

The volcanic foundation of Dutch architecture: Use of Rhenish tuff and trass in the Netherlands in the past two millennia

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Occasionally, a profound but distant connection between volcano and culture exists. This is the case between the volcanic Eifel region in Germany and historic construction in the Netherlands, with the river Rhine as physical and enabling connection. Volcanic tuff from the Eifel comprises a significant amount of the building mass in Dutch built heritage. Tuffs from the Laacher See volcano have been imported and used during Roman occupation (hence called *Römer tuff*). It was the dominant dimension stone when construction in stone revived from the 10th century onwards, becoming the visual mark of Romanesque architecture in the Netherlands. Römer tuff gradually disappeared from the market from the 12th century onwards. Early 15th century, Weiberner tuff from the Riedener caldera, was introduced for fine sculptures and cladding; it disappears from use in about a century. Late 19th century, this tuff is reintroduced, both for restoration and for new buildings. In this period, Ettringer tuff, also from the Riedener caldera, is introduced for the first time. Ground Römer tuff (Rhenish trass) was used as a pozzolanic addition to lime mortars, enabling the hydraulic engineering works in masonry that facilitated life and economics in the Dutch delta for centuries.

Key words: Tuff, trass, Eifel, the Netherlands, natural stone

1 Introduction

Volcanic tuffs have been used as building stone in many countries over the world. In the Netherlands, with only a small supply of natural stone within its borders, building stones have traditionally been imported from Germany and Belgium. Among the first natural stone to be imported was volcanic tuff from the Eifel, Germany. It was widely used in the Netherlands in several periods and architectural styles. In Roman times and the

romanesque Middle Ages, the so-called Römer tuff was elaborately used. It was also exported from the Netherlands to the north of Germany and western Denmark. In later times, Weiberner tuff and Ettringer were used. As dimension stone, tuff still constitutes a significant amount of the building mass in Dutch built cultural heritage. Ground Römer tuff, better known as Rhenish trass, was widely used in masonry mortars, in particular in hydraulic engineering works important in a society living in a low country along the sea, intersected by numerous rivers, streams, channels and ditches. The current paper provides a historic overview of the use of these materials in Dutch architecture.

2 Geology

Most of the Netherlands represents a Holocene delta, built up by the rivers Rhine, Meuse and Scheldt and their tributaries. These rivers formed dominant transport routes until far into the 19th century, including for building materials such as dimension stone. One of these, the Rhine, on its way from the Alps to the North Sea, connects the volcanic Eifel in Germany to the Netherlands. Tuffs from the Eifel basically come from two periods of volcanic activity. The Römer tuff, with trachytic composition, represents the lithified ash flows and glow avalanches of the 11,900 bp eruption of the Laacher See volcano [Van den Bogaard and Schmincke, 1984; 1985; Schmincke 1988, 2009]. In older literature, it has been called *duifsteen*, *dufsteen*, *trastuf*, *lapillituf* or *Andernach tuf*. The older Riedener caldera produced a series of leucite-bearing tuffs, the so-called '*selbergitic tuffs*' of Frenchen [1971], that were deposited ca. 510,000 – 620,000 year ago [Viereck, 1984]. These comprise Weibern / Hohenleie, Ettringen / Hasenstoppler and Rieden tuffs, names that reflect their topographical provenance rather than petrographic or material properties. All tuffs are macroporous rocks, with considerable variation within each type. Varying amounts of pumice and rock fragments occur in a fine grained matrix originally composed of volcanic glass. Typical igneous minerals and xenocrysts are sanidine, other feldspars, clinopyroxene (Ti-augite, diopside), olivine, amphibole, biotite, ore minerals and carbonate, in addition to leucite in the selbergitic tuffs [Fitzner, 1990; Nijland et al., 2003]. Volcanic glass has been replaced by zeolites, viz. analcime, chabazite, phillipsite and rare merlinoite [Sersale and Aiello, 1964; Fitzner, 1990; Nijland et al., 2003, 2005a].

3 Material properties

Material properties of volcanic tuff stone from the Eifel, including mechanical properties, hygric and weathering behaviour have been discussed by several authors [Fitzner 1985, 1994, Kraus 1985, Fitner & Lehnert 1990, Schubert et al. 1992, Müller 1999, Van Hees et al. 2003, 2004, Nijland et al. 2005b, Török et al. 2006, Wedekind et al. 2013, Nijland & Van Hees 2014]. Other authors discuss possible conservation treatments, including the use and effect of stone consolidants and water repellents [Weber 1984, Forgó et al. 2006, Wendler 2006] and problems associated with the choice of appropriate replacement stones [Nijland et al. 2008, 2010].

4 Use of Römer tuff

The use of Rhenish tuff as a building stone in the Low Countries, roughly coinciding with the present Netherlands, Belgium and northernmost France, dates back to Roman times. In Roman times, the river Rhine flowed considerably more to the north than now; the current city of Utrecht was located on the river. The Roman castellum of Trajectum (Utrecht) was located on the river, simultaneously the limes of the Roman Empire. The castellum, built between 47 and 275 AD, had 5 consecutive phases; the youngest phase, around 210 AD, was protected by a stone wall predominantly made with Römer tuff, as was the principia [Ozinga et al., 1985; Montforts, 1995] (Fig. 1). By the end of the 2nd century, the wooden defense wall of the nearby fortress Fectio (Vechten near Utrecht) was also replaced by one in tuff [Montforts, 1995]. Also in other Roman castella and villages in the Netherlands, such as Nijmegen [Bogaers & Haalebos, 1975], Elst [Bogaers, 1970], Matilo near Leiden [Van Pruissen & Kars, 2009; Brandenburgh & De Bruin, 2015], Brittenburg [Bloemers & De Weerd, 1993] and now submerged Colijnsplaat [Stuart, 2003]. Also in Roman occupied Belgium, Römer tuff was used for the construction of defence works, for example the Roman castellum of Oudenburg in West-Flanders [Vanhoutte, 2008] as well as other buildings, for example in Tongeren [Dreesen et al., 2015].

In the Netherlands, this tuff became the most important building stone for romanesque architecture, from the 10th until the early 13th century (Appendix). Initially, secondary tuff was obtained from Roman buildings, both local and from abroad. In Utrecht, blocks from the Roman remains were used for example for the 10th century Holy Cross Chapel [De Groot, 1994; Rijntjes, 1994]. In contrast, merchants from Deventer rented part of the Roman



Figure 1. Remains of the Roman castellum wall in a cellar at the Dom square, Utrecht. The lower part is original Roman masonry (ca. 210 AD), the upper part was rebuilt in pre-Medieval times.

castellum in the German city of Xanten from the local St. Vitus Church to quarry it for tuff [Bartels, 2006] and also obtained tuff from Roman Cologne [Hirschfelder, 1994; Bartels, 2006].

After initial quarrying of ruins, fresh Römer tuff was imported in large amounts via the town of Andernach at the Rhine, e.g. [Huiskes, 1980]. The Dutch cities of Deventer and Utrecht s became the major trade centres and staple markets for what was commonly denominated as '*duifsteen*' (and varieties of that). Utrecht, then located at the Rhine, mainly served the west of the Netherlands. Deventer, located on the river IJssel, which connected the river Rhine with the sea (the Zuiderzee), supplied the northern Dutch provinces, northwestern Germany [Haiduck, 1992, 2009] and west Denmark [Helms and Johnstrup, 1894; Helms and Storck, 1894; Von Fisene, 1991, 1992; Feveile, 1996; Lydholm, 1997]. The position of both towns as staple market is illustrated in a Latin manuscript describing the life of the founding abbot of the Mariëngaarde abbey in Frisia, relating of a journey he made around 1170 to Deventer, because '*Eo enim tempore genus lapidis, quod vulgo dufsten*

dicitur, Daventriam et Traiectum in magna quantitate per alveum Rheni deportatur venale' ('In that time, the kind of stone commonly called tuff stone was shipped via the Rhine to Deventer and Utrecht to be sold') [Wybrans, 1879]. From the 11th century until about 1235, large amounts of tuff have been shipped to Deventer, where the oldest tuff dates back to 1025 [Bartels, 2006].

In the 10th-12th century, Römer tuff was used for the cladding of walls, the inner part filled by rubble, erratic boulders and lime mortar. In the 11th century, bishop Bernold founded several large chapter churches in major towns of his bishopric, viz. the churches of St. John and St. Peter in Utrecht and St. Lebuïn in Deventer. Another early example includes St. Walburg church in Groningen (demolished in 1627), of which the oldest building phase of 1046-1054, was constructed in tuff [Van Giffen and Praamstra, 1973]. These too were clad with tuff. In the same period, the parochial church of St. Nicolas was founded in Utrecht, competing in size and lay-out with the chapter churches and also clad with Römer tuff. Not only those prominent churches, but also many smaller ones, including small Romanesque and Romano-Gothic village churches were constructed in Römer tuff, notably in the northern Groningen province [De Olde 2002, 2003] and the western provinces of Holland [Den Hartog, 2002].

Early defence works, including several motte castles and city walls, were made in tuff from the late 10th, early 11th century onwards. The motte castle of Montferland, with a tuff stone tower, was destroyed already in 1018 [Schut, 2003]. The oldest phase of Herepoort gate of the city wall of the northern city of Groningen, dating back to ca. 1100 was constructed in primary tuff [Kortekaas, 1996]. Excavations have shown that the 11th century part of the city wall of the northern city of Groningen was constructed in the city wall of Utrecht (1122) had a foundation of tuff stone rubble; the nine towers were built in tuff, the oldest tower dating back to 1145 [De Groot, 1981; Dolfin et al., 1986]. The city walls of Deventer and Zutphen (to the south of Deventer along the river IJssel) were given tuff towers and gates in the 12th century [Bartels, 2006; Fermin and Groothedde, 2007; Groothedde, 2013]. Another prominent example is the Burcht in Leiden, a 12th century chateau-en-motte [Renaud, 1958; Van der Vlist, 2003]. Römer tuff is also regularly encountered in preserved walls of early medieval stone houses [e.g. Temminck Groll, 1963]. The oldest surviving stone house in the Netherlands, the deanery in Deventer, which oldest part dates from c. 1130 [De Vries et al., 1992] (Fig. 2), still preserves original walls in Römer tuff and Drachenfels trachyte.

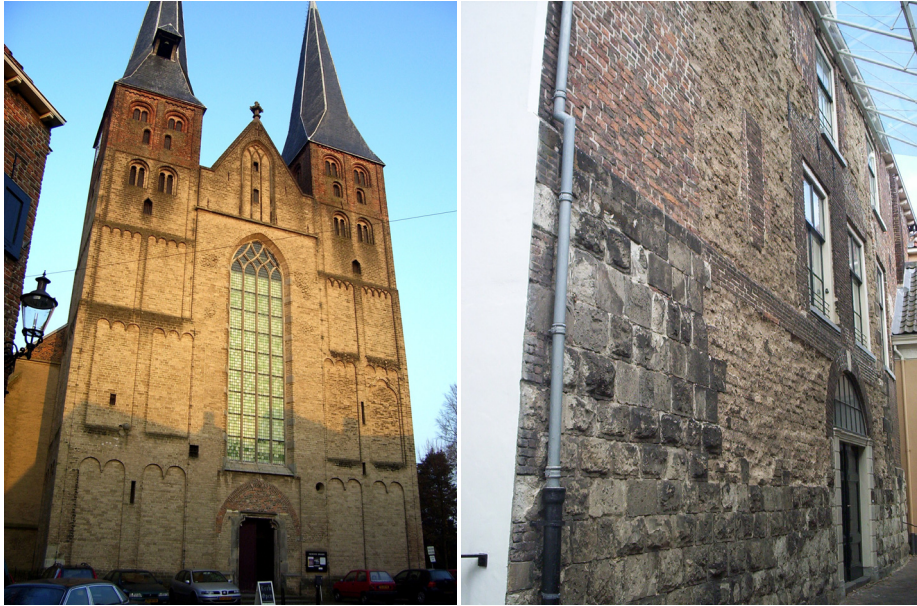


Figure 2. Römer tuff in the staple town Deventer, left the Bergkerk (c. 1200); right the Deanery, the oldest surviving stone house in the Netherlands

Römer tuff was also used for funeral purposes. 11th-12th century tuff stone sarcophages have been found in several romanesque churches, like St. John's church (Janskerk) [Van Wezel, 1982], St. Nicolas' church (Nicolaaskerk) [Haakma Wagenaar, 1979] and the Dom cathedral [Borst et al., 1997] in Utrecht; a tuff stone sarcophagus has also been encountered in the romanesque St. Servaes' church in the southern city of Maastricht, which is otherwise devoid of tuff.

Away from the Rhine, in Belgium, a 11th century manuscript relates that Roman castellum of Oudenburg is quarried for construction in Bruges [Meijns, 1994]. Remaining walls of the romanesque St. Baafs abbey in Gent have also partly been constructed in (secondary ?) Römer tuff [Dewanckele et al., 2009]. Minor amounts of recycled Roman Römer tuff occur on several romanesque / early gothic churches, including St. Martin's in Berg, St. Martin's in Rutten, Our Lady's cathedral and St. Agnes abbey in Tongeren [Dreesen et al., 2001] and Our Lady's church in Damme [Debonne & Dreesen, 2015].

Trade over the river Rhine was frequently severely hampered by the levying of toll [Lacomblet, 1858, 1863; Jappe Alberts, 1982], affecting Römer tuff trade. Reintroduction of

fired clay bricks from the 13th century onward helped to push the Römer tuff out of the market [Janse, 1965]. Tuff from existing buildings was, however, reused. Tuff originally used in the construction of the romanesque Dom cathedral at Utrecht, consecrated in 1023, ended up in its gothic successor, the current Dom cathedral, whose first stone was placed in 1254 [Van Hulzen, 1985]. Locally, Römer tuff was used considerably longer, e.g. around 1400 on the Broederkerk in Deventer [Hogenstijn, 1981]. At St. John's cathedral, 's-Hertogenbosch, Römer tuff was used alongside Weibern tuff well into the 15th century [Peeters, 1985]. As late as 1570, the kerkmeesters of Zutphen bought '*a part Bentheim sandstone, a part Drachenfels trachyte and a part Römer tuff*' [Regional archive Zutphen].

5 Use of Weibern and Ettringen tuff

Early 15th until early 16th century, tuff from the Eifel was used again in the Netherlands. In this period, Weiberner tuff from Riedener caldera was imported. In the Eifel itself, this tuff was (to a very limited extent ?) used by the Romans, and already in the 12th century during the second building phase of the Maria Laach abbey [Müller-Betz, 2007]. Toll registers show various merchants from Andernach passing the tolls on the river Rhine around 1400, shipping so-called *Godelsceide* tuff [Huiskes, 1980; Jappe Alberts, 1967; Westermann, 1939]; surviving bills from construction of the Dom cathedral in Utrecht document the use of this tuff from 1396 onwards [Tenhaeff, 1946]. *Godelsceide* and varieties on that name (the bills of the Dom cathedral mention the stone as *Goedescevel*, *Godelscheer*, *Godelsceer*, *Guedelscher*, *Goedelscher*, *Godelscher*, *Godelaerssteens*, *Gheelscher*, *Ghoelsceer* *Godeschevel*) were used to denominate Weibern tuff and its fine grained variety Hohenleie. The current name Weibern tuff was introduced in the 18th century [Müller-Betz, 2007].

It may be speculated that the import and use of Weibern tuff in the Netherlands was facilitated by larger scale quarrying. At least from 1341 onwards, the Maria Laach abbey owned a quarry in Weibern [Müller-Betz, 2007]. Weibern tuff was applied for cladding of Our Lady's church, Zwolle, the tower of the Grote Kerk, Dordrecht and several other church towers [Slinger et al., 1980]. Fine grained Hohenleie was often used for carved and sculptured works. Well preserved examples include blind traceries in the 15th century cloister of the gothic Dom in Utrecht (Fig. 3), sculptures on the rampant arches of St. John's cathedral, 's-Hertogenbosch, finely carved early 15th century corbels at St. Peter's church, Leiden (Fig. 4) and altars, e.g. in St. Martin's church, Zaltbommel.



Figure 3. 15th Century blind tracery in the cloister of the Utrecht Dom cathedral.



Figure 4. Early 15th century corbel in Weibern tuff, St. Peter's church, Leiden.

During the 18th century, the tuff quarry industry in the Eifel area suffered a period of strong decline, the last firm in the area being closed in 1787 [Hoss, 1922]. From about 1850 onwards, in line with expansion of German industry in general, quarrying and use of tuff was revived. Whereas Römer tuff had always had the advantage of a direct and easy connection to the main transport axis, i.e. the river Rhine, quarry centres of Weibern and

Ettringen tuff, such as the villages of Bell, Engel, Ettringen and Weibern, got a more efficient transport connection only when the railway of Andernach–Niedermendig and the Brohltal railway were established in 1879 and 1900, respectively, connecting the tuff areas to the Bonn-Koblenz railway that had been established in 1858 [Hoss, 1922]. The Brohltal railway, used by the Weibern quarries, however, was small track only, making additional expensive overloading to the regular railway system necessary [Hoss, 1922], a disadvantage the Ettringen quarries were lacking. Though the fast development of the European railway system stimulated the use of natural stone from many sources in the Netherlands [Dusar & Nijland, 2012], Weibern tuff transported in the old way was still cheap in the late 19th century. In 1893, the Amsterdam-based stone merchant Ferdinand Engers (Fig. 5), for example, intervened in a discussion on French limestones [cf. Nijland et al., 2015], stating: *‘to attract the attention of the reader to another material, that, though used in this country on a large scale, does not at all receives the appreciation that it should get from both an aesthetical and economical point of view. I aim at the tuff stone from the good quarries of Weibern. This material is cheaper than most kinds of stones, especially when it can be transported by ship’* [Engers, 1893].



Figure 5. Advertisement for Weibern tuff, to be obtained via F. Engers, Amsterdam, in the Dutch architectural magazine *De Opmerker*, April 14, 1894. The text above the firm names reads: *‘Building tuff stone from the best quarries of Weibern, does not weather, does not become black, cheapest of all good quality natural stone. Excellent references by the foremost Dutch architects.’*

During the second part of the 19th century / first part of the 20th century, Weibern and Hohenleie tuffs were reintroduced in the Netherlands again, both for restoration purposes and newly constructed buildings. In the same period, Ettringen tuff was introduced for the first time. Ettringen tuff has not been used in the Netherlands prior to the late 19th century. It could not have been, because it was not exploited before about the 1870’s [Jacobs, 1914]. A shift in the localization of stone masonry workshops, from the construction site to the

quarries, occurring around 1885, is supposed to have been responsible for the growth of the Ettringen tuff industry [Hoss, 1922]. In 1913, at the onset of World War I, about 140 tuff stone quarries were active in the area, together employing over 1200 workers [Hambloch, 1913]. During World War I, from 1916 onwards, until about 1920, the German export of tuff stone to the Netherlands benefitted from the fact that limestones from northern France, frequently used as replacement stones in the previous decades, were not available anymore due to the war [Quist, 2011]. After World War I, around 1920, 5% of the tuff production was exported to the Netherlands, the only significant export market [Hoss, 1922]. Van der Veen [1920-1923], a mining engineer who conducted elaborate research on both the provenance of natural stone and suitable replacement stones [Quist and Nijland, 2012, 2013], promoted the use of tuff, in particular Hohenleie, as a replacement stone for sandy limestones (Gobertange) traditionally imported from Belgium and widely used on monuments in the south and west of the Netherlands, because of what he considered a 'matching' colour. At the showpiece of Dutch Gothic architecture, St. John's cathedral, 's-Hertogenbosch, Gobertange and Lede sandy limestones have been replaced by Weiberner and Ettringen tuff in 1918-1939 [Peeters, 1985].

Examples of newly constructed buildings in the Interwar period include the town hall of Rotterdam, built in 1916, which has a tower clad with Ettringen tuff, and the KAS bank in Amsterdam, completed in 1932. A typical use of Ettringen tuff during the 1930's is the use for church buildings in an eclectic style, with a clear Christian orthodox influences. Examples include the Holy Heart of Jesus church in Maastricht and the St. Jacques the Greatest church in Enschede (Fig. 6). There are several examples of large scale, monumental sculptures in Ettringen tuff on either façades or free standing (Fig. 7). During this period, the use of Ettringen for small building elements, such as corner stones, sills, etc. as accents in façades otherwise constructed in red fired clay brick, is rather common (Fig. 8). Use of Rhenish tuff, in particular Ettringen, continued well into World War II, till about 1942, when it was still used for both restorations and refurbishment of existing buildings [Nijland et al., 2012].

Ettringen / Hasenstoppler tuff had already been used for both restoration purposes before World War II. After the war, it was used in many restoration and reconstruction campaigns, like in Germany itself. In the Netherlands it has, amongst others, been applied in restoration of the Grote Kerk, Dordrecht (1920's as well as 1953-1966), the St. Steven's church, Nijmegen (completed 1969), the rebuilding of the Eusebius church, Arnhem (1959-



Figure 6. Ettringen tuff on the 1930's St. Jacques the Greatest church, Enschede, by architects H.W. Valk and J.H. Sluijmer.



Figure 7. Monumental sculptures in Ettringen tuff. Left a sculpture of the nun Geertruyt van Oosten by Pieter Biesiot (1926) on the Cornelius Musius school in Delft, right Free standing sculpture in Ettringen tuff, called 'The old and the new town' by Paul Grégoire (1939), also in Delft.

1964) and the Bovenkerk in Kampen (1958-1972) [Slinger et al., 1980]. In the 1950's, the use of Ettringen tuff for small building elements, common before World War I, is revived in a clear return to on pre-war architectural materials combinations. Since the 1950's, use of Rhenish tuff for new buildings is rare, though it has occasionally been used as façade cladding in the 1960's, e.g. the theater Twentsche Schouwburg in Enschede (1965).

Remarkably, the response to weathering by the Ettringen / Hasenstoppler tuff used for restoration purposes during the late 19th-early 20th century differs from that of newly constructed buildings [Nijland et al., 2007]. Whereas in the former case, the Ettringen showed relatively poor durability compared to other Rhenish tuffs, Ettringen tuff applied in newly constructed buildings during the same period generally performed well.

6 Other kinds of Rhenish tuff used

Besides the tuffs mentioned above, a few other types have been used. At the crossing tower of St. John's cathedral, 's-Hertogenbosch, several blocks of an orange brown variety of tuff are present, with an inscription dating them to 1738 (Fig. 9). They are strongly reminiscent of the orange brown tuff, as used in the first, 12th century, building phase of Maria Laach



Figure 8. Ettringen tuff building parts in red clay brick masonry. Left a residential building at Hogehuisstraat 13, Eindhoven, built 1939, right Hoogstraat 99, Schiedam.

abbey in the German Eifel; the latter tuff, denominated as Laacher tuff, is supposed to have been obtained from quarries to the east of the Laacher See [Müller-Betz, 2007] and used latest around 1900 for local purposes [Schumacher & Müller, 2011].

In some studies, Rieden tuff is distinguished from Weibern tuff [Röder, 1957; Schumacher, 1988; Schubert et al., 1992]. It is yet unclear when this distinction came into use. The name Rieden tuff, like Weibern tuff, is not mentioned in medieval sources. The name was, at least locally in the Eifel, in use by the last quarter of the 19th century, as shown by a small newspaper article by the priest of Frenhold village in 1875 [Pfarrer von Frenholt, 1878]. The presence of Rieden tuff has not been established with certainty in the Netherlands [Nijland et al., 2007].

7 Trass

Trass, used as a pozzolanic addition to lime mortars to give these hydraulic properties, is ground tuff, in particular from the Brohltal. Though the raw material is of German provenance and has been denominated as *Rheinische Trass*, *Brohler trass*, en *Andernacher trass*, trass was widely perceived as a Dutch invention, as illustrated by the French *terrasse de Hollande* [De Béliador, 1737-1770] and English *Dutch trass*. The fact that blocks of tuff were imported and ground locally probably contributed to this perception. Trass became a widely known, well reputed material, to such an extent that 19th century travellers wrote of the '*trass valley of Brohl*' [Hibbert, 1832].



Figure 9. Blocks of Laacher tuff on the crossing tower of St. John's cathedral, 's-Hertogenbosch, dating back to the 1730's.

The heyday of trass-lime mortars in the Netherlands was reached in the 17th century. Trass-lime mortars were, however, used considerably earlier. Van der Kloes [1924] noted the presence of trass-lime mortars in the remains of the church of Egmond abbey in the north of Holland, nowadays considered to date from the 10th century [Den Hartog, 2002]. Van Giffen [1949, 1985], in his excavations near the Dom cathedral, Utrecht, also encountered trass-lime mortars that probably date from the 11th century [Hoekstra, 1988], whilst the altar of the romanesque 12th century village church of Termunten in the northeasternmost Netherlands was also placed on a ground tuff-lime mortar [Van Giffen, 1964]. Later, in 1524/1525, pavements of the Markiezenhof, Bergen op Zoom are placed in trass mortar [Janse, 1965].

Especially since the 17th century, trass-lime mortars are widespread in the Netherlands. Early 17th century, local German authorities denied the export of tuff blocks, allowing export of ground tuff (trass) only. This resulted in the founding of trass mills in the Eifel region itself from 1611-1613 onwards [Röder, 1959]. This, however, did not prevent Dutch authorities to require trass to be ground locally, tuff being imported as blocks. Local grinding of trass was prescribed to maintain quality and prevent addition of loose volcanic material. This procedure was stipulated in regulations already in the 17th century, for example in the city regulations of the city of Dordrecht, one of the major staple markets for trass [De Witt, 1696]. At onset of the 18th century, trass mills were widespread in the Netherlands, usually obtaining their tuff from merchant firms located in Dordrecht [Van der Kloes, 1924]. Competition from German trass mills, not regulated like their Dutch counterparts, caused bankruptcy of many Dutch mills during the 18th century. In answer, Dutch authorities imposed a tax on the import of ground tuff (trass) from 1725 onwards, whilst not taxing the tuff itself [Van der Kloes, 1924]. This also served to maintain quality, as the trass imported was often of lower quality due to the admixture of non-pozzolanic stone powders. Nevertheless, this became an increasing problem, to such an extent that around 1800, the French mining engineer Calmelet, in his survey of mines and mineral resources of the then French occupied département Rhin-et-Moselle (comprising parts of the current German Eifel, Mosel and Hunsrück areas), considers it a common fraud [Calmelet, 1809]. Though the aforementioned tax was abolished around 1850, government regulations of 1882 still required that tuff used for trass production should be delivered in blocks of at least 60 dm³, and be ground at the construction site or nearby [Herfeldt, 1884]. Up to late 19th century, trass was indeed grounded at construction sites [Van der Kloes, 1924].

Not all trass was, however, produced from fresh quarried tuff. Though later several authors, e.g. Van der Kloes [1924] warned that weathered tuff was not suitable for trass production, in the 17th, 18th and first half of the 19th century, raw material for trass was in many cases obtained from quarrying of ruins and demolition of churches – in reminiscence of the initial use of Römer tuff in the romanesque period –. When after a great storm affecting most of the inner city of Utrecht in 1674, St. Peter's church was greatly damaged, municipal authorities forced the chapter of the church to demolish both church towers, in order to sell the Römer tuff obtained this way for the production of trass, as a way to finance the reconstruction of the church itself [Van Hulzen, 1985; Temminck Groll, 1988]. Likewise, the 12th-13th century church of the Holy Ghost hospital in Deventer was demolished in 1651 to be grounded for trass [Nalis, 2004], whilst in 1714-1716, expeditions were made to the ancient Roman town of Xanten in Germany (again !) to obtain tuff for trass production [Röder, 1959]. The medieval Valkhof fortress in Nijmegen was sold to a trass mill owner in Wormer (province of North Holland), on the condition that the fortress would be completely demolished within two years, which happened in 1796-1798 [Vollebregt, 1997; Molendatabase, 2015]. With great difficulty, the city succeeded to buy back and save the small chapel and Barbarossa ruin (dating back to the time of Charlemagne). Also 19th century restorations were in part financed by selling the deteriorated tuff that had to be replaced for the production of trass, for example during the mid 1825-1840 restoration of the tower of the Dom cathedral in Utrecht [Van Heukelom, 1929].

Kraus [2006, 2012] gives a detailed overview of the use of trass in 19th and 20th century Germany. In the Netherlands, in the late 19th century, trass was often advertised in Dutch (architectural) magazines (Fig. 10), but actually, the use of trass started to decline. The story of a single mill at a 19th century industrial estate near the northern Dutch town of Groningen illustrates this: Whilst at c. 1850, it was apparently profitable to refit an existing peeling mill into a trass mill, as well as to provide it with steam power in 1880, the last remains of the same mill were demolished in 1938 [Bastmeijer & Overbeek, 2001]. Quality problems deriving from the use of tuff from other sources and addition of loose volcanic material, already a problem a century before [Calmelet, 1809], again provoked ferocious discussions [anonymous, 1874; Hambloch, 1881] and contributed to the decline of use of trass. Nevertheless, trass continued to be used well into the first half of the 20th century, mixing proportions for trass-lime mortar still being standard in text books, e.g. [Van der Kloes, 1924; Sirag, 1933]. End 19th, early 20th century, trass-lime-portland cement mortars

are used, whereas in early concrete constructions, for example the 1923-1925 Noordersluis lock complex, trass was added to the mix [Nijland et al., 2007b], whereas trass-portland cement was used a few years later for coastal defence works at the island of Texel [Trasszement-Kontor, 1931]. In the same period, pure trass-lime concretes have also been applied, for example for the underwater parts of the IJssel bridge at Zwolle, constructed 1929 [Tubag, 1934]. The practice of adding trass to cement-based concrete occurred in marine constructions up to the 1970's in the Port of Rotterdam [Nijland et al., 2007b].

8 Conclusions

Rhenish tuffs are amongst the most prominent natural stones on Dutch monuments of all ages. They have widely been used in the Netherlands, first by the Romans, and later from the romanesque times onwards. During the earliest phases (10th-13th century), only Römer tuff was used, followed by Weibern tuff in the 15th-16th century. Ettringen tuff was introduced as late as the last quarter of the 19th century, both for restorations and new buildings, simultaneously with reintroduction of Weibern tuff. Remarkable differences exist between the durability of medieval and 19/20th century Weibern tuff, as well as between Ettringen tuff used in 19/20th century restorations and early 20th century new buildings.



Figure 10. Example of advertisement for trass from Andernach, as delivered by the quarries of J. Meurin since 1851 from the Dutch architectural magazine *Architectura*, January 7, 1883.

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Appendix. Occurrence of various Rhenish tuffs in the Netherlands

Römer tuff

ACHLUM: NH c. (12th cen.), ALKMAAR: Laurens c., ALPHEN AAN DE MAAS: NH c. (10th cen. ?), ANGERLO: v.c., ANJUM: v.c., ANLOO: Magnus c. (11th cen.), APPELTERN: v.c. (12th cen. ?), ASPEREN: t.v.c., BAFLO: Laurentius c. (partly sec.), BARGERHEEM: m.s.h. (exc. 1828), BEDUM: t. St. Walfridis c., BEEKBERGEN: t.v.c. (14th cen.), BEERTA: v.c. (1506), BIERUM: Sebastiaankerk, BORUM: v.c., BOZUM: v.c. (13th cen.), CASTRICUM: St. Pancras c., DELDEN: NH c., DELFT: Oude Kerk, DEN BURG (TEXEL): NH c. DEVENTER: Bergkerk, Broederenkerk, Lebuinus c. (1080), Maria c., Proosdij (12th cen.), DODEWAARD: t.v.c., DOESBURG: St. Martinus c., DOETINCHEM: St. Catharina c.k, DOEZUM: t.v.c., DOORN: NH c. (12th cen.), DREMPT: t.v.c., ECHELD: NH c. (12th cen.), EETHEN: v.c., EGMOND: abbey (late 10th cen.), ELLECOM: t.v.c. (12th cen. ?), ELST: v.c. (10th cen. ?), ENKHUIZEN: St. Gommarus c., ERMELO: v.c., FARMSUM: v.c. (dem.), FRANEKER: Martinikerk, GARSTHUIZEN: v.c. (dem.), GELSUM: v.c., GENDT: t. NH c., GENUM: NH c. (12th cen.), GIEKERK: v.c. (sec.), GODLINZE: v.c. (12th cen.), GOUTUM: NH c. (12th cen.), GRONINGEN: Martinikerk, St. Walburgkerk (1046-1054, dem. 1627), GROOT WETSINGE: t.v.c. (dem. 1840) GROUW: NH c. (12th cen.), HALLUM: v.c., HANTUM: v.c. (12th cen.), HASSELT: St. Stephanus, HEILOO: v.c., HELLENDOORN: NH c., HELLUM: v.c. (12th cen.), HENGELO (GLD.): t. NH c. (1450, 1956, 1985), 'S-HERTOGENBOSCH: St. Janskathedraal, HILVARENBEK: t. RK Kerk (1450), HOLWIERDE: t.v.c. (dem.), HOUWINGAHAM: m.s.h. (exc. 1998), JELSUM: NH c. (1150), JORWERD: NH c. (12th cen.), KAMPEN: St. Nicolaas c. (early 14th cen.), KANTENS: v.c. KIMSWERD: v.c. (11th cen.), KLEIN MAARSLAG: t.v.c. (dem. 1811), LEENS: v.c. (13th cen.), LEERMENS: St. Donatus c. (11th cen.), LEIDEN: Burcht (1200), Pieterskerk, LISSE: v.c., LOPPERSUM: St. Petrus & Paulus c., MARUM: v.c., MIDLAND (TERSCHELLING): v.c. (demolished 1880), MIDDELSTUM: Hyppolytuskerk., NIEKERK: v.c. (12th cen.), NIJMEGEN: former city wall, St. Stevens c. (1307), Valkhof (1030-1050), NOORDLAREN: v.c., NOORDWOLDE: v.c., OENE: t.v.c., OIRSCHOT: NH c. (12th cen.), OLDEKERK: v.c., OLDENZIJL: v.c., OMMEREN: v.c., ONDESMABUREN: m.s.h. (exc. 1999), OOSTERBEEK: Oude Kerk (11th cen.), OUDDORP: NH c. (1500), OUDEWATER: St. Michaels c. (sec.), RHEDEN: NH c., RESSEN: v.c., RIJNSBURG: v.c., RIJSWIJK: v.c., RINSUMAGEEST: NH c. (12th cen.), SASSENHEIM: v.c. (c. 1100), SCHILDWOLDE: v.c. (dem. 1686), SIDDEBUREN: v.c. (13th cen.), SINT ODILIËNBERG: St. Plechelmus, Wiro &

Otger c., SPANKEREN: t.v.c., STIENS: NH c. (11th cen.), STEENWIJK: electricity building Paardenmarkt, St. Clemens c., SUSTEREN: St. Amelberga c., TERMUNTEN: v.c., TIEL: St. Maartens c. (sec.), TJAMSWEER: v.c., UITHUIZEN: v.c., UITWIERDE: v.c., USQUERT: v.c., UTRECHT: Bisschoppelijk Officiaalshuis (13th cen.-1550, exc. 1927), Bisschopshof (spinde, 1300-1315), Cathrijneklooster (12th cen.), Buurkerk (1280, 1979-1981), Domkerk, Drakenburg h. (11th cen.), Geertekerk, Jacobikerk, Janskerk (1080, 1150), Lichtenberg h., Nicolaaskerk (11th cen.), Oudwijk abb. (exc.), Pieterskerk (1040), Putruwiel h. (late 14th cen.), Roman castellum (3rd cen.), St. Mary (cloister, 13th cen., 1903-1908), St. Paulus abb., VALKENBURG (Z-H): v.c. (sec.), VELD: v.c., VELSEN: tower NH c. (13th cen.), VIERHUIZEN: t.v.c. (dem. 1840), VLAARDINGEN: v.c., VRIES: v.c., VUGHT: St. Lambertus c. (1950's), WADENOYEN: v.c., WARFFUM: v.c., WARNS: v.c. (12th cen.), WARNSVELD: St. Maartens c., WASSENAAR: v.c. (partly sec.), WELL: v.c., WESTEREMDEN: t.v.c. (dem.), WILSUM: v.c. (11th cen. ?), WINSUM: v.c., WINTERSWIJK: tower NH c. (1507), ZALTBOMMEL: Grote Kerk, 'T ZANDT: v.c., ZELHEM: t. Lamberkerk, ZUIDHORN: t.v.c., ZUIDWOLDE: t.v.c., ZUTPHEN: Proosdij, St. Walburg c., ZUURDIJK: m.s.h. (exc. 1830), ZWOLLE: Sassenpoort

Weiberner tuff

ALKMAAR: Laurens c., BERGEN (NH): Rudine c. (15th-16th cen.), BRIELLE: St. Catharina c., DORDRECHT: Grote kerk (15th-16th cen.), FRANEKER: Martinikerk, 'S-HERTOGENBOSCH: St. Janskathedraal (15th cen.), KAMPEN: St. Nicolaaskerk c., KOCKENGEN: v.c. (15th-16th cen.), LEIDEN: Pieterskerk (c. 1425; sc.), NAARDEN: v.c. (15th-16th cen.), NIJMEGEN: Valkhof (1030-1050), UTRECHT: Dom cathedral cloister (mid 15th cen.), ZWOLLE: Our Lady church (15th-16th cen.)

Weiberner tuff, 19th - 20th century new buildings

AMSTERDAM: Herengracht 128, Minervalaan 28/29 (sc.), Rokin 115 (1928), ARNHEM: Markt 29, DEVENTER: Sallandsche Bank (1912), HEERLEN: Emmaplein 16 (1940), Synagoge, HILVARENBEEK: RK Kerk (1950, 1955, sc.), KAMPEN: Oudestraat 38, MAASTRICHT: Grote gracht 72, NIJMEGEN: Nebo kerk (1928), ROTTERDAM: Atlantic House (rem.), De Heuvel (1950's), TEGELEN: Heilige Hartkerk (1925), TILBURG: Theresiakerk (1930).

Weiberner tuff, 19th - 20th century new buildings, as ornaments with red clay brick

ROTTERDAM: Atlantic House (1930's), UTRECHT: Hamburgerstraat 11 (19th cen.)

Weiberner tuff, 19th – 20th century restorations

AMERSFOORT: St. Joris, AMSTERDAM: Nieuwe Kerk, ANLOO: NH c. (1944),
CASTRICUM: St. Pancraskerk, DELFT: Oude Kerk, DEVENTER: Lebuinuskerk, LEIDEN:
De Burcht (2006), Pieterskerk (c. 1870), NIJMEGEN: St. Stevenskerk (1965),
OOSTERBEEK: Grote Kerk, SUSTEREN: St. Amelberga, UTRECHT: Buurkerk (1982-1984),
Domkerk (1875, 1979-1988), ZUTPHEN: Walburgkerk

Ettringer tuff, 19th – 20th century new buildings

AMSTERDAM: Herengracht 179-197, 255, KAS Bank (1932), ARNHEM: Moscowa
cemetery (1950's), DELFT: Markt 9, DORDRECHT: Lindershuis (1920), EINDHOVEN:
Rechtestraat 56 (1954), ENSCHEDE: Fire Brigade Building (1950's ?), Jacobus de Meerdere
church (1932-1933), Twentse Schouwburg (1965), GOIRLE: town hall (sc), GRONINGEN:
corner Grote Markt – Boteringstraat, Phebenstraat 1, Radesingel – corner Trompstraat,
GULPEN: town hall, HAARLEM: General Post Office Gedempte Oudegracht, 'S-
HERTOGENBOSCH: apartment building Burgemeester Loeffplein 199 (1965), corner
Vughterstraat – Snelle straat, St. Jans centre, MAASTRICHT: Brusselsestraat 20,
Dominicanerstraat 3, Heilige Hart van Jezus of Koepelkerk (1930's), Oude Tweebergen
Poort 2-11, St. Jacobstraat 19, St. Jacobstraat 21, Wycker Brugstraat 7a, Wycker Brugstraat
13a, MARGRATEN: St. Margarita NIJMEGEN: Augustijnenstraat 35, Broerstraat 33-35,
ROTTERDAM: t.h. (1916), St. Hildegardis abb. (1922), THE HAGUE: Kortenaerkade 12,
Korte Poten 6, Lange Houtstraat 24, Passage, Spuistraat 13-15, TUBBERGEN: t.h. (1968),
UTRECHT: Rijnlandhuis (1924), St. Gregoriusschool (c. 1965), St. Willibrordus statufte,
VALKENBURG-BROEKHEM: St. Jozef (1930-1931).

Ettringer tuff, late 19th - 20th century new buildings, as ornaments with red clay brick

ALKMAAR: former police station, AMERSFOORT: parkeerservice office, AMSTERDAM:
Nieuwendijk 182, DELFT: Architecture faculty (TU Delft), Cornelius Musius school,
former Mechanical Engineering faculty (TU Delft), EINDHOVEN: Hoogehuisstraat 4, 13
(1939), Hoogehuisstraat 25, corner Hoogehuisstraat – Rechtestraat, Keizersgracht 2-4a,
corner Keizersgracht-Kleine Berg, Rechtestraat 63 (1950's), ENSCHEDE: Molenstraat 27,
GRONINGEN: Martinikerkhof 15, Oude Kijk in 't Jatstraat 47a-51, HAARLEM: t.h. (1928),
'S-HERTOGENBOSCH: Ridderstraat 16, St. Jorisstraat 34, Verwerstraat 29, Vughterstraat
85, Vughterstraat 257, HOOGLAND: St. Martinus c., KAMPEN: Geertestraat 42,
MEDEMBLIK: former t.h., MIDDELBURG: corner Korte Brug- Bogartstraat, St. Petrus &
Paulus c., NIJMEGEN: H&M, Hertogstraat 68-72, corner Klein Mariënborg – Achter
Mariënborg, ROTTERDAM: Schielandse Vest 89 (1942, sc.), Veurstraat 7, Willem

Buytewechstraat 70, RUURLO: RABO Bank (1953), SCHIEDAM: Hoogstraat 99, THE HAGUE: Hoogstraat 33-35, UTRECHT: Biltstraat 25, Lange Nieuwstraat 40-42, Maliebaan 50, Moira, WEST-TERSCHELLING: t.h. (1954).

Ettringer tuff, late 19th - 20th century free standing sculptures

DELFT: sc. 'The old and the new town' (P. Grégoire, 1939), NIJMEGEN: war memorial (Jac Maris, 1951).

Ettringer tuff, 19th - 20th century restorations

ALKMAAR: Laurenskerk, AMERSFOORT: St. Joris c., AMSTERDAM: Nieuwe Kerk, ARNHEM: Eusebius c. (1920's, 1959-1964), Presickhaeffs Huys, CASTRICUM: St. Pancras c., DELDEN: Oude Kerk, DELFT: Oude Kerk, DEVENTER: Lebuïnus c., DOESBURG: t.h., DORDRECHT: Grote Kerk (1920, 1929, 1953-1966), HAARLEM: St. Bavo c., HASSELT: St. Stephanus, 'S-HERTOGENBOSCH: St. Janskathedraal (1920's), KAMPEN: St. Nicolaas c. (1958-1972), LEIDEN: De Burcht, Pieterskerk, NIJMEGEN: St. Stevens c., Valkhof, SITTARD: St. Petruskerk (1955), SUSTEREN: St. Amelberga c., UTRECHT: Domkerk, Janskerk, WINTERSWIJK: NH c. (1942), YERSEKE: NH c., ZUTPHEN: Nieuwstadkerk.

Sources

Bom [1950], Ratiobouw [1956], Temminck Groll ([1963, 1988], Van Giffen [1964], Janse [1965], Van der Wal [1979], Van Spronsen [1979], Slinger et al. [1980], Van Hoogevest [1983, 1986], Kramer & Feenstra [1994], Van Deijk [1993], Tolboom [1998], De Olde [2002, 2003], Nijland et al. [2007a], and observations by the authors.

Abbreviations

abb. - abbey, c. - church, cen. - century, dem. - demolished, exc. - excavated, h. - house, m.s.h. - remains medieval stone house, NH c. - Nederlands Hervormde (Dutch Reformed) church, rem. - removed during restorations, sc. - sculpture, sec. - secondary use, t. - tower, t.h. - town hall, t.v.c. - tower village church, v.c. - village church
