White marble from Laas (Lasa), South Tyrol – its occurrence, use and petrographic-isotopical characterisation

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Abstract

Laas Marble is one of the most important marbles in Central Europe. It occurs within the S-charl-Campo Crystalline in Northern Italy. Laas Marble is often pure-white, sometimes grey, and is mostly calcitic. It frequently contains quartz, mica and sometimes tremolite as accessory minerals. Its grain size decreases from east to west depending on the (Alpine) metamorphic grade, with a maximum grain size ranging from 2.5 mm near Morter (east) to between 0.6 and 1.75 mm near Laas (west). The whiteness values of Laas Marble ranges from 94.63 to 97.04 %. The highest whiteness values were recorded for samples from the operating "Weißwasserbruch" underground quarry near Laas.

Laas Marble has been used since prehistoric times and is still in use today. It is currently extracted from three quarries: the Weißwasserbruch quarry near Laas (1526 m.a.s.l.), the Göflanerbruch quarry near Göflan (with 2250 m.a.s.l. the highest active quarry in Europe), and the Quadrat quarry near Töll / Meran. Laas Marble continues to be used for important buildings and ornamental objects all over the world.

This study delineates the geological setting of Laas marble, marble findings from the Vinschgau Valley, it’s historical use, its quarries and its petrographic-geochemical characterisation, providing a database for provenancing marble objects.

Der Laaser Marmor ist einer der wichtigsten und bekanntesten Marmorgesteine Zentraleuropas. Er kommt innerhalb des S-charl-Campo Kristallins in Norditalien vor. Laaser Marmor ist oftmals reinweiß, manchmal auch grau und meist kalzitisch. Er enthält vielfach Quarz, Glimmer, sowie manchmal Tremolit und akzessorische Minerale. Seine Korngröße nimmt von Westen nach Osten hin zu, bedingt durch den alpidischen Metamorphosegrad. Die maximale Korngröße erreicht im Osten (bei Morter) 2.5 mm, im Westen (Laas) zwischen 0.6 und 1.75 mm. Der Weißegrad von Laaser Marmor beträgt zwischen 94.63 und 97.04 %. Die höchsten Weißegrade wurden bei Proben des heute aktiven "Weißwasserbruches" bei Laas gemessen.

Laaser Marmor wurde bereits in prähistorischen Zeiten verwendet, aber auch römerzeitlich und besonders im Mittelalter. Der auch heute noch weitum geschätzte hochwertige Naturstein wird heute in drei Brüchen abgebaut: dem “Weißwasserbruch” bei Laas (1526 m), dem “Göflanerbruch” nahe Göflan (mit 2250 m der höchstgelegene aktive Steinbruch in Europa) und dem Steinbruch “Quadrat” nahe Töll / Meran.

Diese Arbeit beschreibt die geologische Stellung von Laaser Marmor und charakterisiert das Material petrographisch-geochemisch. Sie erklärt weiters die historische Verwendung des Laaser Marmos, gibt zahlreiche Verwendungsbeispiele und zählt die historischen wie aktiven Steinbrüche dieses Materials auf. Somit legt die Arbeit eine bedeutende Basis für die Herkunftsbestimmung alpiner Marmorobjekte.

1. Introduction

Most Europeans tend to think of marble in terms of the pure white varieties of Carrara marble from Italy, or the world-famous marbles from Greece and Asia Minor. These marbles were already being quarried in large quantities during Roman times, and were even transported to the northern provinces of the Roman empire (e.g. Kremer et al., 2009; Unterwurzacher, 2010).

The Romans, however, also found numerous marble occurrences within the northern provinces of their imperium, some of which were exploited. The most important quarries in the Eastern Alps that are known to have been in use during Roman times were the Gummern-Krastal quarries in Carinthia and the Pohorje quarry in Slovenia (e.g. Müller and Schwaighofer, 1999; Unterwurzacher et al., 2005; Jarc et al., 2010; Unterwurzacher et al., 2010). In addition to these quarries of supra-regional importance, several smaller marble occurrences were also excavated, and achieved local, or even regional, importance (e.g. Müller and Schwaighofer 1999; Unterwurzacher, 2010). One such quarry area was the Laas Marble district, in the north-western part of South Tyrol, northern Italy (Fig. 1). Although the quarrying of this marble has only been documented for the late Middle Ages, this paper shows that this material has been in use over a period of several millennia. Laas Marble is one of the highest quality marbles in Europe in respect to its purity, whiteness and fine grained texture.

2. Geological setting

Laas Marble, an authentic metamorphic calcite-marble (Obojes et al., 2007), is located within the tectonic Laas Unit in the

Ortler-Campo Crystalline (Nappe); also the adjacent Pejo Unit contains some marbles, the so-called Ulten marbles, that cannot be distinguished from Laas marble. Together with the S-charl Crystalline (Nappe) it forms the S-charl-Campo Crystalline Complex, located south of the Vinschgau Valley between Töll (near the city of Meran) and Laas (Nocker, 2007; Mair et al., 2007; Martin et al., 2009) (Fig. 1).

The Ortler-Campo Crystalline is a part of the polymetamorphic Austroalpine basement unit between the Vinschgau and Ulten valleys. At the tectonic Schlinig Line in the west and the Vinschgau Shear Zone, the Ortler-Campo Crystalline has been overthrust by the Stubai-Ötztal Crystalline (Nocker, 2007). The eastern limit of the Ortler-Campo Crystalline is marked by the Giudicarien fault (Viola et al., 2001), the southern limit by the Pejo Line, and the western limit by the Engadine Line (Nocker, 2007).

Mair et al. (2007) suggest that the Ortler-Campo Crystalline can be subdivided into three tectonic units: the Laas Unit, the Pejo Unit, and the "Zebru scale-area".

The Laas Unit forms the lowest part of the Ortler-Campo Crystalline and extends from Prad to Töll. It consists of highly deformed and partly mylonitic mica schists, paragneisses and amphibolites, as well as marbles that are often almost pure white. The northern boundary of the Laas Unit is marked by the Schlinig Line and the Vinschgau Shear Zone, while the southern boundary is marked by the mylonites of the Laas Line. The rocks of this Unit exhibit Variscan (amphibolite) and Eo-Alpine (upper greenschist) metamorphic grades.

The Pejo Unit lies immediately south of the Laas Unit, with the Pejo Line forming its southern boundary. Both its northern and southern boundaries are formed by broad detachment zones along tectonic lineaments, i.e. the broad mylonitic shear zone of the Laas Line to the north, and the mylonitic and cataclastic Pejo Line to the south.The Pejo Unit consists mainly of micaschists, but also includes amphibolites, orthogneisses, and rather impure yellow or grey marbles. These rocks are cut by numerous intrusions, e.g., the Permian Martell Granite. Permian granodiorite and gabbro-diorite intrusions are also common, as are intermediate dykes of Oligocene age. The rocks exhibit Variscan (amphibolite) and Eo-Alpine (greenschist) metamorphic grades (Mair et al., 2007).

The "Zebru scale-area" (below the Permo-Triassic rocks of the Ortler Nappe) has tectonic borders on all sides and has been thrust over the Pejo Unit. It consists mainly of (quartz) phyllites, with inter-layered chlorite schists, quartzites or gneisses (Mair et al., 2007).

Both the Laas and the Pejo unit suffered similiar P-T conditions of about 550 to 620 °C and 9 to 11 kbar during the Variscan Orogeny (Cortecci et al., 2000; Recheis, 2004; Nocker, 2007). An Alpine metamorphic zoning from west to east can be distinguished: while the eastern parts of these units reached upper greenschist facies (T: 490 to 530 °C, P: 6 to 8,5 kbar), the western parts only attained temperatures of 380 to 430 °C and pressures of 4.5 to 6 kbar (Nocker, 2007).

3. Archaeological and historical background

Archaeological discoveries have shown that the region around Laas was already populated in pre-Christian times. The most important of these discoveries is the settlement at Tartscher Bichl near Mals (Early La Tène Period - 2nd half of 5th century to 1st half of 3rd century BC), which consisted of 80 houses. A hill-top settlement also existed at Ganglegg, near the village of Schluderns, during the Bronze and Iron Ages (Late La Tène Period, Gamper, 2002).

The people that lived in these settlements used stone men-

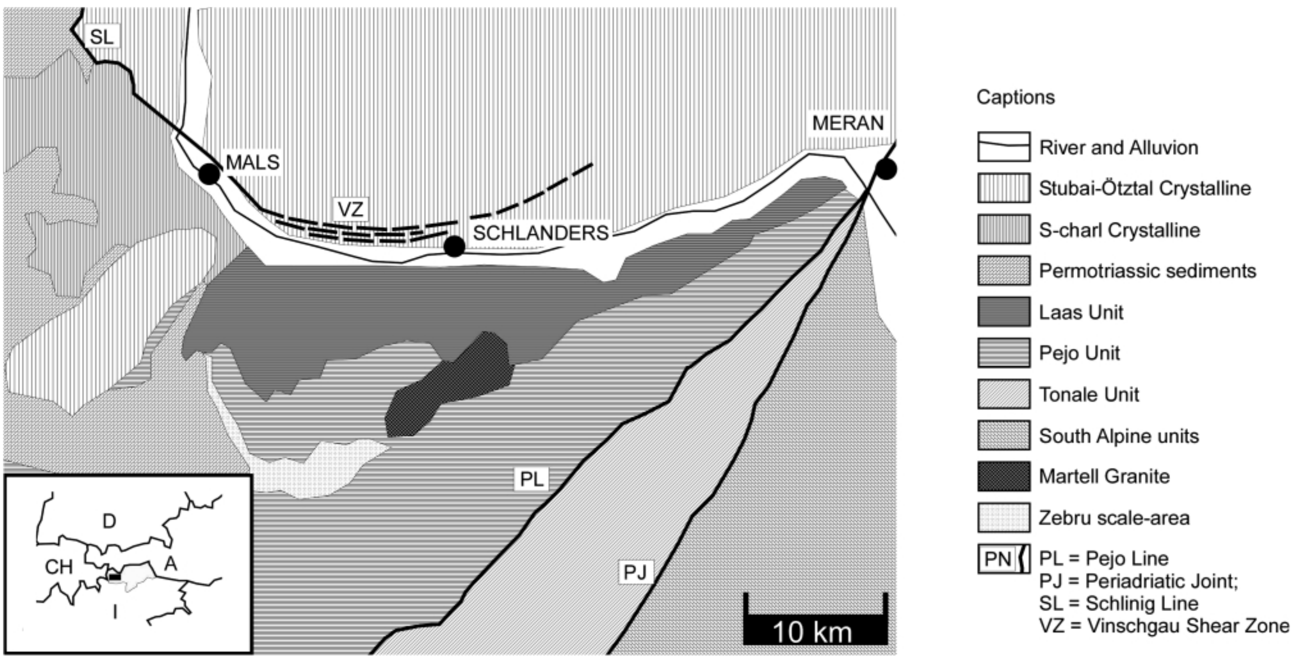

Figure 1: Location and geology of the Vinschgau Valley (after Mair et al., 2007, modified).

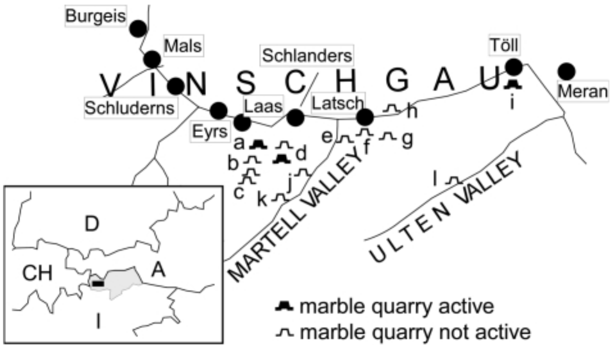

FIGURE 2: The Vinschgau Valley and Laas marble quarry areas. The black circles mark important cities and villages, the numbers a-l the occurrences and quarries of Laas marble (see chapter 4).

hirs for sacrifices to their gods. Menhirs are monoliths that often include ornamentation showing male and female forms. They may also exhibit engravings of objects such as dirks, pole hatchets and other tools, as well as humans, animals, and even heavenly bodies.Two menhirs have been found in the Vinschgau Valley. Fragments of one of these were found near the village of Kortsch, but they were subsequently lost. A second menhir (Fig. 3) was found in 1992 in the Bichlkirche church in Latsch, where it remains on display. This important monument, which is made from white marble, displays images of weapons and other tools, a carriage, a plough blade, human figures with a bow and arrow, and two animals (possibly deer) on one side, and three illustrations of the sun on the other. A belt-like ornament encircles both sides of the menhir. The figures represent scenes from everyday life.

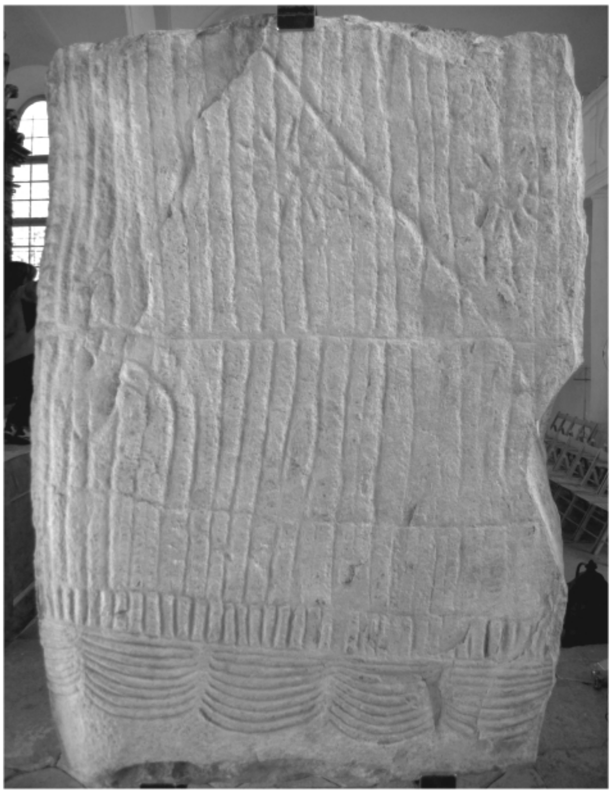

FIGURE 3: The Latsch menhir.

From Roman times several marble objects, especially milestones, are known in the Vinschgau Valley and adjacent areas. Two milestones were found in the Vinschgau Valley: one between Eyrs and Laas (unfortunately this milestone was reworked into a gravestone in later times) and another near Rabland/Töll. An altar, dedicated to goddess Diana, was found near this latter milestone, and is now on display in the Archaeological Museum of Bozen. The milestone has the following inscription:

Ti[berius] Claudius Caesar
Augustus German[icus]
Pont[ifex] max[imus] trib[unicia]
Pot[estate] VI cons[ul]
Desig[natus] III imp[erator] XI
P[ater] p[atriae]
[vi]am Claudiam Augustam
quad Drusus pater Alpibus
bello patefactis derexserat
munit a flumine Pado at
[f]lumen Danuvium per [milia]
p[assuum] CC

Another Roman milestone (Fig. 9) was found in the autumn of 2002 during excavations on a building near the Reschenpass at the border Austria-Italy. A soiled and weathered milestone, 1.71 m long and weighing about 700 kg, was found at a depth of about 1.5 m. This milestone features a round to slightly oval shaft with a diameter of between 36 and 42 cm. The base of the milestone is formed by a rectangular, 29 cm high socle with a nearly square base measuring 39 x 39 cm. Archaeologists suggest that this milestone was originally about 3 m long. In contrast to the above-mentioned milestone from Rabland, this milestone contains virtually no decoration and the only engraving is an "XL", which is interpreted as distance information (Pöll, 2006). Its origin from Laas marble was proved by archaeometrical investigations (Unterwurzacher, 2006).

Remarkable marble objects in the region have also been found from Carolingian times (8th century). The St. Johann monastery of Müstair (Val Müstair, Eastern Switzerland: UNESCO World Heritage Site) is well known for its impressive frescos, and numerous historically and archaeologically important objects have also been found and stored at this site. Among these, the most outstanding are "basketry stones" (Sulser, 1980) that are made from white marble with engraved patterns, figures and basketwork (Unterwurzacher and Goll, 2009). Other "basketry stones" have been found in Burgeis, Göflan and Laas (Waldner, 2008).

Historically, the Vinschgau area belonged to the Bishop of Chur (Switzerland) until 1818. A bishop's marble gravestone from the 9th century, containing an inscription "...ORDINABIT VENIRE DE VENOSTES..." is known to have been ordered from Vinschgau by Bishop Victor 3rd of Chur (Waldner, 2008).

Another impressive use of marble from the 12th century is in the apse of the Laas parish church (Fig. 5). The Romanesque apse was destroyed in the middle of the 19th century during reconstruction work, but marble blocks from the original apse were found during renovations in 1973/74, and were subsequently restored. From the same time are also the impressive Romanesque marble portals of Schloss Tirol near Meran (Recheis et al., 2003).

Until the Early Middle Ages, except the above mentioned inscription, no written sources on the use of Laas Marble exist. Neither could any tool marks or archaeological findings be found that prove the quarrying of Laas marble before the Late Middle Ages.

From the 18th century on Laas Marble has been used and quarried more intensively. Compilations can be found in the works of von Klebelsberg (1935) and Köll (1964). The most important examples of objects made from Laas Marble are statues and monuments of Mozart, Haydn and Lenau in Vienna, the Sissi monument in the Volksgarten, the figures at the Burgtheater, and the high altar of the Votivkirche, all in Vienna, the war memorial in Düsseldorf (raw block: 27 t), the Andreas Hofer monument in Meran, the high altar of the Stefanskirche in Bremen, the Gefallener Löwe monument in Kassel, and the use of Laas Marble in the High Court building in New York.

In recent years Laas Marble has also been very much appreciated as a building and decorative stone, and has, for example, been used in the Europa-Center in Berlin, Stuttgart Airport, Orly Airport (Paris), the Bozen/Bolzano City Hall, the Meran/Merano Hospital, the City Hall of Memphis Tennessee (USA), a mosque in Abu Dhabi in Bahrain (UAE), the Saudi Arabian Monetary Agency in Riyadh (Saudi Arabia), the Raffles City Tower (Singapore) and the Metro Station One World Trade Center in New York (USA).

Figure 4: The milestone from Nauders.

4. Laas Marble quarries

There are numerous marble occurrences within the Ortler-Campo Crystalline, several of which have been quarried and still are today. The marble layers and lenses are commonly several meters to tens of meters in thickness but can even reach hundreds of meters near Laas, and are often intensively folded.

The marbles occur mostly within the Laas Unit. Within the adjacent Pejo Unit in the Ulten Valley also some ancient quarries exist. Some of those marbles are also pure-white, fine to medium grained and are very similar to Laas marble – due to the similar formation conditions and metamorphosis conditions. Those Ulten marbles are not distinguishable from the Laas marble by any petrographical, geochemical or isotopical features. That's why those Ulten marbles are – especially in historical contexts – sometimes also named “Laas marble”.

Laas Marble is today quarried at three locations (Fig. 2):

1) The Quadrat quarry, near Töll, from which "Töll Marble" is exploited for plaster production (WGS 84: 11,098748; 46,663484),
2) Very high quality white, and in parts almost pure, "Laas Marble" is quarried underground from the Weißwasserbruch quarry near Laas (WGS 84: 10,700005; 46,587906) and
3) "Göflan Marble" is quarried above the Göflaner Alm at

Figure 5: Apse of Laas parish church.

the Mitterwandlbruch, Göflanerbruch quarries (WGS 84: 10,730648; 46,580411).

After a break of several years these quarries have now been reactivated during the past few years.

Different types of Laas Marble are sold under different names, depending on the quality and, in particular, on the colour. Some of these names are "Lasa Bianco Cevedale", "Lasa Bianco Cevedale Nuvolato", "Lasa Bianco Ortles", "Lasa Bianco Classico", "Lasa Bianco Vena Oro", "Lasa Fior di Melo" and "Lasa Bianco Vena Verde". The pure white and most expensive variety from Weißwasserbruch is called "Lasa Bianco Perla"and the pure white variety of Göflan Marble is called “Bianco Neve”.

The material from Weißwasserbruch and Göflanerbruch is today quarried underground and transported by road, rail, or brake incline down to factories in the valleys, where it is mainly worked into slabs of various sizes. Laas Marble is today mainly used for wall cladding, baseplates, paving stones, flooring, stairs, window-sills, massive works and skirting boards.

The main occurrences of Laas Marble are (see Fig. 2):

a) Weißwasserbruch: The Weißwasserbruch quarry is the

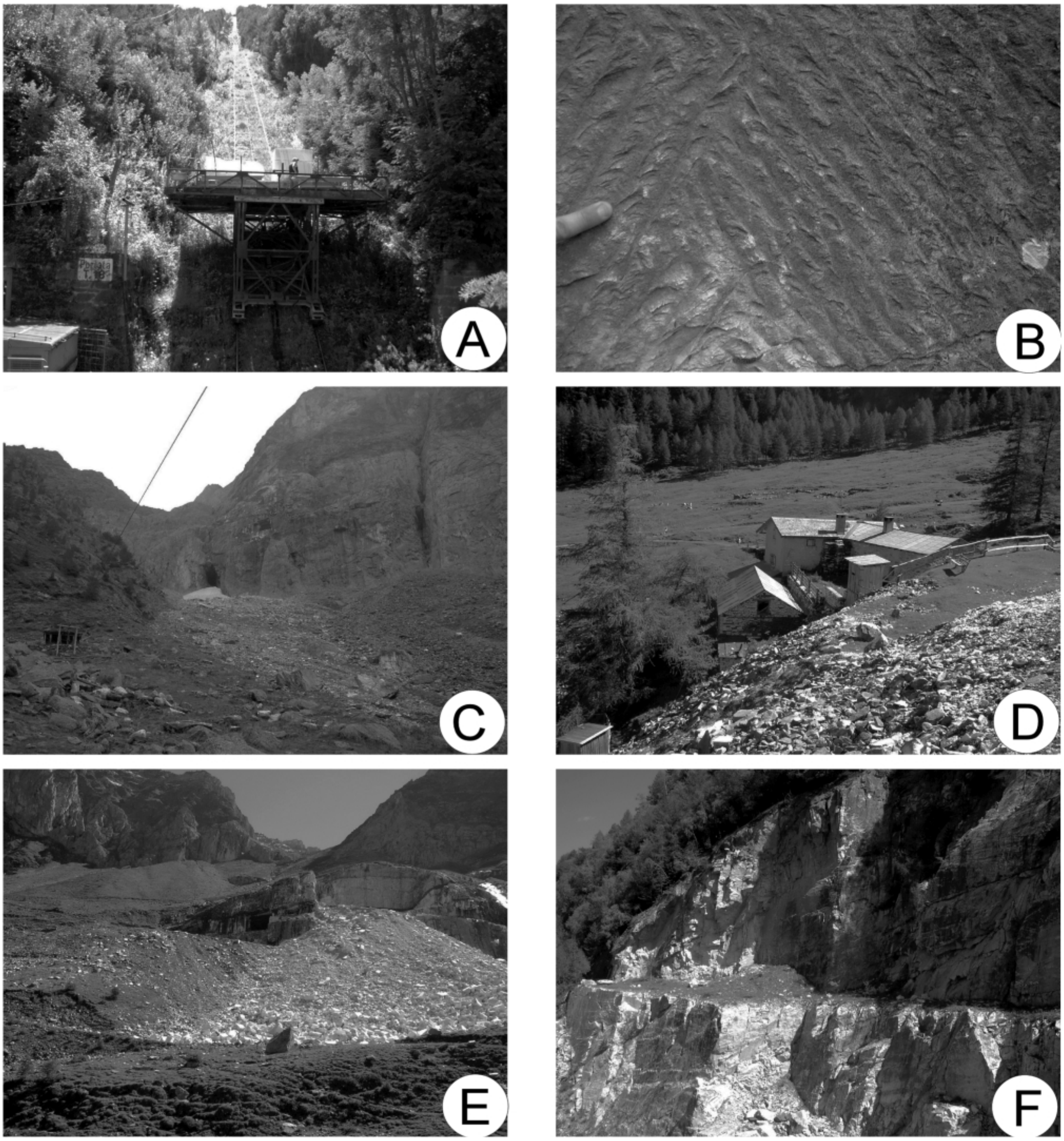

Figure 6: Laas Marble quarries: A: Transportation of marble blocks from the Weißwasserbruch quarry down to the valley; B: Tool marks on the quarry face of Tarnellerbruch; C: Jennwand quarries and upper part of the Jennwandreise; D: Alpbruch quarry and farmhouses built of marble; E: Göflanerbruch quarry; F: Morter Montani quarry

best known and most important Laas Marble quarry. It is situ-ated at an altitude of 1,526 m (about 700 m above the valley floor) on the eastern side of the Laas Valley. It is an under-ground quarry in which up to 60 workers have been employed (Fig. 6A).

b) Tarnellerbruch: The abandoned Tarnellerbruch quarry (Fig. 6B) is located to the south of the Weißwasserbruch quarry. Material was extracted from this quarry around the year 1900, as can be proved by tool marks on the quarry face. Marbles from Tarnellerbruch have been used for sculptures in Philadelphia, USA, and also in Frankfurt, Germany.

c) Jennwand and Jenngraben (Fig. 6C): The Jennwandreise, a rock scree from the Jennwand mountain peak down to the Laas Valley, is thought to be the oldest marble extraction site in the valley. Marble has already being produced from here at the beginning of the 19th century, without quarrying. Quarries were opened later in the 19th century but only small quantities of marble were recovered from the Mittelbruch, Hinterbruch, Zirmwand, Obere Nesselwand and Untere Nesselwand quarries due to the difficult access; most of these quarries are located at around 2.000 m above sea level, in rugged terrain. At Neubruch, which is the lowest of these quarries, an adit was driven in the 1920s. The material from Jennwand and Jenngraben is of very high quality, and the re-opening of these quarries is in process since 2011.

d) Göflan: Marble quarrying has also taken place in the vicinity of the Göflaner Alm, and the farm building itself is partly made from marble blocks. There are several disused quarries within this alpine region, of which two have been re-opened since 2005.

Göflan marble is a white to bright grey or blueish, mostly pure, calcitic marble, often containing layers of attractive green amphibolite. With a mean grain size of about 0.75 mm and a maximum of about 1.5 mm it is somewhat coarser than marble from Laas and a little finer than marble from Morter.

Köll (1964) described four quarries, as well as five depressions from which boulders had been extracted. The Alpbruch and Vernösterknöttbruch quarries are situated behind the farm building (Fig. 6D). These quarries were mainly excavated during the last years of the 19th century. The mostly platy material was used for crosses, slabs and the base of monuments.

The Niederwandlbruch and Mitterwandlbruch quarries are situated next to each other at 2.170 m above sea level. Together these two quarries are known as Göflanerbruch, and material is extracted there today, both from above ground and underground workings (Fig. 6E).

e) Morter (Fig. 6F): The Montani quarry of Morter is situated on the eastern side of the entrance to the Martelltal Valley. Slabs from this quarry were mainly used for tombs. This marble is also of high quality and is very white.

f) Latsch: Marble was quarried near Latscherhof around the beginning of the 20th century. This platy marble was used only as track ballast. Since we have been unable to locate the original site of the quarry, we suggest that it may have been overbuilt when the Latscherhof building was constructed.

Figure 7: marble boulders at the slopes above Göflan.

g) Tarsch: Several small marble lenses, only few meters in thickness, have been quarried near the village of Tarsch, below the St. Medardus Chapel. The material is of rather poor quality, fissured, grey, impure marble with a maximum grain size of up to 3 mm, and was used for lime-burning, as is evidenced by a beautifully restored limekiln next to the marble outcrops.

h) Kastelbell: Köll (1964) described a quarry of white marble near Kastelbell. The material was of low quality and was only used for gravel.

i) Töll: The third active marble quarry today is the Quadrat quarry, located above the village of Töll, near Meran. This quarry currently produces 40.000 tons of marble per annum for use in render production. Von Klebelsberg (1935) also described the use of Töll marble for carbide production.

j) Eichberg, Martell Valley: Marble was extracted at the beginning of the 20th century from the remote Eichberg Wall, in the Martell Valley. The material was quarried by explosives and used for gravel or render production.

k) Zelimbruch, Martell Valley: White-grey, mainly impure marble has been quarried from the Zelimbruch quarry, in the Martell Valley. Despite the presence of impurities, Zelimbruch Marble has been used for several important monuments, the best known of which is the statue of Moses in Philadelphia, USA, made from a 40 t marble block.

l) Ulten Valley (Ulten marble): Marble has also been produced from several quarries in the Ulten Valley, near the village of St. Walburg. Ulten Valley marble is a pure white, fine-grained calcitic marble. Up to 100 workers were employed in these quarries, especially in the years between 1900 and 1914. This marble has been used for several important monuments, such as the Sissi monument in Meran. Fischer (1985) described several other small marble lenses in the Ultental Valley that have been at least partly quarried. This material has been used mainly for lime burning.

m) Marble boulders: Of high importance in this area are the

sample	quarry	variety	c/d	grain boundaries	non-carbonate fraction	grain size mean (mm)	grain size max. (mm)
LAS1	a	w	c	w	q, a	0.70	1.50
LAS2	a	lg, i	c	w	q, a	0.70	1.30
LAS3	a	w	c	w	q, a	0.70	1.30
LAS4	a	lg, i	c	w	q, a	0.40	1.30
LAS5	a	w	c	m	q, a	0.80	1.40
LAS8	a	w	c	w	q	0.50	1.00
LAS6	b	lg, i	c	w-m	-	0.80	1.50
LAS7	b	lg, i	c	w-m	-	0.60	1.10
LAS22	b	w	c	w	q, f	0.50	1.00
LAS9	c	dg	c+d	w	q	0.40	0.60
LAS10	c	w	c	m	q	0.60	1.00
LAS11	c	w-g	c+d	m	q, f	0.30	0.75
LAS12	c	w-g	c	m	q	0.70	1.10
LAS13	c	w	c	w	q, ap	0.50	0,75
LAS14	c	w	c	w	q	1.00	1,50
LAS15	c	w, i	c	w-m	q	1.00	1,25
LAS16	c	w	c	w-m	q, m	0.90	1,50
LAS17	c	w	c	m	q, m	0.80	1.00
LAS18	c	w	c	m	q	0.70	1.00
LAS19	c	w	c	w	q	0.80	1,50
LAS20	c	w-b	c+d	m	-	0.50	1,50
LAS21	c	w-b	c+d	w	q	0.30	1.00
GOF2	d	w	c				
GOF5	d	lg, i	c				
GOF6	d	w	c	w	-	0.80	1.50
GOF7	d	w	c	m	q	0.70	1.50
MOR1	e	w	c	w	q, f	1.40	2.50
MOR2	e	w	c	w	q, f	1.40	2.50
MOR3	e	g	c+d				
MOR4	e	g	c	w	a	0.80	2.50
TÖL1	i	g	d	w-m	q, f, ta	0.70	2.00
TÖL2	i	g	d	w-m	q, f, ta	0.70	1.50
TÖL3	i	w-g	c				
MAR1	k	w-g, i	c	m	-	0.80	1.10
MAR2	k	w	c				
MAR3	k	g	c				
ULT1	l	w	c	m	a	0.30	2.00
ULT2	l	w	c				
ULT3	l	w	c	m	-	0.20	0.90
ULT4	l	w	c	m-s	-	0.50	1.50
ULT5	l	w	c	m-s	q	0.50	1.75
ULT6	l	w	c	m	-	0.60	1.30
FGR1	m	w		m	q, a	0.90	1.80
FGR2	m	w		w-m	q, m	0.80	1.70
FGR3	m	w		w-m	q	1.00	1.30
FGR5	m	w		w	q, m	0.70	1.50
FGR6	m	w-g		w-m	q, m, t	0.70	1.40
FGR7	m	w-g		m	-	0.50	2.20
FGR8	m	w		m	q	1.00	2.00
FGR9	m	w		m	q, a	0.80	1.80
FGR10	m	w		m	q, m, a	0.80	2.00
FGR11	m	w-g		w-m	q	1.10	2.00
FGR12	m	w		w-m	q	0.70	1.40
FGR13	m	w		w-m	q, m	0.40	1.40
FGR14	m	w-g		w	-	0.60	1.10
FGR15	m	w		w-m	q, m	0.70	2.20
FGR16	m	w		w-m	q, m	0.70	1.80
FGR17	m	w		m	q, a	0.50	2.10

Table 1: characteristics of investigated Laas Marble samples; - sample name; - origin (quarries a to l, see chapter 4.; m…samples from boulder depressions); - sample colour (w...white, g...grey, lg...light-grey, dg...dark-grey, w-g...white-grey, w-b…white-blueish, i…impure); - rock forming carbonate mineral (c…calcite, d…dolomite); - accessory minerals (q...quartz, m...mica, a...accessories (zircone, apatite, epidote,…), t…tremolite, ap...apatite, f...feldspar, ta...talc); - maximum and mean grain size; - type of grain boundaries (w...weakly sutured, m...medium sutured, s...strongly sutured)

marble boulders that can be found especially on the North-facing slopes of the Vinschgau valley. Above the village of Göflan, Köll (1964) describes several boulder depressions, from which marble boulders were extracted (Fig. 7). However, these depressions, filled with glacially relocated marble blocks up to several meters in diameter, have surely been of importance in earlier history, as the blocks are of high quality and easily extractable due to their size and appearance. Therefore we conclude that these blocks were the predominant material used by the Romans, as well as in the Early Middle Ages.

5. Petrographical and geochemical characterization – sampling and methods

In this study 57 samples of Laas Marble have been taken from quarries (41) and boulders (16). The objects were described macroscopically and cut for thin section preparation. Another part was powdered for geochemical characterisations.

Trace elements of Laas Marble have been measured by ICP-OES at the Institute of Mineralogy and Petrography, Innsbruck University (detection limits for the here discussed trace elements 0.5 to 1 ppm).

Due to big divergences with trace element data given by Cortecci et al. (2000) additional measurements have been done at ACME Analytical Laboratories, Canada. Main elements have been measured by ICP-OES, trace elements by ICP-MS. Ba content has been measured by ICP-MS, detection limit: 0.5 ppm.

Stable isotopes of C and O have been measured by MS at the lab of the Institute of Geology and Palaeontology, Innsbruck University (C. Spötl) by a Finnigan ThermoQuest DeltaPlusXL.

Additionally, for some powdered samples the whiteness value has been measured on an "Elrepho Datacolor 2000" at the Austrian Geological Survey, Vienna.

The grain size of the carbonate minerals was measured from 100 to 200 grains per thin section.

6. Petrographical and geochemical characterisation – results

Table 1 and 2 give the data for the investigated marbles. Table 1 contains sample name, its origin and the rock forming carbonate mineral (calcite/dolomite) as well as accessory minerals, maximum and mean grain size and type of grain boundaries. Table 2 gives important trace elements (measured by ICP-OES) of the investigated samples and stable isotopes of C and O.

The marbles investigated are frequently almost pure white calcitic marbles, but also contain small quantities of dolomite, quartz, mica and feldspar. Dolomitic marbles are rare and can be distinguished from the calcitic marbles by their brown weathering. These marbles also contain calcite, quartz and mica. Grey, fine grained marble often contains microscopic inclusions of graphite and pyrite in addition to calcite and dolomite.

sample	quarry	Ba	Fe	Mn	Sr	Zn	Mg	$\delta^{18}O$	$\delta^{13}C$
		(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(‰)	(‰)
LAS1	a							-5.35	0.48
LAS2	a	1	181	10	120	11	1820	-5.57	1.29
LAS3	a	1	74	7	153	1	1842	-9.03	1.72
LAS4	a	1	167	28	153	32	1968	-6.41	1.05
LAS5	a	2	473	12	154	3	3674	-5.44	0.43
LAS8	a	3	215	10	138	3	1818	-6.16	2.15
LAS6	b	2	108	8	168	1	2036	-8.67	1.69
LAS7	b	2	660	59	458	1	1793	-7.50	0.69
LAS22	b	2	139	6	145	1	1536	-8.46	1.89
LAS9	c	6	351	156	167	40	16915	-8.50	0.31
LAS10	c	2	237	229	149	3	4448	-8.23	0.24
LAS11	c	7	1234	31	177	10	27922	-10.07	0.08
LAS12	c	2	146	6	135	2	1862	-6.38	0.89
LAS13	c	0	23	3	27	2	433	-7.29	1.68
LAS14	c	3	199	151	163	3	1727	-7.49	0.77
LAS15	c	3	241	42	155	30	3813	-7.51	0.28
LAS16	c	1	762	32	158	6	1591	-6.84	1.04
LAS17	c	2	164	159	112	1	1173	-11.21	1.60
LAS18	c	2	98	53	166	1	2191	-7.59	0.91
LAS19	c	2	193	28	141	1	1347	-9.46	1.95
LAS20	c	5	403	18	1115	75	10100	-8.62	1.06
LAS21	c	8	278	9	110	5	20135	-10.01	1.11
GOF2	d	5	319	11	176	29	3747	-7.03	0.74
GOF5	d	3	31	4	189	1	3047	-6.11	1.98
GOF6	d	3	219	15	267	4	4980	-6.34	0.83
GOF7	d	2	220	32	351	4	2578	-7.04	1.53
MOR1	e	5	208	22	158	9	2320	-7.40	1.49
MOR2	e	7	651	22	198	10	6503	-8.65	1.04
MOR3	e	8	221	20	233	9	13912	-5.42	0.35
MOR4	e	6	420	18	199	8	7434	-7.69	0.25
TÖL1	i	15	1334	88	319	20	87863	-8.73	1.46
TÖL2	i	11	797	71	239	18	62324		
TÖL3	i	10	260	23	139	8	963	-7.92	0.36
MAR1	k	9	256	113	401	5	3250	-7.43	1.07
MAR2	k	4	487	16	170	2	2794	-6.18	1.41
MAR3	k	4	709	715	379	4	6092	-10.22	1.42
ULT1	l	4	454	21	167	1	1869	-6.58	0.43
ULT2	l	14	120	8	108	1	1729	-7.01	0.74
ULT3	l	3	91	8	52	2	1046	-7.12	1.30
ULT4	l	4	106	11	113	6	1930	-5.75	0.71
ULT5	l	3	76	13	122	2	1522	-7.24	1.4
ULT6	l	6	63	11	96	1	1229	-7.47	1.27
FGR1	m							-6.36	1.13
FGR2	m							-5.64	1.11
FGR3	m							-5.89	1.59
FGR5	m							-6.07	0.58
FGR6	m							-5.39	0.71
FGR7	m							-8.63	0.68
FGR8	m							-8.99	0.15
FGR9	m							-6.09	0.76
FGR10	m							-8.23	0.94
FGR11	m							-5.41	1.47
FGR12	m							-7.08	2.14
FGR13	m							-9.10	0.87
FGR14	m							-6.44	1.84
FGR15	m							-6.52	2.07
FGR16	m							-7.67	-0.17
FGR17	m							-6.03	0.66

Table 2: characteristics of investigated Laas Marble samples; - sample name; - origin (quarries a to l, see chapter 4.; m…sample from boulder depressions); - trace element contents (Ba, Fe, Mn, Sr, Zn, Mg, measured by ICP-OES); - stable isotopes (O, C)

Another type of marble contains tremolite crystals up to several cm in size, occurring along the foliation plains or as porphyroblasts. These marbles also contain quartz, mica and plagioclase.

From thin section analyses not only the accessory minerals, but also grain boundaries and grain size were analyzed. Most of the marbles investigated show weakly to medium sutured grain boundaries.

The mean grain size throughout the marble zone that runs from Laas to Morter ranges between 0.3 and 1.0 mm in the west (Laas), and between 0.8 and 1.4 mm in the east (Morter). The maximum grain size ranges between 0.6 and 1.75 mm near Laas up to 2.5 mm near Morter (Fig. 8 and 9). Such an increase in grain size for the rock-forming mineral calcite within marbles can be interpreted as a clear sign of increasing metamorphic grade (Müller 1984-1998) or less deformation.

The grey-white to blue-grey marble lens near Töll has a mean grain size of about 0.7 mm and a maximum grain size of about 1.5 to 2.0 mm. Compared to other white-coloured Eastern Alpine marbles (Fig. 10) Laas Marble is rather fine grained. Taking into account that most of the used Laas Marbles as well as most of the boulders come from the area of Laas and Göflan, it is even finer grained and reaches up to 1.6 mm in maximum grain size (Fig. 9). This small grain size is an important feature of Laas marble, compared to other widely used Alpine marbles like Sterzing Marble, Gummern Marble, Treffen Marble or Pohorje Marble, that are much coarser grained (see Fig. 10).

Taking into account its isotopic composition (stable isotopes, C and O, as important discrimination parameter in provenance analysis (e.g. Herz, 1988; Attanasio, 2003), Fig. 11) Laas Marble forms a distinct field but shows some overlap with several other important central European marble districts, especially with the important marbles from Gummern and Sterzing (Fig. 11). But, as mentioned before, due to its much smaller grain size Laas Marble can be distinguished from Sterzing and Gummern Marble rather easily.

Laas Marble does not show any characteristic trace element patterns. The contents are generally low and the variations within the quarries are larger than between Laas Marble and other marbles. Table 2 gives the concentrations of the trace elements Ba, Fe, Mn, Sr, Zn and the element Mg. Low and variable concentrations of trace elements are generally typical for most marbles (e.g. Attanasio, 2003). However Cortecci et al. (2000) give extraordinary high Ba concentration for Laas Marble (138 to 278 ppm). As no other occurrence is known

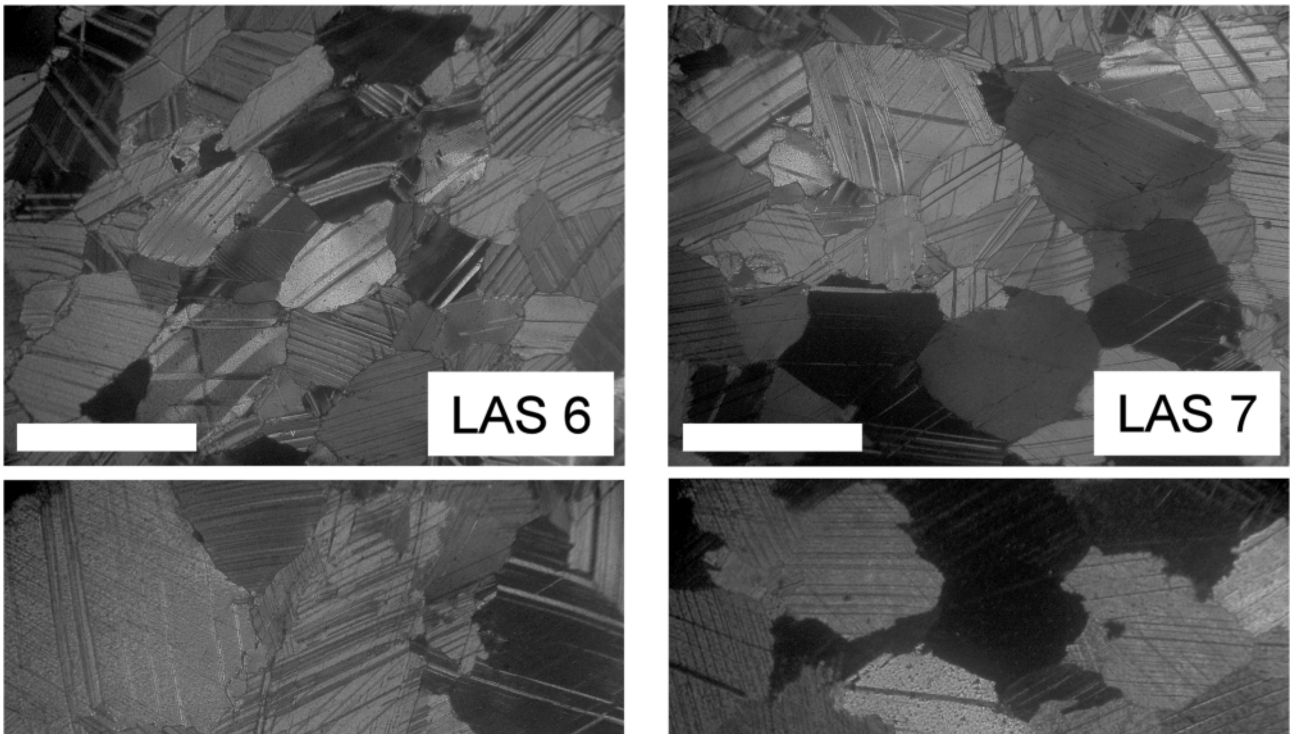

Figure 8: Thin sections (crossed nicols) of Laas marbles from Laas (LAS) and Morter (MOR). The marbles are pure calcitic marbles with low (MOR) or low to medium sutured grain boundaries. While the marbles from Laas have a mean grainsize of 0.6 and 0.8 mm and a max. grain size of 1.5 and 1.1 mm, the Morter marbles have a mean grain size of 1.4 mm and a max. grain size of 2.5 mm. The white bar in the bottom left marks 1mm.

with such high Ba, this is inferred as characteristic finger print for Laas Marble by Cortecci et al. (2000). Our results obtained for marble samples are displayed in table 2. For Barium the mean concentration measured was 5 ppm, the maximum 15 ppm. Due to the discrepancy between our ICP-OES measurements and the data given by Cortecci et al. (2000) additional ICP-MS measurements were done at an external lab. The results obtained confirm our results and give low Ba contents between 2 and 4 ppm.

7. Provenance analysis of marble artefacts and objects

As mentioned above we have found no evidence of quarrying activities on the Laas marbles in pre-Christian and Roman times. On the other hand even today in the valleys and especially on the North-facing slopes of the Vinschgau Valley numerous marble boulders exist, partly concentrated in boulder depressions, partly as single blocks on the slopes. These glacially relocated marble blocks reach up to several meters in diameter and are of best quality as they have survived glacial and fluviatile transport. We assume that, in general, these blocks were the material used in pre-historic times, by the Romans, as well as in the Early Middle Ages.

The only existing menhir from the "Bichlkirche" church in Latsch has been studied by D'Amico (1993) who inferred that the isotopic composition ($\delta^{18}O$, $\delta^{13}C$) as well as the maximum grain size of 2 mm and a high quartz content speak very much in favour of a provenance from Laas Marble. D'Amico (1993) also investigated several other menhirs found in South Tyrol and Trentino, from Arco, Algund, Revò and Brentonico. Also for these menhirs he indicates a provenance from Vinschgau valley.

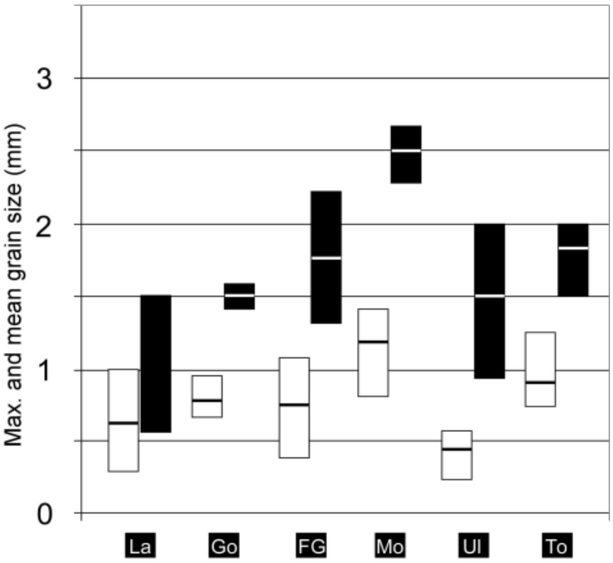

Figure 9: Maximum (black bars) and mean (white bars) grain sizes for Laas Marble (La: quarries around Laas; Go: quarries around Göflan - east of Laas; FG: marble pits between Laas and Göflan; Mo: quarry at Morter - further east; Ul: Ultental Valley; To: Töll, near Meran).

However from the data given (grain size, stable isotopes of C and O, mineral composition and selected trace elements) we assume that most of these objects do not originate from Vinschgau (Laas) Marble. Especially due to the maximum grain size of about 4 mm Laas marble can be excluded as source material for these objects. Due to the data given, and without having had opportunities for macroscopic investigations, we suggest the objects from Arco and Algund were made from Sterzing Marble or marble from the Passeier Valley (marbles from the "Schneebergerzug" of the Stubai-Ötztal Crystalline). The Revò menhir could originate from Laas Marble, even

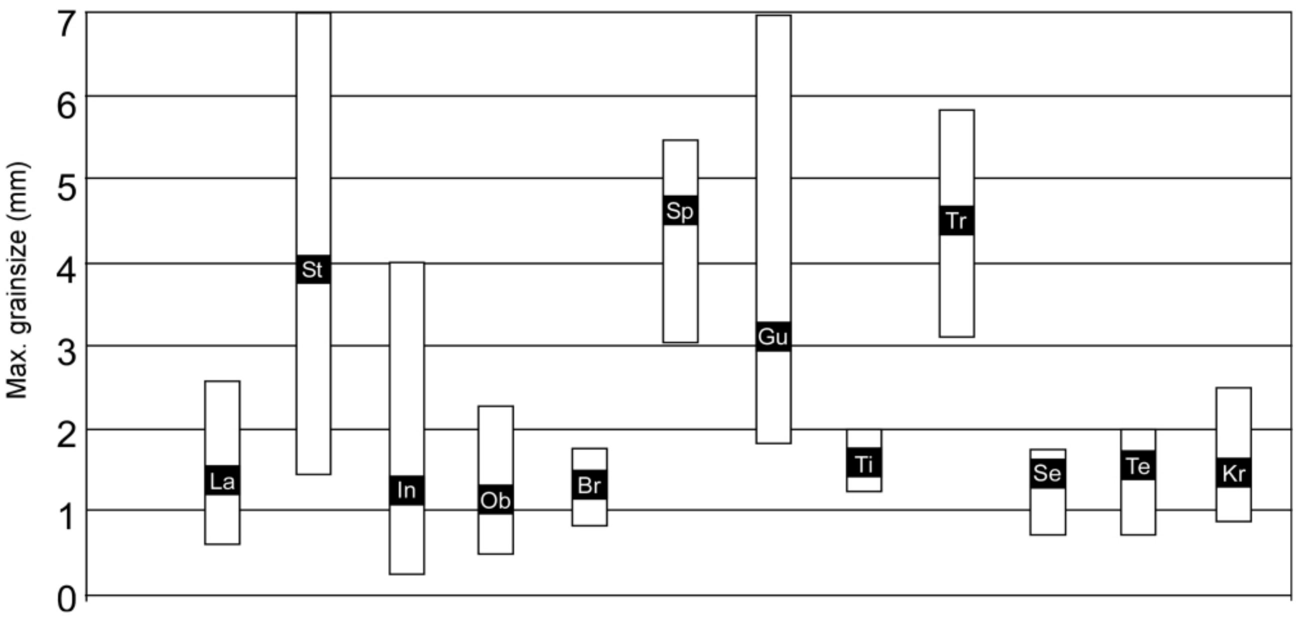

Figure 10: Maximum grain sizes for various Alpine marbles. La…Laas marble; St…Sterzing marble, South Tyrol; In…marbles from the Innsbruck quartz phyllite, Northern Tyrol; Ob…Obernberg marbles, Northern Tyrol; Br…Brenner marbles (Hochstegenkalk, Northern Tyrol; Sp…Spitzelofen marble, Carinthia; Gu…Gummern/Krastal marbles, Carinthia; Ti…Tiffen marble, Carinthia; Tr…Treffen marble, Carinthia; Se…Sekull marble, Carinthia; Te…Tentschach marble, Carinthia; Kr…Kraig marble, Carinthia; n = 20 each.

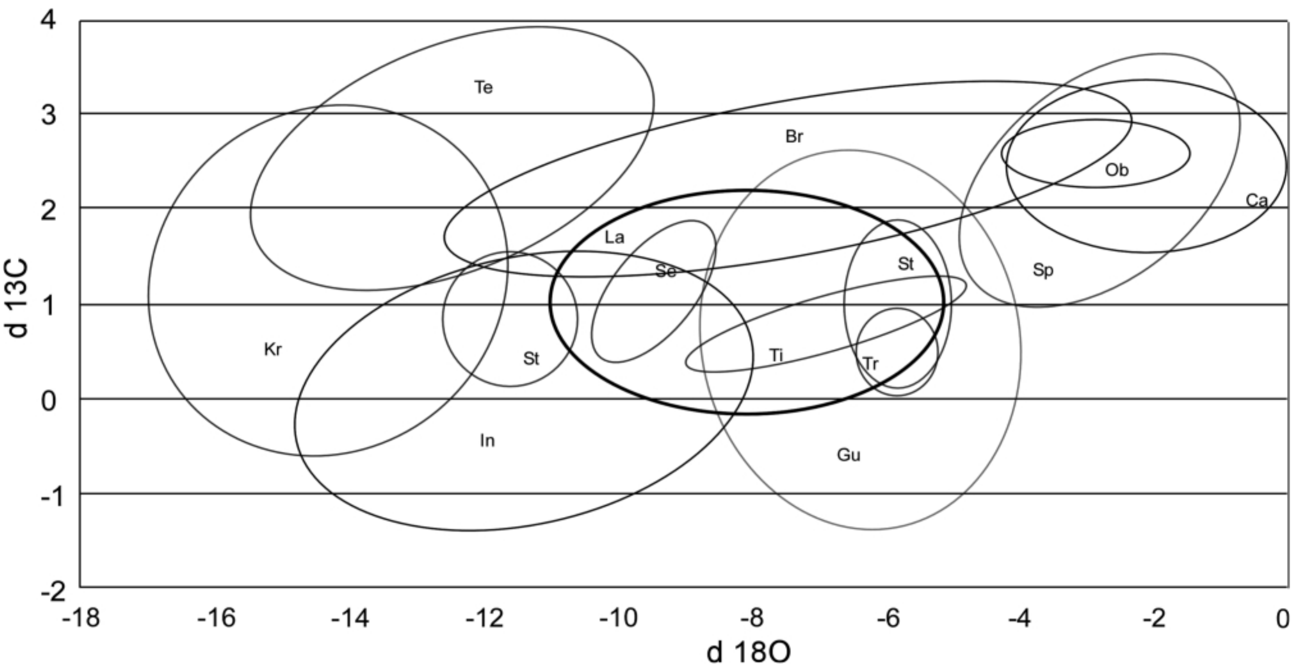

Figure 11: Stable isotopes of various Eastern Alpine marbles (data given in Unterwurzacher, 2010); La…Laas marble; St…Sterzing marble, South Tyrol; In…marbles from the Innsbruck quartz phyllite, Northern Tyrol; Ob…Obernberg marbles, Northern Tyrol; Br…Brenner marbles (Hochstegenkalk, Northern Tyrol; Sp…Spitzelofen marble, Carinthia; Gu…Gummern/Krastal marbles, Carinthia; Ti…Tiffen marble, Carinthia; Tr…Treffen marble, Carinthia; Se…Sekull marble, Carinthia; Te…Tentschach marble, Carinthia; Kr…Kraig marble, Carinthia;.

though its $\delta^{13}C$ value is rather low for Laas Marble.

Despite the apparent absence of Roman quarries, several marble objects from Roman times, especially milestones, are known in the Vinschgau Valley and adjacent areas. These milestones could also not be investigated in detail, but a provenance from the Laas area can be suggested on the basis of macroscopic evidence (grain size, colour, patina).

Another Roman milestone (Fig. 9) was found in autumn of 2002 during excavations on a building site in Nauders at the Austrian-Italian border. It was made from fine to medium grained white marble and detailed investigations suggest a provenance from the Laas marble province (Unterwurzacher, 2006).

Also the Early Medieval "basketry stones" from Müstair were proved to be made from white Laas Marble (Unterwurzacher and Goll, 2009). Detailed archaeometrical investigations on the marble portals of Schloss Tirol near Meran showed that the two portals are made from different materials: while the Chapel Portal was made from Sterzing Marble the Palas Portal was made from Laas Marble (Recheis et al., 2003).

These examples prove the use of Laas Marble as important working material from prehistoric times up to present times.

8. Conclusions

Laas Marble from the Vinschgau Valley in South Tyrol is one of the most important Central European marbles. The lack of any evidence of quarrying in Roman times suggests the usage of boulders that were transported to the Vinschgau Valley by glaciers and rivers. Systematic quarrying is known only since the 18th century. Since then big amounts of marble were extracted and transported worldwide.

The rock-forming mineral of the mostly pure white marble (whiteness up to 97.04 %) is calcite, in some cases calcite and dolomite. Laas Marble is often pure, in many cases contains small quantities of quartz, mica and amphiboles. It is characterized by small to medium grain size. Due to different metamorphic conditions the calcite grains are smaller in the West and coarser in the Eastern part. Laas Marble contains low concentrations of trace elements. Contrary to former studies (e.g. Cortecci et al., 2000) we could not find characteristic high Ba concentrations in Laas Marble; but in most cases Laas Marble can be identified by its small grain size and characteristic isotopic field of C and O. This is particularly important for a distinction from the most important Central European marbles used in antiquity: Carrara, Gummern, Pohorje and Sterzing.

A provenance determination of marble artefacts and their correlation with quarries is of extraordinary importance in archaeology, as by this material use, trade routes and relations can be explained.

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