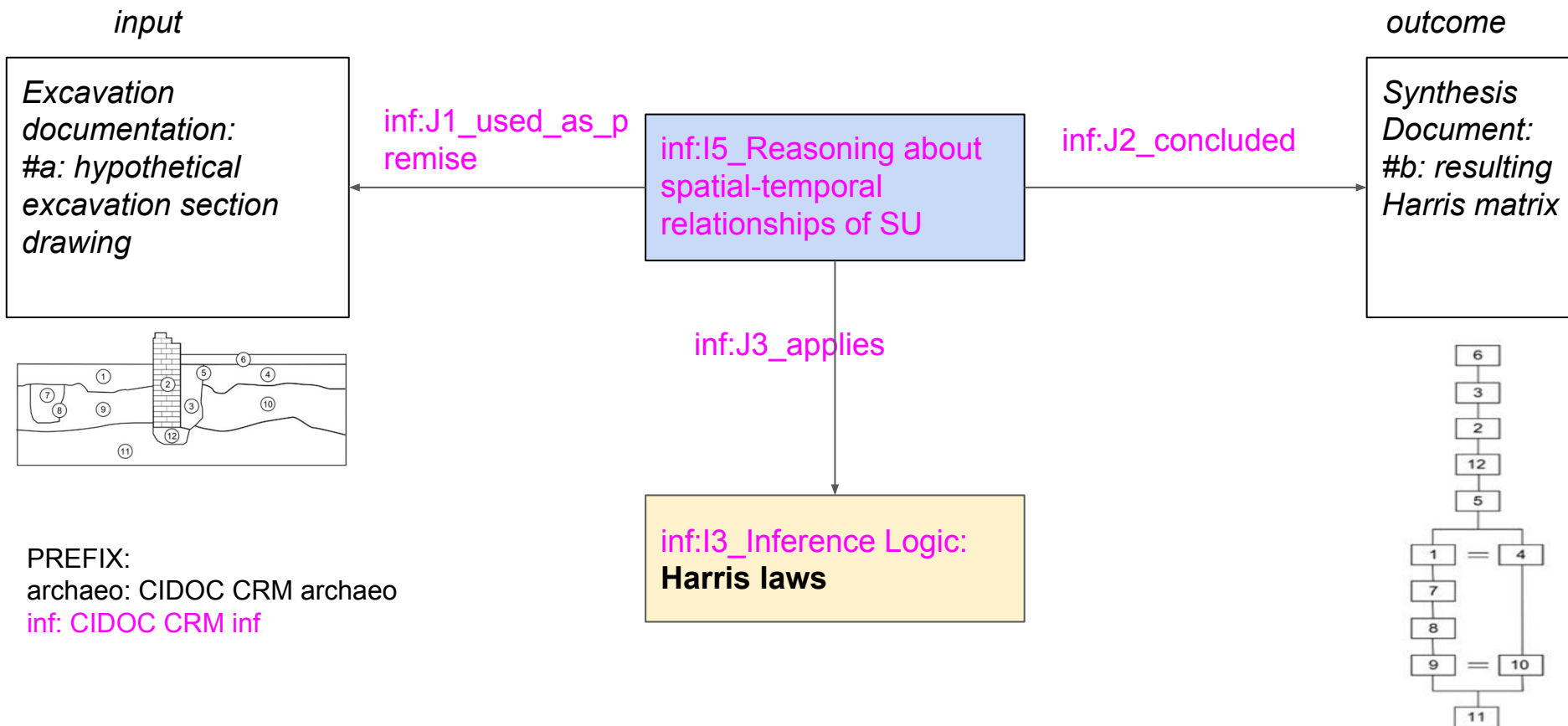
CQ#0.3: Is the reasoning about stratigraphy documented somehow?

CQ#0.4: How does the reasoning about spatio-temporal relationships of SUs applies Harris laws?

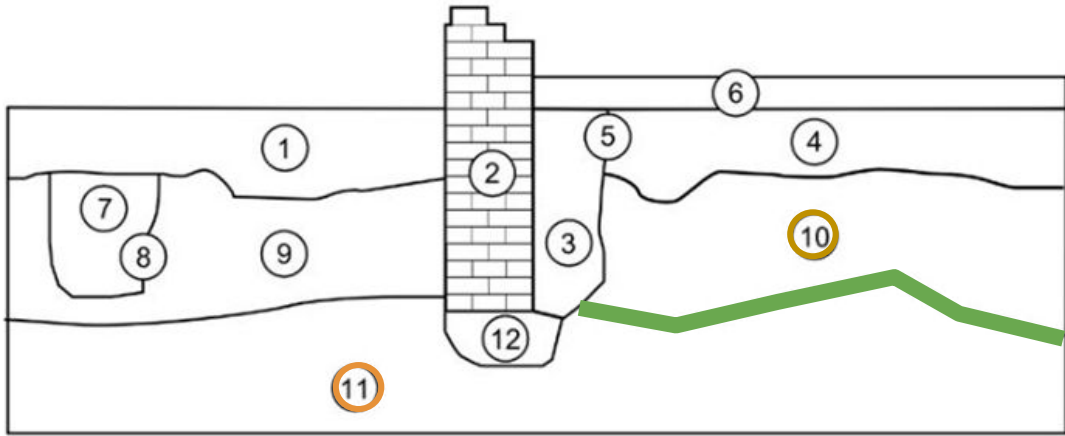
CQ#0.5: What are the Harris laws used for?

CQ#0.6: How many SUs are documented in the considered use case? what is the list of the SUs?

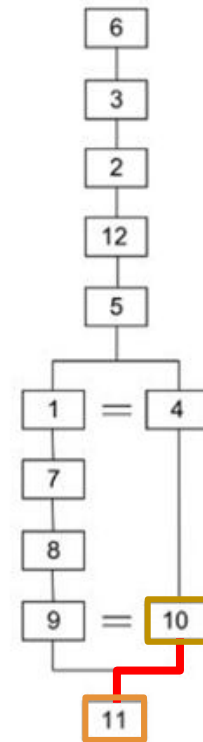
# First level of mapping with CIDOC CRM and CRMinf



# Demonstration and use case



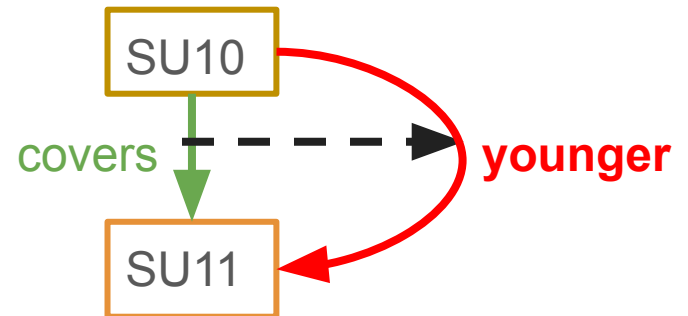
law of  
superposition



## Harris law #1: law of superposition

How to model the law of superposition as an inference using the competency questions and the existing ontologies?

Use case example:



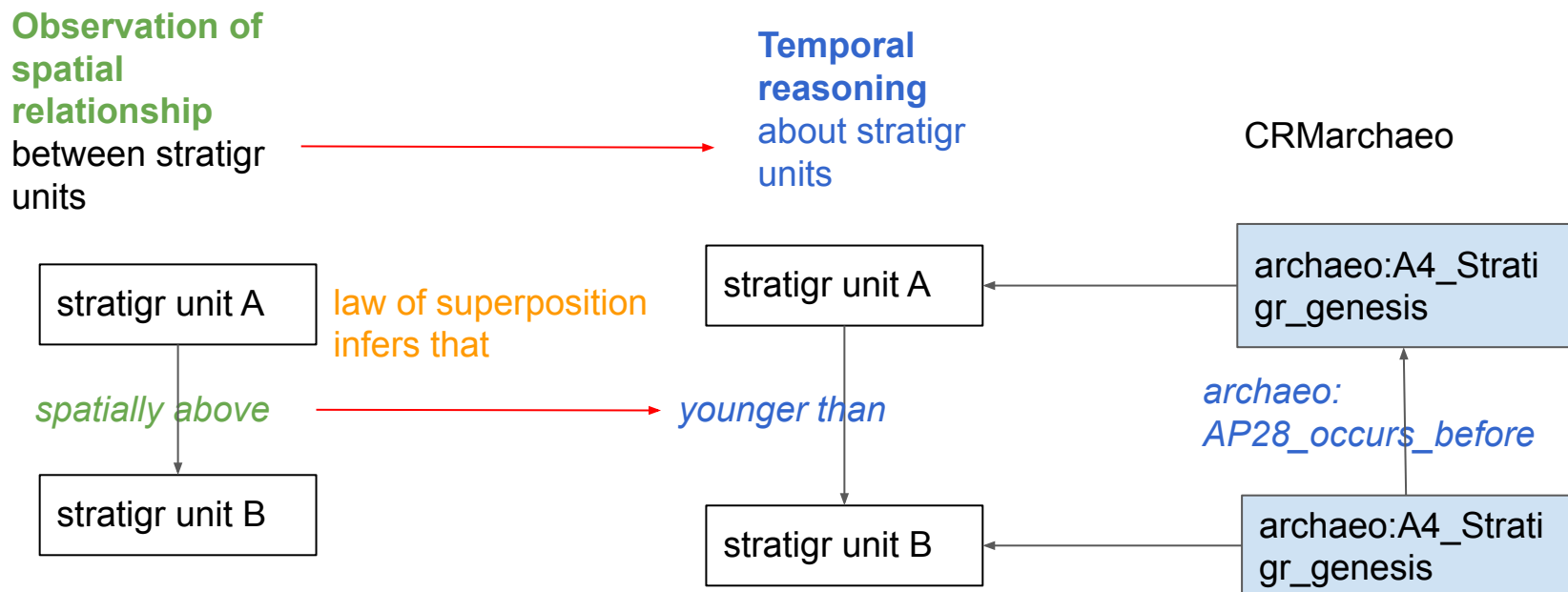


# Harris matrix -

## 1-Law of superposition

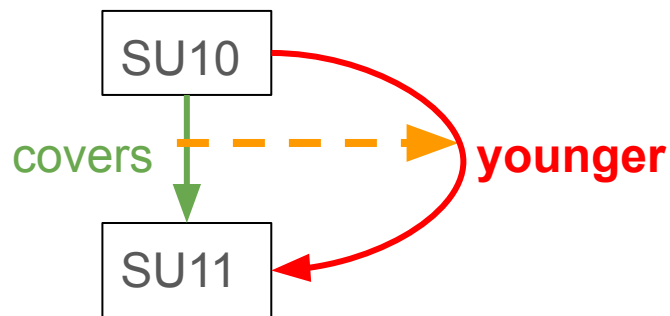
Formulation of the law of superposition:

The law of superposition states that, in a series of layers, the upper units of stratification are younger and the lower are older, for each must have been deposited on, or created by the removal of, a pre-existing mass of archaeological stratification.



# Harris matrix -

## 1-Law of superposition: competency questions

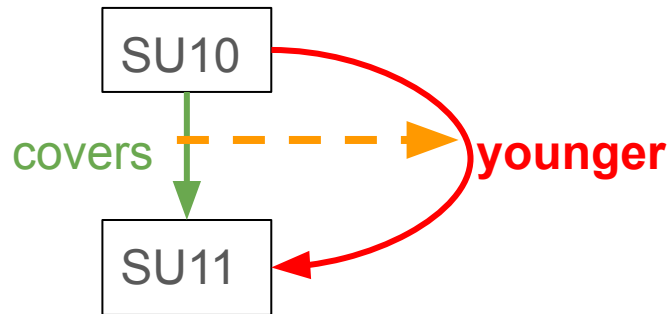


CQ#1.4: If  $SU_x$  covers  $SU_y$ , then according to the law of superposition, one can postulate that  $SU_x$  should be after  $SU_y$  unless proven otherwise.

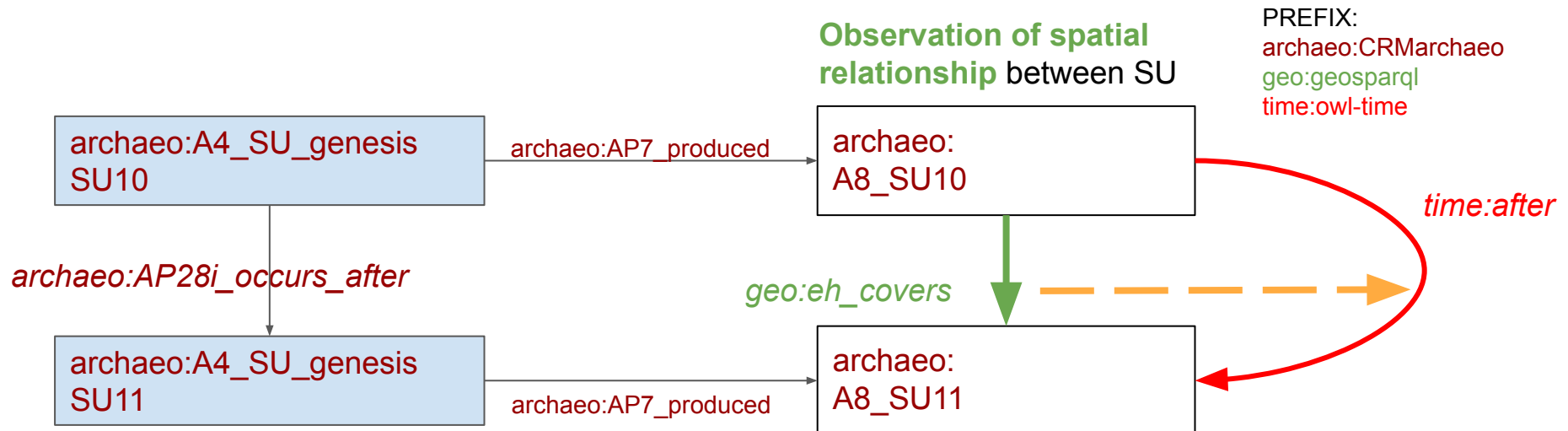
- CQ#1.1 In which use case, does the law of superposition apply?
- CQ#1.2 In which use case, does the law of superposition not apply?
- CQ#1.3 What is the law of superposition?
- **CQ#1.4** If  $SU_x$  covers  $SU_y$ , then according to the law of superposition, one can postulate that  $SU_x$  should be after  $SU_y$  unless proven otherwise.

# Harris matrix -

1-Law of superposition - most common example modeled with CRM *archaeo*, *geosparql*, and *owl-time*:

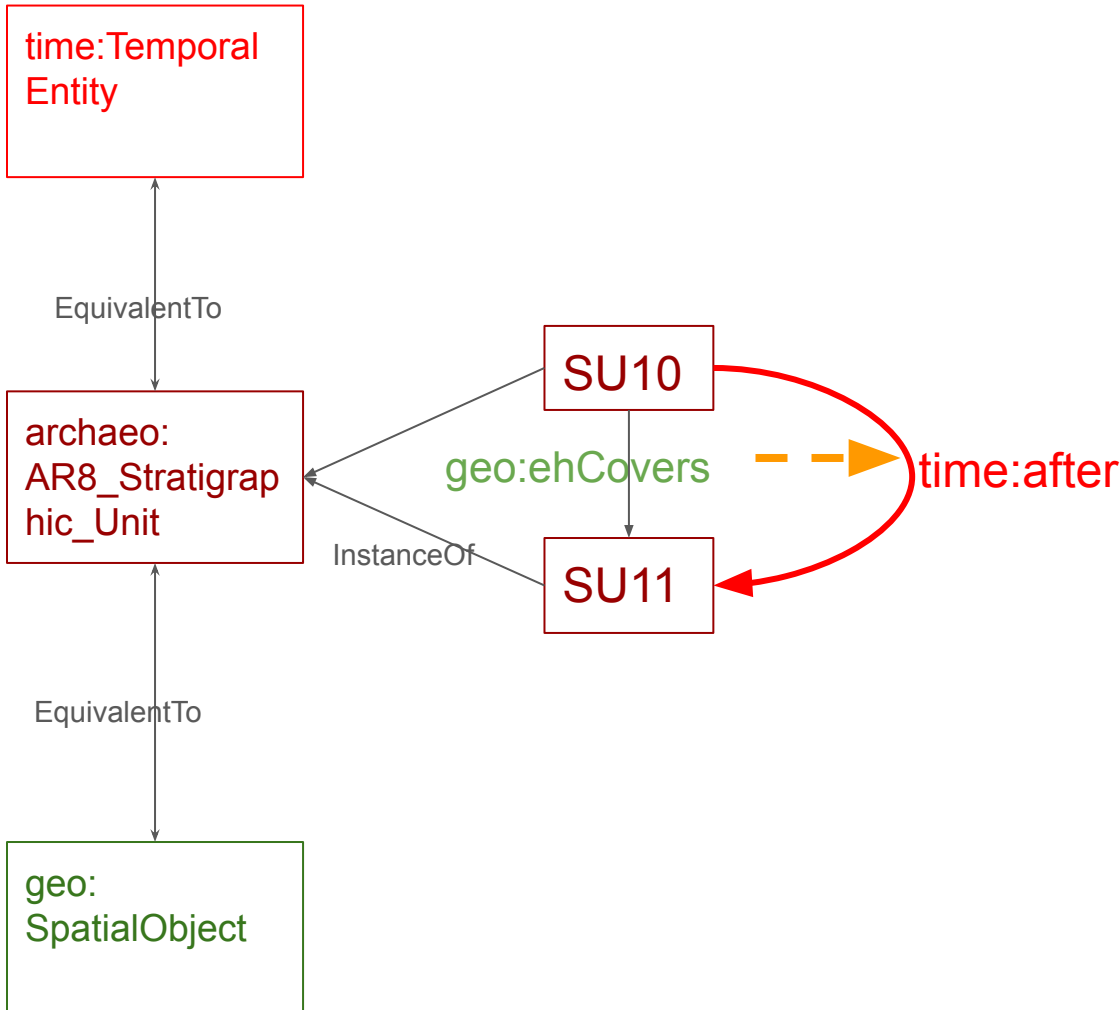


CQ#1.4: If *SU<sub>x</sub>* covers *SU<sub>y</sub>*, then according to the law of superposition, one can postulate that *SU<sub>x</sub>* should be after *SU<sub>y</sub>* unless proven otherwise.



# Harris matrix -

1-Law of superposition - most common example modeled with an **inference (SWRL rule)**:

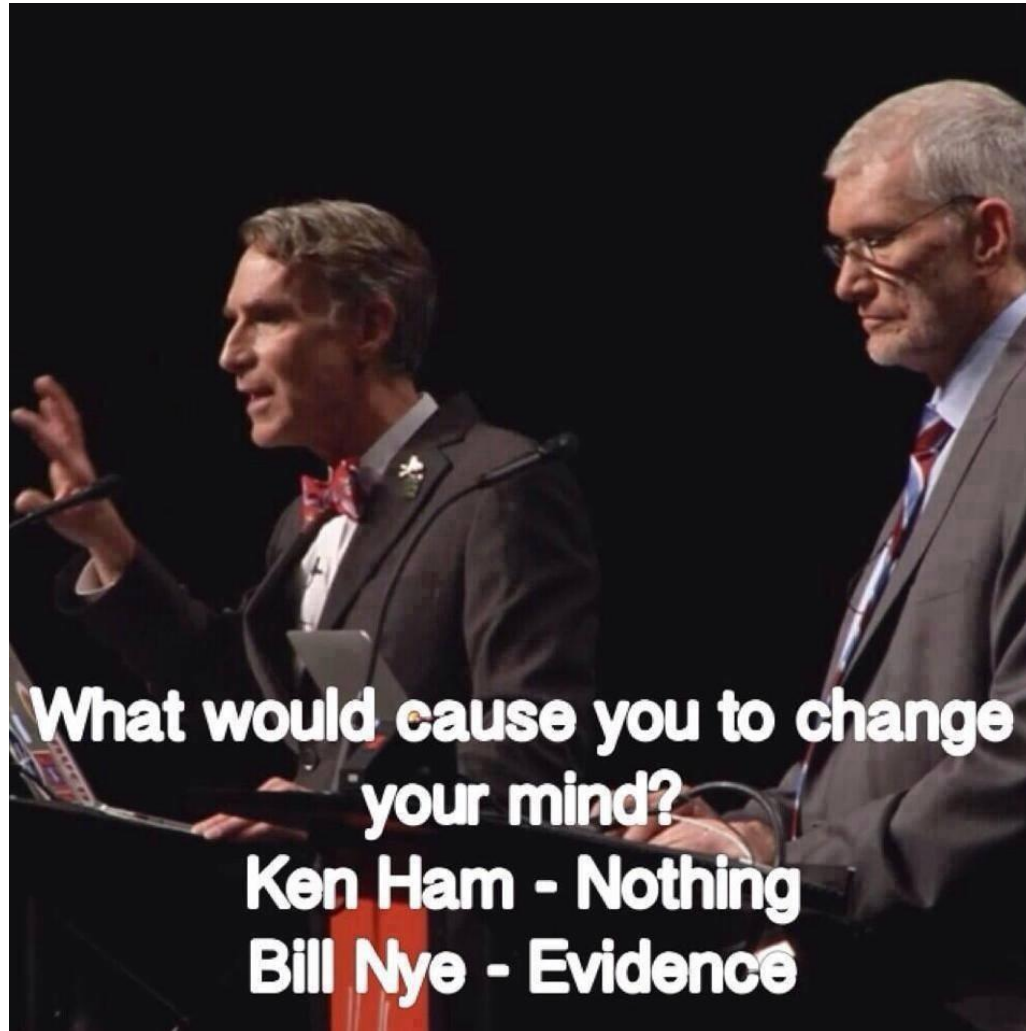


inference space → time

**PREFIX:**  
archaeo:CRMarchaeo  
geo:geosparql  
time:owl-time

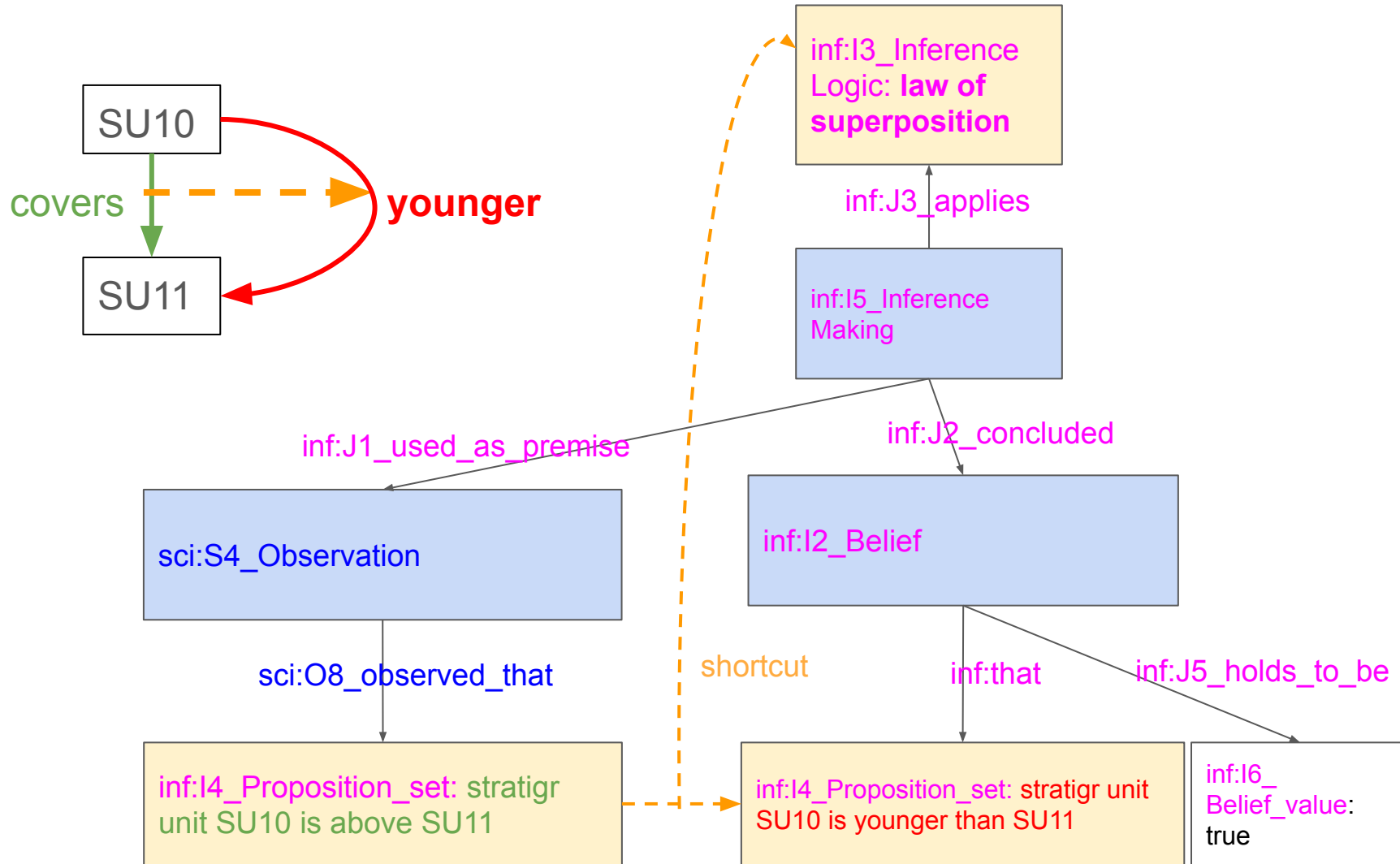
**SWRL rule:**  
archaeo:  
AR8\_Stratigraphic\_Unit(?i),  
archaeo:  
AR8\_Stratigraphic\_Unit(?j),  
geo:ehCovers(?i, ?j) ->  
time:after(?i, ?j)

# Need for argumentation and hypotheses modelling for stratigraphic data





# 1-Law of superposition modeled using CRMInf



# 1-Law of superposition modeled as an **inference** using CRM archaeo

PREFIX:  
crm:CIDOC CRM  
archaeo:CRMarchaeo

**swrl rule:**  
archaeo:AR8\_Stratigraphic\_Unit(?i),  
archaeo:AR8\_Stratigraphic\_Unit(?j),

SU10  
(?i, ?ti)

SU11  
(?j, ?tj)

# 1-Law of superposition modeled as an **inference** using CRM archaeo, geosparql

PREFIX:

crm:CIDOC CRM

archaeo:CRMarchaeo

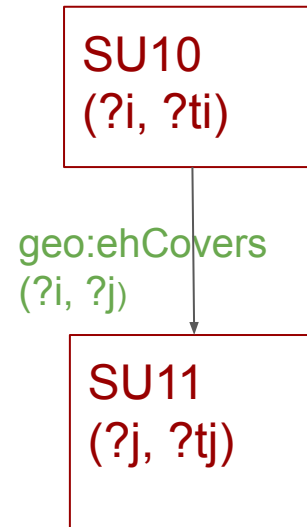
geo:geosparql

**swrl rule:**

archaeo:AR8\_Stratigraphic\_Unit(?i),

archaeo:AR8\_Stratigraphic\_Unit(?j),

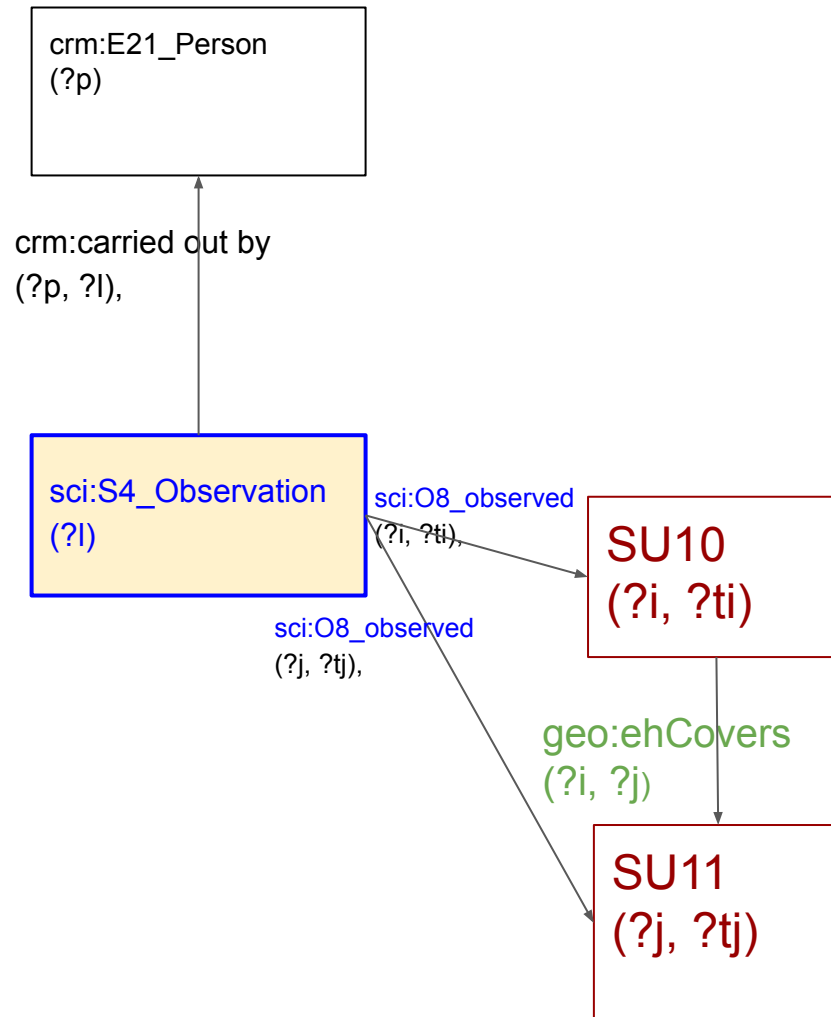
geo:ehCovers(?i, ?j),



# 1-Law of superposition modeled as an **inference** using CRM archaeo, geosparql, CRMsci

PREFIX:  
crm:CIDOC CRM  
archaeo:CRMarchaeo  
geo:geosparql  
sci:CRMsci

**swrl rule:**  
archaeo:AR8\_Stratigraphic\_Unit(?i),  
archaeo:AR8\_Stratigraphic\_Unit(?j),  
geo:ehCovers(?i, ?j),  
sci:S4\_Observation(?l),  
sci:O8\_observed(?i, ?ti),  
sci:O8\_observed(?j, ?tj),



# 1-Law of superposition modeled as an **inference** using CRM archaeo, geosparql, CRMsci, CRMinf

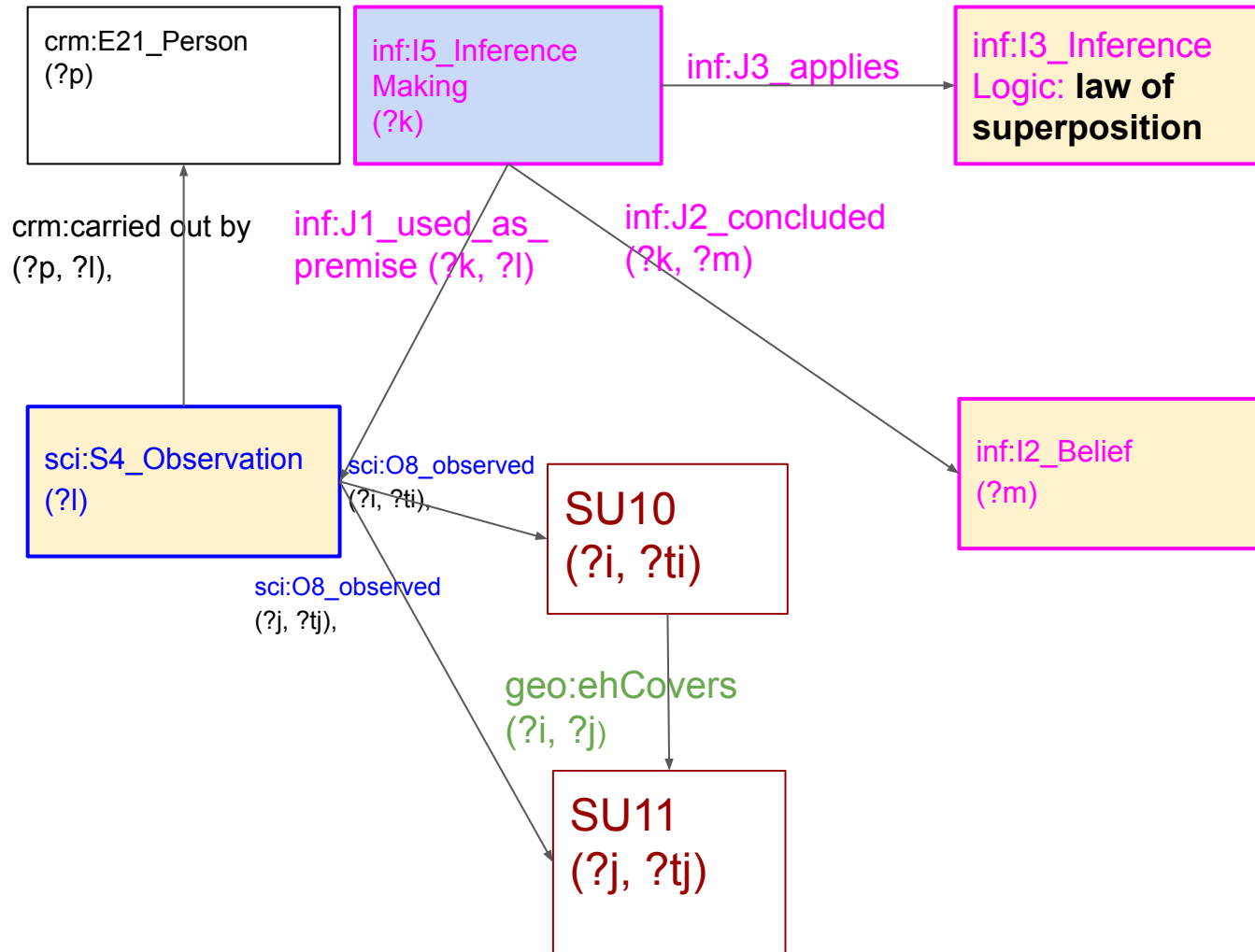
**PREFIX:**

crm:CIDOC CRM  
 archaeo:CRMarchaeo  
 geo:geosparql  
 sci:CRMsci  
 inf:CRMinf

**swrl rule:**

archaeo:AR8\_Stratigraphic\_Unit(?i),  
 archaeo:AR8\_Stratigraphic\_Unit(?j),  
 geo:ehCovers(?i, ?j),  
 sci:S4\_Observation(?l),  
 sci:O8\_observed(?i, ?ti),  
 sci:O8\_observed(?j, ?tj),

crm:P14\_carried\_out\_by(?p, ?l),  
 inf:I5\_Inference\_making(?k),  
 inf:I3\_Inference\_logic (law of superposition),  
 inf:J3\_applies(?k, law of superposition),  
 inf:J1\_used\_as\_premise(?k, ?l),  
 crm:E21\_Person(?p),  
 inf:J2\_concluded(?k, ?m),  
 inf:I2\_Belief(?m),





# 1-Law of superposition modeled as an **inference** using CRM archaeo, geosparql, CRMsci, CRMinf

PREFIX:

crm:CIDOC CRM

archaeo:CRMarchaeo

geo:geosparql

sci:CRMsci

inf:CRMinf

swrl rule:

archaeo:AR8\_Stratigraphic\_Unit(?i),

archaeo:AR8\_Stratigraphic\_Unit(?j),

geo:ehCovers(?i, ?j),

sci:S4\_Observation(?l),

sci:O8\_observed(?i, ?ti),

sci:O8\_observed(?j, ?tj),

statement(?l, ?i, ?j),

crm:P14\_carried\_out\_by(?p, ?l),

inf:I5\_Inference\_making(?k),

inf:I3\_Inference\_logic (law of superposition),

inf:J3\_applies(?k, law of superposition),

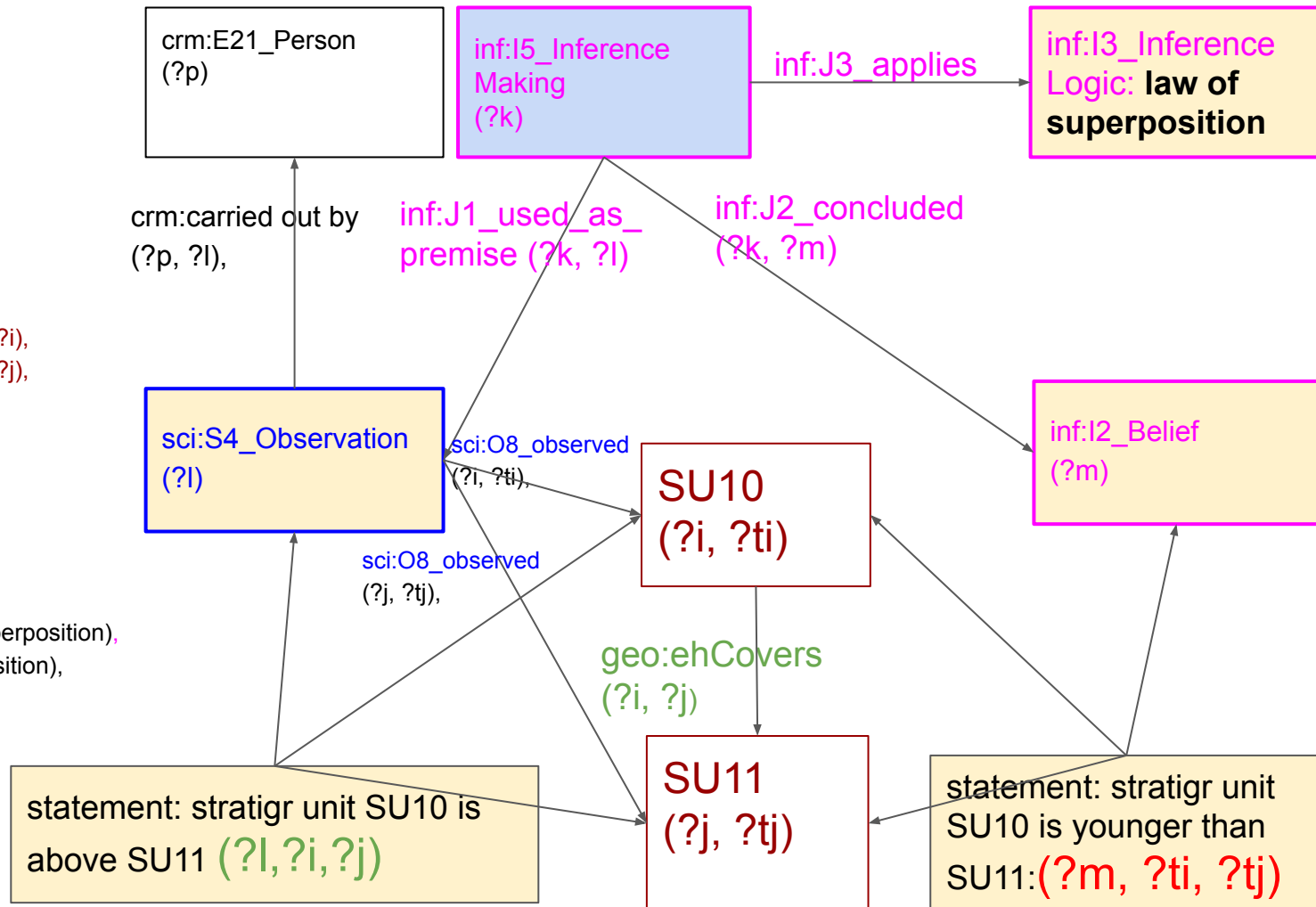
inf:J1\_used\_as\_premise(?k, ?l),

crm:E21\_Person(?p),

inf:J2\_concluded(?k, ?m),

inf:I2\_Belief(?m),

statement(?m, ?ti, ?tj)



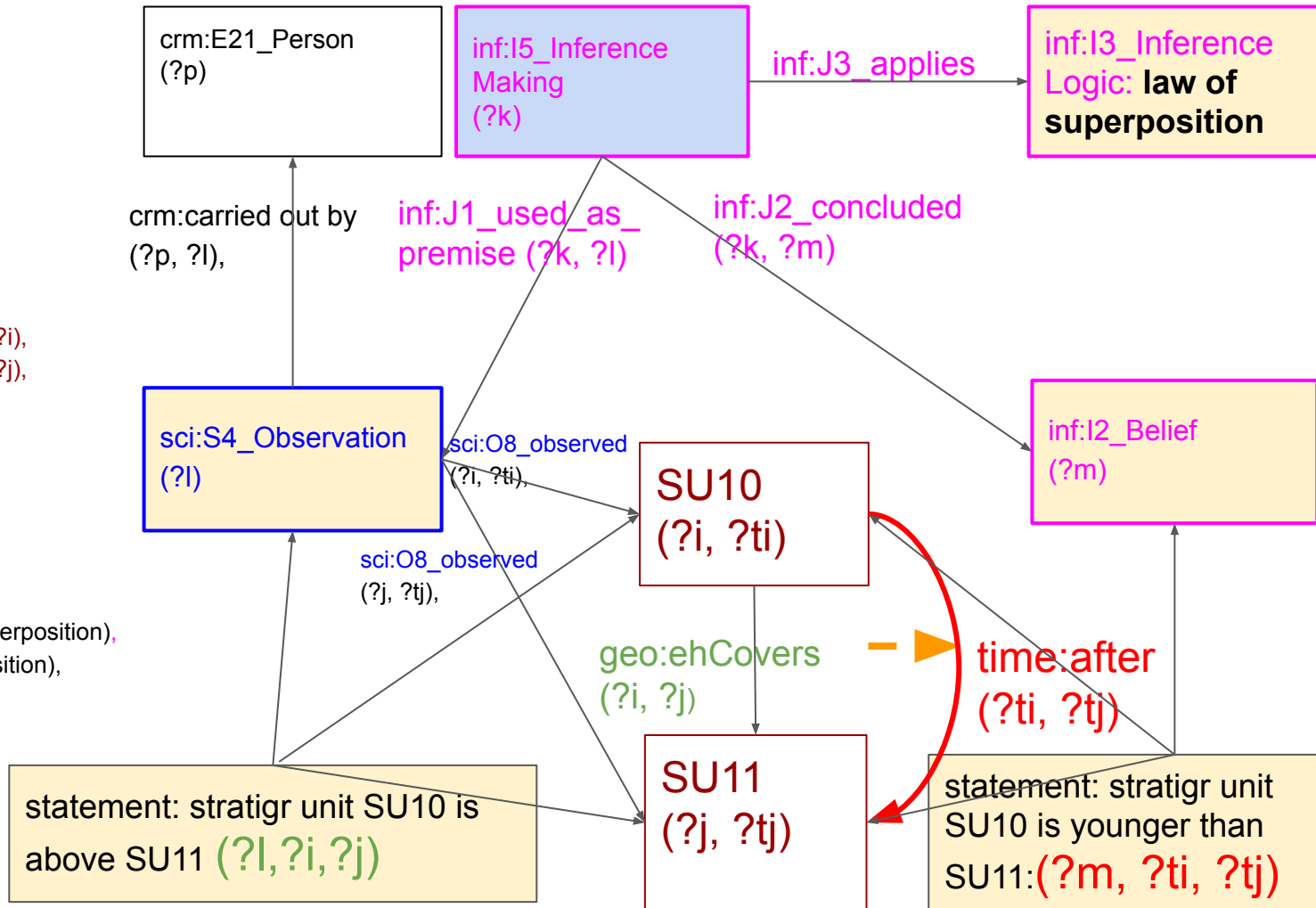
# 1-Law of superposition modeled as an **inference** using CRM archaeo, **geosparql**, CRMsci, CRMinf, and **owl-time**

**PREFIX:**

crm:CIDOC CRM  
 archaeo:CRMarchaeo  
 geo:geosparql  
 sci:CRMsci  
 inf:CRMinf  
 time:owl-time

**swrl rule:**

archaeo:AR8\_Stratigraphic\_Unit(?i),  
 archaeo:AR8\_Stratigraphic\_Unit(?j),  
 geo:ehCovers(?i, ?j),  
 sci:S4\_Observation(?l),  
 sci:O8\_observed(?i, ?ti),  
 sci:O8\_observed(?j, ?tj),  
 statement(?l, ?i, ?j),  
 crm:P14\_carried\_out\_by(?p, ?l),  
 inf:I5\_Inference\_making(?k),  
 inf\_I3\_Inference\_logic (law of superposition),  
 inf:J3\_applies(?k, law of superposition),  
 inf:J1\_used\_as\_premise(?k, ?l),  
 crm:E21\_Person(?p),  
 inf:J2\_concluded(?k, ?m),  
 inf:I2\_Belief(?m),  
 statement(?m, ?ti, ?tj)  
 → time:after(?ti, ?tj)



# Conclusion:

- Harris matrix and the stratigraphy methodology are about reasoning about spatio-temporal relationship and archaeological data:

The semantic modeling need to mirror both spatio-temporal reasoning, argumentation, and hypotheses making

- Modeling with CRMinf of Harris matrix principles shows the potential of archaeological reasoning using inf and its applicability
- Neat demonstration of semantic and inference modeling with CIDOC CRM family of models (CRMinf+CRMarchaeo...) for the community of archaeologists

# Next steps:

- Demonstration about the main law (#1 law of superposition), but
  - 2-Law of original horizontality
  - 3-Law of original continuity
  - 4-Law of stratigraphic succession
  - 5-Law of original consolidation
- Some fine tuning of modeling, consistency checking
- Test data transformation and query
- Test inference making from real-world stratigraphic datasets

# Modelling Applicability: Stratigraphy in excavation archaeology



[1]

[https://www.images-archeologie.fr/Accueil/Recherche/p-3-Ig0-notice-IMAGE-Releve-d-une-coupe-stratigraphique-sur-le-site-de-l-ancienne-abbaye-medievale-de-Saint-Faron-a-Meaux-Seine-et-Marne-2016.htm?&notice\\_id=10745](https://www.images-archeologie.fr/Accueil/Recherche/p-3-Ig0-notice-IMAGE-Releve-d-une-coupe-stratigraphique-sur-le-site-de-l-ancienne-abbaye-medievale-de-Saint-Faron-a-Meaux-Seine-et-Marne-2016.htm?&notice_id=10745)

# Modelling Applicability: Stratigraphy in building archaeology

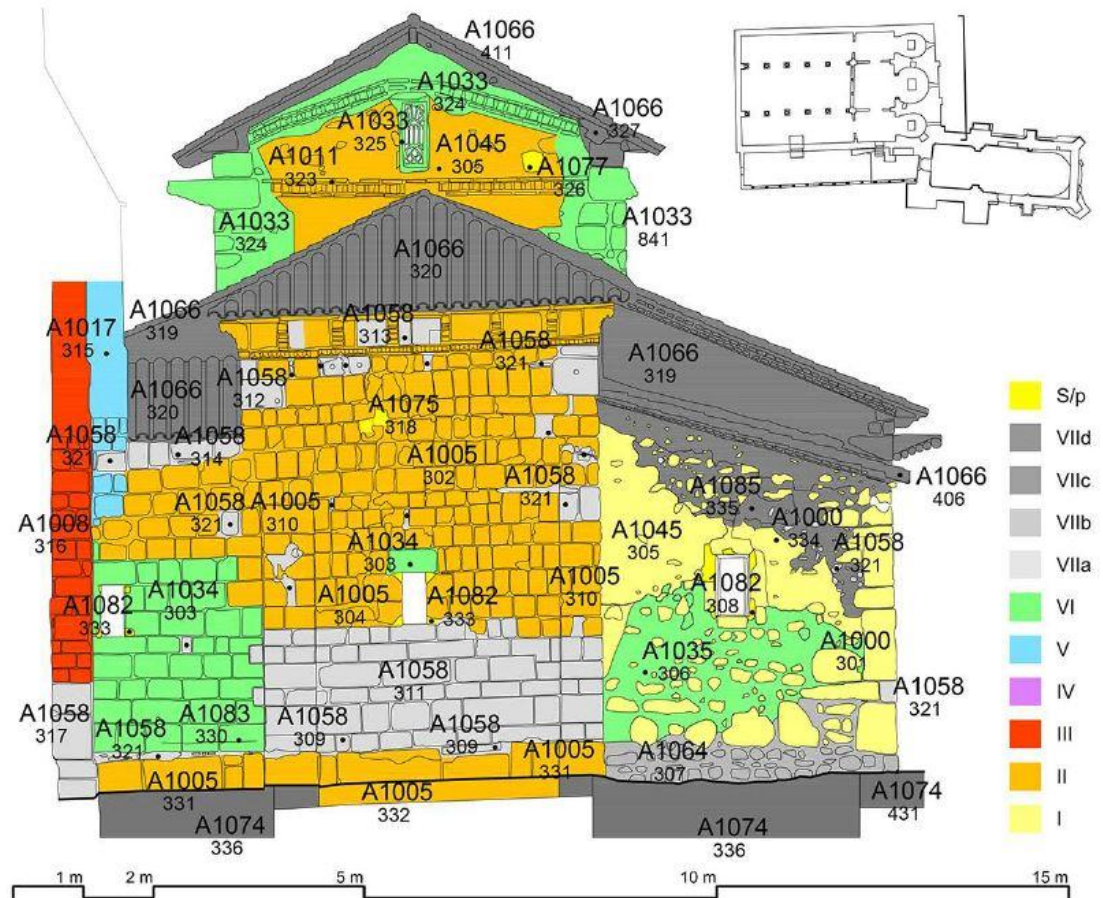


Fig. 9. San Miguel de Escalada (León), east wall, archaeological record. Phase I: rough masonry. Phase II: regular ashlar stone (UTRERO, MURILLO, 2022, in press).

[1] Utrero Agudo, María de los Ángeles, and José Ignacio Murillo Fragero. 2022. “Análisis Arqueológico Del Conjunto de San Miguel de Escalada: De Monasterio Altomedieval a Monumento Histórico-Artístico.” <https://digital.csic.es/handle/10261/287323>.

[2] Utrero Agudo, María de los Ángeles. 2022. “Early Medieval Hispanic Constructions as Material Culture: Archaeology of Architecture and Technology.” <https://digital.csic.es/handle/10261/275241>.



# Modelling Applicability: Stratigraphy in heritage science and material analysis - micro-stratigraphy in polychromy analysis (LRMH)



Figure 4 : Porte rouge de la cathédrale Notre-Dame de Paris, tympan et voussures du portail. Emplacement des prélèvements et leurs images microscopiques. © LRMH, A. Dequier.

[1] RAPPORT n° R403J - PARIS 4e (Paris, 75). Cathédrale Notre-Dame de Paris. Façade extérieure nord, porte rouge. Caractérisation des vestiges de polychromies du tympan sculpté et de la voussure.

# Modelling Applicability: Stratigraphy in heritage science and material analysis - micro-stratigraphy in paintings and artworks (C2RMF)



**Fig. 1 a)** Photograph of the painting *Virgin and Child surrounded by saints and a donor* (RFML.PE.2018.51.1). © C2RMF, T. Clot and **b)** detail showing the locations where the three cross-sections were taken in white (A, B and C), and in red the 22 locations where CXRF depth profiles were applied



**Fig. 2** CXRF prototype LouX<sup>3D</sup> used with the painting at the C2RMF, Paris

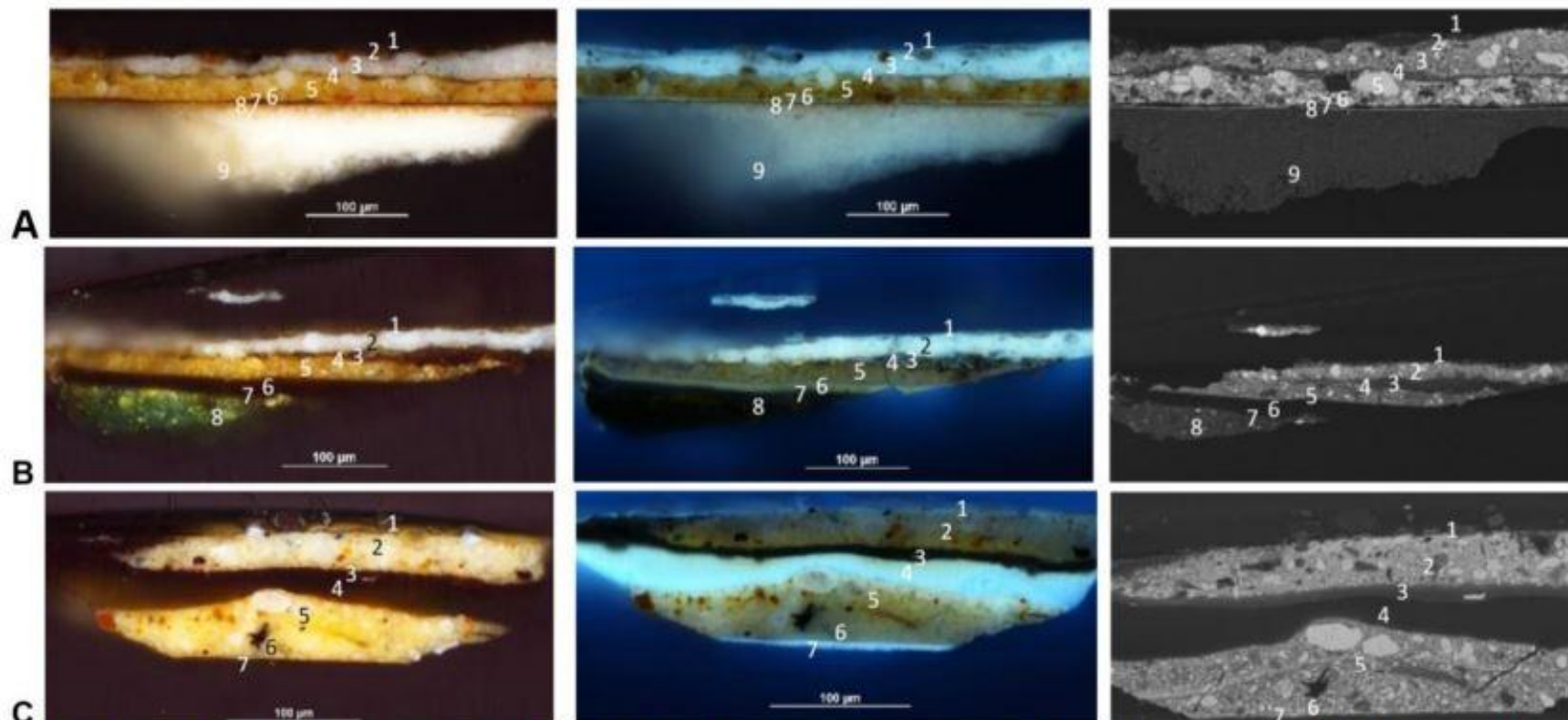
Tapia, José, Myriam Eveno, Thomas Calligaro, Laurent Pichon, Éric Laval, Elisabeth Ravaud, and Ina Reiche. 2023. "Efficiency of Combined MA-XRF and CXRF to Give Nondestructive Insights about Changes of a Historical Painting." *The European Physical Journal Plus* 138 (1): 46.

<https://doi.org/10.1140/epjp/s13360-022-03596-5>.



# Modelling Applicability:

## Stratigraphy in heritage science and material analysis - micro-stratigraphy in paintings and artworks (C2RMF)



**Fig. 3** Optical (left), UV (center) and back scattered electron micrographs (right) of cross-sections A, B, and C.

Tapia, José, Myriam Eveno, Thomas Calligaro, Laurent Pichon, Éric Laval, Elisabeth Ravaud, and Ina Reiche. 2023. "Efficiency of Combined MA-XRF and CXRF to Give Nondestructive Insights about Changes of a Historical Painting." *The European Physical Journal Plus* 138 (1): 46.

<https://doi.org/10.1140/epjp/s13360-022-03596-5>.

# Modelling Applicability: Stratigraphy in heritage science and material analysis - micro-stratigraphy in paintings and artworks (C2RMF)

**Table 1** OM and SEM-EDX descriptions of the paint layers compared with CXRF lateral scans (y) of the cross-sections and CXRF depth scans (z) of adjacent points. Layer one represents the outer layer closest to the surface of the painting. The element underlined (e.g., Cu) means it is the main identifiable element, without underline (e.g., Cu) that it is present, and between parenthesis, e.g., "(Cu)", that it is a minor element. Coat of arms 3 removed by the restorers between the cross-section sampling and the CXRF depth scan.

Cross-section	Layer and composition determined by OM/ SEM-EDX observations	Elements identified by CXRF lateral scan (y)	Elements identified by CXRF depth scans (z) of adjacent locations	Identification
<b>A</b>	1. Thin fluorescent under UV layer (several µm)		<b>Location 11</b>	
	2. Thin organic layer with big orange grains (red ochre; Al, Si, Fe) (several µm)	(Fe) right next to <u>Cu</u>		Coat of arms 3
	3. Light beige layer (lead white; Pb, Ca) with small red, black and blue grains (Cu) as well as grains of green earth (10-30 µm)	<u>Cu</u>		
	4. Organic layer, possible varnish (several µm)			Coat of arms 2
	5. Beige-orange layer of lead white (Pb, Fe, Ca) with red, white and black grains (earth pigments, vermilion; Ca, Fe, Hg, S, Mg) (15-25 µm)	Fe, Hg, Pb	Fe, Hg, Pb	
	6. Organic layer, possible varnish (several µm)			Coat of arms 1
	7. Gold leaf (Au)	<u>Au</u>	<u>Au</u>	
	8. Bole (earth pigments; Al, Si, Mg, Fe) (several µm)	Not clear. Fe, Hg		
	9. White ground layer (calcium carbonate with several alumina silicates; Ca, Al, Si) (66 µm)			
<b>B</b>	1. Organic layer with orange and yellow grains (Pb, Ca). Possibly tinted varnish (several µm)		<b>Location 1</b> (Fe), <u>Pb</u>	Monk's tunic
	2. Lead white and earth pigments (Mg, Al, Si, Fe) with a P, Cl, Pb and Ca layer on the surface (13-16 µm)	Fe, <u>Pb</u>	Fe, <u>Pb</u>	Monk's tunic
	3. Brown organic non fluorescent under UV layer with some earth elements (Al, Si) (13 µm)			Golden detail
	4. Gold leaf (Au)	<u>Au</u>	<u>Au</u>	Golden detail
	5. Beige mordant layer (lead white, earth pigments, lead tin yellow ; Pb, Sn, Al, Si, Fe) (13-17 µm)	Not clear	Not identified	Golden detail
	6. Organic layer, possibly varnish (~7 µm)			Bishop's green tunic
	7. Copper green glaze non-UV-fluorescent layer (Cu, Pb, Sn) (5-6 µm)	Cu	<u>Cu</u> , Pb	Bishop's green tunic
	8. Green copper layer with some grains of lead tin yellow (Cl, Sn and Pb) (30 µm)	<u>Cu</u>	<u>Cu</u> , Pb	Bishop's green tunic
No ground layer present in this cross section				
<b>C</b>	1. Slightly fluorescent under UV organic layer, perhaps a tinted varnish (several µm)	Fe, <u>Pb</u>	<b>Location 4</b> Fe, Hg <u>Pb</u>	Cross
	2. Light beige layer with lead white, earth pigments, blue copper pigment, orange iron oxide and carbon black (20-25 µm)	(Fe), Cu, <u>Pb</u>		Cross
	3. Thick non-fluorescent under UV organic layer with some Cu and Pb (5-6 µm)	Not clear	Not clear	Triangle
	4. Thick organic varnish layer fluorescent under UV (8-20 µm)			Floor
	5. Beige layer (lead white, orange iron oxide, vermilion) (13-16 µm)	Fe, Hg, <u>Pb</u>	<u>Cu</u> , Hg, Pb	Floor
	6. Beige layer (lead white, earth pigments; Al, Si, Fe) (15-25 µm)	<u>Pb</u>	Not identified	Floor
	7. Thin organic layer of impregnation (several µm)			
No ground layer present in this cross section				

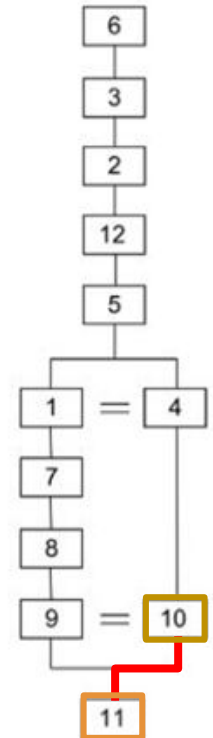
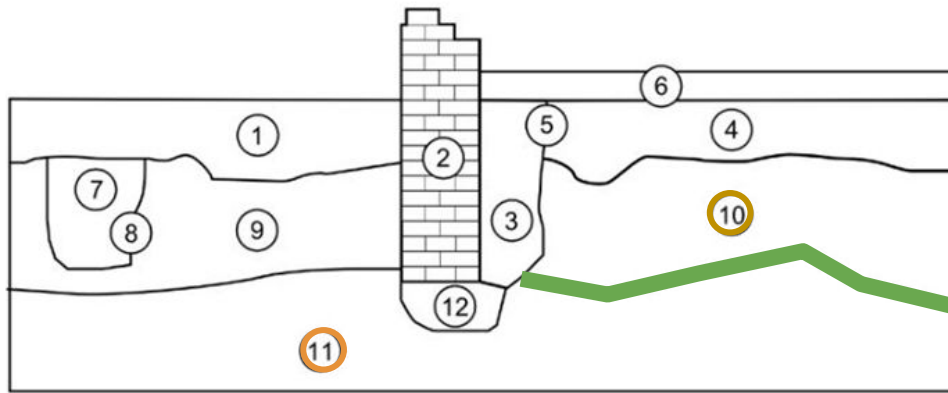
Tapia, José, Myriam Eveno, Thomas Calligaro, Laurent Pichon, Éric Laval, Elisabeth Ravaud, and Ina Reiche. 2023. "Efficiency of Combined MA-XRF and CXRF to Give Nondestructive Insights about Changes of a Historical Painting." The European Physical Journal Plus 138 (1): 46.

<https://doi.org/10.1140/epjps13360-022-03596-5>.

# Guillem Anaïs, Van Ruymbeke Muriel, Eide Øyvind, De Luca Livio, Spatio-Temporal Reasoning on Stratigraphic Data in Archaeology: Formalization of the Harris Laws as Inferences Using CIDOC CRM.

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