Geo-heritage Tour Across the Ornamental Stone of the Historic Centre of Ivrea, UNESCO World Heritage Site (Piedmont region, NW Italy)

Geoheritage

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--Manuscript Draft--

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Corresponding Author:	Alessandro Borghi Universita degli Studi di Torino TORINO, ITALY
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Universita degli Studi di Torino
Corresponding Author's Secondary Institution:	
First Author:	Giorgia Parmeggiani
First Author Secondary Information:	
Order of Authors:	Giorgia Parmeggiani
	Anna d'Atri
	Luigi Perotti
	Alessandro Borghi
Order of Authors Secondary Information:	
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Abstract:	Ivrea, the ancient Eporedia founded around 100–101 B.C. by the Romans and UNESCO site from 2018, is a town where stone has always been the most widely used building material, characterizing the architectural identity of the city. In particular, numerous rocks were still visible in the ancient buildings of the historic centre. For this reason, Ivrea was chosen as place on which developing an informative proposal, of geological interest for the conservation of Cultural Heritage. A minero-petrographic study was carried out to identify the different stone materials and their provenance areas used. The origin of rock samples resulted essentially from local or nearby geological units. The most used stones were diorite, tonalite and gabbro of the Ivrea Verbano Mafic Complex, which crops out in the city of Ivrea itself. Other rocks used were permian granites intruded into the basement of the Serie dei Laghi, syenite and diorite from Oligocenic pluton of Sesia Zone, jadeite orthogneiss and micaschists from the Eclogitic Micaschist Complex of the Sesia Zone; calcschists and Bardiglio marble from the Piemonte Zone and Serizzo othogneiss from the Antigorio unit of Ossola Valley. In lower quantities, rocks from both extra-regional Italian areas (some carbonate rocks from Southern Alps and the Northern Apennines) and foreign countries (Scandinavian granites) were also used. The data collected were managed through digital systems using geomatics techniques and the results consists of an interactive web site that can be used by a wide audience. It can be visited through any mobile or fixed device at the following link: http://www.geositlab.unito.it/ivrea The site consists of 13 historical sites of interest in each of which ornamental stones of historical and scientific interest can be observed in detail.
Response to Reviewers:	Dear Editor, We are resubmitting herein the revised version of our manuscript Manuscript Number: GEOH-D-22-00210"Geo-heritage tour in the historic centre of Ivrea, UNESCO World Heritage site (Piedmont region, NW Italy)" by G. Parmeggiani, A. d'Atri, L. Perotti, A. Borghi

	We would like to express our sincere thanks to you (Editor) and two reviewers, expecially to Alberto Renzulli for the thorough and punctual reviews, from which we have benefited in improving our manuscript. We have carefully considered his constructive comments and suggestions provided and we have provided detailed answers to all the issues raised (see listed comments and related responses in the following). The details are reported in the Authors' Response to Reviewers' Comments attached file We look forward to hearing from you regarding the status of this re-submission. Yours sincerely, Prof. Alessandro Borghi (corresponding Author) Email: alessandro.borghi@unito.it

UNIVERSITA' DEGLI STUDI DI TORINO
DIPARTIMENTO DI SCIENZE DELLA TERRA
Via Valperga Caluso, 35 - 10125 TORINO
Tel.: +39-011-670.51.26 (office)
Fax.: +39- 011-670.53.39

Torino, April 2th 2023

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We have carefully considered his constructive comments and suggestions provided and we have provided detailed answers to all the issues raised (see listed comments and related responses in the following).

We look forward to hearing from you regarding the status of this re-submission.

Yours sincerely,

Prof. Alessandro Borghi ***(corresponding Author)***

Email: alessandro.borghi@unito.it

Reviewer comments #1:

Dear Authors,

The submitted manuscript GEOH-D-22-00210 entitled "Geo-heritage tour in the historic centre of Ivrea, UNESCO World Heritage site (Piedmont region, NW Italy)" contain very interesting data to be published in Geoheritage. Nevertheless, the manuscript needs some re-arrangements of figures and changes before being published. Some incongruences, type errors, missing parts in the captions ecc….have to be clarified.

Response: an in-depth revision of the manuscript was carried out also to improve the language, in particular the iconographic part has been improved, also adding some figures

Comment 1) ABSTRACT and TITLE: the abstract should be more informative about the main stone materials…e.g. a couple of phrase on the most important groups of building stones among the investigated igneous and metamorphic lithotypes. In this way, also the title should report something about the focus of the work, i.e. building stones. In the title, "Geo-heritage tour" is okay as incipit but a glance to stones should be reported….as the stones are the main focus of the article

Response 1a: the title has been changed as suggested by the referee to "**Geo-heritage tour across the ornamental stone of the historic centre of Ivrea, UNESCO World Heritage site (Piedmont region, NW Italy)".**

Response 1b: the abstract has been significantly modified reporting more information about the main stone materials

Comment 2) for the Morainic Amphiteatre of Ivrea you use the acronym AMI but…should be "MAI" ? AMI sounds like in Italian (Anfiteatro Morenico di Ivrea)?

Response: the IMA acronym for Ivrea Morainic Amphitheatre was reported

Comment 3) The chapters Geographic setting and Historical Background of Ivrea could be merged (geographic setting chapter is less than ten rows….).

Response: Done. Also following the suggestions of the referee 2 the chapter Geographic was moved and merged with Geological Setting

Comment 4) A general figure focusing on the location of Ivrea (to insert in the geographic setting part) should appear before the figure of the outcrops (Fig.1). A re-arrangement and logic sequence of the figure is necessary (see later). The new Fig.1 should be a geographic/geomorphologic map also reporting the cited Morainic Amphiteatre of Ivrea? As in the text you mention the importantance of forms of glacial-subglacial modelling

Response: A new figure was drawed, in which is reported the geomorphological sketch map of the Dora Baltea basin, with the location of Ivrea Morainic Amphitheatre (IMA).

Comment 5) In the present Figure 1 caption, however, information about the rocks of the outcrops should be added. In 8addition I strongly suggest to not insert the outcrops as Figure 1 but later, together with thin section photos associated to the two stops concerning the outcrops (Stop 8 and Stop 10): Fig.1a-b, Fig.12a and Fig.12c could be merged in a single figure concerning Stop 8 and Stop 10.

Response: the current figure 1 has been merged with the Fig.12a and Fig.12c in a single figure concerning Stop 8 and Stop 10

Comment 6) Page 3, Line38-41: so-called "Ordine dei Libri Sibillini". In addition, this phrase should be rewritten without footnotes but including the information along with the phrase.

Response: in the Historical Background of Ivrea, reducing its length, this sentence has been deleted

Comment 7) Page4, Line9: Roman Empire. Moreover…march? Is it correct?

Response: was corrected with Marquisate

Comment 8) Page4, Line31: since the Unification…

Response: Done

Comment 9) Page5, Line1: intruded by granites

Response: Done

Comment 10) Page5, Line7-11: references should be moved at the end of the phrase.

Response: Done

Comment 11) Page5, Line 11: It consists of kinzigites….Please explain what a kinzigite is….a coarse-grained, biotite-garnet-cordierite-bearing metamorphic rock with a pelitic protolith and in the granulite facies…

Response: Done.

Comment 12) Page5, Line13: …..and ultra-mafic rocks)

Response: Done.

Comment 13) Page5, Line 16: …of Variscan basement.

Response: Done.

Comment 14) Figure 2: in the map the AG acronym (Argentera in the caption) is missing? Please check.

Response: the AG acronym is not reported in the figure

Comment 15) Figure 2 caption: please check punctuations and syntax e.g. Torino Hill. In red the main tectonic lines are reported Aosta-Ranzola

Response: Done.

Comment 16) Page 6, Line25: (Cervo Valley) which is an important

Response: Done.

Comment 17) Page6, Line34: The upper Penninic units consist of

Response: Done.

Comment 18) Page7, Line 5: ornamental stones

Response: Done.

Comment 19) Page7, Line17: with thin sections

Response: Done.

Comment 20) Page7, Line 20-30 (SEM -EDX): yes but….where are these analyses? May be supplementary material is needed?

Response: Representative tables of pyroxene, biotite, plagioclase from Mafic Complex samples and chlorite and garnet from Pietra Ollare samples were reported in the supplementary materials.

Comment 21) Figure 3 caption: the numbers indicate (eliminate on the papers) Jadeite Orthogneiss. 8 is missing on the caption? In addition: circled numbers and the acronyms (AR ecc..) should be of larger size in the map, please change C.L. into CL. Please you have to homogenise caption with the text. Mafic Complex (instead of Basic)

Response: Done. The circled number were enlarged C.L. was corrected

Comment 22) Page 8, Line5: magma reservoir (better than magma chamber which is in general at shallower levels)

Response: Done.

Comment 23) Page8, Line13-20. You say basic-ultrabasic rocks outropping……BUT later on you write about tonalites as well….Tonalite is NOT a basic-ultrabasic rock. A more rigorous petrographic approach using the term basic-ultrabasic has to be applied.

Response: the sentence was corrected

Comment 24) Figure 4 caption: here you say Mafic Complex. You have to homogenise the term: Mafic Complex instead of basic-ultrabasic. For Fig.4 c and Fig4d add in the caption they are thin section images. In addition "The more diffuse lithology are quartz diorites ……subsequently altered by a very low-degree metamorphic event characterized….. clinopyroxene tonalites; and hypersthene….

Response: the caption was corrected. The term Mafic Complex was used in the whole paper

Comment 25) **Fig.5; Granite (e)**

Response: Done.

Comment 26) Page9, Line59-61: ….Oligocene pluton of Traversella, about 10 km West of Ivrea (Canavese Diorite) and the Cervo Valley north of Biella (Balma Syenite). The Diorite is…

Response: Done.

Comment 27) Page 10, Line2-7: ….and opaques (REFERENCES ?). Where it is used the Canavese Diorite? For this lithology you do not give information of use in Ivrea…

Response: Done. A reference was added (Sandrone et al., 2004).

Comment 28) Balma Syenite, on the other hand……..and scarce biotite

Response: Done.

Comment 29) Page10, Line18: …..heterogeneous grainsize

Response: Done.

Comment 30) Page10, Line22: ….by aplitic veins (REFERENCES?)

Response: Done.

Comment 31) Page10, Line37: …..grainsize consisting

Response: Done.

Comment 32) Page10, Line41-42: Please use Maggiore Lake (instead of Verbano Lake) as in the maps Lago Maggiore appear.

Response: Done.

Comment 33) Page 10, Line51: ……..in the Ossola Valley (Verbania). Also for Serizzo Antigorio you do not provide the information where it is used in Ivrea.

Response: information of use in Ivrea was reported.

Comment 34) In general, for the mineralogical assemblage reported for the Canavese Diorite, Balma Syenite, Eclogite micaschists, Graniti dei Laghi, Serizzo Antigorio some references are needed. Also some references for Baltic Brown, Red Balmoral and Carmen Red are needed.

Response: Some reference were reported (Sandrone et al., 2004, Compagnoni, 1977: Selonen and Suominen, 2003).

Comment 35) Page11, Line3: …the ornamental stones here described

Response: Done.

Comment 36) Page11, Line7-11: How do you can affirm the Travertine is just that from Tivoli ? The same question for the Carrara Marble.

Response: the sentence referring to travertine provenance was deleted

Comment 37) Figure 6 caption: ….of the main investigated buildings, squares and geological outcrops.

Response: Done.

Comment 38) Chapter "Ivrea Stones: Geo-heritage tour across Historic centre of Ivrea" SHOULD be changed into "Geo-heritage tour across the stones of the historic centre of Ivrea"

Response: Done.

Comment 39) Page 12, Line1-2: The itinerary proposed in this work comprises the most representative historic sites…

Response: Done.

Comment 40) Page 12, Line7: ….of ther Dora Baltea River

Response: Done.

Comment 41) Figure 7: in the visualization of the card, NO mention to stones are reported. Please you have to revise the card, also addressing it to the heritage stones..

Response: The historic description of the site and mention to the stone employed are reported in the "web site card" and the "rock card", respectively

Comment 42) Page13, Line26: please add the civic number of Via Jervis if available.

Response: Done.

Comment 43) Page13, Line44: should be Red Balmoral (not Rosso Balmoral)

Response: Done.

Comment 44) Page14, Line16: few additional words on the "Pietra Ollare" is due…..Also in Fig.9 the authors write Pietra Ollare (soapstones) BUT not all the Pietra Ollare are soapstones. There are eleven groups of the pietra ollare (some of them are saopstones i.e. carbonate-talc schists) as divided by Mannoni et al 1987, but some pietra ollare groups are serpentinites ecc…Which kind of Pietra Ollare is that used in the external walls of Santo Stefano Tower?

Response: the type of Pietra Ollare was specified following the classification reported in Mannoni, T., Pfeifer, H. R., and Serneels, V., 1987, Giacimenti e cave di pietra ollare nelle Alpi, in Proceedings of "La Pietra Ollare dalla Preistoria all'Età Moderna", 7-45. A new figure (Fig. 9) was dedicated to the description of Santo Stefano Tower, adding two macroscopic views of the used stones. In addition a new figure (Fig. 10) was dedicated to the Amphitheatre description, with a detailed image of rock blocks emplyed

Comment 45) Page15, Line4: websites? Is it a mistake?

Response: Yes, changed with websterites

Comment 46) Page15, Line9: Bardiglio marble ? It would be better the use of the term Bardiglio-like marble, as the provenance is not Bardiglio from Apuane Alps?

Response: specified. Bardiglio Mmarble is an historic listed marble coming from Aymavilles (Aosta), used by Ancient Roman as reported in Borghi A, Fiora L, Zoja A (2006) The grey marble of Porta Praetoria (Aosta, Italy): a minero-petrographic characterisation and provenance determination. Periodico di Mineralogia LXXXVI: 59-74.

Comment 47) Page15, Line20: ….of stone products such as the colours

Response: Done.

Comment 48) Figure 10 and Page 16, Line3: Pietra Ollare (soapstones)? See comments above

Response: Specified

Comment 49) Page 16, Line35-38: The indoor ornamental stones include……..please the italina names of stones should be reported in quotation marks…"Rosso Verona", "Botticino" ecc. ecc..

Response: Done.

Comment 50) Page 16, Line40: …..and Apulian marble (sensu commercial meaning) for flooring.

Response: Done.

Comment 51) Page 16, Line46: …..take Via della Cattedrale

Response: Done.

Comment 52) Page 16, Line49-57: ….with the outcropping substrate ….Here the Mafic Complex of the Ivrea Zone, consisting of different lithologic varieties is represented by orthopyroxene- and biotite-bearing quartz-diorite. The mineral description was eliminated as already given previously

Response: Done.

Comment 53) Page16, Line60: ……grainsize and irregular contours suggesting late static recrystallization phenomena

Response: Done.

Comment 54) The Stop 8 and Stop 10 should be merged in a figure dedicated to outcrops only. Fig.1a-b, Fig.12a and Fig.12c could be merged in a single figure concerning Stop 8 and Stop 10.

Response: A new figure (Fig. 13) was reported, in which the rocks of the Stop 8 and Stop 10 are described at macroscopic and microscopic scale

Comment 55) Fig.11: Rosso Verona, Botticino ecc in quotation marks. NOT Oficalci (italian) BUT Ophicalcite! Concerning the Apulian: Apulian marble (sensu commercial meaning)

Response: Done.

Comment 56) STOP 9: at this stop an exclusive figure should be deserved (not merged as presently together with Stop 8 which is a stop for outcrop….). In the figure deserved for Stop 9 some macroscopic views of the used stones are needed (similarly to the other building stops). It can be suggested that all stops represented in figures should contain some macroscopic views of the stones.

Response: Done. A new figure (Fig. 14) was dedicated to the description of Ivrea Synagogue, adding two macroscopic views of the used stones.

Comment 57) Page18, Line1: Mafic Complex of the Ivrea Zone can be distinguished: hypersthene…..

Again, you can not use as alternative the terms BASIC and MAFIC!

Response: Done.

Comment 58) The lines 3 to 7 of Page18 should be eliminated because already said previously: from "The latter is an intrusive…..until….titanite, and iron hydroxides.

Response: Done.

Comment 59) Fig.12 caption: I know, I am a petrologist but the term regressed/retrogressed is too specialistic for a reader of Geoheritage. Please explain in other words.

Response: Done. The image is now Fig. 13d

Comment 60) Page19, Line6: ….stones used outside the Cathedral include the Balma Syenite…..

Response: Done.

Comment 61) Page19, Line17: Greek White marble….IT IS TOO GENERAL. Please try to distinguish which kind of Greek white marble.

Response: since it was not possible to better define the origin of the white marbles, the term Greek has been deleted

Comment 62) Page19, Line20: Caius Atecio ?? or ATHERIEUS. Please try to homogenise the name throughout the text (see e.g Fig.3 Atherius…)

Response: Done. The correct term is Caius Atecio

Comment 63) Fig. 13c: add in the caption this is a thin section image, plane polarized light. GRAPHIC SCALE should be also added in the thin section image.

Response: The Fig. 13c (now 15c) is a macroscopic image of eclogitic micaschist

Comment 64) Page 20, Line38-39: ……the Civic Museum Pier Alessandro Garda…..is it in Ivrea as well? Please specify.

Response: the Civic Museum Pier Alessandro Garda is in Ivrea as reported in the Stop 5

Comment 65) Page 20, Line53: ….now part of the cultural heritage.

Response: Done.

Comment 66) Page 20, Line53: In Ivrea stones have always…

Response: Done.

Comment 67) Page 21, Line6: followed by stones of Italian extra-regional origin

Response: Done.

Comment 68) Page 21, Line11: above the rocky basement (instead of substrate)

Response: Done.

Comment 69) Page 21, Line17: the fundamental principle of "Cultural Heritage" is pursued studying the interactions…..

Response: Done.

Comment 70) Page 21, Line23-24: The study also contains ideas aimed at promoting….

Response: Done.

Comment 71) Page 21, Line29: conservation (instead of preservation)

Response: Done.

Comment 72) Page21, Line33: To promote geo-dissemination……(eliminate "To enhance the chosen sites and")

Response: Done.

Comment 73) Page21, Line40-42: and the petrographic descriptions of them.

Response: Done.

Comment 74) Page21, Line42-46: The phrase "The dissemination of itineraries……on the ground" is not clear at all. It has to be rewritten.

Comment 75) Page21, Line55: in the framewok (instead frame)

Reviewer comments #2:

Comment 1) I appreciate the paper for its original content, but not for the structure. I think the paper should be better structured because it does not respect the standard structure of a scientific article. The authors should take into consideration to move in the Introduction the Historical Background of Ivrea, suitably reducing its length.

Response: The historical Background of Ivrea was reduced and inserted at the end of Introduction

Comment 2) Geographical setting is a section too short and the sections Geographical setting and Geological Setting could be merged into Geographical and Geological Setting.

Response: Geographical setting was cutted and merged into a new Geographical and Geological Setting chapter after The historical Background of Ivrea.

Comment 3) Materials and methods is an unclear section. Authors should detail the samples they studied and the methodologies they used.

Response: in the Materials and methods chapter is better specified that the studied rock samples belong to a scientific collection of our department and that they reflect the stone materials employed in the historic building of Ivrea

Comment 4) The ornamental stones of Ivrea and IvreaStones: Geo-heritage tour across Historic Centre of Ivrea are results of the work and they should be into a Results and Discussion section.

Response: this comment has been rejected because generally the articles of your magazine do not have a "results" chapter, but there are chapters describing the topic of the paper.

Comment 5) Concluding remarks is a too general section and it should be revised taking into account the results and discussion and remembering everything said before, selecting what is very important

Response: some improvements have been made, also following the suggestions of referee #1

Geo-heritage tour across the ornamental stone of~~in~~ the historic centre of Ivrea, UNESCO World Heritage site (Piedmont region, NW Italy)

Giorgia Parmeggiani [1], Anna d'Atri[1], Luigi Perotti[2~~1~~], Alessandro Borghi,[1]

1 Dipartimento di Scienze della Terra, Università degli Studi di Torino, Italy

2 Dipartimento di Scienze Agrarie, Forestali e Alimentari

Corresponding Author: alessandro.borghi@unito.it

Abstract

Ivrea, the ancient Eporedia founded around 100–101 B.C. by the Romans and UNESCO site from 2018, is a town where stone has always been the most widely used building material, characterizing the architectural identity of the city. In particular, numerous rocks were still visible in the ancient buildings of the historic centre. ~~Ornamental stone has always been largely used in Ivrea as a building material for historic and contemporary buildings, characterising its architectural identity. Ivrea (the ancient *Eporedia*, UNESCO site from 2018) bases its roots in Roman times:.~~ F~~f~~or this reason, Ivrea ~~it~~ was chosen as place on which developing an informative proposal, of geological interest for the conservation of Cultural Heritage.

A minero-petrographic study was carried out to identify the different stone materials and their provenance areas used. The origin of rock samples resulted essentially from local or nearby geological units. The most used stones were diorite, tonalite and gabbro and of the Ivrea Verbano Mafic Complex, which crops out in the city of Ivrea itself. Other rocks used were permian granites intruded into the basement of the Serie dei Laghi, syenite and diorite from Oligocenic pluton of Sesia Zone, jadeite orthogneiss and micaschists from the Eclogitic Micaschist Complex of the Sesia Zone; calcschists and Bardiglio Marble from the Piemonte Zone and Serizzo othogneiss from the Antigorio unit of Ossola Valley. In lower quantities, rocks from both extra-regional Italian areas (some carbonate rocks from Southern Alps and the Northern Apennines) and foreign countries (Scandinavian granites) were also used.

~~The city has been influenced by the great variety of stone materials available by the Alps, as well as by their ease of finding directly on site. This article describes the main locally sourced stone materials, by referring on the one hand to their petrographic characteristics and areas of provenance, and on the other to the main examples of use, with the aim of spreading the knowledge about stone, both from a scientific and cultural point of view through the creation of a geo-tourist tour.~~

The data collected were~~and~~ managed through digital systems using geomatics techniques and the results consists of an interactive web site that can be used by a wide audience. It can be visited through any mobile or fixed device at the following link: http://www.geositlab.unito.it/ivrea
The site consists of 13 historical sites of interest in each of which ornamental stones of historical and scientific interest can be observed in detail. ~~systems were processed using geomatics techniques and the results will be prepared as multimedia storytelling product by means interactive webmap published on the web that can be used by wide audience.~~

Keywords Cultural Heritage, Building and ornamental stones, Urban Geology, Geo-tourism, Ivrea.

Introduction

According to the UNESCO Convention Concerning the Protection of the World Cultural and Natural Heritage (UNESCO 1972), it is necessary to promote awareness and knowledge of geodiversity and geoheritage as an integral part of the natural heritage centred on unique and representative geosites. In this context, the University of Turin aims to develop a scientific, informative, and teaching proposal focused on enhancing, protecting and promoting the Piedmont geosites (Lozar et al., 2019). This project stems from the awareness of having a territory rich in geologic~~al~~ and geomorphologic peculiarities, rarely studied and enhanced, but that represent a starting point for local growth. This knowledge promotion includes the study of ornamental stones that have always been considered as one of the most important natural resources, given their use as raw material for construction, but also as a restoration material for the preservation of the artistic and architectural heritage (Barale et al., 2020). The historical and contemporary ornamental stone resources analysis represents one of the most valuable means to combine geology with cultural heritage within an urban context (Cooper 2015). Geological heritage is, in fact, part of the territory history and material culture (Borghi et al. 2014), and consequently of prominent importance for its enhancement. Stone itineraries have been proposed through the downtown of some Italian cities such as Catania (Punturo et al. 2006), Rome (Giampaolo et al. 2008), Florence (Pecchioni et al. 2012), Reggio Emilia (Vernia 2014), Turin (Borghi et al. 2014; Gambino et al. 2019), Pisa (Lezzerini et al. 2019), Petralia Sottana-Palermo (Torre et al. 2020) and Urbino (Santi et al., 2021) to reach a better use of the geological and cultural heritage in the last two decades. Taking the above mentioned studies as a reference, an itinerary in the historic centre of Ivrea (NW Italy) has been developed, a geosite with both a geological-morphological and a historical-architectural value, characterized by the presence of historic buildings and rocky outcrops (attributable to the Mafic Complex of the Ivrea Zone Unit, Zingg et al., 1990), as well as forms of subglacial modelling. At Ivrea, there is a close relationship between building stone

used over the centuries for the construction of the most important historical place and geological context.

~~Geographical Setting~~

~~The municipality of Ivrea is located in the north-western sector of Piedmont (Canavese area), 50 km north of the city of Turin. The city grows in a wide flat area placed within the Morainic Amphitheatre of Ivrea (AMI), which developed during the Pleistocene from the Balteo glacier (Gianotti et al., 2008). Among the morainic systems of the south of the Alps, the AMI is known for its geomorphology with the presence of forms of subglacial modelling preserved also in the city of Ivrea. The erosive action of the glacier has reached the rocky substrate exposing it to glacial modelling and making it a suitable place for the construction of the first settlements (Fig. 1a). The direct interaction between the historical and contemporary buildings of the city with the outcropping substrate represents a peculiar feature that makes Ivrea a unique place (Fig. 1b).~~

Historical Background of Ivrea

~~The city of Ivrea is characterized by an ultra-millennial history marked by its main historic buildings, in which stone has always played a fundamental role.~~The municipality of Ivrea is located in the north-western sector of Piedmont (Canavese area), 50 km north of the city of Turin. Ivrea is ~~locates~~ along the principal connecting routes between Val Padana and Northwestern Europe, a strategic position since when, about ten thousand years ago, the retreat of the glaciers at the end of the last glaciation had freed the Alpine valleys and the morainic amphitheatre (Fig. 1).

The city of Ivrea is characterized by an ultra-millennial history marked by its main historic buildings, in which stone has always played a fundamental role.The most ancient evidence of a dense human presence in the area dates back to the Middle Neolithic shortly after 5000 BCE. In ancient times, the territory where Ivrea has been founded was inhabited by the Salassi, ~~of which, due to a lack of historical data, neither the origin nor how long they lived there are known.~~ Taking the internal clashes between the Salassi as a pretext, ~~and as a response to the "Ordine dei Libri Sibillini"[1] (opidum Eporedia Sibyllinis a populo Romano conditum iussis)[2],~~ the Romans decided to found a new city named *Eporedia*, around ~~in~~ 100 BCE (Perinetti, 1965). ~~The meaning of the name remains unknown, with various interpretations. The most accredited reading sees it as a combination of the word "epo",~~

[1] ~~Greek collection of oracles~~
[2] ~~Plinio il Vecchio, Naturalis Historia, III~~

~~meaning horse in Greek, and "reda", meaning wagon in Gallic, resulting in "equestrian wagon" and by extension "equestrian wagon station".~~

It is a shared opinion that Eporedia experienced a monumental increase in the second half of the first century AD, a period to which the construction of the amphitheatre dates back. With the spread of Christianity and the subsequent freedom of profession, the ~~first Christian churches began to arise in the Canavese area.~~ ~~The~~ SS. Maria Assunta Church was built in the twelfth century on the most important pagan temple in the city~~., and it is one of the oldest in Ivrea~~. ~~After being subjected to Odoacer, it fell under the rule of Theodoric and then his successors.~~ ~~During this period there was a great development of monastic centres. Nowadays, the only testimony that remains, is the tower of Santo Stefano, the ancient bell tower of the homonymous abbey~~. In 553, Ivrea became part of the Byzantine kingdom, in 572 of the Lombards, and later of the Franks in which Ivrea became the seat of a County. During this period there was a great development of monastic centres. Nowadays, the only testimony that remains, is the tower of Santo Stefano, the ancient bell tower of the homonymous abbey. After the end of the Empire, Ivrea was the capital of a Marquisate~~march~~ whose Marquis, Arduino, became King of Italy from 1002 to 1014. In these years the Church of Sant'Ulderico was built reusing elements ~~of recycling~~ of the Roman theatre. After the disappearance of Arduino, ~~the struggles between the descendants and the opponents continued until, on the threshold of the twelfth century~~ , the Marca came into the possession of the emperor. In these years further, impetus was given to the construction of religious buildings including the Tre Re Chapel and the Monastery of Santa Chiara, later converted into the current Civic Museum P.A. Garda. ~~In the meanwhile, approximately in the middle of the eleventh century, the Ivrea Municipality was founded.~~ In 1356, the city passed under the Savoy dominion~~. In the sixteenth century Ivrea was involved in a period of foreign invasions and struggles and was occupied by French soldiers until 1560 when it returned under the Duchy of Savoy~~ . The construction of the Sanctuary Monte Stella dates back to this period. ~~The Napoleonic advance characterises the next century, and, on 26th March 1800, Napoleon was welcomed in Ivrea which became the capital of the "Département de la Doire" until 1814 when the city returned to the Savoy~~ . From 1859 to 1927 Ivrea became, sinceuntil the Unification of Italy, the capital of the homonymous district. The twentieth century saw the city protagonist of a new industrial growth, with the foundation of the Olivetti typewriter factory. On 1 July 2018, it became part of the UNESCO heritage (54th Italian site) as Industrial City of the 20th century.

Geographic and Geological Setting

The city grows in a wide flat area placed within the Ivrea Morainic Amphitheatre (IMA), which developed during the Pleistocene from the Balteo glacier (Gianotti et al., 2008). Among the morainic systems of the south of the Alps, the IMA is known for its geomorphology with the presence of forms

of subglacial modelling preserved also in the city of Ivrea (Fig. 1). The erosive action of the glacier has reached the rocky substrate exposing it to glacial modelling and making it a suitable place for the construction of the first settlements. The direct interaction between the historical and contemporary buildings of the city with the outcropping substrate represents a peculiar feature that makes Ivrea a unique place.

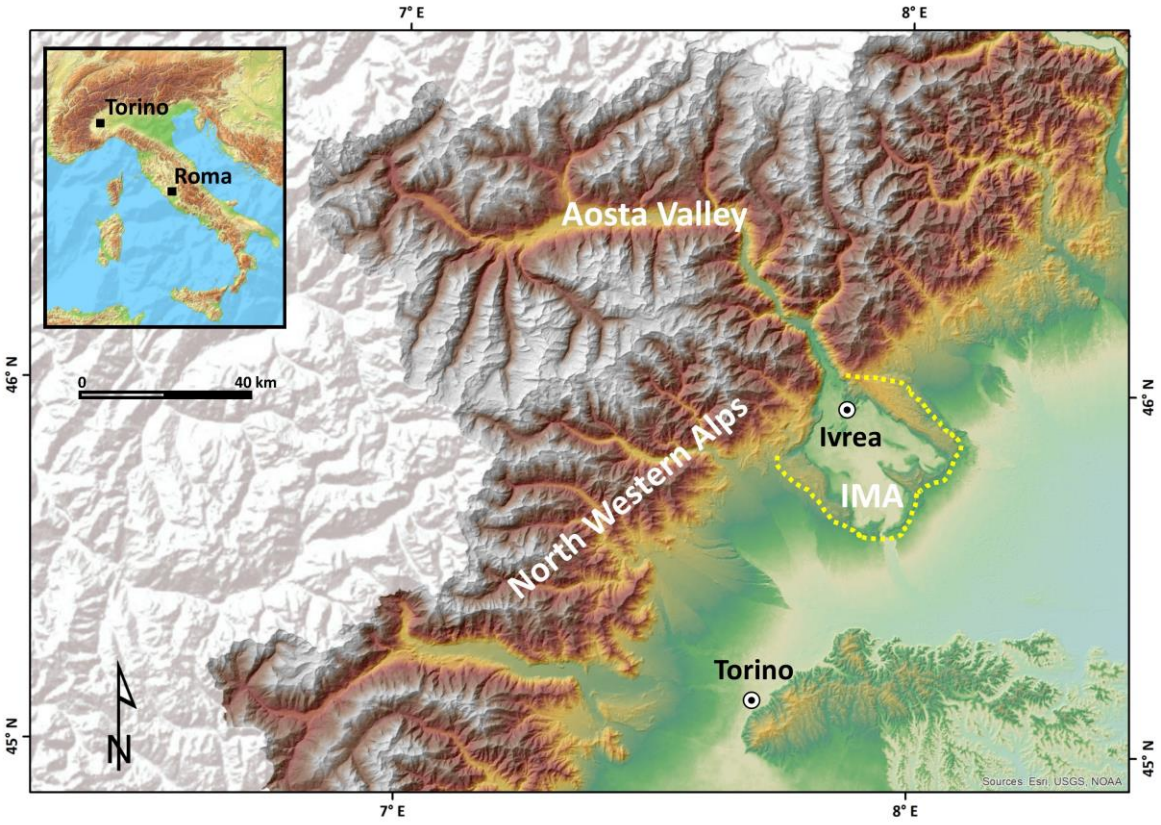

Fig. 1 Geomorphological sketch map of the Dora Baltea basin, with the location of Ivrea Morainic Amphitheatre (IMA).

The great variety of ornamental stones used in Ivrea relates to the composite geological nature of the Canavese, a geographical area of which the city is the town of reference. The wide variety of outcropping rocks in the Alpine chain has been grouped into four main domains according to lithostratigraphic characteristics, metamorphic evolution, and the age of metamorphism, separated by important tectonic contacts (Dal Piaz 1992). These domains, from the inside to the outside of the chain, have been called South~~ern A~~lpine, Austroalpine, Penninic, and Helvetic-Dauphinois (Dal Piaz et al. 2003; Schmidt et al. 2004) (Fig.2).

The SouthalpineSouthern Alpine domain, bordered to the South by the SouthalpineSouthern Alpine Front and to the North by Insubric Line, is made up of Variscan metamorphic basement units, Permian magmatic bodies and Permian, Triassic-Jurassic and Cretaceous-Paleogene sedimentary successions. The Western SouthalpineThis domain is traditionally divided into three main units: the Serie dei Laghi, the Ivrea Zone and the Canavese Zone. The Serie dei Laghi mainly consists of micaschists and gneiss intrudedrs from granites (Graniti dei Laghi) which represent an important quarry district (Boriani et al. 1992) in which the Baveno pink Granite, the Montorfano white Granite and the Alzo Granite are exploited, widely used in the building of Ivrea as ornamental stones. The Ivrea Zone corresponds to a lower crust section (Handy et Zingg, 1991; Handy et al. 1999; Zingg et al. 1990; Klotzli et al. 2014) interpreted as one of the best examples of continental "magmatic underplating"(Handy et Zingg, 1991; Handy et al. 1999; Zingg et al. 1990; Klotzli et al. 2014). It consists of kinzigites, a coarse-grained, biotite-garnet-cordierite-bearing metamorphic rock in the granulite facies with a pelitic protolith, with minor quartzites, and metabasites (Kinzigitic Complex) intruded by basic Permian bodies (gabbros, diorites, tonalites, and ultra-mafics) (Mafic Complex) (Quick et al. 1994) and by mantle peridotites (Balmuccia, Baldissero, and Finero). The Canavese Zone corresponds to a portion of the upper crust and consists of Variscan basememt (Wozniak 1977; Biino et Compagnoni 1989; Borghi et al. 1996; Ferrando et al. 2004), Permian igneous bodies (Borghi et al. 1996; Ferrando et al. 2004) and Permo-Mesozoic volcano-sedimentary and carbonate successions covers (Festa et al. 2020).

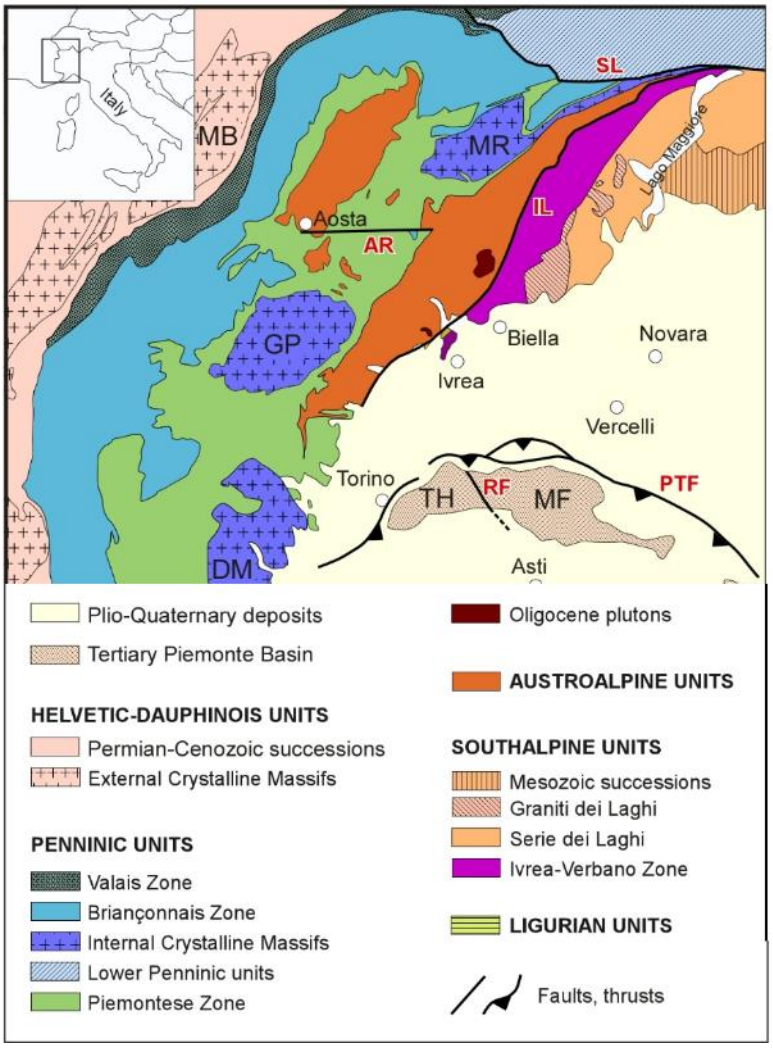

Fig. 2 Geological sketch of Western Alps, (Modified by Gambino et al., 2019). ~~AG = Argentera;~~ DM = Dora Maira; GP = Gran Paradiso; MB = Monte Bianco; MF = Monferrato; MR = Monte Rosa; TH Torino Hill; ~~.~~ In red the main tectonic lines are reported ~~the main tectonic lines~~: AR = Aosta – Ranzola Line: IL = Insubric Line; PTF = Padan~~e~~ian Thrust Front; SL = Simplon Line; RF = Rio Freddo Line.

The Austroalpine domain, bounded to the South-East by the Insubric Line and to the North-West by multiphase fault zones, is made up of continental crust units (Sesia-Lanzo and Dent Blanche s.l.) and represents the geometrically highest tectonic element in the axial sector of the chain (Dal Piaz, 1999). The Sesia-Lanzo Zone is traditionally divided into the Eclogitic Micaschists Complex (polymetamorphic basement intruded by basic Permian metagranitoids and metaintrusives), Gneiss Minuti Complex (metapelites and rare metabasites intruded by post-Variscan granitoids transformed into monometamorphic orthogneisses), Dioritic-Kinzigitic Complex (metapelites and metabasites), and the Rocca Canavese unit. The Sesia Zone was affected by post-collisional magmatic activity (Oligocenic Periadriatic Magmatism) with the intrusion of the plutons of Traversella and Biella (Cervo Valley), which is an important district for the quarring of Balma Syenite and Canavese Diorite

ornamental stones. The Dent Blanche s.l. system consists of a polymetamorphic basement unit and minor Mesozoic covering.

The Penninic domain, bordered to the North-West by the Penninic Front, is made up of continental crust units (upper, middle, and lower Penninic) and oceanic crust units (Piedmont Zone) deriving from the Ligure-Piemontese ocean (Dal Piaz 1999). The upper Penninic units consists of~~are constituted by~~ the Internal Crystalline Massifs (Dora Maira, Gran Paradiso and Monte Rosa Units), formed by mono- and polymetamorphic micaschists, and orthogneisses and Mesozoic carbonate covers (De Giusti et al. 2004). Dora Maira unit represent an important quarry district for ornamental stone varieties such as Luserna Stone and Bargiolina quartzite. The intermediate Penninic units correspond to the Great St Bernard Zone, consisting of a polymetamorphic basement, Permian igneous bodies, and Permian and Mesozoic coverings (Briançonnais s.s.). The lower Penninic domain represents the deepest tectonic element of the axial sector of the Alpine chain and represents an important quarry district of stones (Beole and Serizzi) and marbles. The oceanic units are instead represented by the Piedmont Zone, divided into an upper tectonic element (Combin Zone, consisting largely of metasedimentary successions with marbles and calcschists) and a lower tectonic element (Zermatt-Saas unit, consisting of meta-ophiolites equilibrated in eclogite facies conditions). Finally, the Helvetic-Dauphinoise domain, bordered to the North-West by the Helvetic Front and the South-East by the Penninic Front, is made up of Variscan polymetamorphic basement units, Permian igneous bodies, and Permian to Mesozoic sedimentary successions, which have undergone weak Alpine metamorphism (Von Raumer 1987).

Materials and methods

Given the great variety of stone materials used for the construction of the city, this work will briefly describe some examples of ornamental stones of Piedmont and Aosta Valley origin that characterize the historical and contemporary buildings of Ivrea, whose quarrying sites, coming from sites close to the city or from neighbouring geological units are shown in Fig. 3. The principal investigation methodology was the direct observation (macroscopic recognition) of the stone materials, as it was not possible to take samples from the study sites.

Once the different materials had been identified, petrographic study was conducted through an optical microscope on some city outcrop samples~~s~~, integrated with thin sections ~~–~~from the ~~University~~ Collection of the Department of Earth Sciences of Torino ~~for non-sampled stone materials~~ of the lithology detected on the historic building.

SEM-EDX measurements were subsequently performed to determine the chemical composition of the main minerals of the rocks. Representative tables of pyroxene, biotite, plagioclase from Mafic

Complex samples and chlorite and garnet from Pietra Ollare samples were reported in the supplementary materials. For the determination of the major elements, a scanning electron microscope (JEOL JSM-IT300LV) equipped with an energy dispersion X-ray spectrometer (EDX), with an SDD (a silicon drift detector from Oxford Instruments), hosted at the Department of Earth Sciences of Torino, was used. The Oxford INCA Energy 300 Microanalysis Suite was used, which allows spectra visualization and element recognition.

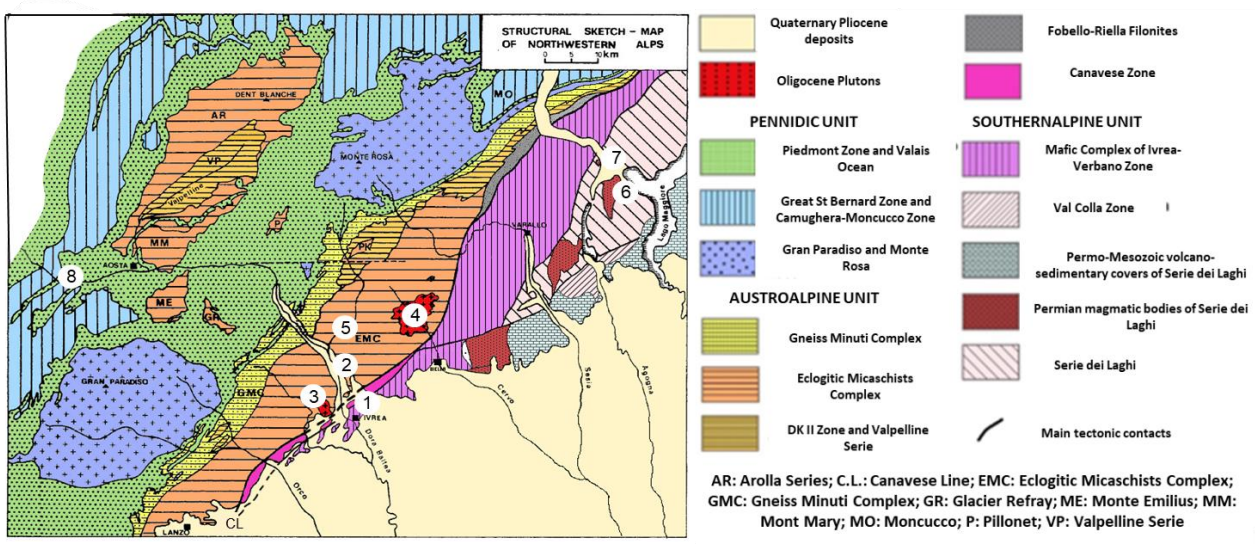

Fig. 3 Geological sketch of the North-Western Alps; the numbers ~~on the paper~~ indicate the location of the ornamental rocks described: 1) Rocks of the Mafic~~Basic~~ Complex; 2) Jadeitie Orthogneiss; 3) Canavese Diorite; 4) Balma Syenite; 5) Eclogitic Micaschists; 6) Baveno pink Granite; 7) Montorfano white Granite. 8) Bardiglio Marble.

The ornamental stones of Ivrea

Rocks of the Mafic Complex

The city of Ivrea was built above the Mafic Complex of the Ivrea Zone ~~of the Southern Alpine domain~~. The complex represents a huge magmatic system placed in the deep crust by continuous contributions of mantle magma in an extensional tectonic regime inside a relatively stationary magma reservoir~~chamber~~. The particular stratified magmatic structure is explained by the model of the "gabbro glacier" (Quick and Denlinger 1992; Quick et al. 1994) by which large mafic plutons are generated thanks to convective flows of a "crystal mush" inside a small magma chamber continuously fed by pulsations of external magma in an extensional regime. This model justifies the strong chemical and modal heterogeneity at the meso and macroscopic scale of the basic to intermediate ~~ultrabasic~~ rocks outcropping in correspondence with the town of Ivrea (Fig. 4a). The more diffuse lithology are quartz diorites (Fig. 4b) subsequently altered by a metamorphic event of very low degree

characterized by the association prehnite and pumpellyite (Fig. 4c); other petrographic variety are clinopyroxene bearing tonalites; hypersthene bearing quartz diorites (Fig. 4d) and gabbro.

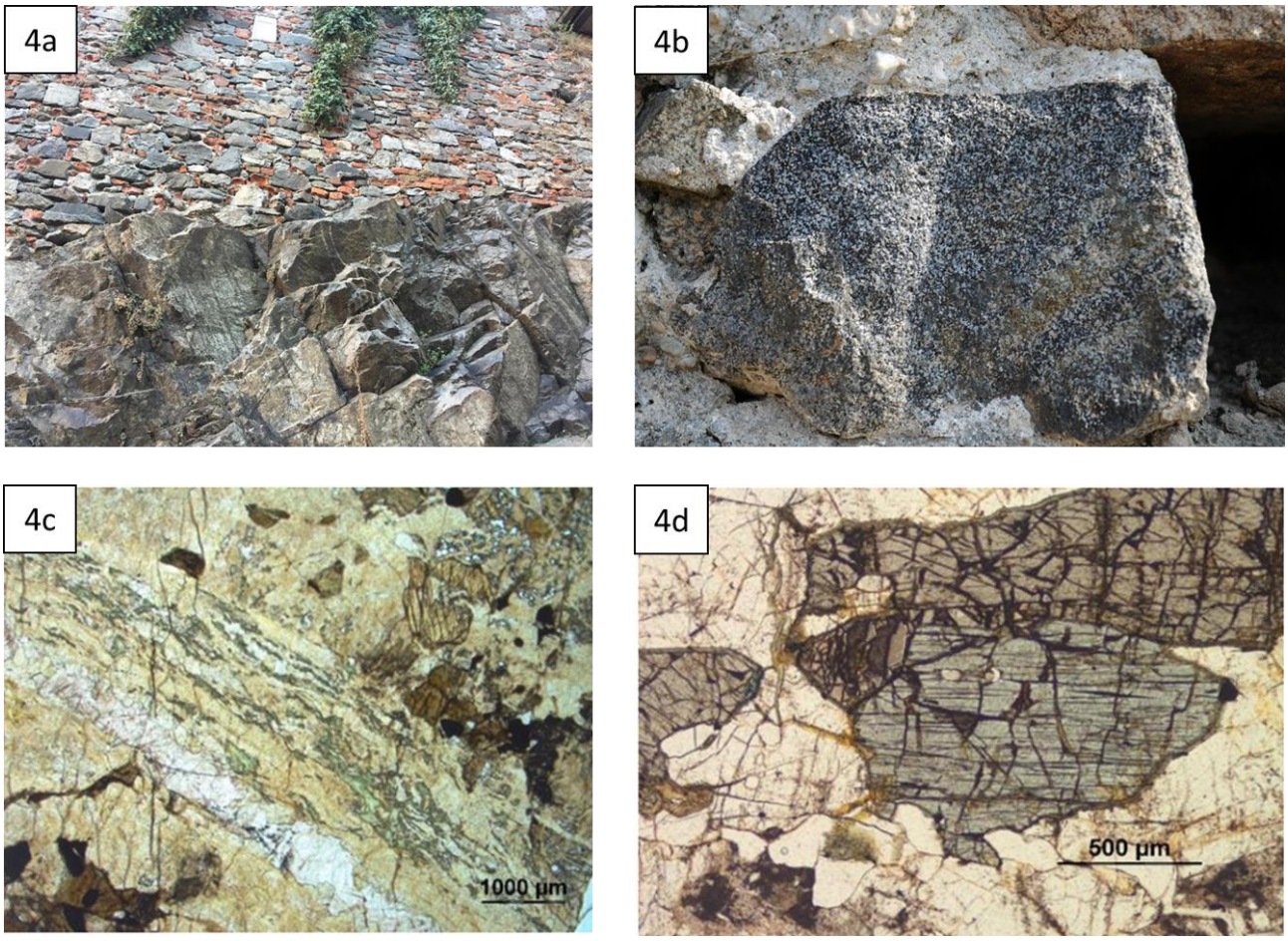

Fig. 4 Representative images of the Mafic Complex rocks outcropping in correspondence with the town of Ivrea (Fig. 4a). The more diffuse lithology are quartz diorites showing granoblastic teture (Fig. 4b). Prehnite and pumpellyite association related to a~~subsequently altered by a~~ metamorphic event of very low degree which affected the quartz diorite; microphotograph, only polarized.~~characterized by the association prehnite and pumpellyite~~ (Fig. 4c); Hypersthene bearing gabbro; microphotograph, only polarized ~~other petrographic variety are clinopyroxene tonalites; hypersthene bearing quartz diorites~~ (Fig. 4d)

Jadeite Orthogneiss

This rock, also known as Granite Verde Argento or Verde Selene, belongs to the Sesia-Lanzo Zone and represents the metamorphic product of Permian plutons intruding into the polymetamorphic basement of the Eclogitic Micaschist Complex. The quarry sites where this lithological variety is still quarried today are located near Settimo Vittone, not far from Ivrea. It is a metamorphic rock in eclogitic facies of light green color (due to the presence of jadeite), with a weak schistosity defined by phengite lepidoblasts oriented according to the main foliation (Bottino et al., 1989) (Fig. 5a). Quartz and K-feldspar are also recognizable. This rock was mainly used for the construction of access

portals and balconies of private houses in the historic centre of Ivrea and in particular along via Arduino (the city main street) and outside the Tre Re Chapel.

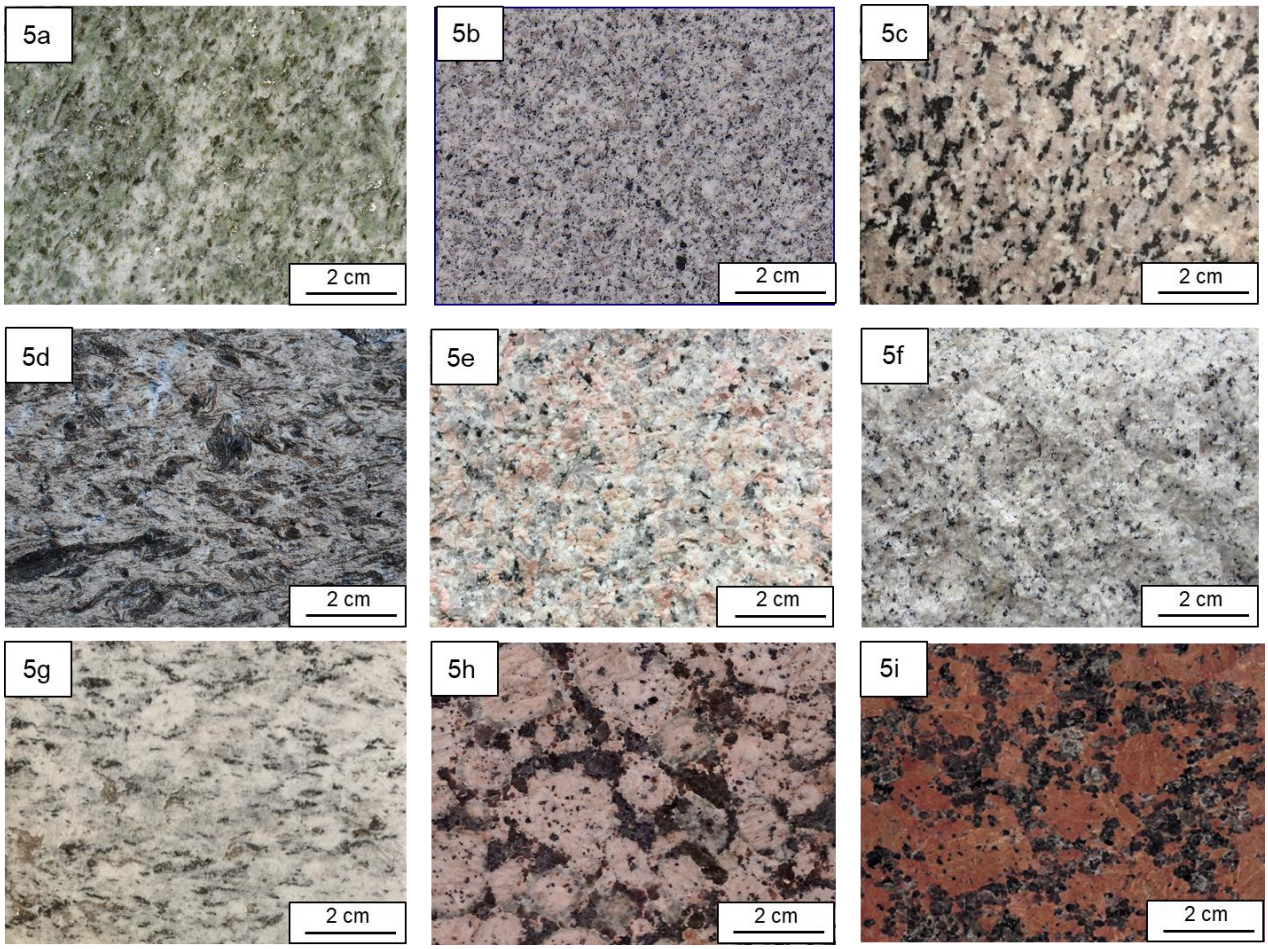

Fig. 5 Representative images of the ornamental stones described. Jadeite Orthogneiss (a); Canavese Diorite (b); Balma Syenite (c); Eclogitic Micaschist (d); Baveno pink Granite (e); Montorfano white Granite (f); Serizzo Antigorio (g); Baltic Brown (h); Carmen Red (i).

Canavese Diorite and Balma Syenite

These are local rocks coming from the Oligocene plutons of Traversella about 10 km West of Ivrea (Canavese Diorite) and ~~the~~ Cervo Valley north of Biella (Balma Syenite)~~, respectively~~. Diorite is an intrusive grey magmatic rock, medium-fine-grained consisting of plagioclase, amphibole, pyroxene, biotite, and small amounts of quartz and K-feldspar (Fig. 5b) and accessory minerals such as zircon, titanite, apatite, chlorite and opaque (Sandrone et al., 2004). This rock is employed in the wall of the Santo Stefano Tower,in the external building of the Monte Stella Sanctuary, in the entrance stairway of Sinagogue and, more recently, in the street furniture of Ottinetti Square.

Balma Syenite~~, on the other hand,~~ is an intrusive magmatic rock of grey-brown-violet colour, medium-grained consisting of plagioclase, K-feldspar, amphibole, and poor biotite (Fig. 5c) and accessory minerals such as apatite, zircon, titanite and opaque. It is the material used in the external

cladding of the Olivetti Office Building, the Monte Stella Sanctuary, the Tre Re Chapel and in the flooring in front of the Cathedral and the Santo Stefano Tower.

Eclogitic Micaschists

It is a metamorphic rock belonging to the Eclogitic Micaschists Complex of the Sesia Lanzo Zone characterized by a strongly heterogeneous grainsize, with evident metamorphic foliation, lepidoblastic texture and schistosity defined by the alternation of phengitic micaceous levels. There are porphyroblasts of glaucophanes and the rock is often crossed by aplitic veins (Compagnoni, 1977). In the most impure varieties ankeritic carbonate is also present (Fig. 5d). This rock has been ~~considerably~~largely used as a building material in Ivrea, mainly in the facade of the Cathedral of Santa Maria Assunta, in the flooring and external walls of the Tower of Santo Stefano and as reuse material for the walls of the Roman Amphitheatre.

Graniti dei Laghi

The Baveno pink Granite (Fig. 5e) and the Montorfano white Granite (Fig. 5f) belong to a Permian composite batholith intruded into the basement of the Serie dei Laghi. They are intrusive igneous rocks with medium-fine grainsize consisting of quartz, K-feldspar (pink in the case of Baveno due to microdispersions of hematite), plagioclase, and biotite with accessory minerals such as titanite, apatite, zircon, white mica, and allanite. The quarry sites are located, in the lower-Ossola Valley, near the Maggiore~~Verbano~~ Lake, making easy their transport by water. In Ivrea, the Baveno pink Granite was used as part of the external cladding of the Olivetti Office Building, built in the 1960s, while the Montorfano white Granite is the material for~~with which~~ the frame of the entrance door to the Synagogue of Ivrea ~~is made~~ and the external flooring of the Olivetti Buildings.

Serizzo Antigorio

It is a gneiss belonging to the lower Penninic unit quarried in Ossola Valley (Verbania). It is a metamorphic rock of dark grey colour due to the abundant presence of biotite that defines the regional schistosity developed in conditions of amphibolite facies during the alpine metamorphic event (Sandrone et al. 2004) (Fig. 5g). It has a micro-augen gneissic structure, with a medium-fine grain, with a more or less light grey background colour and biotite levels of millimetre thickness interrupted by K-feldspar augen. It mainly consists of quartz, K-feldspar, plagioclase, and biotite, and accessory minerals such as apatite, zircon, allanite, and titanite. Serizzo Antigorio is the material used to make part of the external cladding of the Olivetti Office Building

In addition to the ornamental stones here described, ~~other~~ rocks from other Italian regions were used in Ivrea such as the Botticino limestone, a carbonate allochemical sedimentary rock, coming from the Lombard Basin (Southern Alps); the Travertine, a quaternary orthochemical vacuolar sedimentary

rock, ~~coming from the basin of the Acque Albule near Tivoli and Guidonia (Rome)~~ and the Carrara marble, from the Apuan Alps.

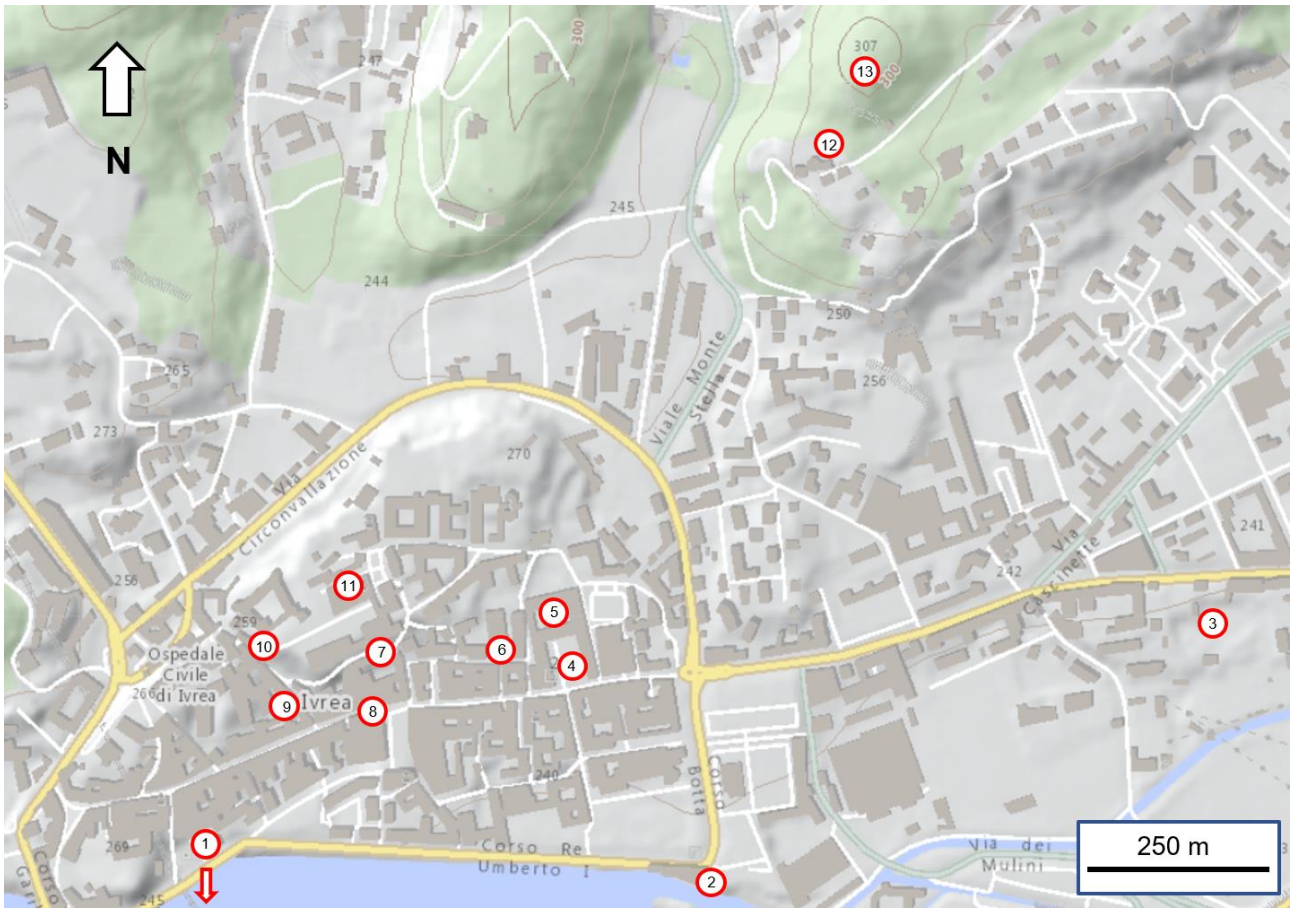

Fig. 6 The historic centre of Ivrea with the location of the main investigated buildings, squares and geological outcrops. 1) Olivetti Office (out of the figure; 2) Santo Stefano Tower; 3) Roman Amphitheatre; 4) Ottinetti Square; 5) P.A. Garda Museum; 6) Giacosa Theatre; 7) Sant'Ulderico Church; 8) outcropping substrate; 9) Ivrea Synagogue; 10) outcropping substrate; 11) Santa Maria Assunta Cathedral; 12) Monte Stella Sanctuary; 13) Tre Re Chapel.

In recent years, ornamental rocks from the international market have also been used in Ivrea, in particular three granites from Scandinavia occur in the inner of Olivetti Office Building. They are the Baltic Brown (Fig. 5h) a sienogranite belonging to the Vyborg batolite, Red Balmoral~~,~~ a monzogranite-sienogranite belonging to the Vehmaa multistadial batolite from SW Finland and the Carmen Red (Fig. 5i)**,** a syenitic granite extracted from Virolahti batolite in southern Finland (Selonen and Suominen, 2003) ~~the~~

IvreaStones: Geo-heritage tour across the stones of the h~~H~~istoric Centre of Ivrea

The itinerary proposed in this work comprises~~article winds through~~ the most representative sites of the city centre, places where it is possible to highlight the use of stone materials and rocks on which the city has been built. The position of the selected stops is shown in Fig. 6. All t~~T~~hese ~~are~~ sites ~~all~~are

located in the historic center of Ivrea or on its hill, with the exception of the first site (Olivetti building), which is located south of the Dora Baltea River in the more modern part of the city.

Fig. 7 Visualization of an example of site of interest (Santa Maria Assunta Cathedral) of IvreaStonesVREASTONE site, with a brief description window and description card. The historic description of the site and mention to the stone employed are reported in the "web site card" and the "rock card", respectively

The purpose of the itinerary is to spread knowledge about stone materials, both from a scientific and touristic/cultural point of view, creating a geo-tourist path highlighting the fundamental role that the stone had in the culture and economic wealth of the city.

In the light of the above, tTo make the product more usable, the attention has been focused on digital frontiers that represent a practical and important tool for heritage usage. Specifically, the Qgis® software has been used to enhance the path within the city, which allows recreating the areas that can potentially be visited, giving the opportunity of virtually testing the future touristic experience.

As some previous multitransmedial projects of the research group (Gambino et al., 2019), even this one has been published on the Geositlab website: Gis and Geomatics Laboratory, managed by the Earth Science Department of the University of Turin. It can be visited through any mobile or fixed device via the following link: http://www.geositlab.unito.it/ivrea.

It is possible to interact with the map by querying the selected points and view a series of cards containing: a brief description of the site, stone materials used, images, and differentiation of the sites themselves according to the type of interest (religious, historical, cultural, etc.) of the sites (Fig. 6 and Fig.7).

STOP 1: Olivetti Office Building (Via Jervis 77, Ivrea)

Coming from Torino, the first building you meet is the Olivetti Office Building (Fig. 8a) built in 1960-1964 on a project by architects Annibale Fiocchi, Gian Antonio Bernasconi, and Marcello Nizzoli to meet the needs of the company to equip itself, at a time of great industrial expansion, with a representative office. The building planimetry consists of a central body with a main monumental staircase (Fig. 8b), the ground floor that housed a large space for the presentation of Olivetti products, and the area behind the Data Processing Centre, completed in 1962. The ornamental stones used in the façade of this building include Balma Syenite (Fig. 8c), Baveno pink Granite, and Serizzo Antigorio, while the Montorfano white Granite was used for the external flooring. The ornamental stones used inside this building include the white Carrara marble for the monumental staircase and foreign granites such as Baltic Brown, Carmen Red, and Red~~osso~~ Balmoral for the flooring.

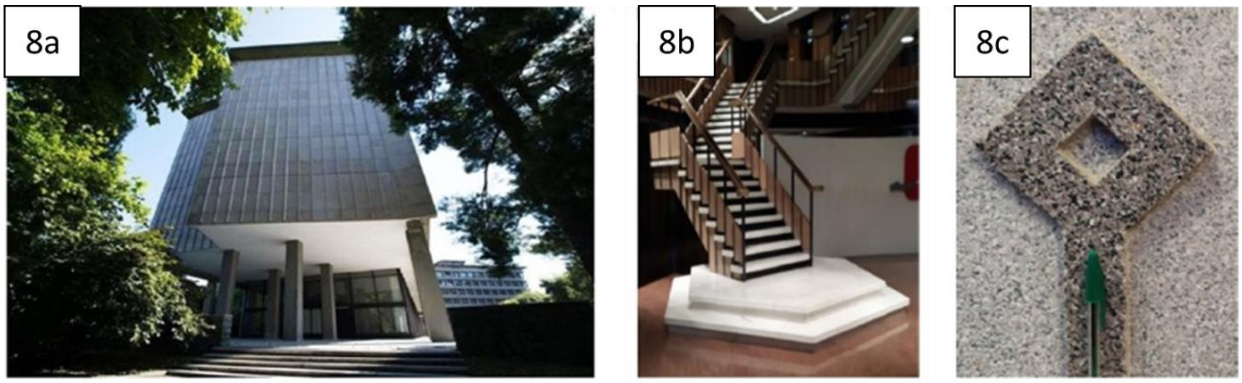

Fig. 8 Stop 1: Olivetti Office (a); Monumental staircase (b); Details of Balma Syenite used in the façade (c).

STOP 2: Santo Stefano Tower (Corso Re Umberto 30, Ivrea)

Continuing along the main road towards the centre of Ivrea, you will find the Santo Stefano Tower (Fig.9a), the only testimony of the homonymous abbey ~~of the same name~~ assigned ~~given~~ to the Benedictine monks in 1044. The monastic complex derived from a pre-existing church consecrated to the proto-martyr Stephen, perhaps dating back to the fifth century, built with bricks and some salvaged materials of probable Roman origin. With its almost one thousand years of existence, it represents the only remaining testimony of one of the most ancient places of worship in Ivrea. The tower has become one of the most important testimonies of the role played in the religious and social field by the monastic centre of the city. In the early 2000s, the tower underwent a major restoration. The ornamental stones used in the external walls include various lithologies such as "Pietra Ollare" (fine grain-sized chloritoschists according to Mannoni et al., 1987~~soapstone~~), marked by the occurrence of millimetre porphyroblasts of garnet and chloritoid, embedded in a foliated matrix of chlorite (Fig. 9b), Canavese Diorite, Balma Syenite, Eclogitic Micaschists, Barge Quartzite,

gabbronorites from the Mafic Complex of Ivrea, serpentinites, bricks, and mortars. The ornamental stones used for the paving include ~~–~~Balma Syenite, Eclogitic Micaschists, and ~~-~~Canavese Diorite.

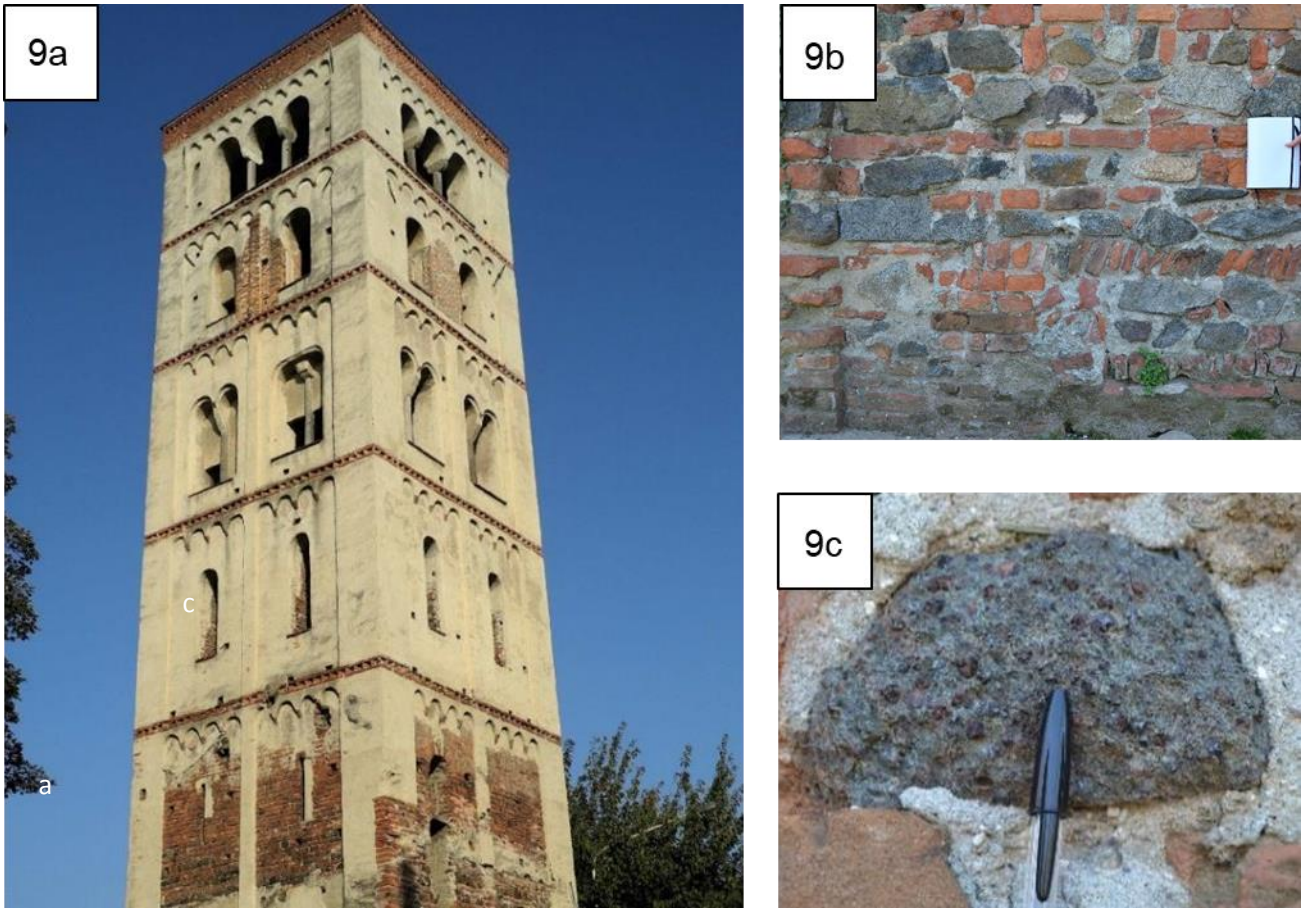

Fig. 9 Stop 2: Santo Stefano Tower (a); image of the medieval masonry of the tower, made up of bricks and river stones, among which can be distinguished), Canavese Diorite, Balma Syenite, Eclogitic Micaschists, Barge Quartzite, gabbronorites from the Mafic Complex of Ivrea, "Pietra Ollare", serpentinites, bricks, and mortars ~~Details of "Pietra Ollare" (soapstone) used in the external walls~~ (b); Details of "Pietra Ollare" (fine grain-sized chloritoschists according to Mannoni et al., 1987) used in the external walls (c) ~~Stop 3: Roman Amphitheatre (c); Details of Roman Amphiteatre wall (d).~~

STOP 3: Roman Amphitheatre (Corso Vercelli 60/1, Ivrea)

Between 1955 and 1964, the Roman Amphitheatre of Ivrea was brought to light by the Superintendence of Antiquities of Piedmont (Fig.10a~~9c~~). It is believed that the Amphitheatre, built between the end of the first century AD. and the beginning of the second century AD near the road to Vercelli outside the walls, could accommodate ten to fifteen thousand spectators. The remains of the amphitheatre represent one of the few architectural testimonies of the ancient Roman city of *Eporedia*. The stone materials used for its construction (Fig. 10b~~9d~~) include rocks of local origin (diorites, gabbronorites, and websterites~~sites~~ of the Mafic Complex of Ivrea Zone) or from nearby geological units (granites and metagranophyrs of the Canavese Zone, acid granulites of the II Dioritic-

Kinzigitic Zone, micascists of the Sesia-Lanzo Zone, Calcschists from the Piedmont Zone and ortogneiss from the Dent Blanche), in addition to the *Bardiglio M~~m~~arble*, an historic listed marble coming from Aymavilles (Aosta), used for the central portions of the arena (Borghi et al., 2006) .

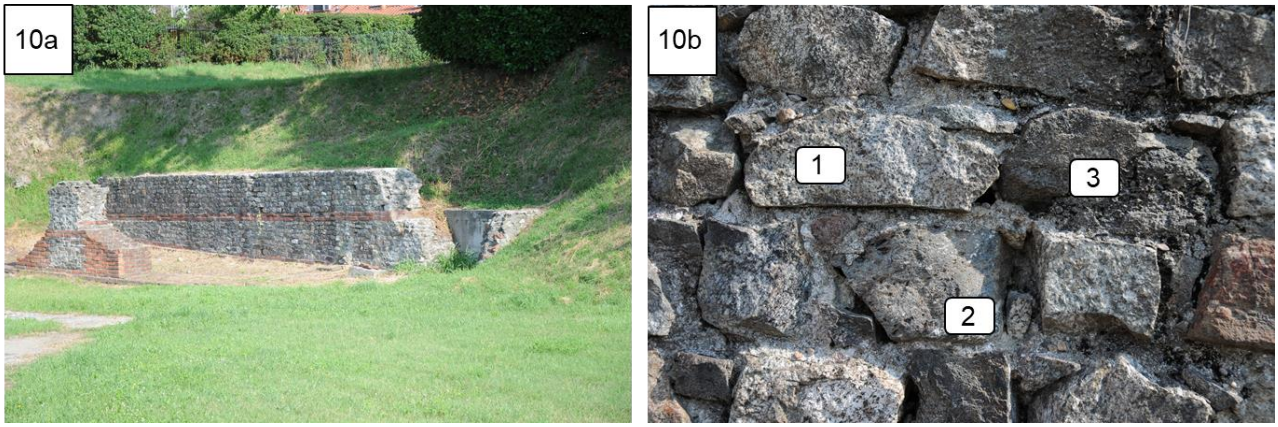

Fig. 10 Stop 3: original masonry of the Roman amphitheater of Ivrea (a); detail of the masonry in which blocks of white granite (1), metabasites (2), diorite (3) can be distinguished (b).

STOP 4: Ottinetti Square (Piazza Ottinetti, Ivrea)

Numerous ornamental rocks characterized by different surface treatments have been used in the urban furnishing of this square (Fig. 11~~0~~a). The term surface treatments refer to the set of processes to which the surface of the stone is subjected in order to give it a certain appearance. It is a fundamental process for exploiting the expressive possibilities of stone products such as the colours, textures, roughness and all the natural aesthetic characteristics and certain mechanical properties of the rock are enhanced, modified, or minimized through appropriate treatments. According to the UNI 8458 standard, there are different types of surface treatment. In particular, those applied to the stone used in Ottinetti Square (Balma Syenite, Canavese Diorite) include trimming and scoring. In the first case, surfaces with alternating depressed and raised areas are obtained on fine-grained rocks used as external coatings. In the second case, more or less wide (8-15 mm), more or less deep (2-5 mm), and spaced with a centre distance of 8-15 mm are obtained. This technique is suitable for rough, smooth, shiny, or even previously bush-hammered and/or flamed artefacts.

Fig. 11 Stop 4: Ottinetti Square; details of Canavese Diorite pilaster showing trimmed surface treatment (a); Stop 5: P.A. Garda Museum (b); "Pietra Ollare" (fine grain-sized chloritoschists according to Mannoni et al., 1987) millstones (c).

STOP 5: Pier. Alessandro. Garda Museum (Piazza Ottinetti, Ivrea)

Remaining in Ottinetti Square, there is the Civic Museum P.A. Garda in the former Monastery of Santa Chiara built in 14th century (Fig. 110b). Although the historical documentation relating to the following centuries is scarce, it can be argued that the Monastery underwent good development until 1793, the year of the beginning of the French Revolution, when the monastery was converted into a military quarter. Currently, the building houses the Museum, which hosts paintings and archaeological collections that bear witness to the city and its territory from the Neolithic age to the low medieval period. Among these, numerous finds in white marble of Alpine and Mediterranean origin and "Pietra Ollare" (Soapstone) millstones of Alpine origin can be found (Fig. 110c).

STOP 6: G. Giacosa Theatre (Piazza Teatro 1, Ivrea)

The Giacosa theatre history (Fig. 121a) begins in 1829 when the Ivrea Municipal Administration gave the architect Maurizio Storero the task of designing the New "Italian-style" Civic Theatre: a horseshoe-shaped hall with boxes superimposed and a gallery. The ornamental stones used outside include the Baveno pink Granite and the Montorfano white Granite for the staircase and for the external flooring.

STOP 7: Sant'Ulderico Church (Via Arduino 2, Ivrea)

According to the historiographical tradition, the church of Sant'Ulderico was built in 993 following the canonization of Sant'Ulderico (bishop of Augusta), where he made a miracle in 971. The first structure was built using elements of recovery from the Roman Eporedian theatre. The building, which has undergone profound transformations over the centuries after the restoration work carried out in 1952, has a Romanesque bell tower, datable to the first half of the 11th century, and the probable 14th-century facade as the only evidence of the original construction (Fig. 121b). The ornamental stones used on the outside of this building include Eclogitic Micaschist and bricks for the facade and for the access stairway. The indoor ornamental stones used inside include carbonate breccias of uncertain origin (probably Serravezza Breccia), "Giallo Verona", "Nero Ormea" and "Rosso Languedoc" for the construction of the altar and balustrades, "Botticino", "Rosso Verona", Ophicarbonate (probably "Rosso Levanto") and Apulian marble (sensu commercial meaning) for flooring (Fig. 121c).

Fig. 12 Stop 6: G. Giacosa Theatre (a), Stop 7: Sant'Ulderico Church (b~~);~~;"Botticino", "Rosso Verona", Oficalcite~~i~~ (probably "Rosso Levanto") and Apulian marble (sensu commercial meaning)~~fillet~~ for flooring (c).

STOP 8: outcropping substrate (Via Peana, Ivrea)

Leaving the Sant'Ulderico Church and going back a few metre, ~~you can~~ take Via Della Cattedrale on the left to the beginning of Via Peana, where it is possible to observe the direct interaction between the historic buildings of the city (remains of the Roman Theatre) with the outcropping substrate (Fig. 13a)~~.~~. Here the Mafic Complex of the Ivrea Zone, consisting of different lithologic varieties is represented by orthopyroxene- and biotite-bearing quartz-diorite (Fig. 13~~2~~b~~a~~).. ~~here consisting of different lithologic variety belonging to the Basic Complex of the Ivrea Unit, as quartz-diorite with orthopyroxene and biotite, an intrusive magmatic rock made up of plagioclase, quartz, biotite, orthopyroxene, K-feldspar, chlorite, epidote, and accessory minerals such as zircon, ilmenite, and apatite~~ ~~(Fig. 12a).~~ The rock is characterized by an evident magmatic flow structure defined by the preferential orientation of the orthopyroxene. All sialic minerals show a medium and homogeneous grainsize and irregular contours to indicate late static recrystallization phenomena.

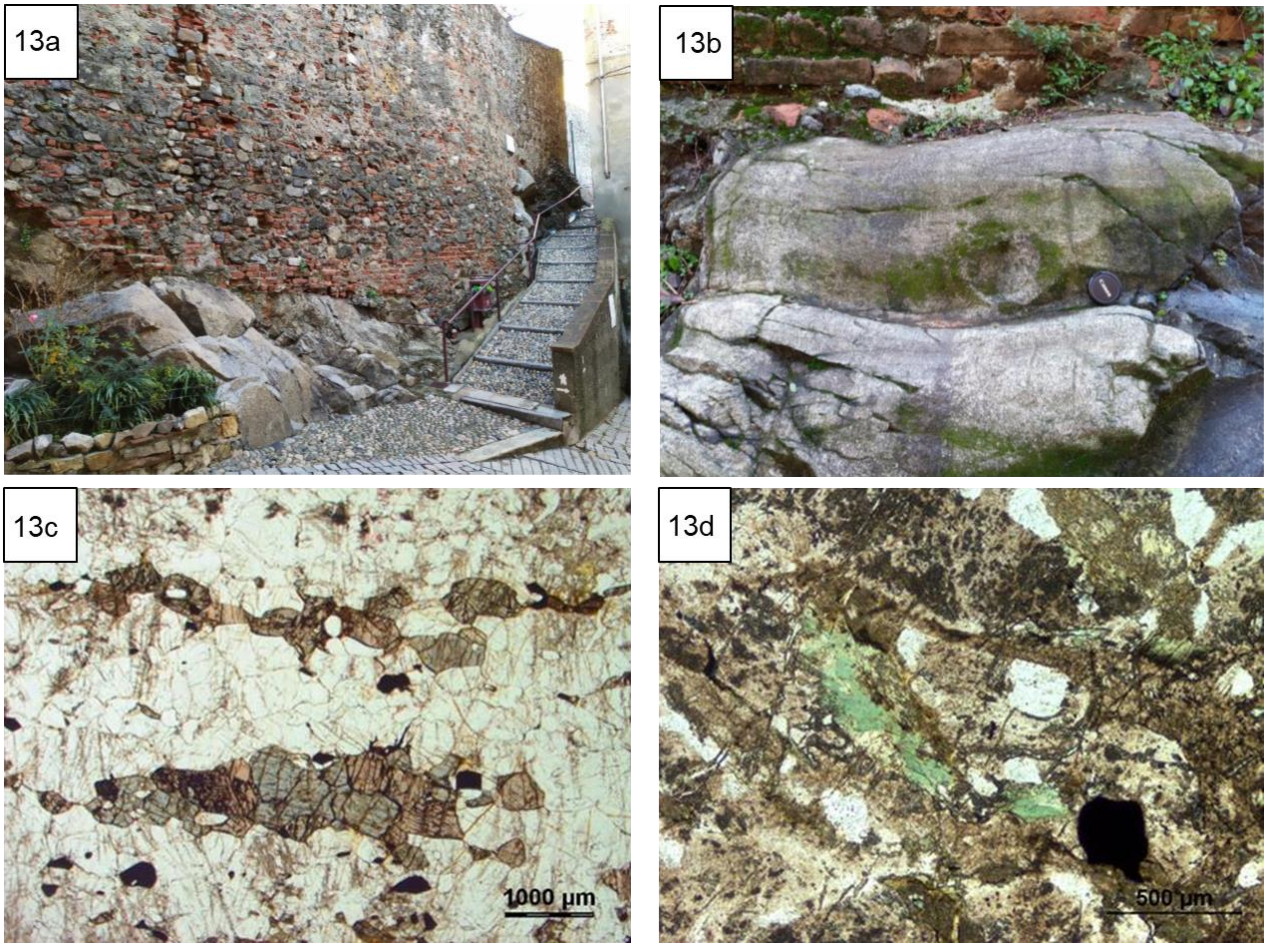

Fig. 13 Stop 8 and 10: Representative figures of the outcrops in the city of Ivrea modelled by the glacier (a) and the direct interaction between the historical and contemporary buildings of the city with the outcropping substrate constituted by stratified rock of the Mafic Complex (b); (microphoto, only pol.) hypersthene bearing quartz diorites showing oriented texture of magmatic origin; quartz diorites altered by a metamorphic event of very low degree characterized by the association prehnite and pumpellyite.

STOP 9: Ivrea Synagogue (Via Quattro Martiri 20, Ivrea)

Synagogue (Fig. 13a~~2b~~) is where the Jewish ghetto was established in 1725. Due to a demographic increase in the Jewish community of Ivrea, a larger synagogue was built, completed, and opened for worship in 1875. Today nineteenth-century structure has two facades. These facades blend into the urban fabric, not letting the existence of a place of prayer leak out. Currently, the structure is used as an exhibition hall and conference room. The ornamental stones used in the façade include Montorfano white granite for the construction of the entrance door frame (Fig. 13b), Canavese Diorite, and Jadeitic orthogneiss for the access stairway (Fig.13c).

Fig. 14 stop 9: Entrance door of the Ivrea Synagogue (a): detail og the Montorfano Granite employed the entrance door frame; detail of the jadeitic orthogneiss for the access stairway

STOP 10: outcropping substrate (Via delle Torri, Ivrea)

From the previous stop, continue along Via Castellamonte for about 100m until you reach Via delle Torri where, as in stop 8, it is possible to observe the direct interaction between the historic buildings of the city (Ivrea Savoy Castle) with the outcropping substrate, and the presence of forms of subglacial modelling such as mountain rocks with striae and rocks on the back of a cetacean (Fig. 12ca). Here, too, different rocks of the MaficBasic Complex can be distinguished as a hypersthene quartz diorite and strongly regressed quartz diorite.

The latter is an intrusive, medium-grained magmatic rock consisting of plagioclase, quartz, pumpellyite and prehnite, chlorite, epidote, and accessory minerals such as apatite, ilmenite, pyrite, titanite, and iron hydroxides . The rock is very altered, retrogressed, and deformed by Alpine tectonics with the development of cataclastic bands, rare mylonite bands with reduction of grain, and widespread intracrystalline deformation. As a whole, the rock is crossed by prehnite and pumpellyite veins (Fig. 12dc).

STOP 11: Santa Maria Assunta Cathedral (Piazza Castello 16, Ivrea)

The Cathedral of Ivrea dedicated to Santa Maria Assunta was built by Niccolò Giglio Tos in 568 AD. It develops in the old part of the city near the Castle and represents the most important place of worship in the city. Its millenary history is evidenced by the preserved parts of its Romanesque structures and by the series of subsequent interventions that have changed its appearance, gradually adapting it to emerging aesthetic tastes (Fig. 13a). The retrieval of Roman remains reused in the oldest parts of the church now kept in the crypt (the sarcophagus made for the quaestor Caius Atherius Valerius in the first century AD) suggests that it was built above a Roman temple (Fig. 13b). The ornamental stones used outside the Cathedral include the Balma Syenite for the flooring and serpentinites pebbles for the square in front of the entrance. The ornamental stone used in the façade is the Eclogitic Micaschists of the Sesia Lanzo Zone, ~~and it is~~ characterized by porphyroblasts of glaucophanes and crossed by frequent aplitic veins. Ankeritic carbonate is also present in the most impure varieties of micaschists (Fig. 13c) The ornamental stones occurring inside this building include numerous examples of re-use in medieval times of stone materials of the Roman age also coming from historical sites of Ancient Greece such as Cipollino Marble, Marble of Eubea and other~~,~~ ~~Greek~~ white marble difficult to determine. ~~and~~ The Proconnesio Marble from the island of Marmara (current Turkey) was used for the columns of the crypt and apse of medieval times and for the sarcophagus of the first century AD by Caius Atecio Valerius.

Fig. 1~~5~~3 Stop 11: Santa Maria Assunta Cathedral (a); sarcophagus made for the quaestor Caius Atecio~~herius~~ Valerius in the first century AD conserved in the crypt (b); details of sodic amphibole porphyroclasts ~~ankeritic carbonate~~ in ~~impure varieties of~~ Eclogitic Micaschists of the Sesia Lanzo Zone (c).

STOP 12: Monte Stella Sanctuary (Viale Monte Stella 16, Ivrea)

The Monte Stella Sanctuary was built in 1627 on the hill standing near the market square on the top of Stella Mount (Fig.14a). Only the bell tower and a wall adjacent to the current church ~~have~~ remained intact as part of the initial skeleton. Today structure has the shape of a circular temple in neo-Gothic style and dates back to the nineteenth century. The ornamental stones used in the façade of this building include various lithotypes including Canavese Diorite, Balma Syenite, gabbros and diorites of the Mafic Complex of Ivrea, felsic granulites and bricks.

The ornamental stones used inside this building include Apuan marbles, serpentinites for the altars; Canavese Volcanics, Apuan marbles, and serpentinites for the pavement.

Fig. 1~~6~~4 Stop 12: Monte Stella Sanctuary (a); Detail of Diorite del Canavese used on the outside of the Sanctuary (b); Stop 13: medieval external masonry of Tre Re Chapel (c~~b~~); Details of diorite (d), jadeitic orthogneiss (e) and serpentinite (f) of rock block employed in the mansory.

STOP 13: Tre Re Chapel (Viale Monte Stella 16, Ivrea)

On the top of Monte Stella stands the sacred place dedicated to the Tre Re (Fig. 14b), originally dedicated to the Blessed Virgin Mary of the Star, built around 1220 by the community of Ivrea, following the passage of St. Francis of Assisi. In 1980, the church underwent restoration; from the square below, a staircase was built, leading to the chapel that housed on the main altar a late-fifteenth-century sculptural group with the Adoration of the Magi, now kept at the Civic Museum Pier Alessandro Garda. The stones used outside this building include different lithological varieties as gabbros and diorites of the Mafic Complex of Ivrea Zone, Balma Syenite, Canavese Diorite, Jadeite Orthogneiss, serpentinites.

Concluding remarks

~~Stone resources have always been one of the main sources of construction components and an important cultural element, given their use as a raw material in creating architecture works that are now part of the heritage~~ . In Ivrea, stone~~s~~ ha~~ves~~ ~~always~~ been used in historical and contemporary buildings, monuments, and urban furniture, demonstrating the close link between the urban area and the natural stone resources, and emphasizing the role that stone has always had in the culture and economic wealth of the city. Therefore, the knowledge of stone resources, their petrographic characteristics, and their use provides a starting point for disseminating geological heritage knowledge. The main lithological varieties of the stones used in Ivrea were briefly described, referring on the one hand to the geological origin and petrographic characteristics and on the other hand, reporting the main examples of use. ~~In general, it emerged that m~~Most of the stone materials used come from the Piedmont quarry districts, followed by stones of Italian extra-regional origin, and finally, in sporadic cases, from Scandinavian countries. ~~Following~~ In the study, the geological and environmental characteristics of the ~~involved~~ city ~~areas~~ were also taken into account. The Ivrea historic centre was indeed built directly above the rocky basement~~substrate~~, which crops out in many city sites. It was therefore decided to combine the study of stone materials with the characterization of the substrate from a petrographic and compositional point of view.

The chosen site (the city of Ivrea) has, therefore, a geological and an historical-architectural value. In this way, the fundamental principle of "Cultural Heritage~~Geology~~" is pursued~~realized, which studies~~ studying the interactions between the geological elements of the natural landscape and the "cultural" ones determined by human activity (i.e., archaeological, historical, architectural, and religious heritage). The study also contains ideas ~~for enhancement~~ aimed at promoting the development of the territory through the recovery of the geological and archaeological heritage. The enhancement of the identified sites should lead to greater awareness, underlined by a strong need for conservation~~"prevention"~~ that looms over these and many other sites in the area. A timely intervention would lead to the preservation of these places that have been maintained (saved) ~~preserved~~ over the centuries.

To ~~enhance the chosen sites and to~~ promote geo-dissemination within the city of Ivrea, a web itinerary has been created, allowing the general public to embark on a virtual journey in the geo-cultural heritage of the city, through an online map containing stops and GPS tracks. It will also be possible to consult explanatory sheets relating to the sites of interest containing a brief historical-architectural description ~~of the site~~ accompanied by a list of stone materials used outdoors and indoors and the~~a~~ petrographic description of them. The diffusion~~ssemination~~ of ~~itineraries~~geo-heritage tour via ~~the~~ web is ~~proves to be~~ an excellent tool for free online use, allowing an educational approach and a virtual

visit in preparation for the real excursion~~exit~~ on the field~~ground~~. The information will thus be made easily accessible not only to professionals but also to a wider public in order to create a link between the Earth Sciences, the territory, and the city of Ivrea itself, through the enhancement and protection of Cultural Heritage.

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Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Giorgia Parmeggiani and Lugi Perotti. The first draft of the manuscript was written by Giorgia Parmeggiani, review and editing by Alessandro Borghi and Anna d'Atri. Supervision: Alessandro Borghi. All authors read and approved the final manuscript.

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Captions

~~**Fig. 1** Representative figures of the outcrops in the city of Ivrea modelled by the glacier (a) and the direct interaction between the historical and contemporary buildings of the city with the outcropping substrate (b).~~

Fig. 1 Geomorphological sketch map of the Dora Baltea basin, with the location of Ivrea Morainic Amphitheatre (IMA).

Fig. 2 Geological sketch of Western Alps, (Modified by Gambino et al., 2019). ~~AG = Argentera;~~ DM = Dora Maira; GP = Gran Paradiso; MB = Monte Bianco; MF = Monferrato; MR = Monte Rosa; TH Torino Hill;~~.~~ In red the main tectonic lines are reported ~~the main tectonic lines~~: AR = Aosta – Ranzola Line: IL = Insubric Line; PTF = Padanian Thrust Front; SL = Simplon Line; RF = Rio Freddo Line

Fig. 3 Geological sketch of the North-Western Alps; the numbers ~~on the paper~~ indicate the location of the ornamental rocks described: 1) Rocks of the Mafic~~Basic~~ Complex; 2) Jadeitie Orthogneiss; 3) Canavese Diorite; 4) Balma Syenite; 5) Eclogitic Micaschists; 6) Baveno pink Granite; 7) Montorfano white Granite. 8) Bardiglio Marble.

Fig. 4 Representative images of the Mafic Complex rocks outcropping in correspondence with the town of Ivrea (Fig. 4a). The more diffuse lithology are quartz diorites showing granoblastic teture (Fig. 4b). Prehnite and pumpellyite association related to a~~subsequently altered by a~~ metamorphic event of very low degree which affected the the quartz diorite; microphotograph, only polarized.~~characterized by the association prehnite and pumpellyite~~ (Fig. 4c); Hypersthene bearing gabbro; microphotograph, only polarized ~~other petrographic variety are clinopyroxene tonalites; hypersthene bearing quartz diorites~~ (Fig. 4d)

Fig. 5 Representative images of the ornamental stones described. Jadeite Orthogneiss (a); Canavese Diorite (b); Balma Syenite (c); Eclogitic Micaschist (d); Baveno pink Granite (e); Montorfano white Granite (f); Serizzo Antigorio (g); Baltic Brown (h); Carmen Red (i).

Fig. 6 The historic centre of Ivrea with the location of the main investigated buildings, squares and geological outcrops. 1) Olivetti Office (out of the figure; 2) Santo Stefano Tower; 3) Roman Amphitheatre; 4) Ottinetti Square; 5) P.A. Garda Museum; 6) Giacosa Theatre; 7) Sant'Ulderico Church; 8) outcropping substrate; 9) Ivrea Synagogue; 10) outcropping substrate; 11) Santa Maria Assunta Cathedral; 12) Monte Stella Sanctuary; 13) Tre Re Chapel.

Fig. 7 Visualization of an example of site of interest (Santa Maria Assunta Cathedral) of IvreaStonesVREASTONE site, with a brief description window and description card. The historic description of the site and mention to the stone employed are reported in the "web site card" and the "rock card", respectively

Fig. 8 Stop 1: Olivetti Office (a); Monumental staircase (b); Details of Balma Syenite used in the façade (c).

Fig. 9 Stop 2: Santo Stefano Tower (a); image of the medieval masonry of the tower, made up of bricks and river stones, among which can be distinguished), Canavese Diorite, Balma Syenite, Eclogitic Micaschists, Barge Quartzite, gabbronorites from the Mafic Complex of Ivrea, "Pietra Ollare", serpentinites, bricks, and mortars Details of "Pietra Ollare" (soapstone) used in the external walls (b); Details of "Pietra Ollare" (fine grain-sized chloritoschists according to Mannoni et al., 1987) used in the external walls (c) Stop 3: Roman Amphitheatre (c); Details of Roman Amphiteatre wall (d).

Fig. 10 Stop 3: original masonry of the Roman amphitheater of Ivrea (a); detail of the masonry in which blocks of white granite (1), metabasites (2), diorite (3) can be distinguished (b).

Fig. 11 Stop 4: Ottinetti Square; details of Canavese Diorite pilaster showing trimmed surface treatment (a); Stop 5: P.A. Garda Museum (b); "Pietra Ollare" (fine grain-sized chloritoschists according to Mannoni et al., 1987) millstones (c).

Fig. 12 Stop 6: G. Giacosa Theatre (a), Stop 7: Sant'Ulderico Church (b););"Botticino", "Rosso Verona", Oficalcitecei (probably "Rosso Levanto") and Apulian marble (sensu commercial meaning)fillet for flooring (c).

Fig. 13 Stop 8 and 10: Representative figures of the outcrops in the city of Ivrea modelled by the glacier (a) and the direct interaction between the historical and contemporary buildings of the city with the outcropping substrate constituted by stratified rock of the Mafic Complex (b); (microphto, onlypol.) hypersthene bearing quartz diorites showing oriented texture of magmatic origin; quartz diorites altered by a metamorphic event of very low degree characterized by the association prehnite and pumpellyite.

Fig. 14 stop 9: Entrance door of the Ivrea Synagogue (a): detail og the Montorfano Granite employed the entrance door frame; detail of the jadeitic orthogneiss for the access stairway

Fig. 153 Stop 11: Santa Maria Assunta Cathedral (a); sarcophagus made for the quaestor Caius Atecio~~herius~~ Valerius in the first century AD conserved in the crypt (b); details of sodic amphibole porphiroclasts ~~ankeritic carbonate~~ in ~~impure varieties of~~ Eclogitic Micaschists of the Sesia Lanzo Zone (c).

Fig. 164 Stop 12: Monte Stella Sanctuary (a); Detail of Diorite del Canavese used on the outside of the Sanctuary (b); Stop 13: medieval external masonry of Tre Re Chapel (c~~b~~); Details of diorite (d), jadeitic orthogneiss (e) and serpentinite (f) of rock block employed in the mansory.