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Case study

The medieval stained glass in Catalonia: Girona cathedral

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ABSTRACT

The production and distribution of stained glass in Mediterranean Europe during the Middle Ages remains inadequately understood. This article focuses on Catalonia, where local glass production is documented as early as the 13th century, but little is known about the production of window glass. This study analyses a collection of stained glass fragments from Girona Cathedral, dating from the 13th to the 16th century, some of which is the work of renowned master glassmakers. The data obtained is compared with contemporary stained glass documented from other parts of Europe, and with a collection of 15th and 16th century archaeological window glass from Barcelona. The data is also contrasted with historical documentation on glass production in Catalonia. The findings reveal that the glass from Girona from the 13th and 14th centuries is of the potassium-lime type, similar to that produced in the workshops of north-western France. By the late 14th and 15th centuries, the composition aligns more closely with that of north-eastern France. In the 16th century, however, the glass changes to a soda-lime composition, similar to the glass found in Barcelona, suggesting a transition from central European to Mediterranean sources, and indicates a change in the raw materials involving the use of soda-lime plant ash instead of potassium-lime forest ash. These results indicate that the production of window glass shifted from France to Barcelona at the close of the 15th century.

Introduction and research aim

Relatively little is known about the chemical composition of medieval stained glass in southern Europe. Potassium-lime glass, made from wood ash typical of Central Europe, was the first and main type of window glass used. Soda-lime glass, made from the ash of halophytic (salt-tolerant) plants, such as *salicornia,* and bushes, such as *salsola kali* (*barrilla*) growing in salt marshes typical of Mediterranean regions which are sodium rich, has also been found in southern France, northern Italy and Catalonia [1–5].

Although there is uncertainty about when soda-lime glass made of local plant-ashes began to be used as window glass, it is known that glass was being made locally in Catalonia between 1258 and 1659. The geographical area of Catalonia at this time included the present-day region of Catalonia in northeastern Spain and some regions in southeastern France (known as Catalunya Nord). Local glass production existed on both sides of the Pyrenees [6–9], including Barcelona [10], see Fig. S1.

Girona is located in the middle of these areas, and it preserves an important collection of stained glass dating from the 13th to the 16th centuries. This includes the earliest figurative windows in the region and the only two surviving whitewashed tables in the world used to make the 14th-century windows above the high altar [11] in Girona Cathedral. Originally a Romanesque cathedral consecrated in the 11th century was rebuilt from the 14th century onwards. It also has one of the widest Gothic naves in the world, due to the transformation of the three naves into a single nave at the beginning of the 15th century (Fig. S2).

A selection of glass fragments from Girona Cathedral, dating from the 13th to the 16th centuries, and a collection of archaeological flat glass from excavations in the city of Barcelona with terminus post quem from the 15th and 16th centuries have been analysed. It should be noted that flat window glass was not necessarily produced in the same workshops as glass objects. Our study therefore focusses on stained glass windows and, in archaeological contexts, on flat glass. The data obtained is compared with the

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Fig. 1. The lower panels of the 13th century stained-glass window found in the Corpus Christi Chapel. © Fons capitol Catedral de Girona.

data from other parts of Europe and with known glass production centres.

The two aims of this study are to determine the origin of the glass used in Girona Cathedral, of particular importance due to its strategic geographical location; and to obtain direct information on the production and trade of stained glass in the south of Europe.

Materials and methods

The samples analysed have different origins:

1) In 2019, during the restoration of a chapel next to the high altar (Fig. S2), several 13th (Fig. 1) and 14th century glass panels, mounted together as a composite stained glass window, were discovered hidden behind the large Corpus Christi altarpiece installed in 1562 [12], thereby establishing a terminus post quem for the stained glass. This is important as there is no documentary evidence of the execution of these windows.
   A total of 27 samples were recovered from the windowsill (Table S1), 18 are associated with the 13th-century panels, 5 with the 14th-century panels, and 3 may be part of a later restoration. The 13th century glass fragments are all coloured and 9 have *grisaille* paint while the 14th century are uncoloured, 3 have *grisaille* and one has yellow staining. The colours and grisailles were characteristic enough to distinguish between those belonging to the 13th and 14th centuries.
2) Other samples come from a collection kept in the Diocesan Archive. A glass fragment with a *grisaille* paint with the same pattern as the 13th-century panels and another with a cold paint were collected from behind the altarpiece (placed there in 1678) in the neighbouring chapel dedicated to Saint Catherine.
3) Further samples were obtained from those collected by the Corpus Vitrearum Medii Aevi Internacional team in 1982. 16 fragments were obtained from the Window of the Apostles, made by Antoni Tomàs of Tolosa de Llenguadoc (1437) and 1 fragment was obtained from the Window of the Sibyls, Evangelists and Doctors made by Jaume Fontanet of Barcelona (1520) [13] (Table S2).
4) Five and eight flat glass fragments with termini post quem from the 15th and 16th centuries respectively were also obtained from excavations in the city of Barcelona (under the current market of Santa Caterina).

The chemical composition of the glasses was measured on polished cross sections of the fragments using a JEOL JXA-8230 electron Microprobe from the Scientific and Technological Centre of the University of Barcelona. The instrument was equipped with five wavelength dispersive X-ray spectrometers and a probe current of 15 nA. The *grisailles* were analysed by FE-SEM (GEMINI) with attached EDS (Ultim EDS Detector, Oxford Instruments. Aztec Oxford Instruments), with a probe current of 20 nA and 120 s measurement time. The spectrometers were calibrated with mineral and glass standards and verified with secondary glass standards (Table S3) [14].

Results

The chemical analyses of the samples and the average limits of detection for each element following the procedure described in [15] are given in Table S4. Principal Component Analysis (PCA) was performed on the data, the result is shown in Fig. 2 and the chemical composition of the glass groups in Table 1.

The PCA analysis distinguishes six groups. Group 1 includes all the potassium-lime glasses and can be divided into two subgroups: Group 1a, which includes samples from the 13th and 14th centuries (window found behind the Corpus Christi altarpiece of 1562), and Group 1b, which includes samples from the Apostles window of 1437 excluding the fragments suspected of being repairs. Group 2 corresponds to lime-soda glass and contains a sin-

Table 1
Average chemical composition (bold) and standard deviation (italics) in wt % of the glass groups determined. *bdl*: below detection limit.

Group (number of samples)	samples	glass type (dating)	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	MnO	FeO	CoO	CuO	ZnO	As_2O_5	Sb_2O_5	BaO
Group 1a	Gi1 to Gi14, Gi17 to Gi20,	potassium-lime (LLHM)	**1.1**	**5.2**	**2.5**	**47.4**	**5.1**	**0.15**	**0.4**	**18.0**	**17.4**	**0.17**	**0.9**	**0.9**	***bdl***	**0.6**	***bdl***	***bdl***	**0.39**	**0.3**
(22)	G23 to Gi27	(13th c.–14th c.)	*0.5*	*0.9*	*0.8*	*2.9*	*0.9*	*0.04*	*0.1*	*1.5*	*1.7*	*0.04*	*0.4*	*0.3*					*0.04*	*0.3*
Group 1b	Gi22, GAV1, GAV3, GAV5, GAV8, GAV15 VAG	potassium-lime (HLLM)	**1.3**	**3.0**	**4.0**	**52.8**	**4.3**	**0.18**	**0.4**	**15.4**	**16.1**	**0.12**	**1.0**	**0.5**	***bdl***	**0.1**	***bdl***	***bdl***	**0.3**	**0.2**
(6)		(15th c.)	*1.1*	*1.8*	*2.1*	*2.2*	*1.2*	*0.04*	*0.1*	*0.9*	*1.3*	*0.06*	*0.1*	*0.1*		*0.3*			*0.2*	*0.1*
Group 2	GAV14	lime-soda	**8.79**	**1.20**	**0.83**	**67.90**	**0.58**	***bdl***	**1.34**	**3.23**	**15.98**	***bdl***	***bdl***	**0.3**	***bdl***	***bdl***	***bdl***	***bdl***	***bdl***	***bdl***
(1)		(1520 CE)																		
Group 3	Gi29, GAV9	potash	**1.6**	**1.8**	**0.17**	**69.5**	***bdl***	**0.4**	**0.5**	**21.1**	**4.9**	***bdl***	**0.08**	**0.7**	**0.1**	**4.0**	**0.2**	**0.27**	**0.34**	***bdl***
(2)		(before 1678 CE)	*0.3*	*0.3*	*0.03*	*1.2*		*0.1*	*0.1*	*0.3*	*0.8*		*0.03*	*0.6*	*0.1*	*5.6*	*0.2*	*0.04*	*0.08*	
Group 4	GAV10, GAV11	HLLA	**0.5**	**4.49**	**3.27**	**61.8**	**2.0**	**0.13**	**0.1**	**6.9**	**20.6**	**0.19**	**0.97**	**0.7**	***bdl***	**0.9**	**0.3**	***bdl***	**0.10**	**0.4**
(2)		(1437 CE)	*0.2*	*0.02*	*0.03*	*0.6*	*0.4*	*0.01*	*0.1*	*0.1*	*1.3*	*0.05*	*0.04*	*0.1*		*1.3*	*0.4*		*0.02*	*0.1*
Group 5	Gi15, Gi21, Gi28, GAV4, GAV6, GAV7,	soda-lime (plant ashes)	**15.9**	**2.8**	**2.0**	**65.8**	**0.7**	***bdl***	**1.4**	**3.3**	**7.9**	**0.10**	**1.54**	**1.0**	**0.1**	***bdl***	**0.1**	***bdl***	***bdl***	***bdl***
(8)	GAV12, CGP	(before 1562 CE)	*1.4*	*0.8*	*0.9*	*1.3*	*0.2*		*0.2*	*1.4*	*1.0*	*0.03*	*1.18*	*0.4*	*0.1*		*0.1*			
Group 6	GAV2, GAV13	soda-lime (synthetic soda)	**14.2**	**0.8**	**1.4**	**69.5**	***bdl***	**0.3**	**0.4**	**1.1**	**12.7**	***bdl***	**0.41**	**0.2**	**0.1**	***bdl***	***bdl***	***bdl***	***bdl***	***bdl***
(3)	GAL15	(19th c.)	*1.7*	*1.2*	*1.2*	*2.3*		*0.2*	*0.5*	*0.5*	*0.9*		*0.31*	*0.0*	*0.1*					

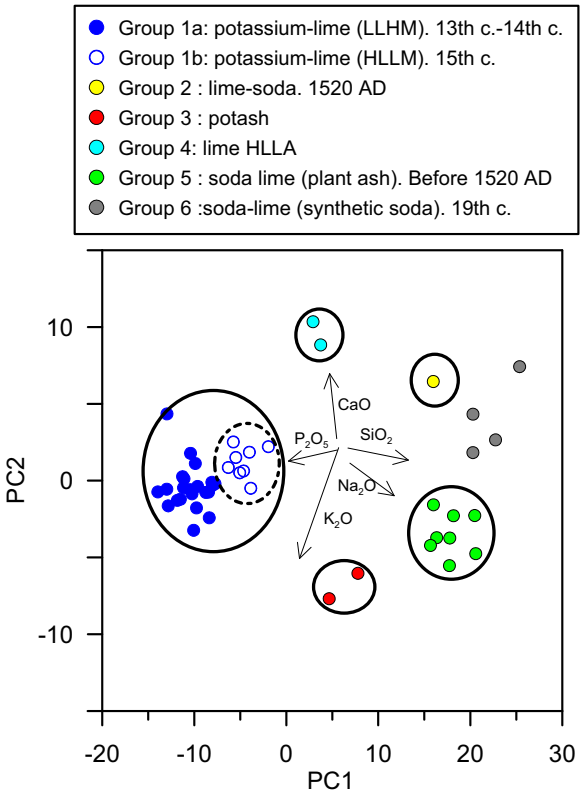

Fig. 2. Chemical Grouping by PCA analysis of the glasses.

gle sample, the glass corresponding to the Jaume Fontanet's Sybils window of 1520. Group 3 corresponds to potash glass, and contains two samples, one of which was found behind the altarpiece of Saint Catherine and has a terminus post quem of 1678. Group 4 corresponds to a high lime and low alkali glass (HLLA), and includes two samples from the Apostles window. Group 5 corresponds to soda-lime glass made from plant ash and includes the repair samples from the Romanesque and Gothic windows, as well as some samples from the Apostles window. Finally, Group 6 is a synthetic soda-lime glass, most likely from a 19th century restoration, and includes four samples obtained from the Apostles window which does not have a terminus post quem.

The potassium-lime glass (Group 1) is the characteristic medieval window glass used throughout Europe made from wood ash and sand. All our glasses have a CaO/K_2O ratio between 0.9 and 1.5 and were made from beech wood ash [15–17]. There are two subgroups of this glass, Group 1a, contains lower amounts of MgO and K_2O and higher amounts of SiO_2 and Al_2O_3 and CaO than Group 1b, among other minor differences. Group 1a with an average of 0.19 MgO/CaO ratio correspond to the low lime high magnesium (LLHM) type (<0.24 MgO/CaO) while Group 1b with an average of 0.30 MgO/CaO ratio to the high lime low magnesium (HLLM) type (>0.24 MgO/CaO) described elsewhere.

We can compare our results with other studies of stained glass in medieval Europe [16–20]. Fig. 3A shows a K_2O vs. Na_2O plot where the circles correspond to the data obtained by other studies from the regions where glass production is known to have taken place in this period. North-west France in blue, the Rhenish area (north-east France and Saxony) in green, and central Europe (Bohemia) in red according to Adlington et al. [19], Wedepohl and Simon [16] and Hunault et al. [20].

We have also included the data from the medieval Mediterranean potassium-lime glass from the south of France studied by

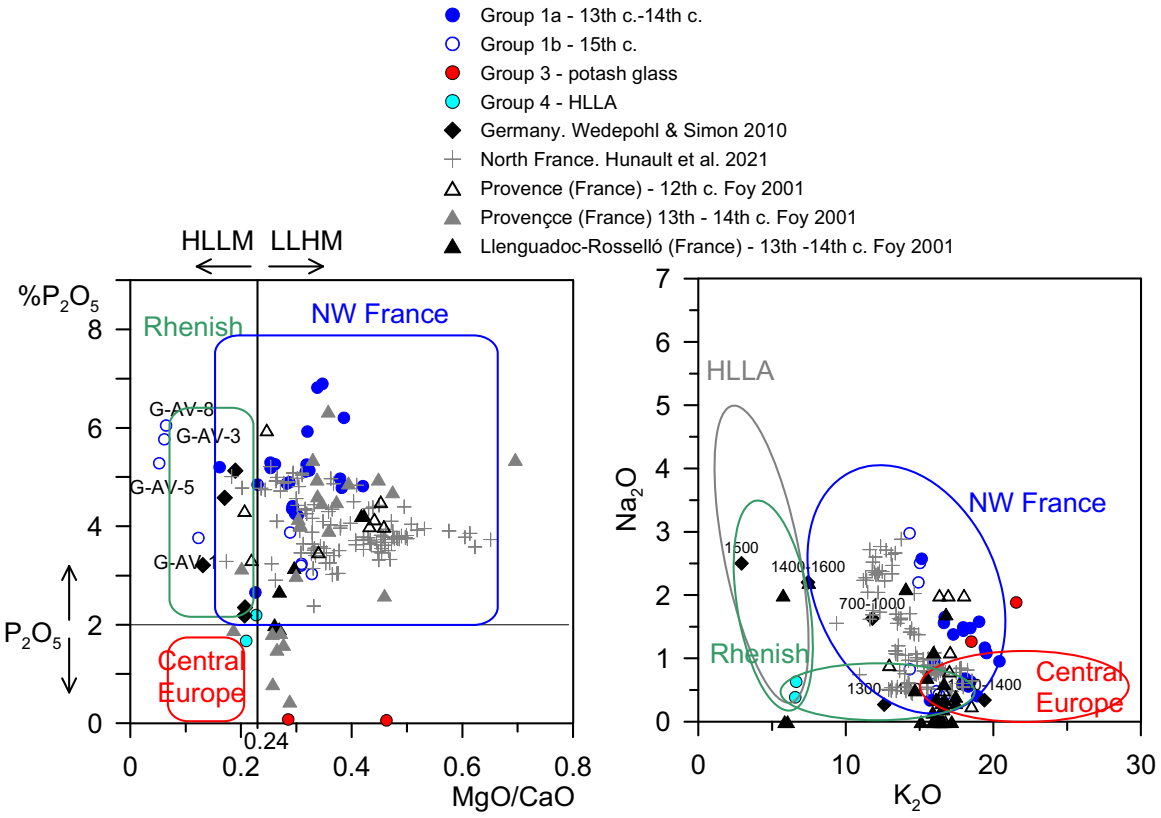

Fig. 3. (A) K_2O vs. Na_2O and (B) MgO/CaO vs. P_2O_5 plots of the potassium-lime glasses, Group 1, potash glass, Group 3 and HLLA, Group 4. The areas marked are indicative of the main composition of the glasses from different production centres of the period [16].

Foy 2001 [1] although soda-lime glass is also found in the region. Fragments of potassium-lime window glass from the 12th and 13th centuries have been found in Provence (Ganagobie, Notre Dame de Lure, Dign and, Marseille) and from the 14th century in the Llenguadoc-Rosselló (Psalmodi, Saint Félix de Montceau, Perpignan). It should be noted that in the Middle Ages, the Rosselló belonged to Catalonia and the Llenguadoc at that time also included part of Provence. This area had very close links with the Catalan counties; in fact, Antoni Tomàs, the Master of the Apostles' window, was actually from Tolosa de Llenguadoc. All the 14th century glasses from Llenguadoc-Rosselló are soda-lime glasses except the red glasses, which are potassium-lime. Red glass was rare and was most likely imported [21].

Fig. 3B shows the change from a low lime high magnesium (LLHM) composition in the 13th-14th-century glasses (Group 1a) to a high lime low magnesium (HLLM) composition in the 15th-century glasses (Group 1b). This has also been found in England at the end of the 14th-century, suggesting a change in supplier of coloured glass [19,21].

Apart from the potassium-lime glasses of Group 1, some of the fragments with different compositions are also related to wood-ash, i.e. groups Group 3 and Group 4. The two samples from Group 3 have a potash glass and Group 4 with two fragments has a HLLA glass. The potash glass, Group 3, has been associated with the use of potash extracted from wood ash [22,23]. The main characteristic is that potash glass is very low in phosphorus, <0.3 % P_2O_5, and relatively high in SO_3, like the fragments from Group 3. This glass is found in central Europe in the Middle Ages [16].

The HLLA glass, Group 4, was made from washed wood ash and has also been found in central Europe [22–24]. However, it could also have been made locally from the ash of the evergreen tree (*Quercus ilex*) which is a common Mediterranean tree. The analysis of the local ash gave us: 86.1 % CaO, 4.5 % MgO, 3.8 % P_2O_5, 1.3 % SO_3, 1.7 % MnO, 0.8 % Al_2O_3, 1.5 % SiO_2, 0.5 % K_2O, 0.1 % Na_2O.

The fragment belonging to the Sybils window made by Jaume Fontanet in 1520 CE has a lime-soda glass (Group 2). Of the glasses identified as having been used in the restoration of the 13th and 14th century windows before1562, three belong to Group 5, the soda-lime glass.

Archival documents attest to the existence of local glass production in Catalonia in the 14th-century, and soda-lime glass has been found in several 14th century stained glass windows from Barcelona [2–4]. Furthermore, the 14th-century glass found in the Llenguadoc-Rosselló [1] is soda-lime glass with the exception of the red glass. In fact, a local production of soda-lime glass objects and, although to a lesser extent, flat window glass has been identified in the region.

Window glass from the 15th and 16th centuries has also been found during excavations at Santa Catarina market (which was a convent in the Middle Ages) in the city of Barcelona which is known to have been an important glass centre in the 15th-century, both in terms of production and distribution [1].

The data corresponding to the 14th-century Mediterranean glass from Llenguadoc-Rosselló, Barcelona and Santa Croce in Florence (Italy) [5] are plotted together with Girona Cathedral's glass, Group 5, in Fig. 4. We can see clearly that the glass found in Girona Cathedral corresponds very well to the glass found in Barcelona, while the Llenguadoc-Rosselló glass has a higher MnO and P_2O_5 content. All this points to a switch from France to Barcelona in the 15th-century.

Finally, there are three fragments of soda-lime glass with a very low phosphorus and magnesium content, probably made from synthetic soda. Synthetic soda was first obtained from salt in 1791 (Leblanc) and later in 1860 (Solvay). The samples belong to the

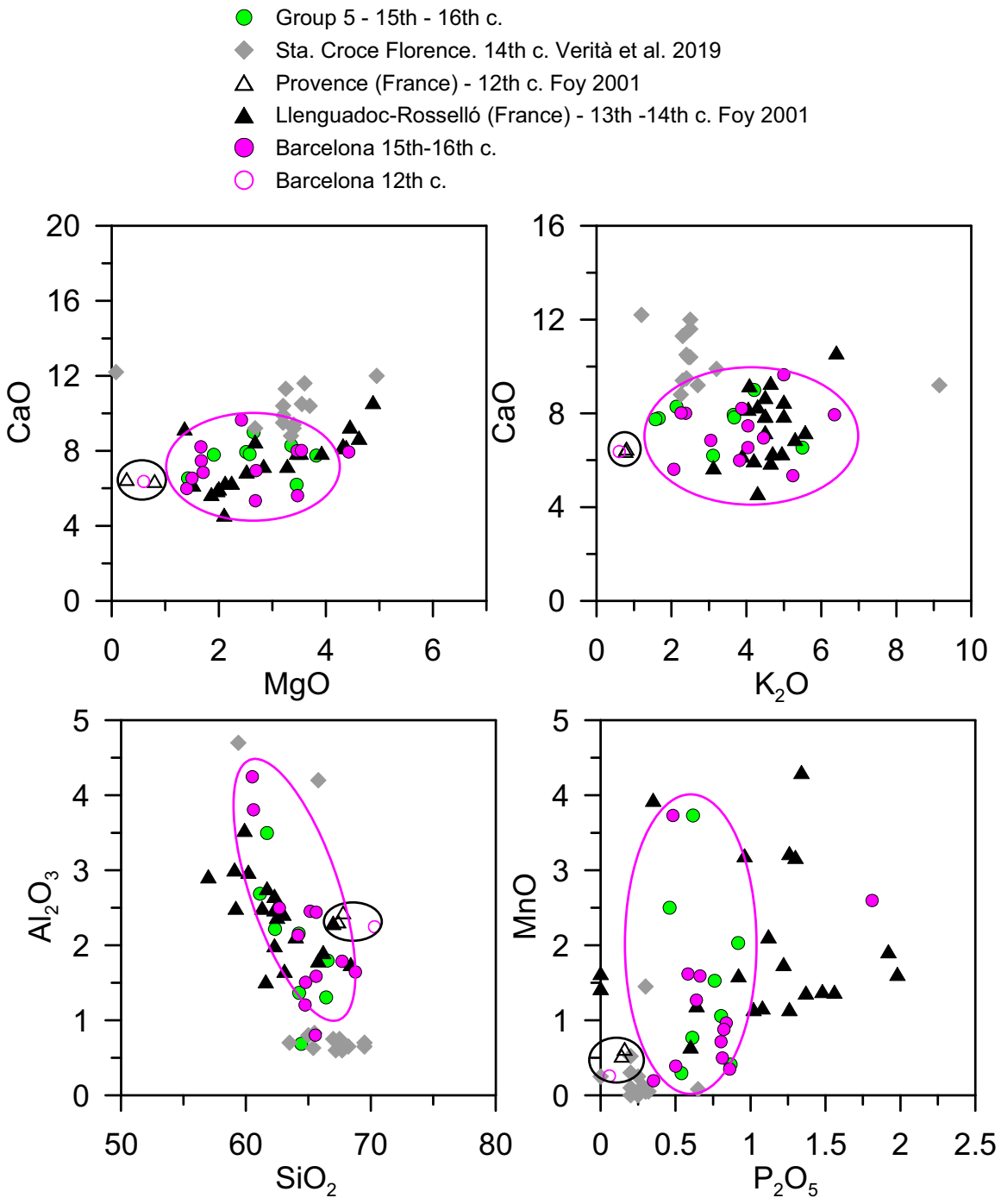

Fig. 4. Chemical composition of soda-lime glass made with plant ash.

lancets of the Apostles window, which does not have a terminus post quem, and may have been repaired in the second half of the 19th-century.

We have analysed the grisailles (Table S6). The average and standard deviation of the composition are given in Table 2. The results show two clear types, according to the pigment particles used. Grisailles from the 13th, 15th and 16th centuries contain iron oxide, while those from the 14th century contain copper oxide particles instead. Both types are described in medieval treatises. Heraclius (10th-13th century) mentions iron oxide, while Theophilus (12th century) and later treatises mention copper oxide. Indeed, copper-rich grisailles were found in Germany between the 14th and the 18th centuries [25].

Discussion

Analysis of the stained glass from Girona Cathedral has shown that the 13th- and 14th century glass panels are of the potassium-lime type, made from beech ash, similar to those found in the workshops in northwestern France (LLHM). The fragments from the Apostles' Window (1437), are also of the potassium-lime type, but with a different chemical composition (HLLM). This is similar to that found in other European regions and has been attributed to a change in the supply of coloured glass at the end of the 14th century.

Two fragments of potash glass (Group 3) have been identified, one which comes from a repair to the 13th-century window and

Table 2
Average chemical composition (bold) and standard deviation (italics) in wt % of the grisailles. -: below detection limit.

Glass group	Date (nº samples)		Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	Cl	K_2O	CaO	FeO	CuO	ZnO	PbO
Group 1a	13th c.	**avg**	**0.5**	**0.7**	**0.6**	**15.4**	**0.8**	**0.3**	**1.4**	**1.6**	**35.4**	**0.3**	**–**	**42.7**
	(10)	*std*	*0.3*	*1.2*	*0.3*	*2.1*	*1.0*	*0.2*	*0.9*	*1.0*	*11.1*	*0.2*		*8.8*
	14th c.	**avg**	**0.8**	**0.4**	**1.0**	**14.5**	**1.2**	**0.5**	**1.4**	**5.3**	**0.6**	**46.3**	**0.5**	**27.0**
	(4)	*std*	*0.0*	*0.2*	*0.1*	*1.4*	*0.8*	*0.1*	*0.6*	*2.2*	*0.1*	*3.6*	*0.1*	*3.2*
Group 1b	15th c.	**avg**	**0.3**	**0.3**	**1.6**	**18.6**	**1.7**	**0.4**	**1.1**	**2.7**	**27.2**	**3.4**	**-**	**41.8**
	(3)	*std*	*0.1*	*0.1*	*1.5*	*1.6*	*1.5*	*0.6*	*0.5*	*1.2*	*7.9*	*0.8*		*12.2*
Group 5	before 1562 CE	**avg**	**0.8**	**0.2**	**0.9**	**21.4**	**0.3**	**0.2**	**1.4**	**3.2**	**26.1**	–	–	**43.1**
	(2)	*std*	*0.6*	*0.0*	*0.0*	*3.3*	*0.2*	*0.3*	*1.4*	*3.0*	*8.9*			*1.9*

the other from the Apostles window which could have been made locally from the ash of the evergreen tree.

The lime-soda fragment from to the Sybils window (dated 1520) together with several soda-lime fragments from the Corpus Christi chapel and from the Apostles' window correspond to the 15th- and 16th-century flat glass found in Barcelona. They are most probably related to repair pieces added before 1562 CE. In fact, Jaume Fontanet from Barcelona signed a contract to supervise the maintenance of the windows in the Cathedral from 1523 to 1538.

The data obtained so far show that glass made from wood ash was replaced by glass made from halophytic plant ash, typical of the Mediterranean climate, and indicate a change in the supply of glass from France to Barcelona at the beginning of the 16th-century or earlier.

The origin of the glass according to the documentation

Archival documents provide some information about the origin of the glass used to make the stained glass windows. A contract signed in 1385 [26] states that the glass used to repair the windows in Girona was bought in Barcelona. However, it is not specified whether these glasses were made in Barcelona or if they were brought to Barcelona from elsewhere. In 1385, only one glassworks (glass kiln) was operating within the city of Barcelona located in close proximity to Viladalls, that is, where the street called "carrer del vidre" still exists today [27].

In the case of Antoni Tomàs, who worked and resided in Girona, it is possible that the glass came from Girona or nearby as there is also documentary evidence that there were several glassworks in Girona and the surrounding area [28]. It is worth mentioning that a document from 1470 states that the stained glass windows of the church of Saint Matthew in Perpignan were to be made of "good, clear glass from Elna and Palau" [7]. Nevertheless, as has been found in the Llenguadoc and Catalonia regions of southern France, soda-lime glass coexisted with potassium-lime glass. We have found that the windows were made of potassium-lime glass from northeastern France.

The Fontanet family lived in Barcelona and worked with the glass that was produced in the city's new glassworks located in Pla de Llull [29]. Mateu Llorens, as head of this glassworks, sold the Fontanet family flat glass for the windows of Santa Maria del Mar (1494) [30], the Royal Monastery of Santa Maria de Pedralbes (1496) [31] and the Casa Llotja in Barcelona (1496) [32]. The contract for the latter, it was specified that the glass should be "of good salicorn, clear and of good quality" (1507) [33].

In 1550, Jaume Fontanet, who was working on the stained glass windows for the Cathedral of Vic, wrote a document in which he explicitly states that the stained glass windows were to be brought in crates from Barcelona and that the master was to be paid for his maintenance and that of his horse for the time he needed to install the windows in the Cathedral [34]. This suggests that the stained glass windows were made in his workshop in Barcelona and then taken to the place where the windows were needed to complete the installation.

Father Pere Gil [29], who visited the glassworks in Barcelona in the 16th-century, stated that among the different types of glass produced in the city, there were some made with *salicornia*, which would correspond to the quality of the glass ordered in the aforementioned contracts. The established price of *salicornia* (referring to a high-quality ash from Valencia), at that time, was almost twice that of the ash obtained from local plants and known as *sosa*.

In summary, there are documents that indicate that flat glass for stained glass was being sold in Barcelona at the end of the 14th-century, whether it was produced there or not. Our results show that at least the glass found in Girona Cathedral, dated to the 16th-century, was made in Barcelona, and that it was made from the ash of halophytic plants.

Conclusion

The Romanesque and Gothic stained glass recently discovered in Girona Cathedral some of which is the work of renowned master glassmakers, has been analysed. The data obtained is compared with contemporary stained glass documented from other parts of Europe, and with a collection of 15th and 16th century archaeological window glass from Barcelona. The study has shown that the stained glass of the 13th, 14th and 15th centuries was of the potassium-lime type, made from beechwood ash. The 13th- and 14th-century glasses had a composition similar to that of the glass produced in the workshops of northwestern France (LLHM), while a change in the glass composition (HLLM) in the 15th-century indicates a shift in the production to eastern France. This concurs with the change in the supply of coloured glass at the end of the 14th-century towards the northeastern France as has been found in other European regions.

The 16th-century glass found in Girona Cathedral is of the lime-soda and soda-lime type. It was made from the ash of halophytic plants rather than from potassium-lime forest ash, indicating a shift from central Europe to a Mediterranean ash source. Its composition has been compared with the 15th-16th century glass from the city of Barcelona and with soda-lime window glass from Llenguadoc-Rosselló and from Florence (Italy). Analytical data obtained suggests that the 16th-century glass found in Girona Cathedral was made in Barcelona. Historical records on glass production in Catalonia show that window glass was already being sold in Barcelona by the end of the 14th-century, regardless of where it was produced. Our research strongly suggests that the production of window glass moved from France to Barcelona by the end of the 15th-century.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.culher.2025.05.012.

References

[1] D. Foy, Le verre médiéval et son artisanat en France méditerranéene, CNRS editions, Paris, 2001.
[2] D. Gimeno, M. Garcia-Valles, J.L. Fernandez Turiel, F. Bazzocchi, M. Aulinas, M. Pugès, C. Tarozzi, M.P. Riccardi, E. Basso, C. Fortina, M. Mendera, B. Messiga, From Siena to Barcelona: deciphering colour recipes of Na-rich Mediterranean stained glass windows at the XIII–XIV century transition, J. Cult. Herit. 9 (2008) e10–e15, doi:10.1016/j.culher.2008.08.001.
[3] E. Bassoa, M.P. Riccardi, B. Messiga, M. Mendera, D. Gimeno, M. Garcia-Valles, J.L. Fernandez-Turiel, F. Bazzocchi, M. Aulinas, C. Tarozzi, Composition of the base glass used to realize the stained glass windows by Duccio di Buoninsegna (Siena Cathedral,1288–1289 AD): a geochemical approach, Mat. Character 60 (2009) 1545–1554, doi:10.1016/j.matchar.2009.09.005.
[4] G. Piñar, M. Garcia-Valles, D. Gimeno, J.L. Fernandez Turiel, J. Ettenauer, K. Sterflinger, Microscopic, chemical, and molecular-biological investigation of the decayed medieval stained window glasses of two Catalonian churches, Int. Biodeterior. Biodegradation 84 (2013) 388–400 [Accessed: February 16, 2025], doi:10.1016/j.ibiod.2012.02.008.
[5] M. Verita, S. Bracci, S. Porcinai, Analytical investigation of 14th century stained glass windows from Santa Croce Basilica in Florence, Int. J. Appl. Glass Sci. 10 (2019) 546–557 [Accessed: February 16, 2025], doi:10.1111/ijag.13446.
[6] A. Frothingham, Spanish glass, Faber and Faber, London, 1963, p. 23. ISBN: 978-0571057696.
[7] M. Camiade, D. Fontaine, Verreries. Verriers catalans. L'Albera - Palau del Vidre – Perpignan, sources, Perpignan, 2006. ISBN: 978-2951593732.
[8] J. Mach, Le verre médiéval en Rosselló, un état de la documentation, Bulletin de l'Association Française pour l'Archéologie du Verre (AFAV) (2004) pag. 27-32 HAL-01858096.
[9] M. Hérold, Vitraux en Llenguadoc et Roussillon, inventaire général du patrimoine culturel de la Région Occitanie /Pyrénées-Méditerranée, Toulouse, 2017. ISBN: 1093747099.
[10] S. Cañellas, C. Domínguez, El forn de vidre del Pla de Llull de Barcelona (1447-1640) en els protocols notarials, Estudis Historics i documents dels Arxius de Protocols XXIII (2005) https://raco.cat/index.php/EHDAP/article/view/288147/479465. [Accessed: February 16, 2025].
[11] A. Santolaria, The white-washed table and the medieval windows of Girona Cathedral, in: 11th Forum for the Conservation and technology of historic stained glass, Barcelona, 2022, pp. 36–44. https://publicacions.iec.cat/repository/pdf/00000319/00000072.pdf [Accessed: February 16, 2025].
[12] A. Santolaria, M.A. Fumanal, El vitrall retrobat de la catedral de Girona, in: X. Barral (ed.), El Vitrall Medieval a Catalunya. Noves aportacions. Institut d'Estudis Catalans (IEC), Barcelona, 2021, pp. 79–85. https://publicacions.iec.cat/repository/pdf/00000513/00000082.pdf [Accessed: February 16, 2025].
[13] S. Cañellas, Els Fontanet, in: F. Fontbona, E. Vallès, B. Bassegoda (dirs.), Diccionari d'artistes catalans, valencians i balears, IEC, https://artistes.iec.cat/artista.asp?id=232 [Accessed: February 16, 2025].
[14] B. Wagner, A. Nowak, E. Bulska, K. Hametner, D. Günther, Critical assessment of the elemental composition of Corning archeological reference glasses by LA-ICP-MS, Anal. Bioanal. Chem. 402 (2012) 1667–1677 Accessed: February 16, 2025], doi:10.1007/s00216-011-5597-8.
[15] D. Domínguez-Carretero, X. Llovet, N. Pujol-Sol, C. Villanova-de-Benavent, J.A. Proenza, Accurate electron probe microanalysis of key petrogenetic minor and trace elements in Cr-spinel, Chem. Geol. 674 (2025) 122579 [Accessed: February 16, 2025], doi:10.1016/j.chemgeo.2024.122579.
[16] K.H. Wedepohl, K. Simon, The chemical composition of medieval wood ash glass from Central Europe, Chemie der Erde 70 (2010) 89–97 [Accessed: February 16, 2025], doi:10.1016/j.chemer.2009.12.006.
[17] S. Lagabrielle, B. Velde, Evolution of franch stained glass compositions during the middle ages. Analysis and observations made on the Cluny collection, in: Annales Du 16e Congrès de L'association Internationale Pour L'histoire Du Verre, AIHV, Nottingham, UK, 2003, pp. 341–346.
[18] J. Barrera, B. Velde, A study of French medieval glass composition, Archéologie Médiévale 19 (1989) 81–130 [Accessed: February 16, 2025], doi:10.3406/arcme.1989.953.
[19] L.W. Adlington, I.C. Freestone, J.J. Kunicki-Goldfinger, T. Ayers, H. Gilderdale Scott, A. Eavis, Regional patterns in medieval European glass composition as a provenancing tool, J. Archaeol. Sci. 110 (2019) 104991. 13p. [Accessed: February 16, 2025], doi:10.1016/j.jas.2019.104991.
[20] M.O.J.Y. Hunault, F. Bauchau, K. Boulanger, M. Hérold, G. Calas, Q. Lemasson, L. Pichon, C. Pacheco, C. Loisel, Thirteenth-century stained glass windows of the Sainte-Chapelle in Paris: an insight into medieval glazing work practices, J. Archaeol. Sci., Rep 35 (2021) 102753, doi:10.1016/j.jasrep.2020.102753.
[21] J.J. Kunicki-Goldfinger, I.C. Freestone, I. McDonald, J.A. Hobot, H. Gilderdale-Scott, T. Ayers, Technology, production and chronology of red window glass in the medieval period-rediscovery of a lost technology, J. Archaeol. Sci. 41 (2014) 89–105 [Accessed: February 16, 2025], doi:10.1016/j.jas.2013.07.029.
[22] W.B. Stern, Y. Gerber, Ancient potassium-calcium glass and its raw materials (wood-ash, fern-ash, potash) in Central Europe, Mitteilungen der Nasturforschenden Gesellschavten beider 11 (2009) 107–122.
[23] W.B. Stern, Y. Gerber, Potassium-calcium glass: new data and experiments, Archaeometry 46 (1) (2004) 137–156 Accessed: February 16, 2025], doi:10.1111/j.1475-4754.2004.00149.x.
[24] A. Machado, S. Wolf, L.C. Alves, I. Katona Serneels, V. Serneels, S. Trümpler, M. Vilarigues, Swiss stained-glass panels: an analytical study, Microsc. Microanalys. 23 (2017) 878–890 Accessed: February 16, 2025], doi:10.1017/S1431927617000629.
[25] C. Machado, A. Machado, T. Palomar, M. Vilarigues, Grisaille in historical written sources, J. Glass. Stud. 61 (2019) 71–86 [Accessed: February 16, 2025], doi:10.2307/26862829.
[26] J. Ainaud, J. Vila-Grau, A. Escudero, A. Vila, J. Marquès, G. Roura, J.M. Marquès, Els vitralls de la catedral de Girona, IEC (1987) 35–36 https://publicacions.iec.cat/repository/pdf/00000493/00000012.pdf. Accessed: February 16, 2025].
[27] S. Cañellas, C. Dominguez, Els forns de vidre de Barcelona i la seva rodalia (segles XIV-XVI), Anuario de estudios medievales 38/2, 2008. 614-615 [Accessed: February 16, 2025] https://estudiosmedievales.revistas.csic.es/index.php/estudiosmedievales/article/view/80/81 .
[28] C. Domínguez, Notícies esparses sobre la vidriera medieval a Catalunya, in: X. Barral (ed.) El Vitrall Medieval a Catalunya. Noves aportacions. IEC, Barcelona, 2021, p. 17. https://publicacions.iec.cat/repository/pdf/00000513/00000082.pdf [Accessed: February 16, 2025].
[29] J. Iglesias, Pere Gil, S.I. (1551-1622) i la seva Geografia de Catalunya, Barcelona: Societat Catalana de Geografia (2002) 329 pp. ISBN 84-7283-648-7.
[30] C. Domínguez, S. Cañellas and M. Segarrés, Addenda documental al volum CVMA1: els vitralls medievals de l'església de Santa Maria del Mar a Barcelona, in: X. Barral (ed.) El Vitrall Medieval a Catalunya. Noves aportacions. IEC, Barcelona, 2021, pp. 43–44. https://publicacions.iec.cat/repository/pdf/00000513/00000082.pdf [Accessed: February 16, 2025].
[31] C. Sanjust, L'obra del Reial monestir de Santa Maria de Pedralbes des de la seva fundació fins al segle XVI. Un monestir reial per a l'ordre de les Clarisses a Catalunya, UAB (Col. Cum Laude, 3) 119 (2010) 112 Annexos.
[32] C. Domínguez, S. Cañellas, Barcelona, Llotja de Mar, in: corpus Vitrearum medii aevi: catalunya 5. 1. Els vitralls de la Catedral de la Seu d'Urgell i de la col·legiata de Santa Maria de Cervera, IEC, Barcelona, 2014, pp. 277–312:289. https://publicacions.iec.cat/repository/pdf/00000513/00000063.pdf [Accessed: February 16, 2025].
[33] A. Duran, Barcelona i la seva història (vol. 2). La Societat i L'organització Del Treball, Curial, Barcelona, 1973, pp. 403–404.
[34] S. Cañellas, C. Domínguez, Catedral de Vic, in: Corpus Vitrearum Medii Aevi: catalunya 5. 1. Els vitralls de la catedral de la Seu d'Urgell i de la col·legiata de Santa Maria de Cervera, IEC, Barcelona, 2014, pp. 141–154:148. https://publicacions.iec.cat/repository/pdf/00000513/00000063.pdf [Accessed: February 16, 2025].