Use of Rhenish tuff and trass in the Netherlands in the past two millenia

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Abstract - Occasionally, a profound but distant connection between volcanos and culture exists. This is the case for 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 in the 15th century, Weibern tuff from the Riedener caldera, was introduced for fine sculptures and cladding; it disappears from use after about a century. Late 19th century, this tuff is reintroduced, both for restoration and for new buildings. In this period, Ettringen 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.

This paper is a revised version of the paper The volcanic foundation of Dutch architecture: Use of Rhenish tuff and trass in the Netherlands in the past two millenia, published in Heron 61:69-98 (2016).

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, Weibern tuff and Ettringen 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.

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 & 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 / Weibern 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 & Aiello 1964, Fitzner 1990, Nijland et al. 2003, 2005a).

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, Fitzner & Lehners 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, Lubelli & Nijland 2016). 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).

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 (Nijland et al. 2017). 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 defence 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; fig. 2), Elst (Bogaers 1970), Matilo near Leiden (Van Pruissen & Kars 2009, Brandenburgh & De Bruin 2015), Brittenburg (Bloemers & De Weerd 1993), the thermae in Heerlen (Fig. 3) 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. 2017, Dreesen & Dusar 2017).

Fig. 1. Remains of the Roman castellum wall in a cellar below a late Medieval house at the Dom square, Utrecht. The left picture shows part of the wall, of which the lower part is original Roman masonry (ca. 210 AD), whilst the upper part was rebuilt in pre-Medieval times. The right picture shows a cross-section of the wall in another part of the cellar (pictures T.G. Nijland, 2009 (before the transformation).

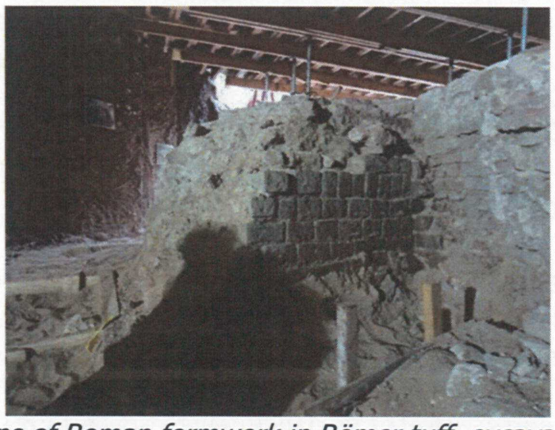

Fig. 2. Remains of Roman formwork in Römer tuff, excavation below the Stratemakerstoren at the foot of the Valkhof, Nijmegen (picture T.G. Nijland, 2017).

Fig. 3. Block of Römer tuff in the Roman thermae in Heerlen (picture T.G. Nijland, 2016).

In the Netherlands, this tuff became the most important building stone for Romanesque architecture, from the 10th till the early 13th century (Appendix 1). 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 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 & Johnstrup 1894, Helms & Storck 1894, Feveile 1996). 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, describing 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 deportabur 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 till about 1235, large amounts of tuff have been shipped to Deventer, where the oldest tuff dates back to 1025 (Bartels 2006).

In the 10th-11th 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's church in Groningen (demolished in 1627), of which the oldest building phase of 1046-1054 was constructed in tuff (Van Giffen & 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), Frisia (Fig. 4) and the western provinces of Holland (Den Hartog 2002). The use is in this period is not limited to villages relatively close to the major rivers or the sea, but, though more rarely, also occurs elsewhere, like the old basilica of St. Plechelmus, Otger and Wiro in St. Odiliënberg (Fig. 5) and the St. Amelberga in Susteren, both in Limburg province.

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 Groningen was constructed in tuff, whereas 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 & 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 back to c. 1130 (De Vries et al. 1992) (Fig. 6), still preserves original walls in Römer tuff and Drachenfels trachyte.

Römer tuff was also used for funeral purposes. 11th-12th century tuff stone sarcophagi have been found in several Romanesque churches, like St. John's church (Janskerk) (Van Wezel 1982), St. Nicolas' church (Nicolaaskerk) (Haakma Wagenaar 1979), St. Peter's church (Pieterskerk) and the Dom cathedral (Borst et al. 1997) in Utrecht (Fig. 7); a tuff stone sarcophagus has even 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 the 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 recyled 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, Dreesen & Dusar 2017) and Our Lady's church in Damme (Debonne & Dreesen 2015).

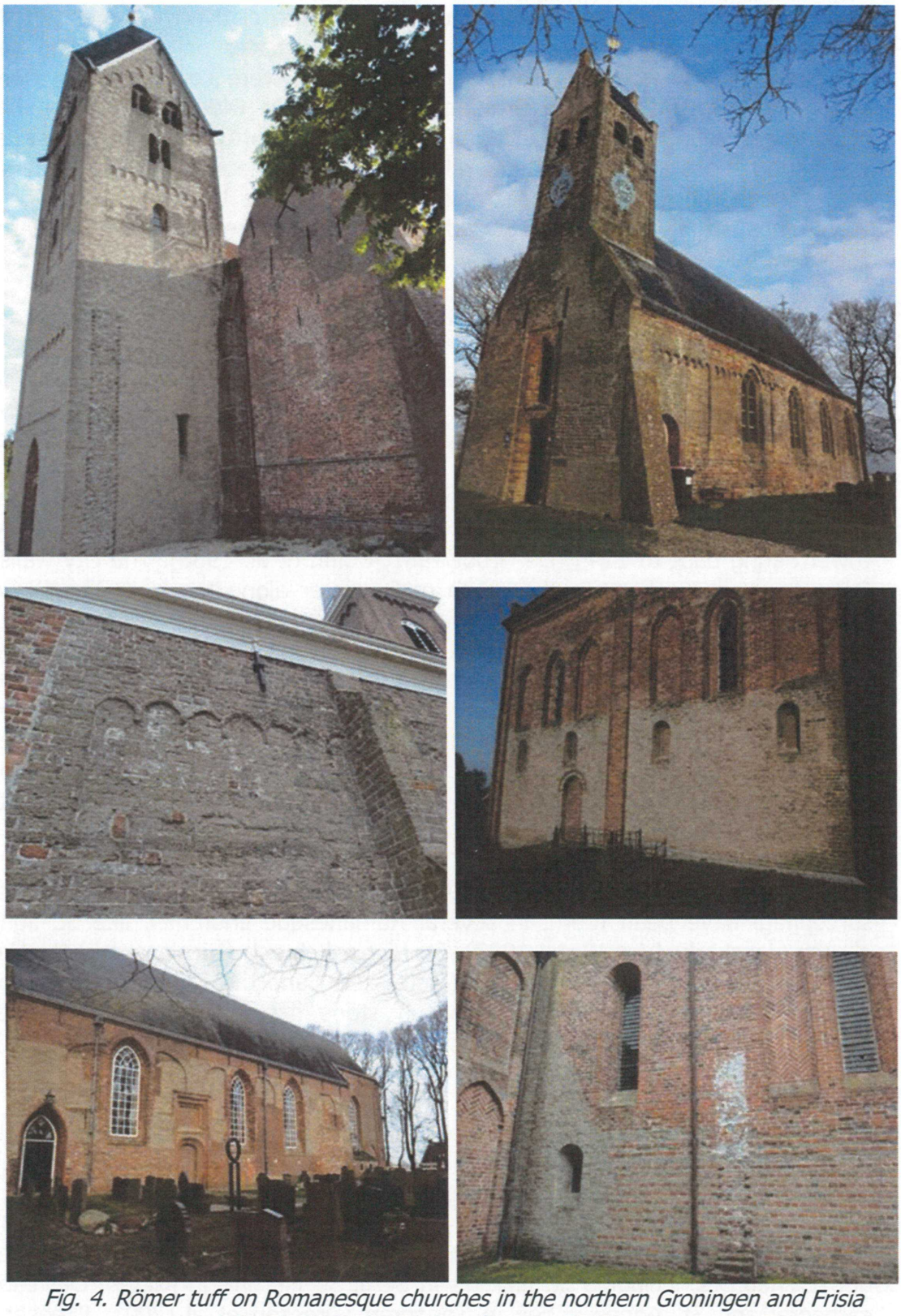

Fig. 4. Römer tuff on Romanesque churches in the northern Groningen and Frisia provinces. Upper left: St. Walfridis, Bedum (picture 2013); upper right: St. Nicolas, Hijum (picture 2016); middle left: St. Thomas, Brantgum (picture 2016); middle right: St. Stefanus, Holwierde (picture 2016); bottom left: St. Vitus, Stiens (picture 2016); bottom right: St. Peter & Paul, Loppersum (picture 2011; all pictures T.G. Nijland).

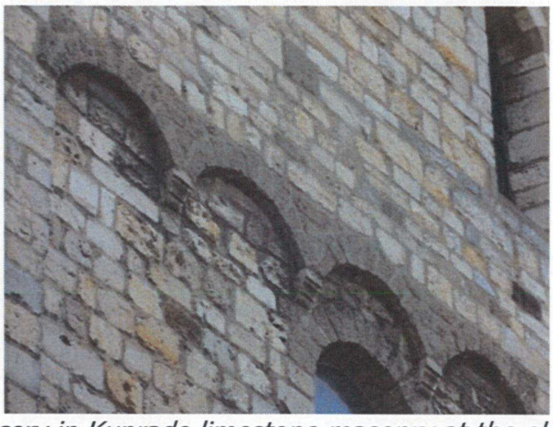

Fig. 5. Römer tuff tracery in Kunrade limestone masonry at the old Romanesque basilica St. Plechelmus, Otger & Wiro in St. Odiliënberg (picture T.G. Nijland, 2016).

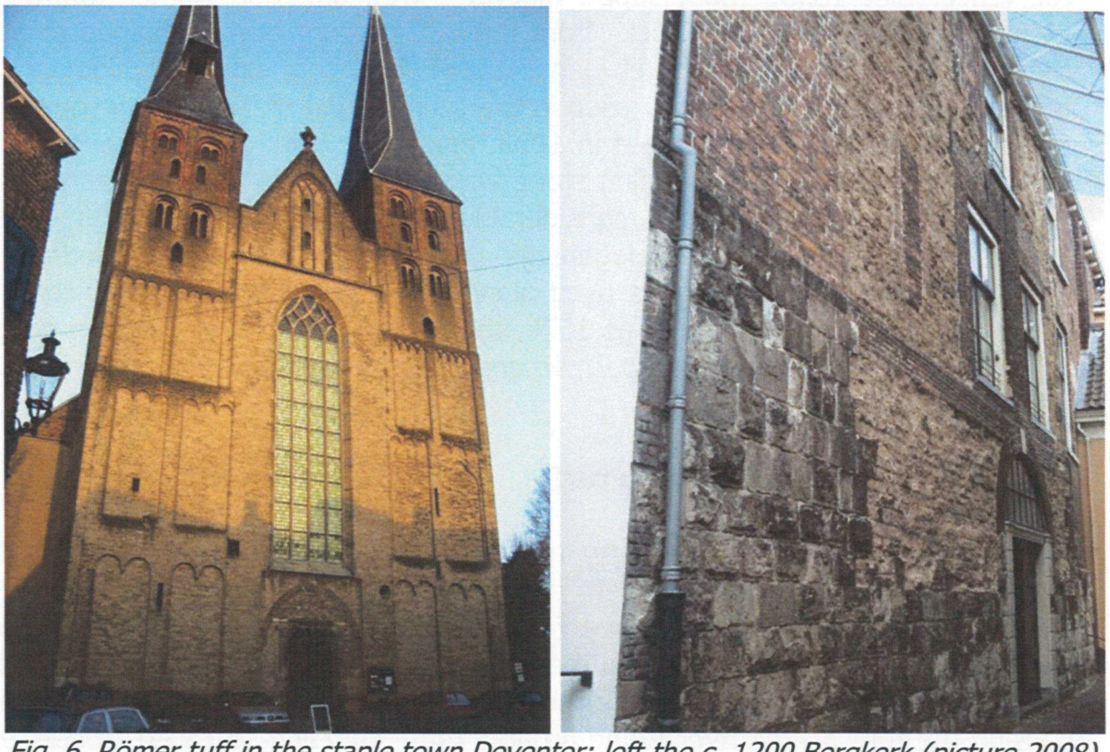

Fig. 6. Römer tuff in the staple town Deventer: left the c. 1200 Bergkerk (picture 2008), right the Deanery, the oldest surviving stone house in the Netherlands (picture 2004; all pictures T.G. Nijland).

Fig. 7. Römer tuff sarcophagus, St. Peter's church, Utrecht (picture T.G. Nijland, 2016).

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 Broederenkerk 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 church wardens of Zutphen bought *'a part Bentheim sandstone, a part Drachenfels trachyte and a part Römer tuff'* (Regional archive Zuphen).

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, Weibern 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 Grote Kerk, Zwolle (Fig. 8), 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. 9), 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. 10) and altars, e.g. in St. Martin's church, Zaltbommel.

Fig. 8. St. Michael's church, Zwolle, clad with Weibern tuff (picture T.G. Nijland, 2014).

Fig. 9. 15th Century blind tracery in the cloister of the Utrecht Dom cathedral (picture T.G. Nijland, 2005).

Fig. 10. Early 15th century corbel in Weibern tuff, St. Peter's church, Leiden (picture T.G. Nijland, 2005).

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 did not have. 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. 11), 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 receive 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 stone, especially when it can be transported by ship'* (Engers 1893). End 19th, early 20th century sees indeed several new buildings clad with Weibern tuff (Fig. 12), that was occasionally (much more rarely than Ettringen tuff) used for ornamental sculptures (Fig. 13).

Fig. 11. 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.'

Fig. 12. Weibern tuff for new buildings. Left: the Sallandsche Bank, Deventer; right Herengracht 179-187, Amsterdam (pictures T.G. Nijland, 2014) .

Fig. 13. Sculpture in Weibern tuff at St. Hildegardis abbey, Rotterdam (picture T.G. Nijland, 2015), a red brick building with, except for the sculptures, details in Ettringen tuff.

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, till 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 & 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 Weibern and Ettringen tuff in 1918-1939 (Peeters 1985).

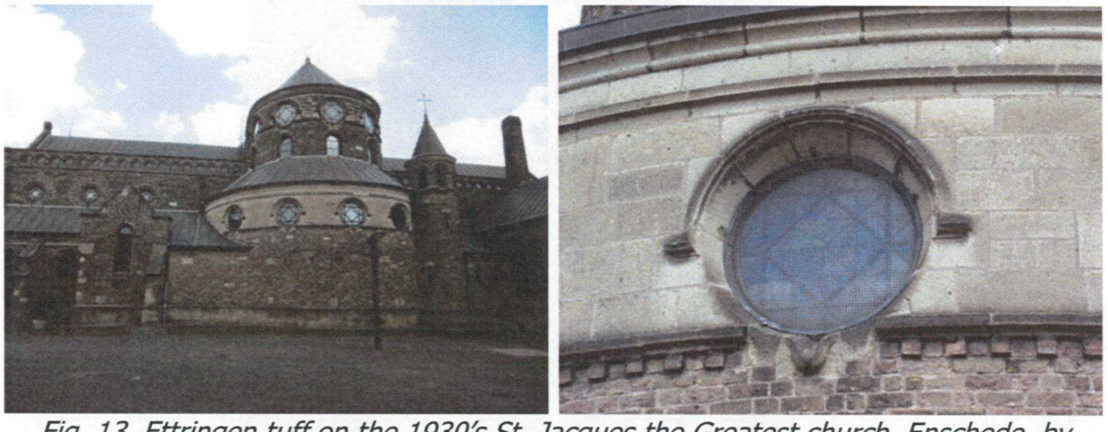

Fig. 13. Ettringen tuff on the 1930's St. Jacques the Greatest church, Enschede, by architects H.W. Valk and J.H. Sluijmer (picture T.G. Nijland, 2015 & 2006).

Fig. 14. Sculptures in Ettringen tuff. Upper left: the nun Geertruyt van Oosten by Pieter Biesiot (1926) on the Cornelius Musius school, Delft (picture 2011); upper right: 'The old and the new town' by Paul Grégoire (1958), Delft (picture 2011); lower left: sculpture at the former town hall of Goirle built 1920-1921 by architect Th. Taen (picture G.J.L.M. de Haas, 2016); lower right: sculpture by Charles Hammes (1954) at Achter Mariënburg, Nijmegen (picture 2016; all pictures T.G. Nijland).

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. 13). There are several examples of large scale, monumental sculptures in Ettringen tuff on either façades or free standing (Fig. 14). 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. 15). 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).

Fig. 15. Ettringen tuff building parts in red clay brick masonry. Left a residential building at Hogehuisstraat 13, Eindhoven, built 1939, right Hoogstraat 99, Schiedam (pictures T.G. Nijland, 2008 and 2014).

Ettringen / Weibern 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 (1959-1964) 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 theatre Twentsche Schouwburg in Enschede (1965), the school building at Phebenstraat 1 in Groningen and the town hall of Tubbergen (Fig. 16). Since the 1960's, use of either Weibern or

Ettringen tuff for new buildings in the Netherlands is extremely rare. A salient exemption is the recent enlargement of the consistory of the Grote Kerk in Vlaardingen (Fig. 17).

Fig. 16. Ettringen tuff cladding from the 1960's. Top: Twentsche Schouwburg, Enschede (picture 2007); lower left: Phebenstraat 1, Groningen (picture 2010); lower right: detail of the town hall of Tubbergen (picture 2014; all pictures T.G. Nijland).

Fig. 17. Enlargement of the consistory of the Grote Kerk, Vlaardingen by architect J.W. Walraad, built in 2015 (picture J.W. Walraad, 2015).

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. They are strongly reminiscent of the orange brown tuff, as used in the first, 12th century, building phase of Maria Laach 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 news paper 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. 2005a).

Trass

Trass, used as a puzzolanic 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 preceived as a Dutch invention, as illustrated by the French *terrasse de Hollande* (De Bélidor 1737-1770) and English *Dutch trass*. The fact that blocks of tuff were imported and grounded 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'* (e.g. Hibbert 1832).

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 back to 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 back to 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 grounding 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-puzzolanic 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 department 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 dm^3, 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).


DE ERVEN H. TRIP.
UTRECHT en ROTTERDAM.
Eigenaren van Tufsteen en Bazaltgroeven
IN RIJN PRUISSEN.
Handelaren in Duitschen en Belgischen Straatkeijen,
Portland-Cement, Tras, Kalk, Vuurvaste Steenen, enz.

Fig. 18. Advertisement of de Erven H. Trip in the architectural magazine De Opmerker, December 27, 1876, promoting itself as 'Owners of tuffstone and basalt quarries in Rhine-Prussia'

Kraus (2006, 2012) gives a detailed overview of the use of trass in 19th and 20th century Germany. In the first half of the 19th century, the use of trass was widespread in the Netherlands. Illustrative is the Utrecht based firm of Hendrik Trip, later Erven Trip (Van Campen 1958). Hendrik Trip originally a trader in lime and coal from Liège. After the Belgian revolution of 1830 disrupted his trade, Trip was obliged to obtain the lime from elsewhere. With one of his 6 ships, he started a regular shipping line to Mannheim, passing the Eifel. Trip soon realized the potential of tuffstone and trass and successfully started to trade in both. In 1842, after the great fire in Hamburg, Trip shipped 20 ship loads of tuffstone a year to the Netherlands, and 20 ship loads of trass to Hamburg for the reconstruction (Van Campen 1958). The firm obtained its own tuffstone quarries in the Eifel (Fig. 18). The firm grew into a trading company in building materials.

Fig. 19. 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.

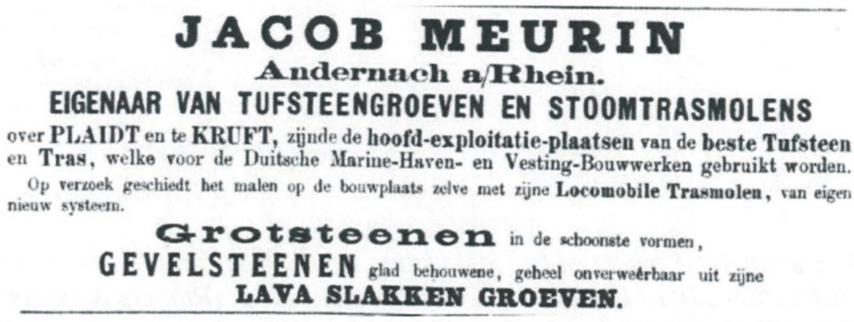

Fig. 20. Another example of an advertisement by Jacob Meurin, in the architectural magazine De Opmerker, February 25, 1882. The first part of the text reads: 'Jacob Meurin. Andernach a/Rhein. Owner of tuffstone quarries and steam trass mills near Plaidt and in Kruft, being the main localities for exploitation of the best quality tuffstone and trass, which are being used for German navy ports and fortifications. On request, grounding occurs at the building site, using a mobile trass mill, of own new design.'

In the late 19th century, trass was often advertised in Dutch (architectural) magazines (Fig. 19, 20), but 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 1924-1928 Noordersluis lock complex, trass was mixed on site with cement in several concrete mixes (Bienfait 1932, Nijland et al. 2007b, Nijland 2017; fig. 21), as was done at the construction sites for the locks and bridges in the 1927-1932 Afsluitdijk (Ministerie van Waterstaat, 1928, Maatschappij tot Uitvoering van Zuiderzeewerken; fig. 22). 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 under water 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).

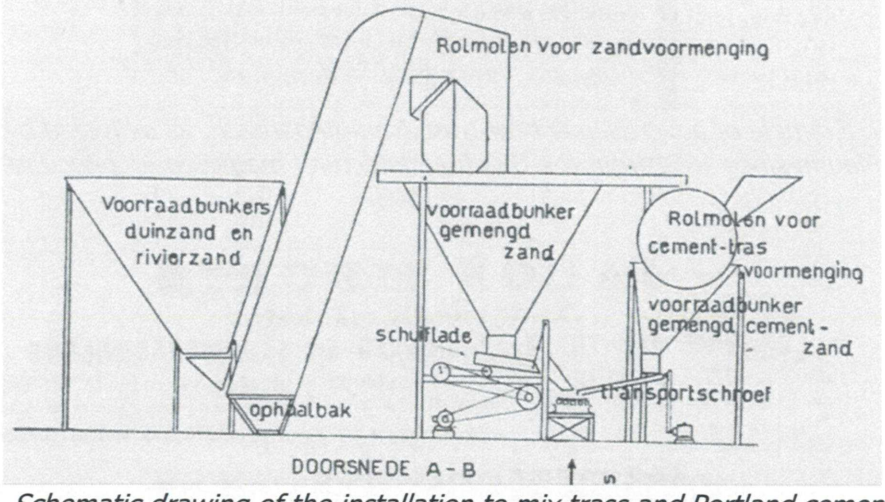

Fig. 21. Schematic drawing of the installation to mix trass and Portland cement at the construction site of the 1924-1928 Noordersluis lock (Ringers & Peiser 1925).

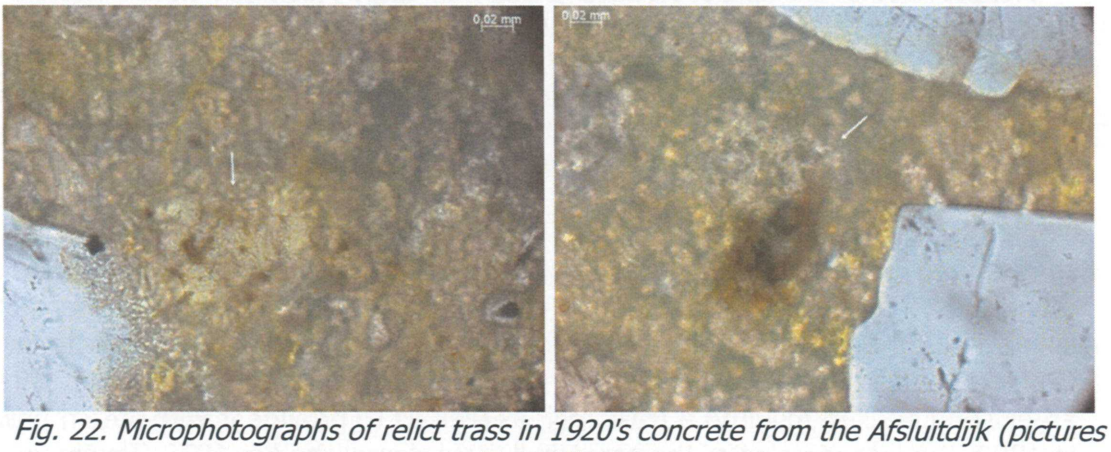

Fig. 22. Microphotographs of relict trass in 1920's concrete from the Afsluitdijk (pictures T. G. Nijland.

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.

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anonymous, 1874. Iets over Dordsche tras. Waarschuwend woord tegen het gebruik van die, welke uit Brohl afkomstig is, op verzoek van eenige eigenaren van tufsteengroeven en trasfabrikanten uit de omstreken van Andernach (translation J.L. Terneden). G.B. van Goor zonen, Gouda.

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Appendix 1. Occurrence of different 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: St. Sebastiaan c., Borum: v.c., Bozum: v.c. (13th cen.), Brummen: St. Pancratius c., 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., Echteld: 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.), Groenlo: Oude St. Calixtus c., 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, Hilvarenbeek: 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. Donatius 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., Ondersmaburen: 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.), Velp: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. Lamberikerk, Zuidhorn: t.v.c., Zuidwolde: t.v.c., Zutphen: Proosdij, St. Walburg c., Zuurdijk: m.s.h. (exc. 1830), Zwolle: Sassenpoort

Weibern 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.)

Weibern 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, St. Martinus c., Nijmegen: Nebo kerk (1928), Rotterdam: Atlantic House (rem.), De Heuvel (1950's), Tegelen: Heilige Hartkerk (1925), Tilburg: Theresiakerk (1930).

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

Rotterdam: Atlantic House (1930's), Utrecht: Hamburgerstraat 11 (19th cen.)

Weibern tuff, 19th-20th century restorations

Amersfoort: St. Joris, Amsterdam: Nieuwe Kerk, Anloo: NH c. (1944), Castricum: St. Pancras c., Delft: Oude Kerk, Deventer: Lebuinuskerk, Doesburg, Martinikerk, Groenlo: Oude St. Calixtus c., 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

Ettringen tuff, 19th-20th century new buildings

Amsterdam: Herengracht 179-197, 255, KAS Bank (1932), Arnhem: Moscowa cementery (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 – Boteringestraat, 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 c., Nijmegen: Augustijnenstraat 35, Broerstraat 33-35, Ransdaal: St. Theresia c., Roermond: Hamstraat 5, 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 statute, Valkenburg-Broekhem: St. Jozef (1930-1931).

Ettringen 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, Goirle: t.h. (1920-1921), 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 Mariënburg – Achter Mariënburg, 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).

Ettringen 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).

Ettringen 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), Groenlo: Oude St. Calixtus c., 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.

Ettringen tuff, 21st century new buildings

Vlaardingen: Grote Kerk (enlargement consistory).

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.