Paper

CT3300-09 Use of Underground Space

TU Delft, Faculty Civil Engineering

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Preface

Use of Underground Space has many different and interesting elements. The manner in which the underground is used and the history of its use are only facets of the whole picture. The safety of underground structures is another one. Nonetheless, these are facets that greatly spike our interest. When asked to write a paper for the course CT3300: Use of Underground Space, we were determined to use at least one of these aspects in our writing.

Our original focus was on the safety levels of underground structures. After finding this subject was somewhat generic, we decided to focus on Metro systems specifically. The original focus on safety was broadened, which led us to our current subject: an inventory of the creation of four metro systems in Europe. Aspects chosen to be discussed were:

- The history of the systems
- The geology of the soil
- The used building methods
- The safety and security levels
- The rolling stock in use
- Special stations in the systems
- Future developments to be expected.

The four cities we chose are London, Paris, Berlin and Rotterdam.

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Introduction

This paper is the result of the exercise of the course CT3300-09 Use of Underground Space.

As read in the preface the subway systems of London, Paris, Berlin and Rotterdam are being discussed in this paper.

This paper has been divided in four chapters corresponding with the four metro systems: London, Paris, Berlin and Rotterdam. Each chapter is divided in the aspects mentioned in the preface. At the end, a conclusion is given about the differences between the systems and the consistency between the aspects discussed.

1. London

The London Underground was the first underground railway system in the world, at the opening of the first line in 1863. From that point on, the system has grown to be one of the largest and most intensely used systems in the world. As of today, the system carries over 3 million passengers a day to and from the 275 connected stations. Contrary to its name, the 402 kilometers of rail that compose the Underground are not all underground: 55% percent of the railway is located above ground, mostly in the suburbs.

1.1. History

As mentioned before, the London Underground was the first underground railway system in the World. In 1854, the city center experienced a lot of traffic congestion. This was caused by the fact that the border of the city center was very accessible by train: just outside of the center, 6 train stations were located. But the traffic from those stations to the actual city center was difficult, because of the high density of buildings there.

Figure 1-1: Construction of the first Underground Railway in London, 1861

Earlier, in the 1830's, a proposal was made for an underground railway to access the center. It took until 1855 for this proposal to be taken into account and being accepted by the Parliament. After the approval, construction was begun on the first stretch of

Underground (See Figure 1-1), between Paddington Station and Farringdon Street. This first line, the Metropolitan Railway, was mainly financed by train operator Great Western Railway, who possessed the railway station at Paddington. GWR was also the company who designed the original rail stock for the underground. Nevertheless, construction was delayed a great deal by shortage of funds, until finally, on the 10th of January 1863, the line was opened for traffic.

After the opening of this first line, more and more lines were build, connecting the city center with the suburban areas. In 1869, the Thames tunnel was taken into use for one of the lines. This tunnel was constructed by Marc Brunel and son Isambard in 1843 as a pedestrian tunnel. It was the first tunnel constructed using Brunel's tunneling shield method, which made the construction of the tunnel possible, but also safer than the existing building methods. See Figure 1-2.

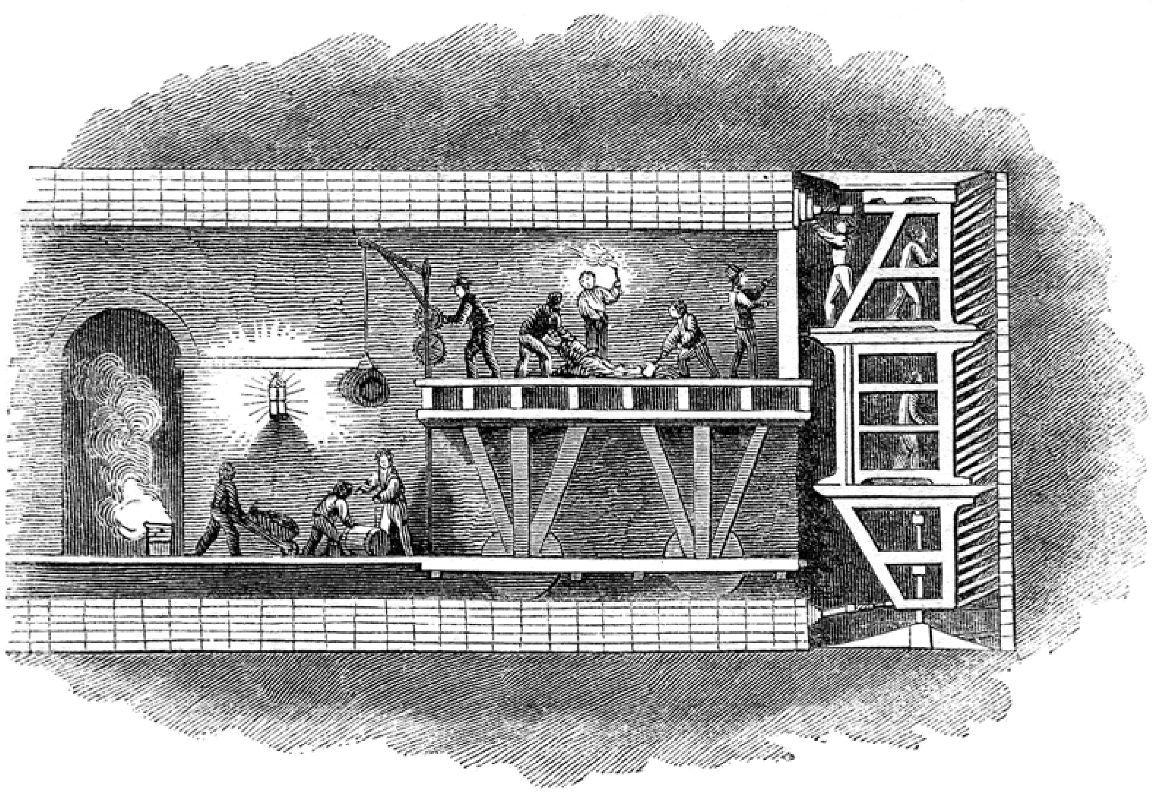

Figure 1-2: Diagram of the tunneling shield used to construct the Thames Tunnel

The tunneling shield method was adapted for the creation of new Underground lines as well. In 1890, the first of these lines (the City & South London Railway) opened. Due to its small, round shape, the line was nicknamed "The Tube", a name now in use for the entire Underground system. Around the same time, the original steam-driven rolling stock was starting to get replaced by electrical driven cars.

Due to the immense popularity of the Underground system, multiple operators had built, extended and operated lines. By the beginning of the 20th century, 6 operators were in business, and not always did this cause the best situation. Transfers between lines often took a lot of time, because the different operators did not cooperate. In 1908 the operators published the first joint map of railways, under the name “The Underground” and with an early version of the Roundel in Figure 1-3. This map was, contrary to the modern ones, based on the actual geographic location of the stations[1]. Later, in 1931, the first diagrammatic map of the underground was designed, solving issues of insufficient clarity at crowded areas of the map. It took until 1933 for the operators to merge into the company known as London Transport.

UNDERGROUND

Figure 1-3: The Roundel, sign of the collective Underground System since 1908

1.2. Geological aspects of the underground

The soil under London is mostly comprised of what is called the London Clay Formation or Thames Group, a soil from the Eocene age (56 to 34 million years BC), up to a depth of more than a hundred meters. This is a mixture silty clay and/or mudstone with sandy (clayey) silts of a marine origin. In Figure 1-4 you can see that close to the river Thames, this clay formation is covered with a layer of Alluvium, a consolidated and compressible form of silty clay that can contain layers of silt, sand, peat and gravel (in the map, this is

[1] See Appendix 1: Maps of the London Underground throughout the years

coloured yellow). Further away from the river, the London Clay is covered with a variable form of River Terrace deposits (pink in the map).

The London Clay is mostly very firm and incompressible, which made the London soil a perfect place for Marc Brunel to start his tunneling shield method. When excavated, the soil will not collapse for some period of time, which makes the method less susceptible for small miscalculations in the pressure delivered by the tunneling shield. Damage, on the other hand, can be caused by the susceptibility of the clay to shrink and swell.

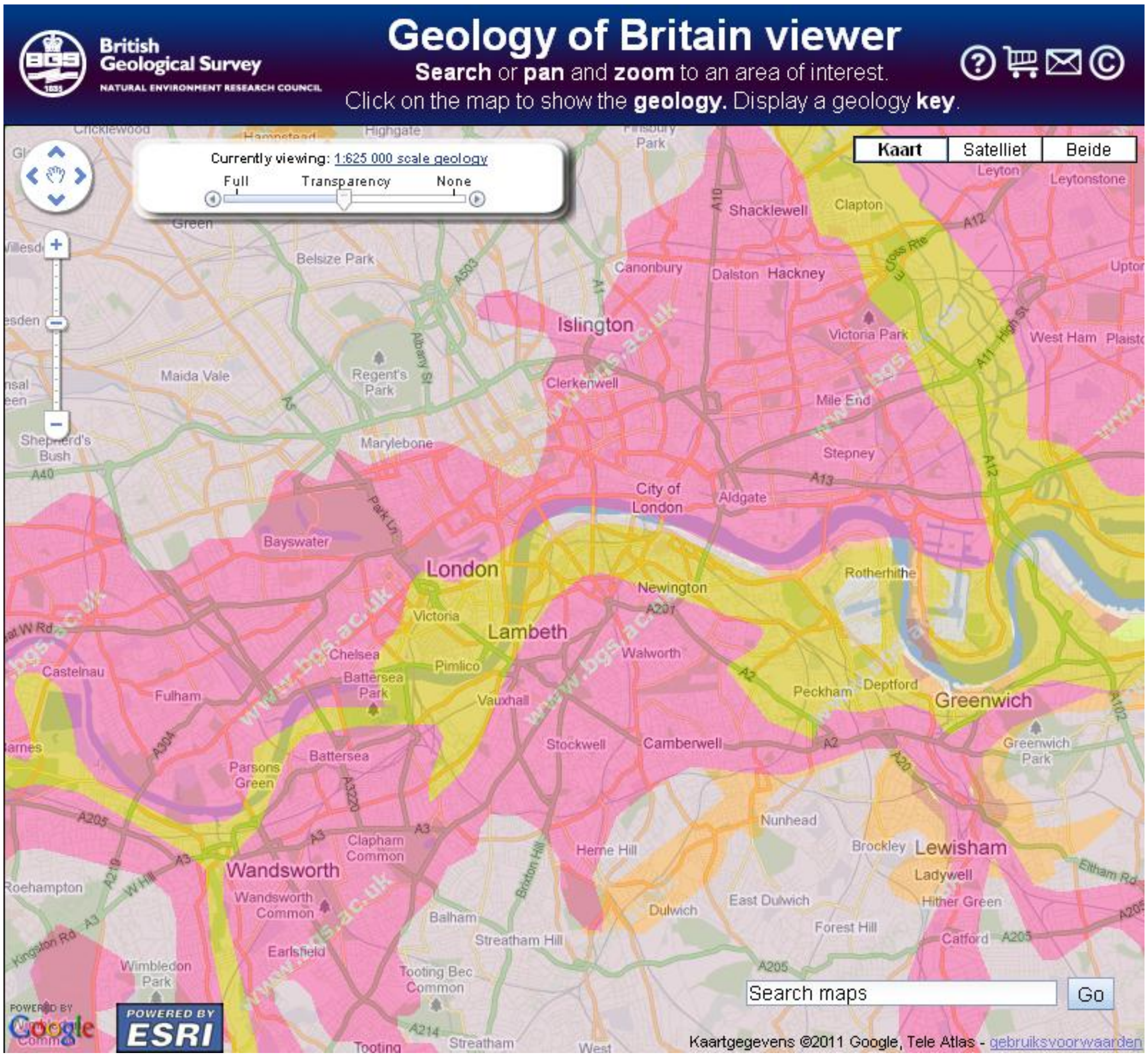

Figure 1-4: Geological map of London

1.3. Building methods

The original tracks (most of what are now the Circle, District, Hammersmith & City, and Metropolitan lines) were built using the cut-and-cover method. Most lines run about 5 meters under the surface, in tunnels giving room for tracks in both directions. In the period these tracks were build, the cut-and-cover method was the most common and proven method to be used. However, the method caused a great deal of disruption at the street level, because buildings had to be demolished in order to make a building pit in which the tunnel was built. The fact that the earlier trains were steam-driven complicated the works, because large ventilation shafts were necessary to expel the steam and bring fresh air into the tunnels (and stations).

From 1890 on, the method used changed to the tunneling shield method. The method, first used by Marc Brunel in constructing the Thames tunnel in 1843, caused less nuisance above ground, because the tunnels were constructed deeper (about 20 meters underground) without the need to demolish buildings above, which also made it cheaper in most cases. The tunnels made using this method are round and carry only one track, so for each line, two tunnels had to be made (one in each direction). Even in the London Clay, a small amount of stabilization of the tunnel walls was needed during construction. The tunneling shield method made smaller excavations than the original cut-and-cover method and gave more stability, making it a safer method.

1.4. Safety and security

The London Underground has a great safety record. Given it is used by 18 million people every week (meaning about a billion passengers a year), as well as the vastness of the system, the number of accidents is very small. In fact, on average only one in three hundred million journeys on the tube results in a fatal accident.

Most of the fatalities are caused by suicide attempts. At most tube stations, there is a pit beneath the track, originally meant for the drainage of water. Later, the pits were found to also significantly reduce suicide fatalities, which gave them their nicknames “anti-suicide pits” and “dead-man’s trenches”. At the extension of the Jubilee line, stations were completed with platform edge doors, which make it impossible to enter the track if there’s no train. See Figure 1-5.


Figure 1-5: Platform Edge Doors at Westminster tube station on the Jubilee Line

In 2004, an independent contractor was hired to make an audit on the safety of the London Underground, going over all safety protocols and using tools such as a Quantified Risk Assessment (QRA). The conclusion of the first phase of this research was that the safety system of the tube is very robust. Furthermore, a Safety Improvement Plan is constructed and carried out every year, monitoring the number of accidents that were fatal as well as caused major injuries, finding explanations for these incidents and producing actions taken to further improve the safety of the system.

In the 147 years of operation, 5 fatal accidents have been caused by train operation, the first of which occurred in 1938 and was caused by writing errors that caused a faulty use of the signals. Most fatalities occurred during World War II, mostly during two bombardments (one at Balham station, one at Bank station). Also, a number of people died in fires at tube stations, one of the most known of which is the fire at King's Cross station in 1987.

The importance of the Underground to the Public Transport system of London makes it a prime target for terrorist attacks. There have been several (suicide) bomb attacks in its history, including at least 5 by IRA[2] between 1939 and 1992, and 2 by Islamist extremist in 2005. The last resulted in the Terrorism Act of 2006, a controversial part of legislation that enables the government to convict someone for 'acts preparatory to terrorism'.

1.5. Rolling Stock

The trains used in the London Underground have changes significantly over the years. Originally, steam-driven locomotives were used, only to be completely withdrawn from use in 1971. Electric locomotives where firstly used in 1980, as the stock for the first tube line. In 1941 the first diesel locomotive was used, but due to a complicated operating system and frequent break-downs, the stock was not used for a long time. The stock now still used is battery-electric driven, meaning the trains can operate on power supplied by the rails, but also on a battery if the power is switched off for any reason.

In the earlier cut-and-cover tunnels, space was not a limitation. Throughout the years, stock changed significantly, each type being given a letter from 'A' to 'T' combined with two numbers indicating the year of production. All sub-surface stock types have certain

[2] The Irish Republican Army is a paramilitary organization that sought the forming of a united Ireland including Northern Ireland (which is part of the UK), through armed force.

characteristics that make them unique. For example, the ‘A’-stock type has high-backed transverse seating, and the ‘C’-type is shorter, which makes it suitable for use on the western part of the Circle line, which has shorter platforms. The latest type is the S-stock, which is taking over all cut-and-cover engineered lines by 2013.

The tube stock is a little different from the sub-surface stock (See Figure 1-6), greatly because of the limited space in the round tunnels, which makes the trains smaller and more curved. The stock used on different lines is not always interchangeable due to wheel and cart size, platform length and signaling systems. The oldest tube stock type still in use dates from 1967 and is driven on the Victoria line.

Figure 1-6: The difference in shape between the sub-surface trains and Tube trains

1.6. Stations

One of the oldest stations of the London Underground is Paddington Station. When building the first Underground line, Great Western Railway, the exploitant of the Railway station at Paddington, offered great financial aid, under the condition that the Underground would be linked to its train terminal.

Nowadays, Paddington Station is served by four lines: the Bakerloo, District, Circle and Hammersmith&City lines. The first two lines are served by a combined sub-surface and tube station to the south of the train terminal, while the H&C line is served by a sub-surface station to the north. The Circle line is routed through both of the stations. Although the two sub-surface stations are not directly linked, they are shown as one station at the Underground map.

Figure 1-7: The Underground stations Paddington (left) and Victoria (right)

The busiest Underground station, serving over 77 million people per year, is Victoria Station. The train terminal above ground is the second busiest one in the UK only after Waterloo. The Underground station exists of two parts, each with its own entrance and ticket hall. The oldest part is a sub-surface station serving the District and Circle lines. The newer Tube station serves the Victoria line.

At its opening on 7 March 1969, Victoria station was not built for the number of passengers it serves today. To prevent dangerous situations due to overcrowding, crowd control measures are in place during the busiest periods. This mostly means that the station operates as an exit-only station by closing all the entrances. This measure can be used for a couple of minutes during minor delays, up to multiple hours when a major incident occurs. To solve these problems, building plans have been made to enlarge the capacity of the ticket hall and entrances. Figure 1-7 gives an overview of the stations.

1.7. Future development

In the coming years, accessibility of the Underground will be improved, for example by replacing the rolling stock by the S-Class stock, which contains a better audio and visual system for information services and has station-leveled entrances and wheelchair space onboard. The new trains are also air-conditioned.

Also, the aim is to increase capacity of the system by 30%, mainly on the Victoria and Jubillee line. Expansion of the system is mostly focused on the newer lightrail and overground systems. Most of these improvements are meant to take effect before the Olympic Games in 2012.

2. Paris

The Paris Metro or Métropolitain as it is also known is more than a century old. In that time it has become a symbol of the city. The network has sixteen lines that are mostly underground and have a total length of 214 km. There are some 300 stations that create one of the densest metro networks in the world, there is no place in the city center that is more than 400 meters away from a station. The network is also the second busiest metro system in Europe with 4.5 million passengers a day. The Paris metro is concentrated in the city center and is under control of the RATP, connections with the suburbs are mostly with RER commuter rail.

2.1. History

Already in 1845 the railway companies and Paris were thinking about an urban railway system to connect the inner districts of the city. Paris favored a new independent network whereas the railway companies wanted to extend their existing lines. This resulted into a disagreement that lasted decades while in the meantime the population grew and the traffic congestions became massive. This deadlock was broken with the approach of the world fair of 1900, this put pressure on the authorities and concentrated the planning and building.

With the city and the railroad companies on one line their agreement went to the national government for ratification. The latter insisted that the track gauge should be the standard one of 1435mm and the width of the carriages 2.4m instead of the proposed 1.9m. On April 20 1896 Paris started the Fulgence Bienvenüe project. The first line was opened after some delay on July 19, 1900 during the world Fair. Only eight of the stations were finished during the inauguration, the ten remaining stations where opened later that year. The line followed the east-west axis of the city. Fulgence Bienvenüe, who supervised the construction and managed the metro for the first three decades, was one of the most experienced engineers of his time. He had supervised the construction of the Belleville funicular and the Avenue de la République.

After some hesitation the new system was embraced by the Parisians and the visitors. The number of passengers rose form 1.8 million in August to almost 4 million in December 1900. With this encouragement the city pressed on the building of new lines and the original plan was finished ahead of schedule in 1910. Bienvenüe was aware of the need to plan the system as a whole and as a result of this advanced planning some of the important and difficult works, crossings of (future) lines etcetera, could be carried out as combined operations. Like in other cities at the time the metro did not start as a monopoly. And in 1901 a second company obtained rights to build an underground line.

During the First World War construction of new lines stopped. After the war the first strike was a fact but the city continued to build new lines as can be seen on Figure 2-1. At the end of this period of building and expending the construction stopped. In 1998 one new line has opened and some lines have been expended in the last sixty years but most of the work has been done before 1949. Another interesting notation is that in the early years of the metro it did not cross the city walls. Many Parisians feared that extending the lines to the suburbs would reduce the safety of the city. This resentment of going in to the suburbs led to the decision that the metro should run on the right opposed to the existing railway lines that ran on the left, to prevent any future connection from being made.

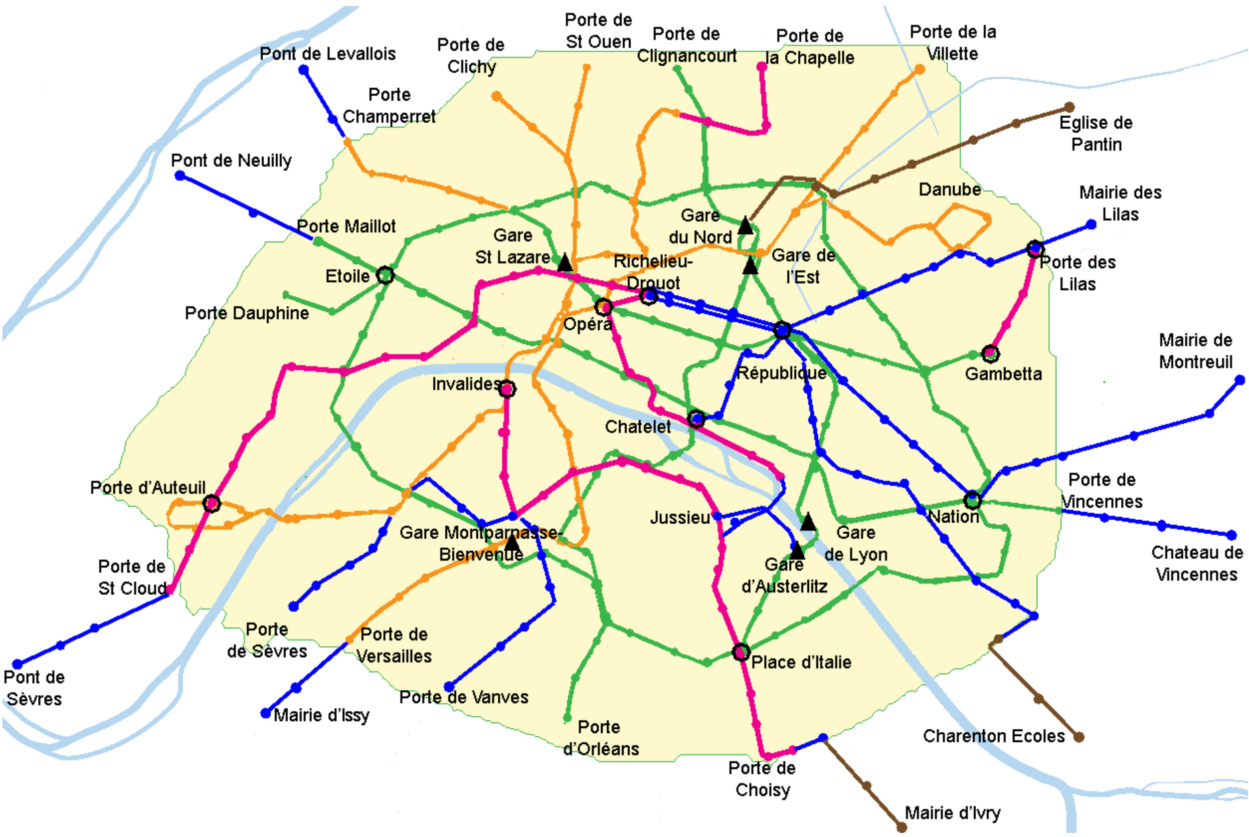

Figure 2-1: the first lines of the Paris metro in time periods. 1900-1910, 1910-1914, 1914-1930, 1930-1939, 1939-1949

2.2. Geological aspects of the underground

Paris lies in the center of the Paris basin. This is a geological formation that goes to three kilometers deep. The top layer of this formation is a tertiary deposition. With the Seine running through the center of the city there is probably a large area of the underground made up of river sediment. The exact layers of the underground are unknown due to the fact that is unable to find the correct data. In Figure 2-2 the Paris basin can be seen.

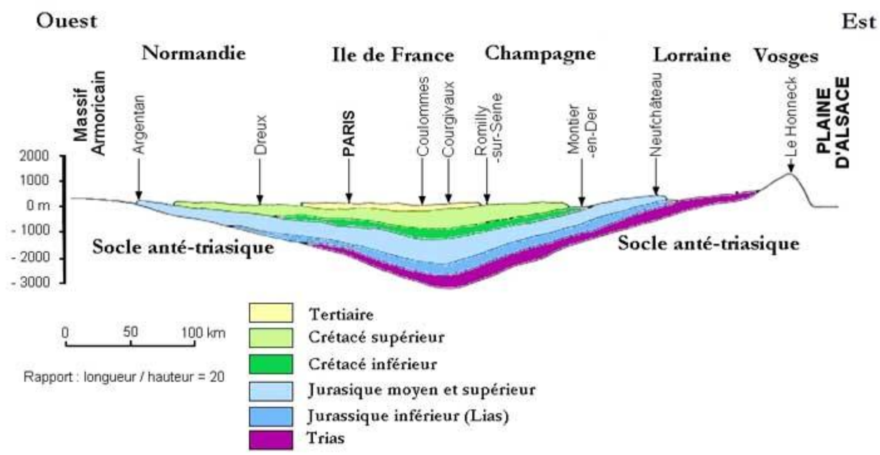

Figure 2-2: Paris Basin, geological formation

2.3. Building methods

Most of the Paris metro was built before 1950 and was created with relatively simple methods. Cut and cover being the foremost of this, like most of the metro systems built around 1900 this was the easiest way to create a tunnel. A trench was excavated in the street to a shallow depth and the tunnel was created in this trench. When this was finished everything was covered up and the street rebuilt. The use of this method instead of cutting the tunnels in rock led to a double track system instead of small separate tunnels like parts of the London underground. Most of the stations from that time therefore have platforms on both sides of the track.

The city center of Paris is divided by the river Seine as can be seen in Figure 2-1. The metro crosses this obstacle with a number of lines. Most of these crossings made in the early phase used metal caissons. These where placed on the bottom of the river and connected to the line in the river bank. In Figure 2-3 can be seen that the Parisians used a pneumatic caisson to get the tunnel at the needed depth. The caissons where floated to the right position as can be seen in Figure 2-4. This system of construction makes use of a pressurized chamber below the caisson that keeps the ground water away. In this chamber the ground is removed so that the construction slowly settles to a lower level. During the construction the ground was also frozen on some locations with cooled down brine to stabilize the ground.

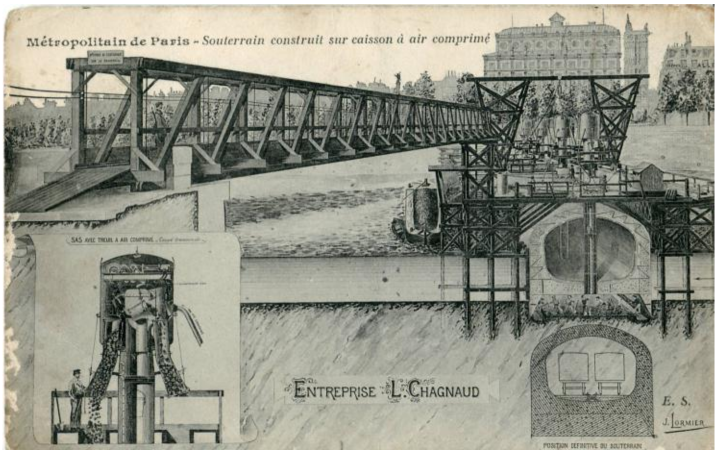

Figure 2-3: placing of caissons in the Seine

Figure 2-4: Caisson floating in the Seine

2.4. Safety and security

In the first years of the metro one of the major accidents of the network happened. In 1903 a locomotive suffered a short circuit. The train was removed but caught fire in a tunnel. When the danger was finally understood and the evacuation started the passengers didn't cooperate. When the burning train down the tunnel destroyed a supply circuit, the station, now in darkness and filled with smoke, became a deathtrap. After this terrible accident many safety precautions were installed. Each line was divided into electrically isolated sections, so power wouldn't fail in the entire system and parts could be cut off to prevent power of reaching a broken down train. The station exits where widened, exits got lighted signs and much more.

Nowadays the RATP has tried to increase the safety like every transport company. In the late seventies it started with better coordination with the fire department. This led to the conclusion that there need to be better smoke removal, communication and more accesses for the Fire brigade. Inside the tunnels dry standpipes have been installed every 100m, allowing to get water in a shorter period of time. At last the French have acquired extra light trolleys to carry rescue and rapidly extinguishing equipment to an accident.

2.5. Rolling Stock

In the Paris metro not all lines use a normal rail system, some use a rubber-tyred system instead. This system combines a mix of road and rail technology. The train runs on rubber tyres but there are still guide tracks for guidance as can be seen in Figure 2-5. Paris was the first to experiment with a Rubber-tyred metro. For at the end of World War II the Germans had used the Metro system with very little maintenance. With a system so worn out thought was given as to how to renovate it. And after successful testing the first line was converted in 1956, line 11, chosen for its steep grades.

Rubber tyres have a number of advantages over normal tracks. They have smoother rides, less jostling around and faster acceleration and shorter braking, allowing for trains to be closer after another. Rubber tyres allow for steeper slopes then conventional rail. The system is also quieter in the open. There are some disadvantages too. The higher friction and rolling resistance cause higher energy consumption and the possibility of tyre blow-outs. It loses the traction advantage in bad weather and in-tunnels it produces more noise due to the roaring sound of the tyres.

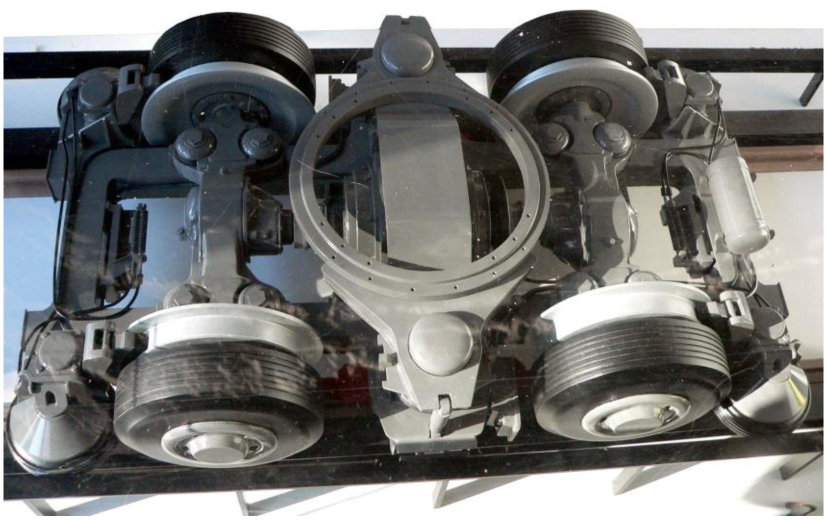

Figure 2-5: Rubber tire bogie from a MP 89

Paris also features some automated lines. Line 13 was the first to be automated and that reduced the turn-back time, so now every 95 seconds a train can enter a station. This system allows for more trains per hour and is less sensitive to strikes. It also requires the adaptation of busy stations because there is no driver onboard. The platform screen doors prevent the passengers from falling on to the tracks when there is no train in the station. The automated trains have no driver position in front of the train. This allows for passengers to see the route of the metro.

2.6. Stations

Gare de Lyon is one of the biggest railway stations of Paris. From this station trains depart to the south of France. The station itself was built for the World Fair of 1900 and included a metro stop for line 1. What is so special about this station is the combination of various transport methods on multiple levels and the different styles and times in which they were built. In Figure 2-6 the platform of line 1 can be seen. This part was built in 1900 very close to the surface. The style and technology of that time can clearly be seen in the low sealing and cast iron beams. The station was created using the cut and cover method and supports the street above it. The lighting and light colours are updated in the style of the security ideas of now a day.

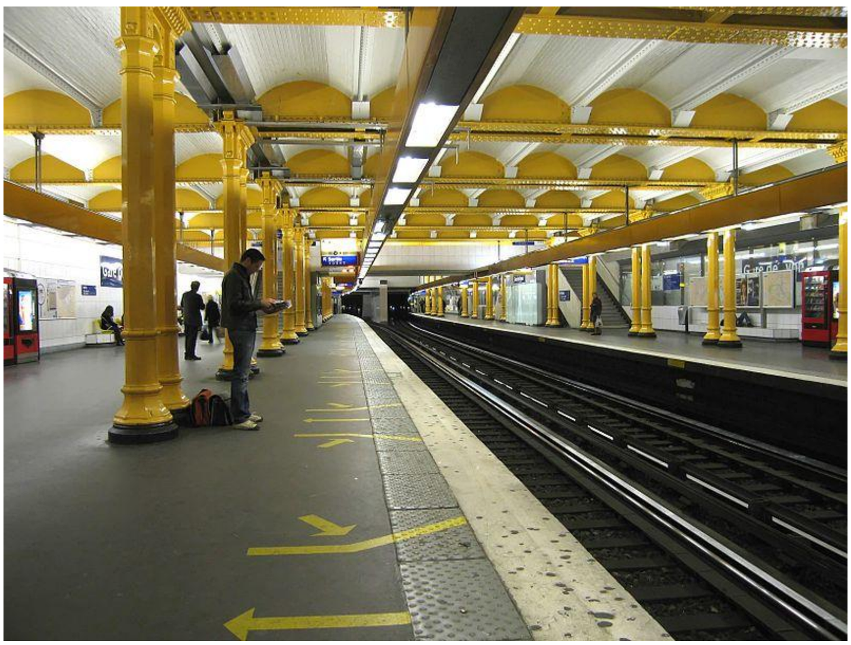

Figure 2-6: Gare de Lyon, Line 1

The station of line 14 was opened in 1998 in the Météor project. The style of this station is in line with the new safety and security ideas, large open platforms with a lot of (natural) light. The station is located to the south of the train station Gare de Lyon. It connects to the train station but also to the local RER lines that connect the suburbs of Paris to the city proper. In this part of the station extra attention has been paid to separation of different flows of arriving and departing passengers, so that the flows do not cross each other and so that it is clear where to go. This line also features automated trains and therefore has special doors on the platform to increase passenger safety. What is so special about this station is the tropical garden in the open space next to the track and the RATP headquarters. This can be seen in Figure 2-7.

Figure 2-7: Gare de Lyon, line 14

2.7. Future development

The development of the metro is currently not a high priority with France policymakers. This lies with the development of the transport systems in the expending suburbs. So priority has shifted to tram lanes that are cheaper and more suited for the less dens areas of the suburbs. There are plans to make a transport ring around the city if this is with a metro line or tram line is unclear. Al this doesn't mean that there is nothing happening with the metro. There are a few lines that are being expended at the moment. Some extra stations and extensions at the end of the lines but no new lines are being built. There are plans to create one using parts of the 3th and 7th line, but it isn't likely that it will happen in the near future.

Outdated equipment is also being replaced with modern trains. And after the success of the automation of the 14th line the 1th and 4th line are now being automated, in Figure 2-7 the automated train of line 14 can be seen. The 1th and 4th are currently running with both manned and automated train, but within a few years this will only be automated trains.

3. Berlin

The subway in Berlin, named U Bahn, is the most extended underground network of Germany. It consists of 10 lines and in the peak hours, the vehicle transports every two till five minutes a lot of travellers. 80% of the total length of 146 km of the U Bahn is in the underground and with 176 stations, the subway can transport 400 million passengers a year. Since 1929, the operator of the U Bahn is the Berliner Verkehrsbetriebe (BVG) which operates the whole public transportation.

3.1. History

After London, Budapest, Glasgow and Paris, also Germany had to make a subway. Berlin was the first city of Germany which got this underground system.
The history can be divided in three periods; from 1880 until the First World War, First World War until 1930 and from 1930/Second World War till present.

First period (1880-1914)

Already in the 19^{th} century, Berlin had a lot of travel problems, but still there hasn't found still had not found a solution. Werner von Siemens, a German inventor and founder of the company Siemens, came in 1880 with the idea to build an elevated train on a steel viaduct at 4.50 meters above the city. He also had already made a precise route of the system, which would start in the north of Berlin and would go with a loop to the south of the city. The viaduct would lie above the already existed roads and the entrance stairs should be located at the houses underlying which had to be purchased by the government.
James Hobrecht, the architect of the city, didn't like this idea very much. He was of the opinion that this solution would interfere with the view of the city. Also, the noise of the train would create unnecessary problems. For these reasons, Werner von Siemens had to come with another solution.
Von Siemens also started about thinking of the idea of the same electric train, but now underground in Berlin. Therefore he had to know the geology of the underground of Berlin. Ernst Dircksen, who ran the light rail in Berlin, was very familiar with this geology. He advised von Siemens strongly not to pursue a subway in Berlin due to the geological conditions. The council of the city agreed with that. Also the existed sewer system would be a problem.


Figure 3-1: High railway (hochbahnhof)

In 1892, the council started to agree that a high railway (see Figure 3-1) would be a good solution. Von Siemens got permission to build the first stage. This stage would only be built above a poor district of the city, because they were afraid for nuisance and pollution. The other part of the route would cross a rich part of Berlin and the government wouldn't give permission to build that part. Anyhow, in 1896, (when there were built subways in already five different countries) they decided to give permission for building that part under the ground. At September the 10th, the firm Siemens & Halske started with the building of the subway. This was the beginning of the subways in Berlin.
In February 1902, the first subway was opened in Berlin. After this one, many crossways were made of this subway and the underground system of Berlin started.

In this period, most of the routes of the U1, U2, U3 and U4 were built.

Second period (1914-1930)
In the first period, the network was mostly west-east orientated, because in these areas the rich people lived. In this period, Berlin also wanted to start building networks north-south orientated. On this way, also districts with laborers would be connected to the U-bahn. They started the new planned line, the north-south line, in December 1912, but in 1914 the First World War started. This was the cause for the stagnation of the building projects of the subway and also the north-south line (the U6). In 1919, they resumed work, but also because of the high inflations after the war, the progress stagnated. Eventually, on 1923, the first part of the new north-south line was opened.
Also, the new connections made Berlin to Great Berlin with 20 districts as we now know it. Before 1920, Berlin was surrounded by small towns and villages. In 1920, most of those villages became also Berlin. This was partly because of the connections between these areas which were now possible.

The new connections were partly just the expanding of the old systems, but now more travelers were expected. This was the reason why it was decided to use wider vehicles (Grossprofil) for the new lines. The already existed lines kept their small profiles (Kleinprofil), because it was too expensive to change all these rails and carriages.

Figure 3-2: Great Berlin

Third period (130/WWII-present)

In 1933, the power of the national socialists and the economic crisis brought many changes. In every station there had to hang the national flag and one station was already named after Adolf Hitler; the Adolf-Hitler-Platz. Also work had to be stopped, which brought the station Hermannstrasse (U8) to an unused station.

When the Second World War started, this station became an air-raid shelter. Most of the stations weren't safe to hide, but because this station had to lie under another underground cross section of the S bahn (normally above surface), it was one of the few stations that was deep enough to prevent damage by bombs. The other stations weren't deep in the underground, because of their building method (see 3.3 Building methods). Those stations were totally unsafe during the war.

Still, at the end of the World War on 25th April 1945, the Red Army (the Russian liberation army) used these underground shelters for hiding. When Hitler heard this, he decided to send water in the tunnels over a length of 63 km. Hereby, a lot of people who were hiding in these shelters drowned. Also the subway of Berlin had suffered a lot of damage.

After the Second World War, Berlin had to be divided into an east side and a west side. This had many consequences for the subway of Berlin. At first, transport between East and West Berlin still existed, but in 1961, when the Berlin wall had to be built, the underlying subways also had to be split. The operator of the subway, the Berliner Verkehrsbetriebe already divided after 1945. Most of the lines became of West Berlin and the stations which had to be closed, because there was no transport anymore, became such called ghoststations. By total, there were 16 ghoststations in East Berlin. Because of the Berlin wall, a lot of routes had to be rebuilt in their own part of Berlin (East or West Berlin). East Berlin decided to keep the already existed subways. In 1989, in East Berlin was only one new line created while West Berlin had built significantly more new lines.
After the reunification of East and West Berlin, a lot of stations had to rebuild and tunnels had to be reopened. The ghoststations became useful again and some lines had still to be finished because these lines where as well as in the eastern as in the western part of Berlin.
At the end of the 90's, Berlin decided to build another line, but already in 2001, they had to stop because of lack of money. They still wanted to finish it, so finally in August 2009 the U55 was opened and became the youngest and newest subway line of Berlin.

3.2. Geological aspects of the underground

Just like the geological history of the Netherlands, also in Berlin plays the last glacial ice age (the Vistula ice age) an important role for the geological aspects. The present shape of the earth's surface in Berlin is made by this last ice age. The most important morphological units of Berlin are the Warsaw-Berlin Glacial Spillway with its Panke Valley (you can see the location in Figure 3-4), the neighbouring Barnim Plateau to the north and the Teltow Plateau with the Nauen Plate to the south of the Warsaw-Berlin plate. The first plate, the Warsaw-Berlin plate, lies in the middle of Berlin and consists mostly of sandy and gravel deposits. The neighbouring plates, the Teltow with the Nauen and the Barnim Plateau, are covered with a thick glacial layer of boulder clay of the moraines of the glaciers.
In the next two figures, you can see the hydrological and geological underground of Berlin. In both the figures you can see the area of Berlin. In Figure 3-4 you can see that most of the underground of Berlin consists of sand. This is indicated with the green and light yellow areas. The blue areas are the waters in Berlin and the orange parts indicate the glacial boulder clays and marly layers.
The sandy layers owe their existence to the tertiary and quaternary period and are 150 m deep. These layers are very important for the foundation of the buildings and the drinking water supply of Berlin.

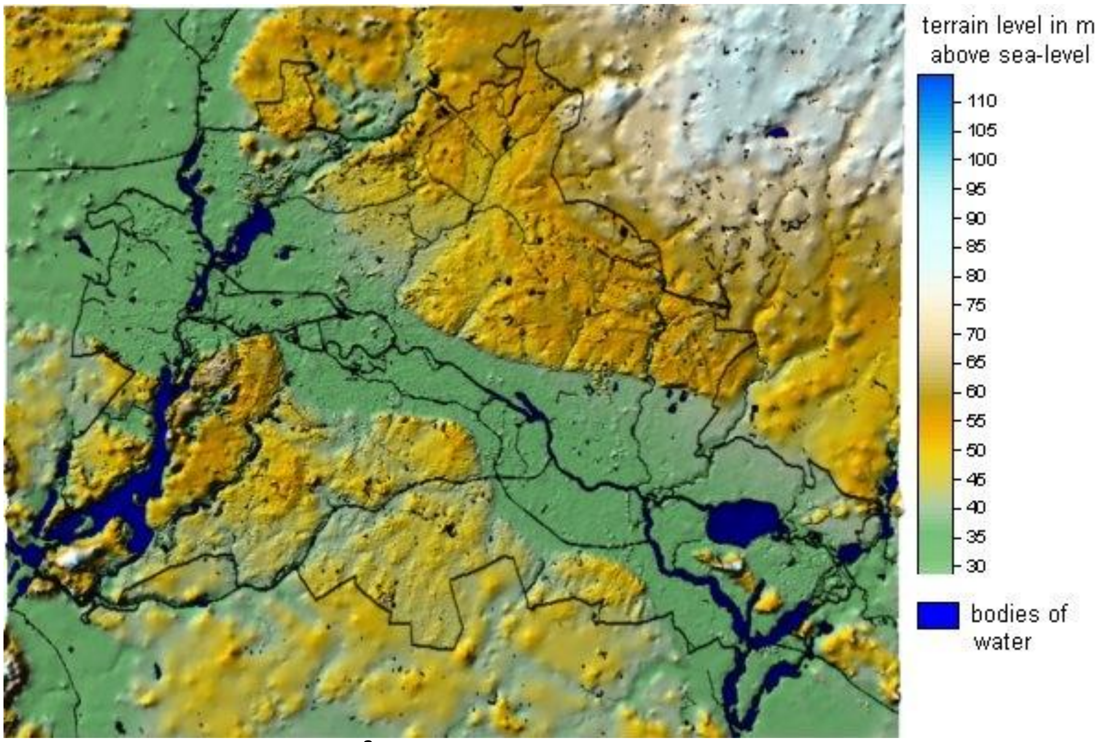

Figure 3-3: Morphology of Berlin[3]

[3] Source: www.stadtentwicklung.berlin.de/umwelt/umweltatlas/e_text/ekl212.doc

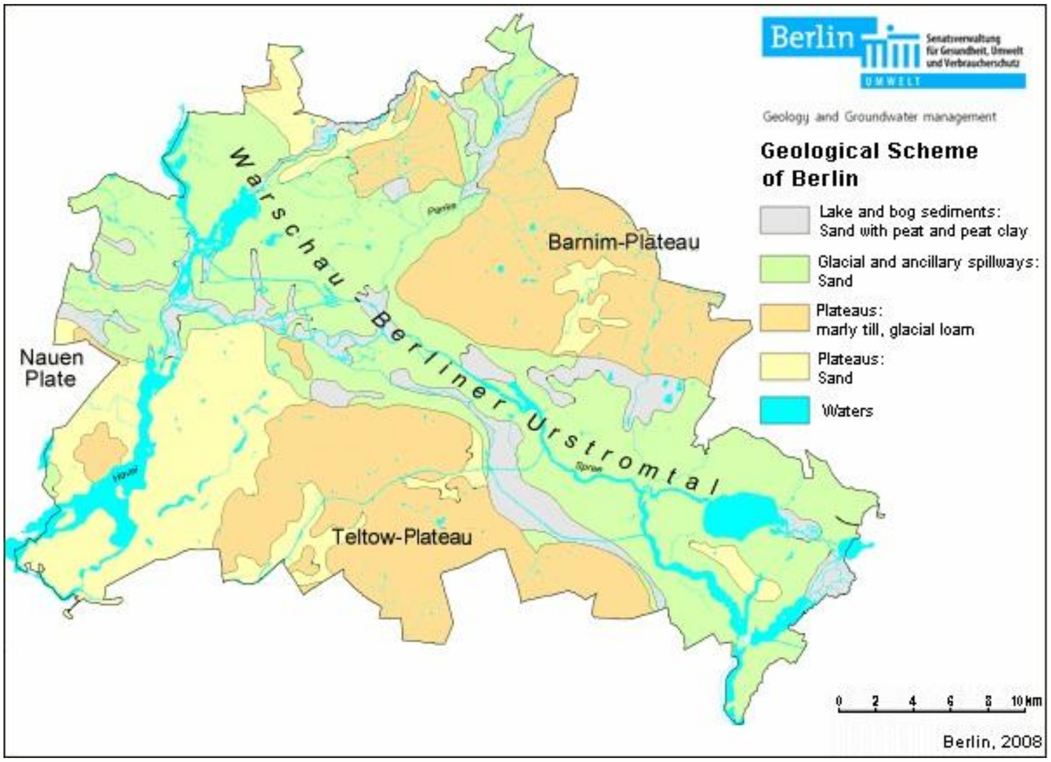

Figure 3-4: Geology of Berlin

From Figure 3-4 you already have a lot of information about the underground of Berlin. The following cross section of Berlin will still be more interesting (see Appendix 2). This cross section starts in the Teltow Plateau (left) and ends in the Barnim Plateau (right). In this figure the different layers in the underground can be seen clearly. The green, blue, brown and yellow layers indicate the aquifers, which consist of sand. The grey ones indicate the aquitard or else the clay layer.

An interesting thing to say is that in the northwestern area of the Barnim Plateau, the ground moraines are so thick that no groundwater aquifer exists, or it only occurs in isolated areas with a thickness of a few meters. In the rest of Berlin, a high groundwaterlevel is the result of the last ice age. The soil exists of soggy soil because in the ice age this soil layer was part of a glacial valley. This layer lies about 7 or 8 m deep.

3.3. Building methods

The first subway was built in 1902 and was made by the open building method. This means that first it is necessary to excavate a building pit, before the building of the tunnel itself can start. Most of the times, the subways lie in a civilised surrounding where there isn't enough place to excavate this pit without walls. That's why sheet piles were used. In this way, there isn't any space needed for the slopes of the walls of the building pit. When the tunnels were completed, the building pit was covered and on this way the subway got a rectangular profile (Figure 3-5). You can see the open building method in Berlin on Figure 3-6.

Figure 3-5: Rectangular profile

Figure 3-6: Open building method

Most of the subways which have their origin in the first or second period of the history don’t lie very deep. They lie just about four meters under the subsurface level, so the roof is actually also more or less the same as the surface of the street. This is also the reason why the tunnels follow the street pattern in Berlin, which is why there are bends in the old networks.

A cross section of these old subways under the street can be found in Figure 3-7.

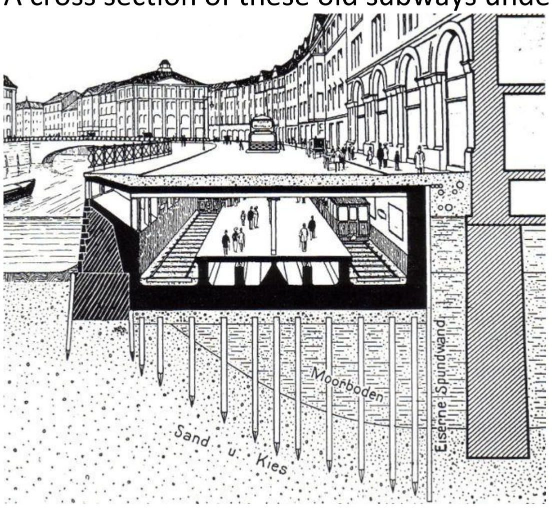

Figure 3-7: Cross section eldest subways

On some places, some lines had to cross rivers or railways. On these places, the tunnels had to lie deeper in the underground. For example for the building of a tunnel segment under the river the Spree, the tunnel had to be built without obstacles for the ships. Here the engineers decided to use still some kind of an open building pit, but also sheet piles as a roof of the pit, so it looked like a box under water. After this, the water could be pumped out of the box and the building of the subway could start. On this way, the ships could still travel above the tunnel. When the tunnel was finished, the walls were removed and in 1913, the tunnel was opened.

In the twenties when the vehicles became bigger (Grossprofil, see chapter3.5), the tunnels had to be built at a deeper level. Because of the high groundwaterlevel, it became more difficult than the previous building method. The tunnel had to lie 8 meters under the streetlevel, which would mean that special measurements were needed to keep the groundwater outside the subway. So from this time on, the building of the tunnels became more difficult.

Because the open building method has a lot of disadvantages (nuisance for traffic and residents), it became more effective to use other building methods. In the sixties of the previous century, the engineers started to use bore methods. This method was only used when it was necessary, for example to prevent disturbing the peace in a hospital. In 1980, there was designed a tunnel (U7) which would have a lot of difficult crossings; the tunnel would have to cross a river, two different passages and two different stations, so a lot of different techniques were necessary; just the open building method where that was possible, the diaphragm wall method and bore method under the passages and the caissonmethod and the cut-and-cover method under the stations. The diaphragm wall method is just the same as the open building method, only it uses longer sheet piles. With the caissonmethod the parts of the tunnel is sunk in the ground/water.

In 2009, the last subway (U55) was opened. This subway is fully made with the micro tunneling method. This means that the tunnel consists of segments which have to be impermeable, because the water level in the ground was 2 m above the tunnel. Also, the tunnel had to make a curve in its route. These points created more difficulty than the previous subways. On the following figure you can see this bending tunnel.

Figure 3-8: Bored tunnel (U55)

When all the stations of the total subways in Berlin will be compared, most of the stations lie underground. From the total of 176 stations are 144 stations underground, 13 stations lie elevated, 5 stations lie at grade, 6 stations are on an embankment and 8 stations lie open cut.

3.4. Safety and security

When looking at the U bahn, it is necessary to look at what kind of accidents has happened in the past. Already in 1908, there was a big accident by the cross point named Gleisdreieck, which means rail triangle. On this intersection, the three railways are connected with switches and because of the stop signs, the driver knows whether or not he has to stop. On 26 September 1908, a driver missed the stop signal and drove in another train. The trains fell of the viaduct (this was the high-railway part) and 18 people lost their lives. The engineers learned a lot from this accident and decided to never use such an intersection again. In 1912, the rail triangle was replaced by a normal cross section (see the figure below) with a station. On this way, the chance that such an accident would occur again was minimized.

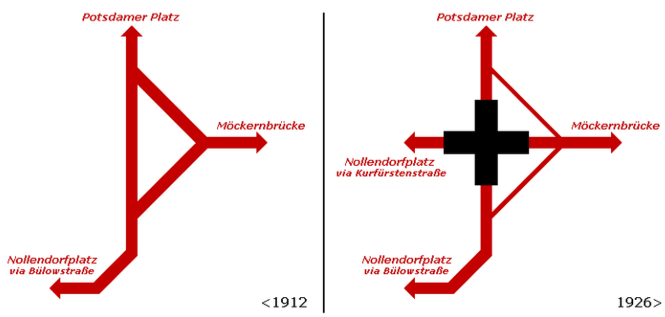

Figure 3-9: Rail triangle Gleisdreieck

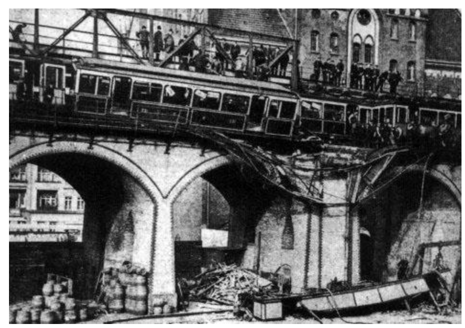

Figure 3-10: Accident 1908

But also in the tunnels were some accidents. In 1972, 1989 and 2000 there were fires in some tunnels. The trains caught fire and the passengers had to run to the nearest exit. Sometimes they couldn't reach the nearest exit in time or the only exit was also on fire. Through these dangerous situations, Berlin decided to build at least two exits in every tunnel. When the exits where in the middle of the tunnel, there still had to be more exits. Also the already existed tunnels had to be rebuilt.
Nowadays, the safety in the subways of Berlin is well organized. There are a lot of exits and there aren't any dangerous intersections any more.

It is also necessary to check how the travellers experience the subway systems. Users of other subways in Europe experience the Berlin U Bahn very good. The Berlin subway is well-maintained, clean and safe, as well as with respect to crime as with respect to train safety. When it is compared with the subways of London or Paris, Berlin had a lot less deadly accidents; after 1902 only 19 passengers died, which is happily not very much. Also in the stations the security can be found. The architect Alfred Grenander played an important role in designing the last stations. For example he designed the Alexanderplatz and Hermannplatz. In the left figure below it is very good to see that the station gives a high and free feeling which will increase the security.

Figure 3-11: Station Hermannplatz

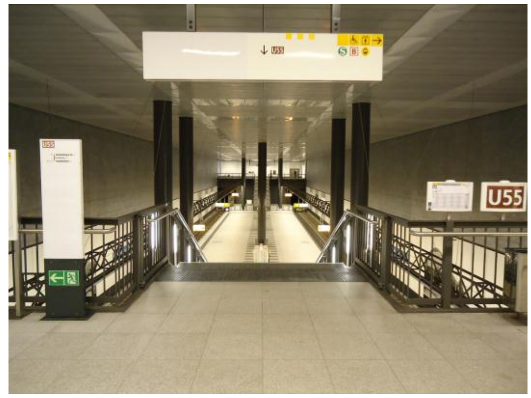

Figure 3-12: Station Hauptbahnhof (U55)

Also the latest stations of the U55 (figure 3-12 is a picture of the Hauptbahnhof station) give this feeling. Because of the naturally looking light and much space, you don't have the idea that you are underground, which give the travellers a feeling that they are outside.

Also the ticket system is use friendly. It is available both on and away from platforms, which allows the easiness of travelling with the subway. The ticket system is also well integrated with other providers, so it is also easy to travel to neighbouring areas. For visitors of the city, they sell special day and group tickets.
In case of emergency, there are red panic buttons on each subway station or emergency devices with the name “SOS/Notruf”.
Still, also in Berlin the police can't prevent pickpockets. So if you travel with the subway, be careful and keep your money and personal belongings gin a safe place.

3.5. Rolling Stock

The equipment can be divided in two different groups: the small profile (kleinprofil) and large profile (grossprofil). In the history (second period) is told why it is decided to change the equipment; because of the creation of Great Berlin more travellers were expected and so the use of wider vehicles was essential. The different types cannot be connected with each other, but these can be deployed on the same lines. Sometimes it isn’t possible that the larger vehicles drive in the smaller tunnels because of the curves. In 1976, the smoke areas in the metros were removed and already in 1927, the difference between the classes was abandoned.
The small profiles are especially used on the old lines; the U1, U2, U3 and U4. The large profiles drive on the newer lines; the U5, U6, U7, U8 and U9.
In today’s subway, the stations are announced and in the latest versions of as well as the small profiles as the large profiles, it is also displayed in the vehicle.

Small profiles (kleinprofil)

The small profiles were based on the streetcars. The vehicles had a width of 2.30 meters and were 3.10 meters high. Because of the small width, it was decided to place the seats along the walls of the vehicles. The top speed was about 50 km/h. This type was called

A-I. When in 1902 the first line was opened, 42 multiple units and 21 pure railroad cars were ready for service.
When in 1908 the amount of travelers increased, the system of the vehicles were improved, which made more connections (larger metros) possible and from 1924, the vehicles were made of steel. An example of an A-I vehicle is showed in the figure below.

Figure 3-13: Small profile (type A-I)

Figure 3-14: Small profile (type HK)

Between 1928 and 1929, there was a new type introduced; the A-II vehicle. The difference between this type and the A-I type was the amount of windows and sliding doors; the new type had three windows and two sliding doors.

After World War II, there was a lot damage of the vehicles. This was the reason there had be made other vehicles. The new vehicles of type A-3 were based on the already existed large profiles and were first consisted of steel, but because the vehicles became larger, a lot of electricity was needed. Because of this reason, it was decided in 1966 to make the vehicles in aluminum.
In 1975 came a totally new type; the GI. The top speed was 70 km/h, but the seats were still located at the walls. This type is also delivered to Greece for train line there. This type still drives in Berlin.
In 2000, the building of a totally new type started. This new type is called the HK type and is running since 2005. It looks a lot like the large profiles. The metro exists of four coupled parts. This type can be found in figure 3-14.

Large profiles (Grossprofil)
When Berlin became Great Berlin, also larger vehicles were needed. In 1923 the first type (A-IK), with a width of 2.65 m, started driving. The new types were especially created to save money by carrying more passengers at a time (111 seats). The large width of the vehicles created more problems at the platform accesses.
In 1924, a new type started already, which had a length of 13.15 meters and three double sliding doors. This type got the name BI. From 1927, the type BII which had improved propulsion came also in the system. The BI and BII systems, drove until 1969.
Also the C types were constructed very early (1926). The only noticeable difference was the length; these types were 18 meters long. Because of the longer vehicles, the weight

became also larger. In 1930, also these types started consisting out of aluminum which entailed a decrease in the weight of 12%.
Also for the large profiles, after 1945 it was necessary to create new vehicles because of the destruction in the war. The new D type was created and had, just like the small profile, seats at the wall side. The vehicles were made of steel, but again in 1965 it was decided to use a lighter material (type DL) which made a decrease of the weight of 26%. These vehicles only travelled in West Berlin; East Berlin had no large profile trains left to use, only small profiles.
From 1972, the new F type followed from the D types. The vehicles were longer and had more seats; instead of the seats on the wall side, the seats were now placed in couple at 90 degrees at the side of the metro. In the following years more variations of this type were created and today this type is still running.
In 1995, the BVG decided to construct another new type. This type, called type H, has completely joined compartments, just like the HK type. Together with the F type, this type is still active in Berlin.

Figure 3-15: Large profile (type DL)

Figure 3-16: Large profile (type HK)

3.6. Stations

Nowadays the U Bahn is very extended in Berlin, so there are a lot of different stations. On 19 stations other subway lines can be taken and on 31 stations it is possible to take the S Bahn (kind of tram). On 10 stations there is also a connection with the regional and national trains. The station which has the most number of lines is the Nollendorfplatz; all the small profile lines come here together. The mean distance between two stations is 785 meters.
The architectural difference between the stations is large. The old stations are mostly small and dark while the newer stations have a light and free feeling (see figure 3-12).

Hermannplatz

Hermannplatz station opened on 11 April 1926. The platform is 7 meters high, 132 meters long and 22 meters wide. A famous mall in Germany is Karstadt. This mall was constructed at the same time near by the station. This was the reason that Karstadt

decided to contribute a large sum of money for the decoration of the station. Thanks to this the station has a nice charisma.
This station was also the first station were escalators were built. Nowadays, Hermannplatz is the intersection between the U7 and U8.

Figure 3-17: Hermannplatz

Alexanderplatz
Another interesting station is the Alexanderplatz. It connects the U2, U5 and U8 together. The first part of the station is opened in 1913. In this time it was only a station of the U2. In 1920, the station is completely redesigned, as well as above as under the ground. This expansion was the result of the new connection between the U2 and the new U8 and U5 lines, still under construction at that time.
Alexanderplatz was also the first station which got underground shopping facilities, designed by Alfred Grenander. Nowadays these facilities can be found in a lot of stations.

Figure 3-18: Alexanderplatz

3.7. Future development

In 2009 the first part of the newest line U55 is opened. This is just the first part; the other part is now in production and the planning is to open that part before 2020. Apart from this new line, Berlin doesn't have any other plans in the coming future, partly because of lack of financial resources and partly because most of the city is already connected with the subway or the tram system. So Berlin decided to lay its priorities on the maintenance, rehabilitation and improvement of the accessibility of the stations.

Still, looking at the long term, there is a large number of planned enhancements of the underground system. Also there is already thought about a whole new line (U11) which will begins at the central station and will go through the north-east of Berlin. There is also a possibility that the U bahn will be extended to the new international airport Berlin-Brandenburg International (currently Airport Schönefeld) after the completion of the U55.
The stations which are still not in use are now temporary used for other purposes. For example a station at the U10 is now in use for exhibition space:

Figure 3-19: Use for exhibition (U10)

4. Rotterdam

The subway in Rotterdam is the eldest subway of the Netherlands and the Benelux. What first started at one line, expended over the years to five lines. The total length of the system is 78,3 kilometer. 17,7 Kilometers of the railways is located under the ground and 8,5 kilometers is conducted as a tram. The subway system of Rotterdam contains 62 stations of which the majority is used jointly by the lines.

4.1. History

The history of the subway in Rotterdam is extensive. On March 14th 1959 the proposal was made to make a subway from the north of Rotterdam to the south. The reason for this decision was that the car-traffic in the years after the Second World War increased fast. There were plans for the construction of a tunnel or a tram, but the transport capacity was too small compared to the capacity of a subway.

On 9 February 1968 there was an official opening of the subway that was called the North-South line, and drove from Rotterdam Central Station to Zuidplein. Princess Beatrix and Prince Claus were present at the ceremony. This first line was only six kilometers long, had seven stations and was the shortest subway in the world. It took about seven years to construct and the costs were 86 million euro. This line was partly under the ground and partly above the ground. The stations Central Station, Stadhuis, Beurs and Leuvehaven became underground stations. After station Leuvehaven the subway crossed the Nieuwe Maas with a tunnel, where the subway came after the Parallelweg above the ground. The stations Rijnhaven, Maashaven and the terminus Zuidplein were the next stations where the subway had to make a stop.
The tunnel underneath the Nieuwe Maas was, at that moment, a top of the art construction.

After the official opening workers began to extend the line in southern direction. The result was that on 25 November 1970 station Slinge was opened for use. At the end of the year 1969 the State agreed on the extension of the line between Slinge and Hoogvliet. The line had four stations: Rhoon, Poortugaal, Hoogvliet and Zalmplaat. On 25 October 1974 the line between Slinge and Zalmplaat was opened by mayor Thomassen of Rotterdam.

In 1990 it was decided that there had to be a new station on the “Kop van Zuid”. This station was located next to the subway tube on the slope of the tunnel under the Nieuwe Maas. In 1997 the station, the now called Wilhelminaplein, was opened. This line was called the East-West Line. This station is nowadays, with a depth of 16 meters below the surface, one of the deepest subway-stations of the Netherlands.
In the 1990’s the Rotterdam’s people decided to rename the North-South Line and East-West-Line respectively Erasmusline and Calandline after Desiderius Erasmus and Pieter

Calan, two of the most famous people out of Rotterdam. The map with the two lines can be found in Figure 4-1.

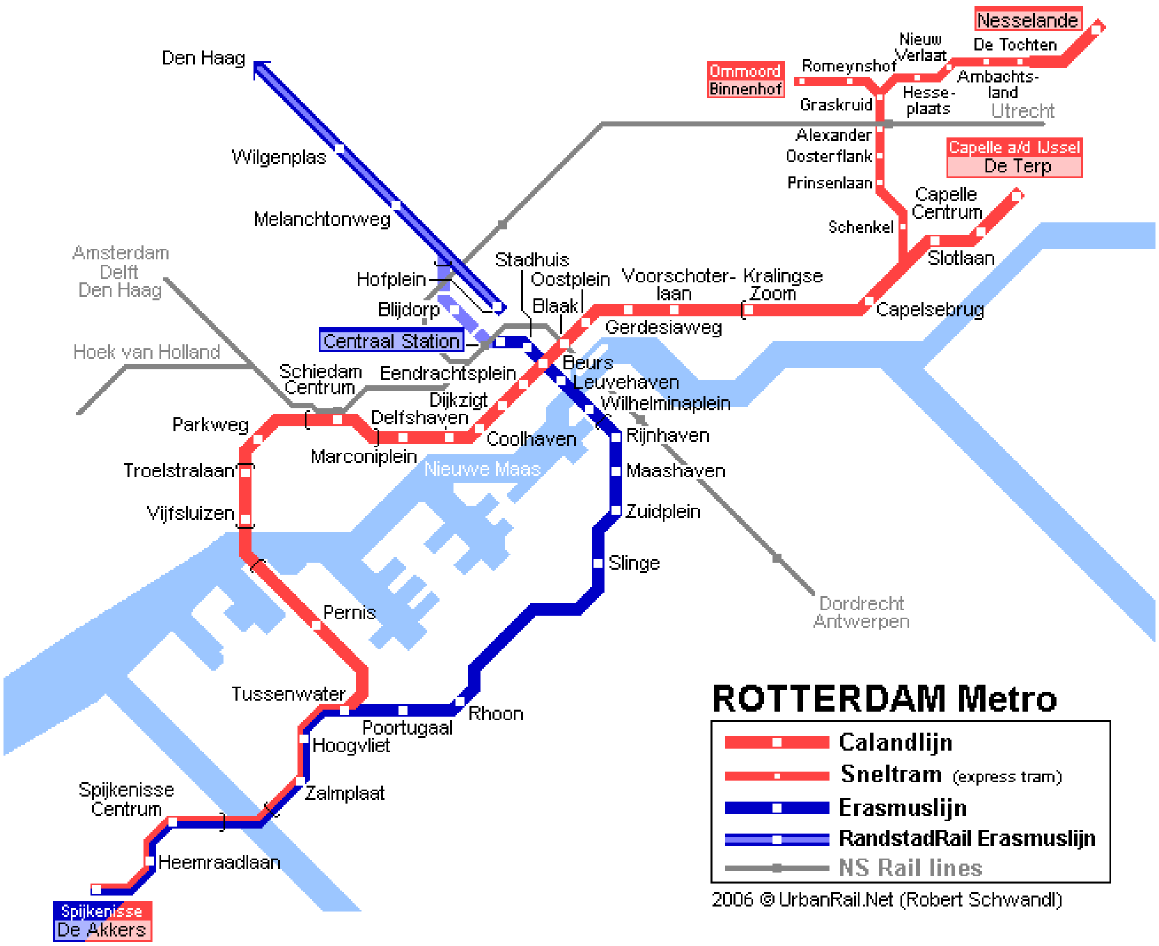

Figure 4-1: Map with the two lines, Calandlijn and Erasmusline

In 2009 the names of these lines were replaced with letters A to E. The former Calandline became lines A, B and C and the Erasmusline D and E.

Since 2010 line E, from Rotterdam to The Hague, is finally connected to the Rotterdam line D at Rotterdam Central. Before this moment, line E had Hofplein as a terminus.

In the table below a summary table can be found that contains the five lines with the number of stations and the length belonging to the lines.

Table 4-1: Summary table with the five lines

Line	From/to	Number of stations	Length
A	Schiedam Centre-Binnenhof	20	17 km
B	Schiedam Centre-	23	20 km

	Nesselande		
C	De Akkers-De Terp	26	30 km
D	De Akkers-Rotterdam Central	17	21 km
E	Rotterdam Central-The Hague Central	15	23 km

So, after more than fourty years the lines are extended to other municipalities around Rotterdam, such as Spijkenisse and Capelle aan den IJssel. There is also a line to The Hague and in a couple of years a line to Hook of Holland. Now, the network of the subway is 78,3 kilometers long, has 62 stations and five lines.

In the figure below, a map can be found containing the current map of the lines.

Figure 4-2: This is how the map looks after renaming

4.2. Geological aspects of the underground

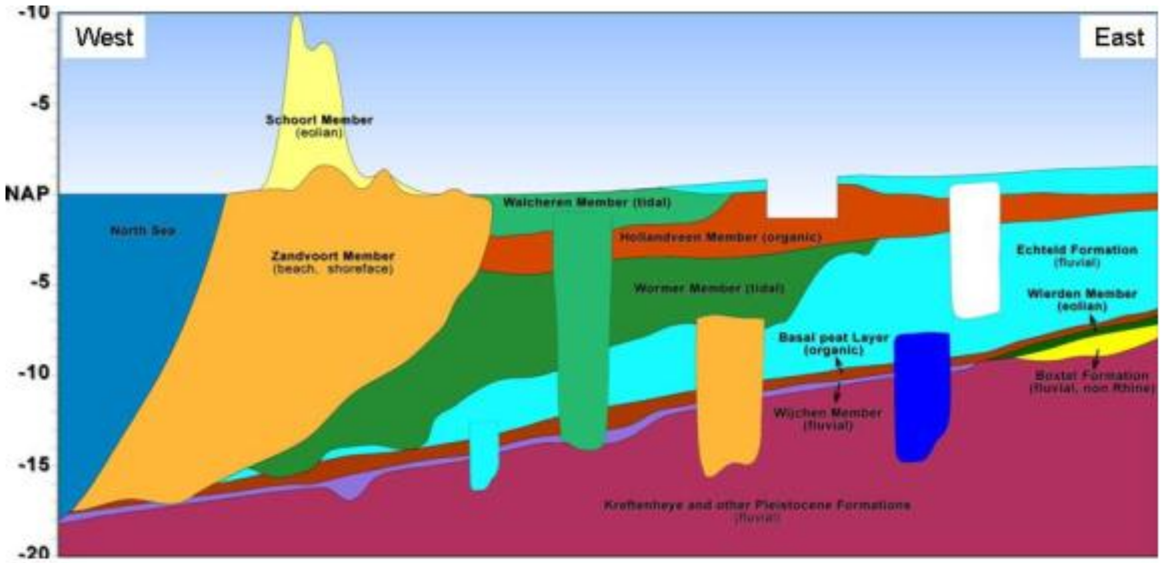

Figure 4-3: Schematic east-west oriented cross section through the Holocene deposits in Zuid-Holland.[4]

Zuid-Holland is positioned at the south border of the North Sea sedimentary basin. The subsurface mainly consists of fluvial and estuarine sediments that were deposited by the Rijn and the Maas throughout Pleistocene and Holocene. The Pleistocene layer of sand can be found at a depth to 25 to 30 meters. In Figure 4-3 a schematic east-west cross section of Zuid-Holland can be found.

The thickness of the Holocene coastal wedge reaches five to twenty meters. Sea level controlled sedimentation in the area started with the formation of the peat layer. In the

[4] Source: http://www.dinoloket.nl/nl/about/modellen/Three-dimensional%20property%20modelling%20of%20a%20complex%20fluvio-deltaic%20environment%20-%20Rhine-Meuse%20Delta%20The%20Netherlands.pdf

north and west of the Netherlands peat is a common type of soil. Peat is a soil that consists, besides peat, also plant material.

Natural sedimentation of rivers and estuaries largely ended after 1000-1200 AD when dikes were established throughout the area.

4.3. Building methods

For the building of the stations and the tracks, there were used different kind of building methods.

The station Wilhelminaplein is with 16 meters below the surface one of the deepest stations in the Netherlands. This station had to be built around the existing tunnel, which had to remain operational during construction work. Even though there was a lot of construction activity, the tunnel had to remain exactly in position, with a tolerance of just one millimeter.
The building method that has been used was building in reverse order. First the walls were poured and then the roof of the station was placed on top. The mass of the roof prevented the tunnel structure drifting upwards under the pressure of the ground water. After the tunnel had been excavated, the structural floors of the platform were poured. Then the tunnel was broken open to provide access to the subway. Last of all, the floors of the level between platform and the surface level were suspended as free-floating additions in the station.

Station Delfshaven was built in a different way. It lies beneath the Schiedamseweg. The station was built at a depth of 13 meters using the “wet” building method. This method was the only way to concur the ground water pressure. The pit was excavated in the ground water. After piling and depositing the floor, the dry grinding of the pit began.

The metro station Leuvehaven lies in the southern part of Schiedamsedijk. This station was built “in the dry” because of the presence of the weir by Maasboulevard. In the tunnel there are automatically functional doors that will close the tube when there is a high rise of the ground water.

Station Blijdorp was built with the “polder”construction. On both sides of the station, fourty meters deep diaphragm walls made of concrete were placed. After this, the space between these walls was excavated and the groundwater was pumped away. The tunnel from and to the station is bored with a TBM (see the figure below).

The tunnel underneath the Nieuwe Maas was built using prefabricating pieces that were sunk to the bottom. The caissons were built on the Eiland van Brienenoord and then navigated to the right place. The track from Rotterdam to the Maas was achieved using open pits.

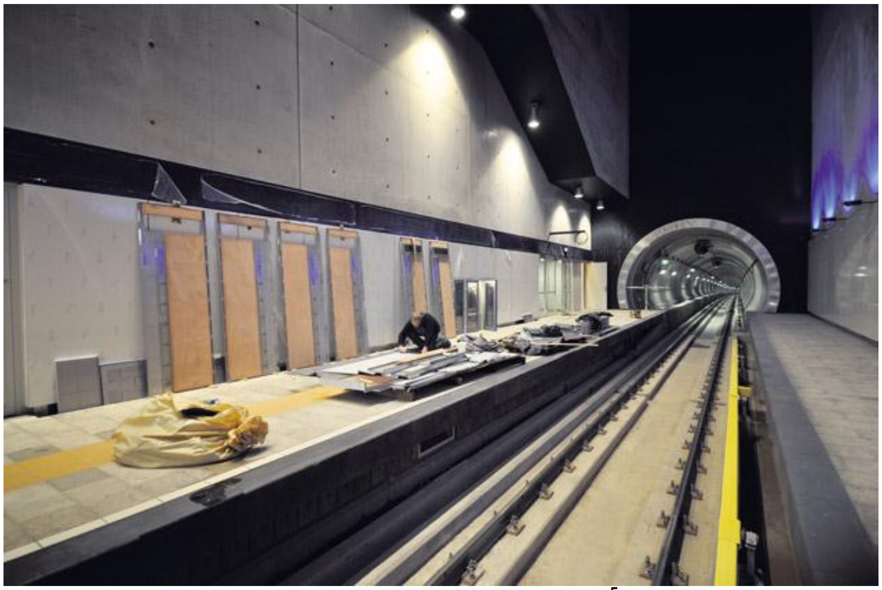

Figure 4-4: Tunnel at station Blijdorp, build with a TBM[5]

4.4. Safety and security

To give passengers a secure environment in the stations, architects give the stations a secure charisma. The new stations all consists these kind of aspects. A couple of aspects are intrusion of daylight, use of light material, mirrors, security cameras and so on. In the paragraph Stations, two of the new stations will be discussed further.

At the station Wilhelminaplein a great deal of attention was paid to the platforms, which are sloped because of the upward climb of the tunnel. The slope is visible in the

[5] Source: http://www.skyscrapercity.com/showthread.php?p=50529009

detailing of the station. For the safety of wheelchair-users and prams a banked gradient was created so that rolling objects veer away from the rails towards the sidewalls.

In the subway of Rotterdam a couple of little accidents had taken place. An example of an accident in a subway tube near station Slotlaan in 2009 is that two guys who were in a subway tube and probably spraying graffiti on the walls, were hit by a subway train which was having a test ride to check the switches and signals. One of the two guys died.

4.5. Rolling Stock

In this paragraph will be spoken about the different equipment that drives on the track.

Type MG2 (5001-5027, 5051-5066, 5101-5126, 5151-5152)
On 15 June 1966 the first vehicle of the subway of Rotterdam arrived in Rotterdam. The vehicle was made in Utrecht by manufacturer Werkspoor and was a vehicle of the serie 5001-5027. They were built from 1966 to 1975.The subway vehicles had the following dimensions: 29 meters long, 3,63 meter high and 2,676 meter wide. They had six direct current engines and a continue power of 49 kW. The maximum speed was around 80 km/h. After this serie other series were created. That were the series 5051-5066, 5101-5126 and 5151-5152. In the year 2002 the removal of these old vehicles began. The vehicles were always used on the Erasmusline (Line D).

In January 1972 there was placed an order for 28 subway-vehicles, numbered 5101-5126, with the German railway carriage named “Uerdingen AG werk Düsseldorf”. With the order of these vehicles, there were ordered also two special vehicles, 5151 and 5152, which were ordered as a test to try reverse flow system.
In Figure 4-5 the type MG2 can be found.

Figure 4-5: Subway-vehicles in Hilledijk

Type SG2 (5201-5271)
Because the lines A and B were on the ground floor, the vehicles on these lines must have the same safety requirements as the city trolley car, like rail brakes and alarm lights. In total there were 71 vehicles delivered, from which in 2006 11 of them were transformed for subway line E. The dimensions are: length 29,8 meter, weight of 43 ton and maximum speed of 80 km/h. They were built from 1980 to 1984.

Type MG2/1 (5301-5363)
In 1998 there was used new material for the Erasmusline which replaced the old vehicles. There were 63 vehicles delivered by Bombardier Eurorail. These days they are used on line C and D and are combined to type SG2/1. They were built from 1997 to 2001. The length of the vehicle is about 30,5 meters and has a maximum speed of 100 km/h.

Type SG2/1 (5401-5418)
The type SG2 (see the figure below) is on the following aspects different from the MG2/1: every vehicle has alarm light, rail brakes, a pantograph and extra windows for a better view at grade crossing.
These vehicles were built in 2002 by Bombardier Eurorail. The length is almost the same as the type MG2/1 and has the same maximum speed.

Figure 4-6: Vehicle type SG2/1

Type RSG2 (5261-5271)
Since 2010 the subway line E rides from The Hague Central to Rotterdam Central Station. The subway-tram type SG2 was provided with a different external look and were equipped with a protection system. Type SG2 was renamed type RSG2. At the end of 2009 the RSG2 vehicles were replaced with type RSG3. The maximum speed of this type was 80 km/h, had a length of 29,8 meters and were built from 1980 to 1984.

Type RSG3 (5501-5522)
In April 2008 the first “dubbelgelede” RandstadRail-verhicle came in Rotterdam. In total there were made 22 of these new vehicles by Bombardier Transportation in Germany. They were made to the highest requirements in the region of fire and crash safety. After a testing period, the vehicles were used in December 2008 on the line D and since January 2009 on the line E. They were built from 2007 to 2009, have a maximum speed of 100 km/h and a length of 42,71 meters.

In the figure below a picture can be found of vehicle 5501.

Figure 4-7: Vehicle 5501

Type SG3 (5601-5642)
On 3 July 2009 the first “dubbelgelede” subway-vehicle for lines A, B and C was introduced in Rotterdam. There were 42 new vehicles (5601-5642) built by Bombardier Transportation in Germany. Technically they are the same to the type RSG2, only the colour is different.

4.6. Stations

Two special stations of the subway of Rotterdam will be discussed in this paragraph. These are station Wilhelminaplein and station Blijdorp.

Station Wilhelminaplein
In 1990 the decision was made to realize a new station on the existing North-South line. The main point for this station was to create a luxurious look and quality finish in an effort to upgrade public transportation network to a fully-fledged alternative to transport by car. This ensured that the rapid growth of new constructions on this

location and the building of the Wilhelminahof could be resisted by the public transportation. The architects of this station are Zwarts and Jansma Architects.


Figure 4-8: Station Wilhelminaplein

In 1994 the work started with associated work of the station, with sometimes a bit of water leaking. The existing tunnel remained operational during construction work.
The building method of this station is special, as mentioned before in paragraph “Building methods”. In April 1997 the construction was completed.
There are two ways to access this station; one access is on the Erasmusbrug side, the other one on the Wilhelminahof. Because of the slope of the tube, the platforms are on a sloping too.

Because of the deep location of the station the entrance hall became twelve meters high. An opening in the roof provides the natural daylight in the station. At ground level this opening is shielded with an insulated glass balustrade.

In figure above and Figure 4-9 a picture can be found of the escalator which reaches to the platforms.

Figure 4-9: Station Wilhelminaplein

In July 2005 a new entrance was opened right across the Luxor Theater at the Wilhelminapier and is an entrance hall which is connected with a moving pavement. Visitors of the Luxor Theater can walk safe and secure from and to the theater. A picture of the moving pavement from Wilhelminaplein to Luxor Theater can be found in Figure 4-10.

Figure 4-10: Moving pavement from station Wilhelminaplein to Luxor Theater

When the subway arrives at the station, lights on the platforms go on. And when the subway leaves the station, the lights go off.

Station Blijdorp

Station Blijdorp is a new station in line E. It is the first station that lies between two drilled tunnels. The platforms are separated through glass walls and it needs certain requirements of fire safety. This station is, with a depth of 18 meters below the surface, the deepest station of the Netherlands.

Figure 4-11: Entrance station Blijdorp

On August 16th 2010 the station was partly opened for the passengers.
The architect of this station, and of the other stations for RandstadRail, is Maarten Struijs. The figure of the entrance of the station can be found in the figure above.

Station Blijdorp consists of materials like polished stone and enameled steel. The station is designed clean and uncluttered and gives passengers a secure feeling even under the ground thanks to the daylight. Passengers can reach the platforms with the stairs, an elevator and three excavators.

The lay-out of this station is equal to station Wilhelminaplein. Because of the depth of the station, passengers have to descend a lot. The escalators of the station can be seen in the figure below.

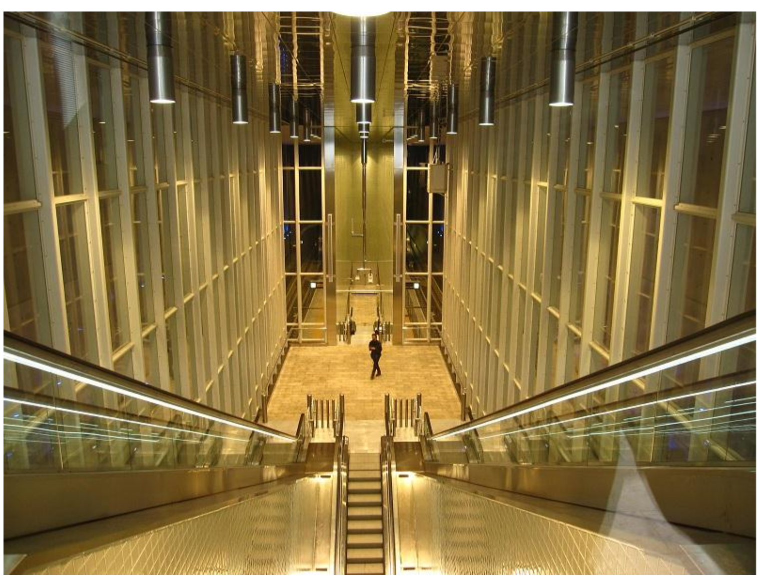

Figure 4-12: Escalator station Blijdorp

4.7. Future development

The subway of Rotterdam will be expanded in a couple of years. In this paragraph the expansions of the lines are discussed. In Figure 4-13 a featuring map of the subway of Rotterdam can be found.

Line A

In 2013 the Hoekse Lijn will be connected to the subway system, line A at Schiedam-Centrum. From that point, line A rides, in the rush hour, to Vlaardingen West.

Line B

In 2013 the Hoekse Lijn will also be connected to the line B at Schiedam-Centrum. From that point, the subway of line B rides to Hook of Holland. There will be a new station at that point, called Hook of Holland Beach.

Line D

From 2011 line E will use the track between Rotterdam Central and Slinge.

Line E

Line E will be expanded to station Slinge, so the subway will ride from Slinge to The Hague Central.

Other lines

Rotterdam is investigating the possibility to construct a whole new subway line from station Zuidplein to station Kralingse Zoom. In the stadiumpark there will be made a new football stadium, a 400 meters long ice rink and houses, firms, shops etcetera. This new line will advisory diversion of the tracks Kralingse Zoom to Beurs and Central Station to Zuidplein. In a later stadium the line can be expanded in western direction to Stadshaven.

In the spring of 2010 the community Prins Alexander has accepted the project Integrale Visie Alexanderknoop. The project started in the autumn of 2010 and is expected to open in 2030. Station Alexander will be completely renewed. The station will become longer in eastern direction; it is going to be roofed and it will get four tracks.
The reconstruction of station Rotterdam Alexander will happen in one of the last phases, because there will be undertunneling of the tramtrack.

Figure 4-13: Featuring map of the subway of Rotterdam

5. Conclusion

Looking at the decisions which were made for the start of the building of the subway systems, Berlin, London, Paris and Rotterdam have a large similarity. Each of the cities experienced a large demand for a better transport system. Because of the lack of space, all the cities decided to use the underground for this. This way, the traffic would also decrease in the city centers. Still, there was a lot of difference between the ways of making the subways.

At first, when looking at the history of the subways of the different cities, it was clear that London was the leader of the subway system. Soon Paris and Berlin followed with their systems, when it was clear that the subway system in London was a great success. Rotterdam on the other hand decided to build a subway system only in the late 20th century, which was over a century behind on the other cities.
Another difference is the extent to which the subway systems are connected with other districts around the city. Nowadays, London and Berlin have a wide area of connections to the subway, whereas the Parisian subway only covers the city center. Rotterdam is now also increasingly connecting the suburbs. In the future this subway will be expanded even more.

Also, the geological aspects of the underground of the cities were described. Unfortunately, the specific information about the underground of Paris could not be found, so when only considering the three other cities, it is clear that Berlin and London have a much easier geological composition than the underground of Rotterdam. This is probably the reason why the building of the subway in Rotterdam started only a few decades ago. This can also be found in the building methods; where London, Paris and Berlin used the cut-and-cover method in the beginning, Rotterdam had to use the bore method as well. Probably Paris has also a relatively easy underground. Still, another reason for Rotterdam to use the bore method is because of the lack of space; the cut-and-cover method needs a lot of space. Because London already started in 1863, they were far ahead of the other cities that have been discussed. This is the reason why the engineers started this early with another building method, compared with Paris, Berlin and Rotterdam.
It also shows clearly that the building methods become more and more complex in time. Nowadays all the cities can cross rivers, groundwaterheads, buildings, etcetera, whereas these constructions weren't possible in the beginning of the subway system.

Safety and security nowadays is a lot better than a century ago. Especially fires in tunnels have had an important influence on history; these were an important reason to reach a better safety level in the tunnels. This was the case in Paris as well as Berlin and London.
A century ago, there wasn't a subway in Rotterdam. When Rotterdam started building, the safety levels had already improved a lot in the other cities, so Rotterdam could copy

a lot of safety improvements. This could be the explanation for the limited number of accidents in Rotterdam.
There are also a lot of improvements to increase the experiences of the travellers in the latest decades. This is especially clear at the stations. Whereas Paris has a whole garden next to the station and Rotterdam has windows in the roofs for daylight, some of the stations of Berlin and London are totally renovated to facilitate more space and light, which gives the traveller a safe feeling.

Lastly, there are already new plans for expanding or improving the subway systems. So in all these cities, there will still be a lot of work in the future to optimize the public transportation systems.

When we were writing this paper, we also found another interesting aspect: the influence of big events. For the cities discussed, this definitely plays a role. The world fair in Paris was the reason for expanding the subway system and in London the expanding of the transport system is now in progress, because of the Olympic Games in 2012. In the future, Rotterdam will get a new football stadium, which will also mean that the system has to expand to handle the pressure of the visitors.

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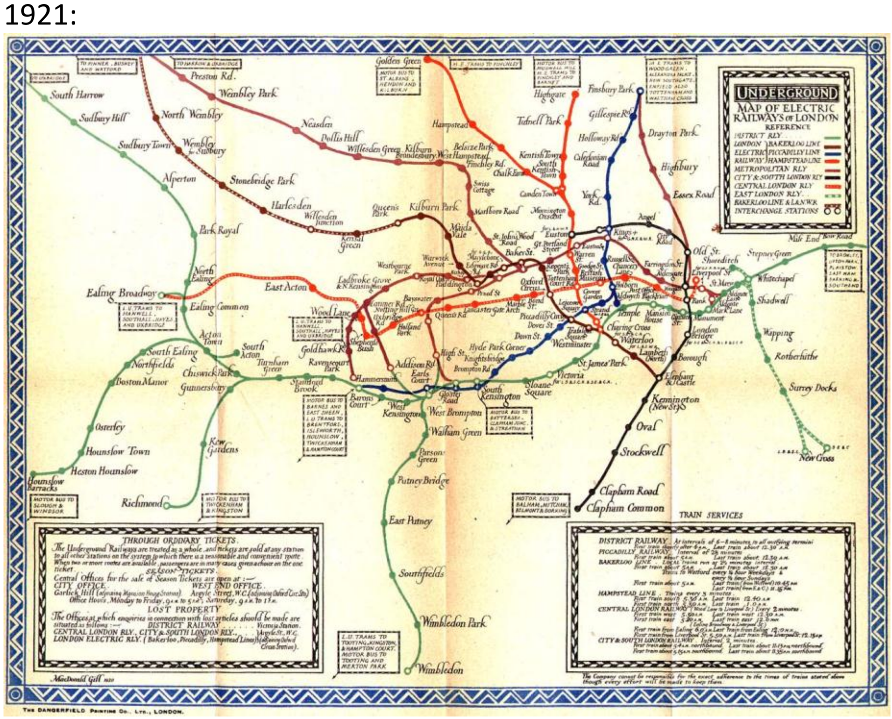
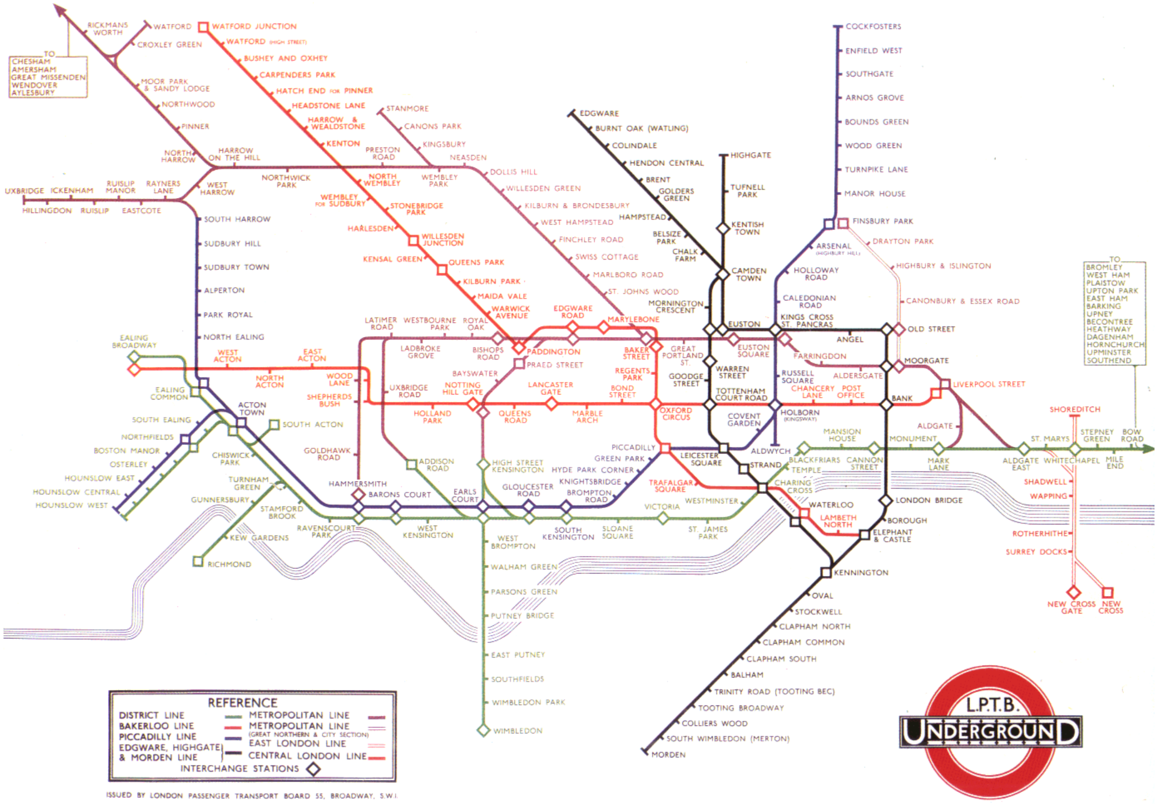
Appendix 1: Maps of the London Underground throughout the years

1908:

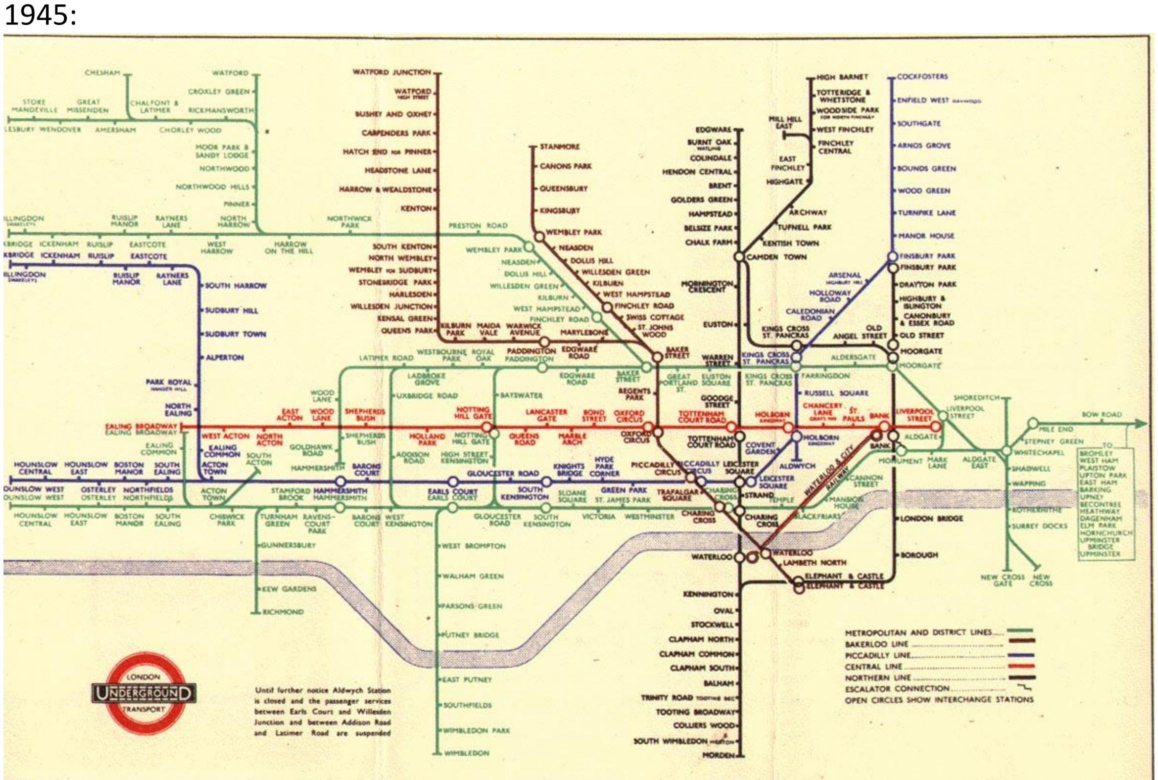
1921:



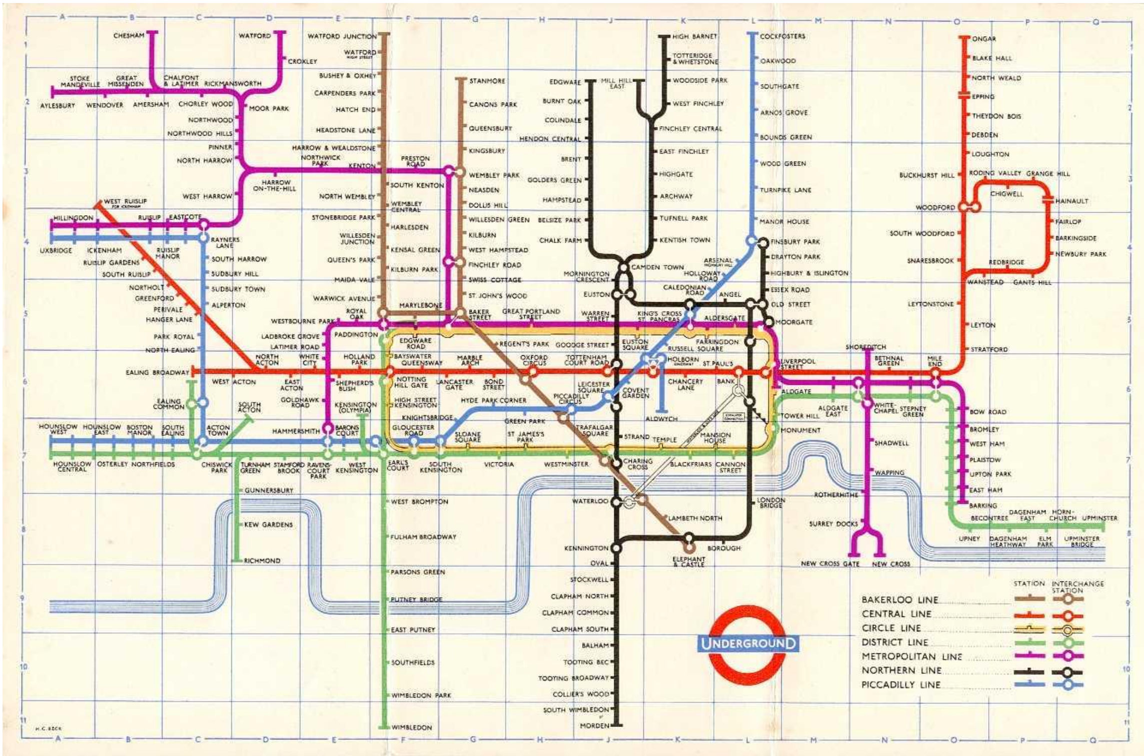
1933:


REFERENCE
DISTRICT LINE
BAKERLOO LINE
PICCADILLY LINE
EDGWARE, HIGHGATE & MORDEN LINE
METROPOLITAN LINE
METROPOLITAN LINE (GREAT NORTHERN & CITY SECTION)
EAST LONDON LINE
CENTRAL LONDON LINE
INTERCHANGE STATIONS
ISSUED BY LONDON PASSENGER TRANSPORT BOARD 55, BROADWAY, S.W.1
L.P.T.B.
UNDERGROUND

1945:


METROPOLITAN AND DISTRICT LINES
BAKERLOO LINE
PICCADILLY LINE
CENTRAL LINE
NORTHERN LINE
ESCALATOR CONNECTION
OPEN CIRCLES SHOW INTERCHANGE STATIONS
LONDON
UNDERGROUND
TRANSPORT
Until further notice Aldwych Station is closed and the passenger services between Earls Court and Willesden Junction and between Addison Road and Latimer Road are suspended

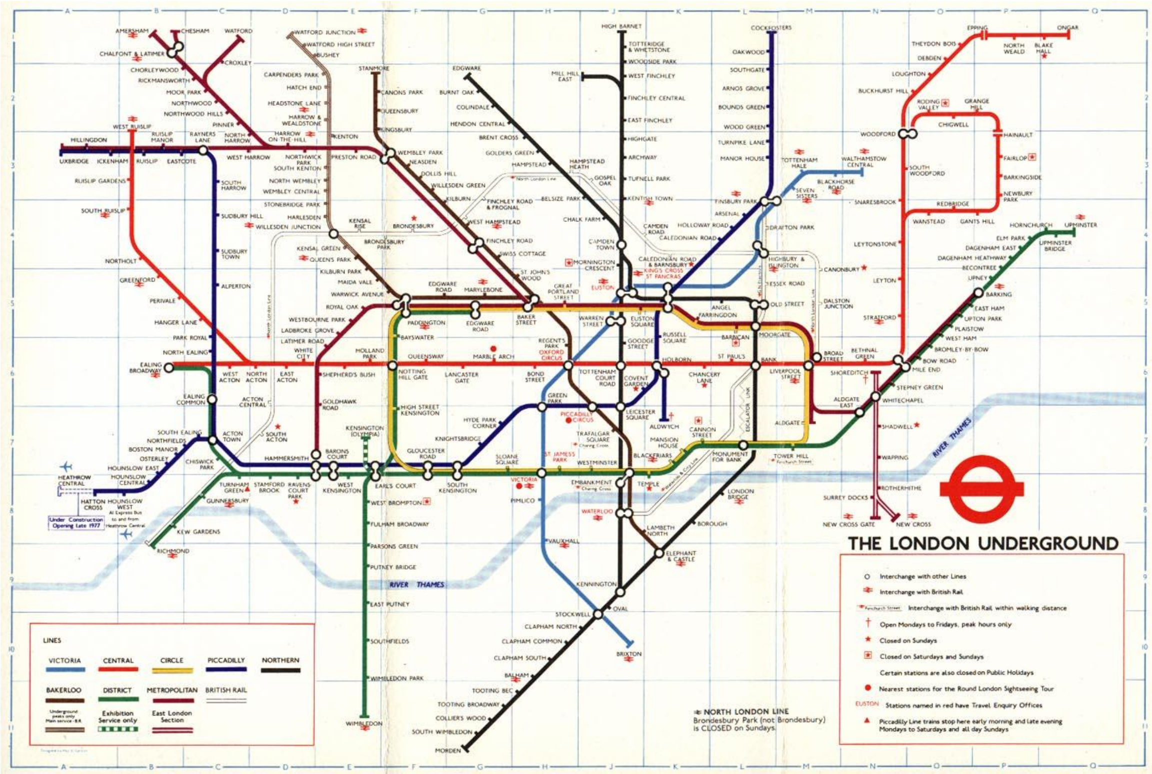
1958:


UNDERGROUND
BAKERLOO LINE
CENTRAL LINE
CIRCLE LINE
DISTRICT LINE
METROPOLITAN LINE
NORTHERN LINE
PICCADILLY LINE
STATION
INTERCHANGE STATION

1968:


UNDERGROUND
RIVER THAMES
Victoria Line under construction
Opening Highbury to Warren Street .... December 1968
Warren Street to Victoria ....Spring 1969

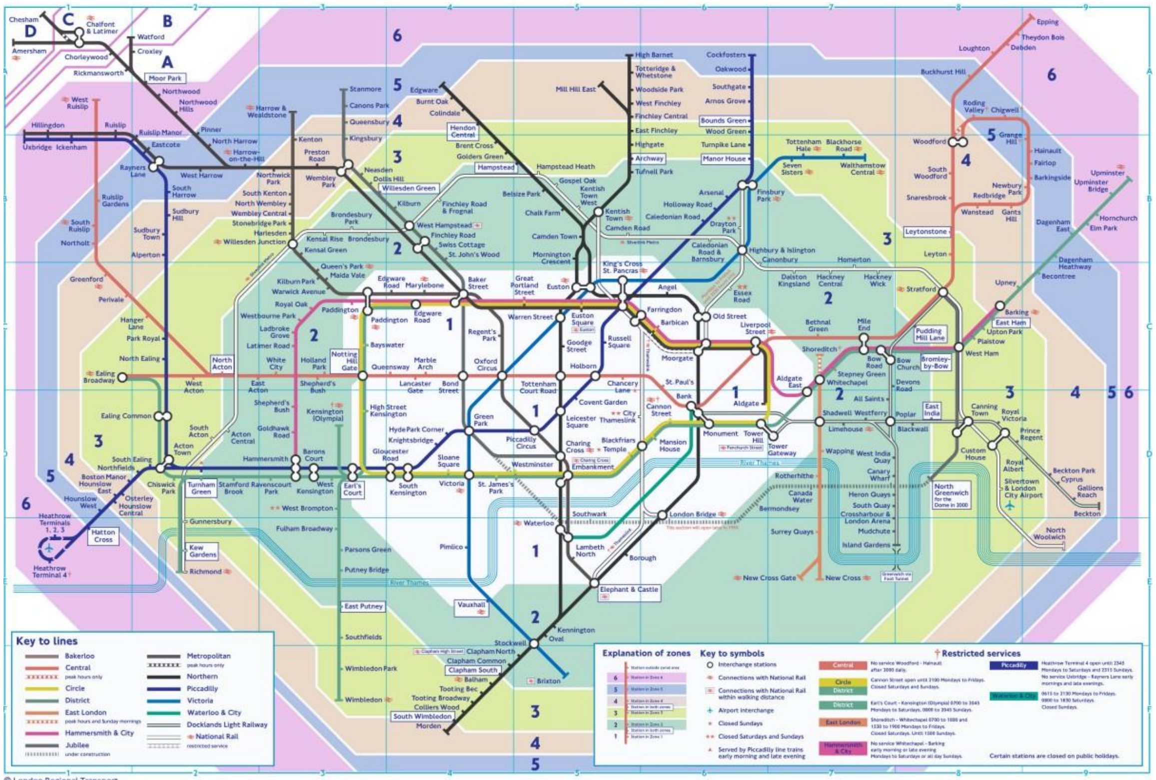
1977:


THE LONDON UNDERGROUND
RIVER THAMES
LINES
VICTORIA
CENTRAL
CIRCLE
PICCADILLY
NORTHERN
BAKERLOO
DISTRICT
METROPOLITAN
BRITISH RAIL

1987:

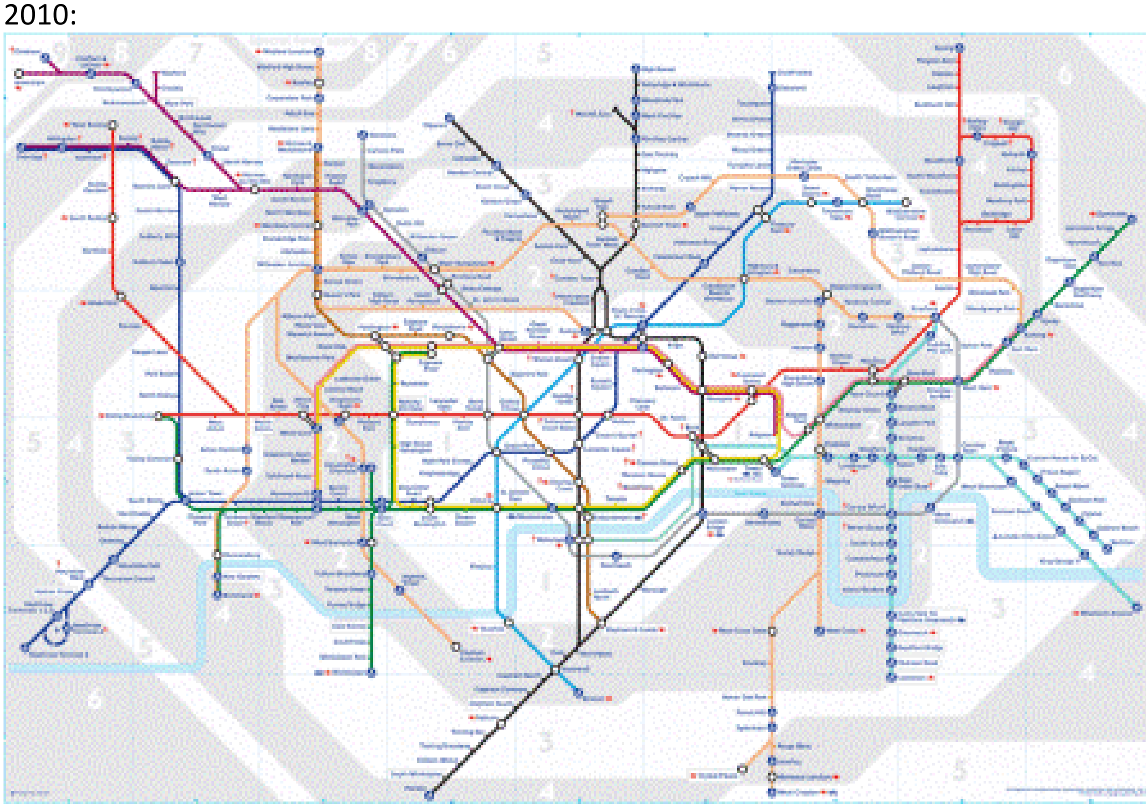

Colour Key to lines
Bakerloo
East London
Piccadilly
Central
Jubilee
Victoria
Circle
Metropolitan
British Rail
District
Northern
Docklands Light Railway
Key to symbols
UNDERGROUND
RIVER THAMES

1999:



© London Regional Transport

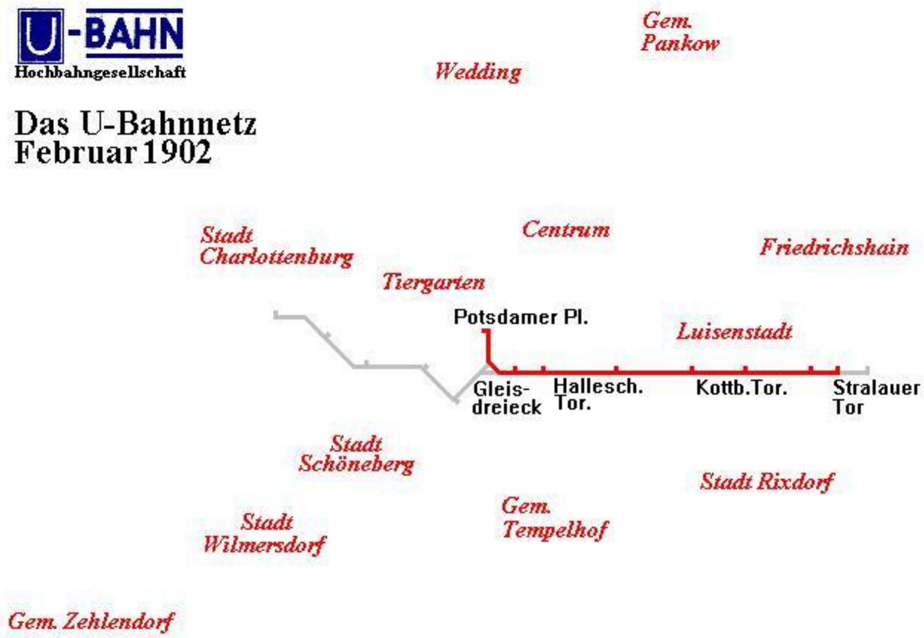
2010:



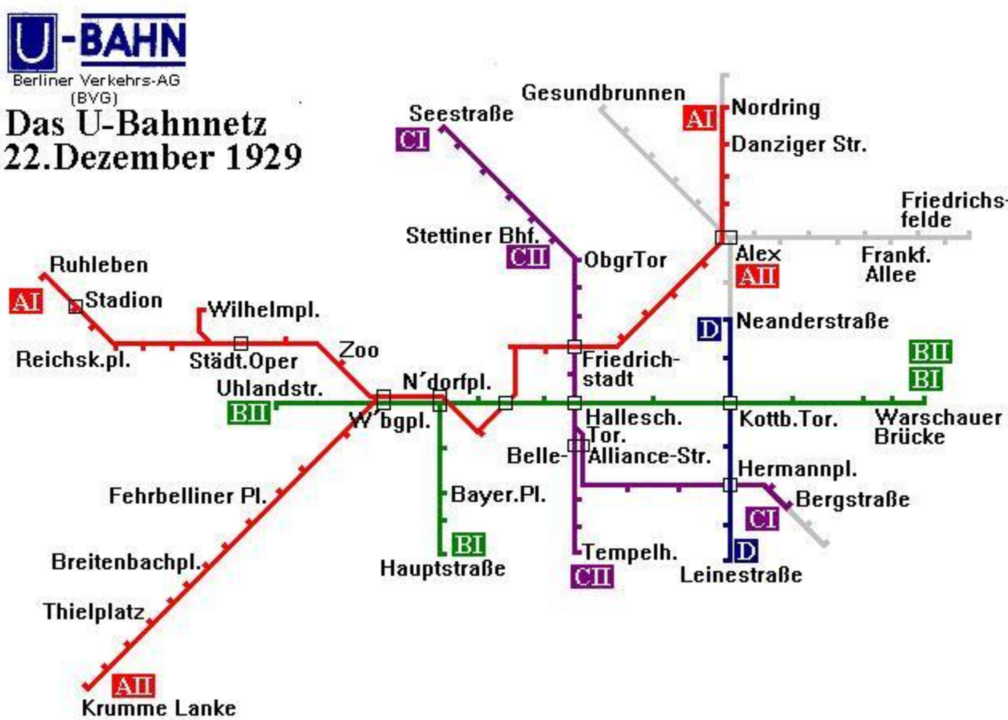
Appendix 2: Berlin

Maps of the Berlin Underground throughout the years.

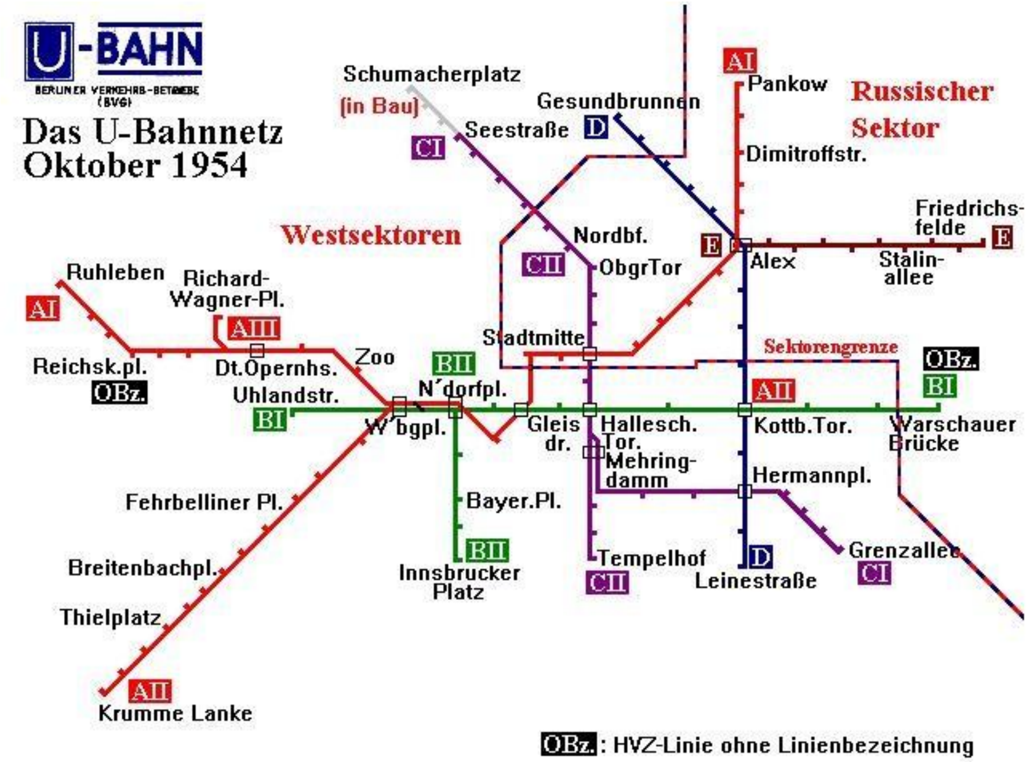
1902: First line



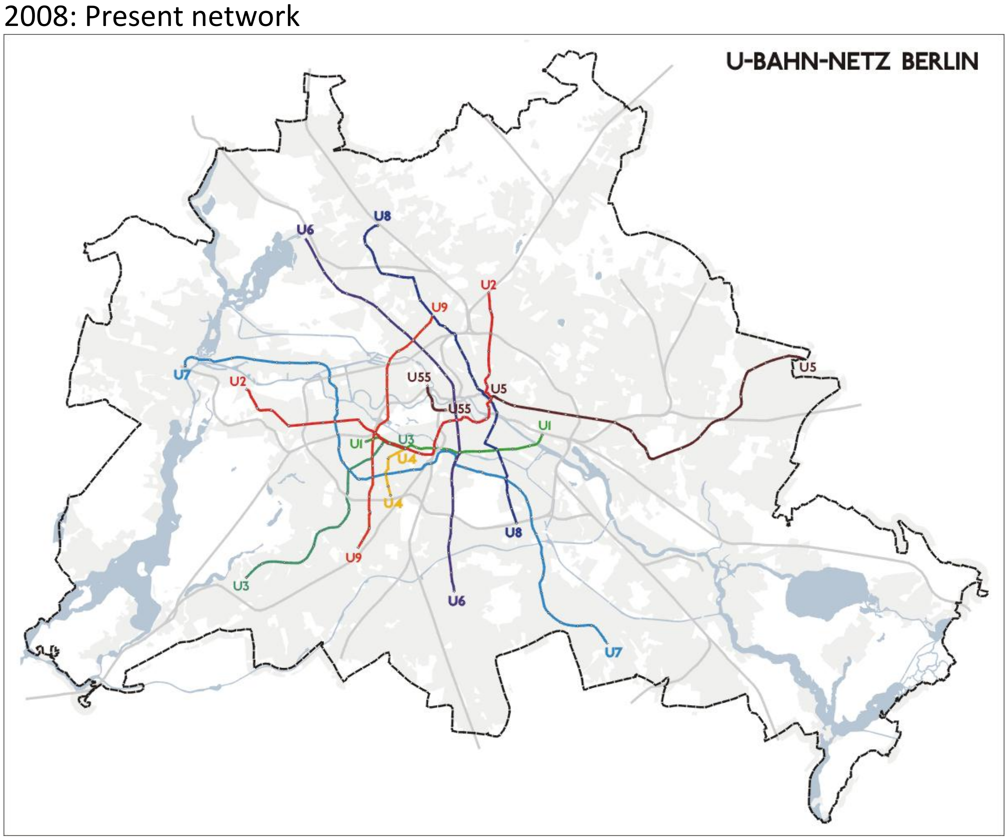
1929: Network at the end of the second period



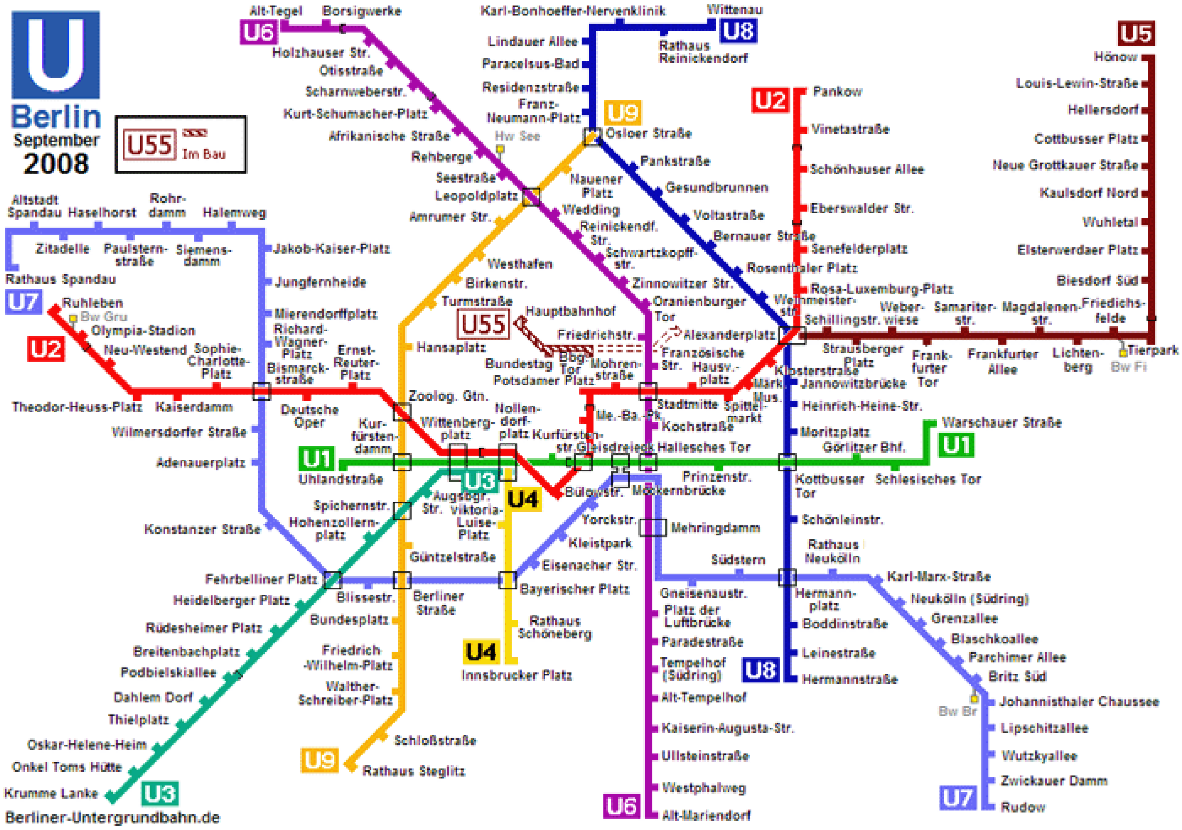
1954:



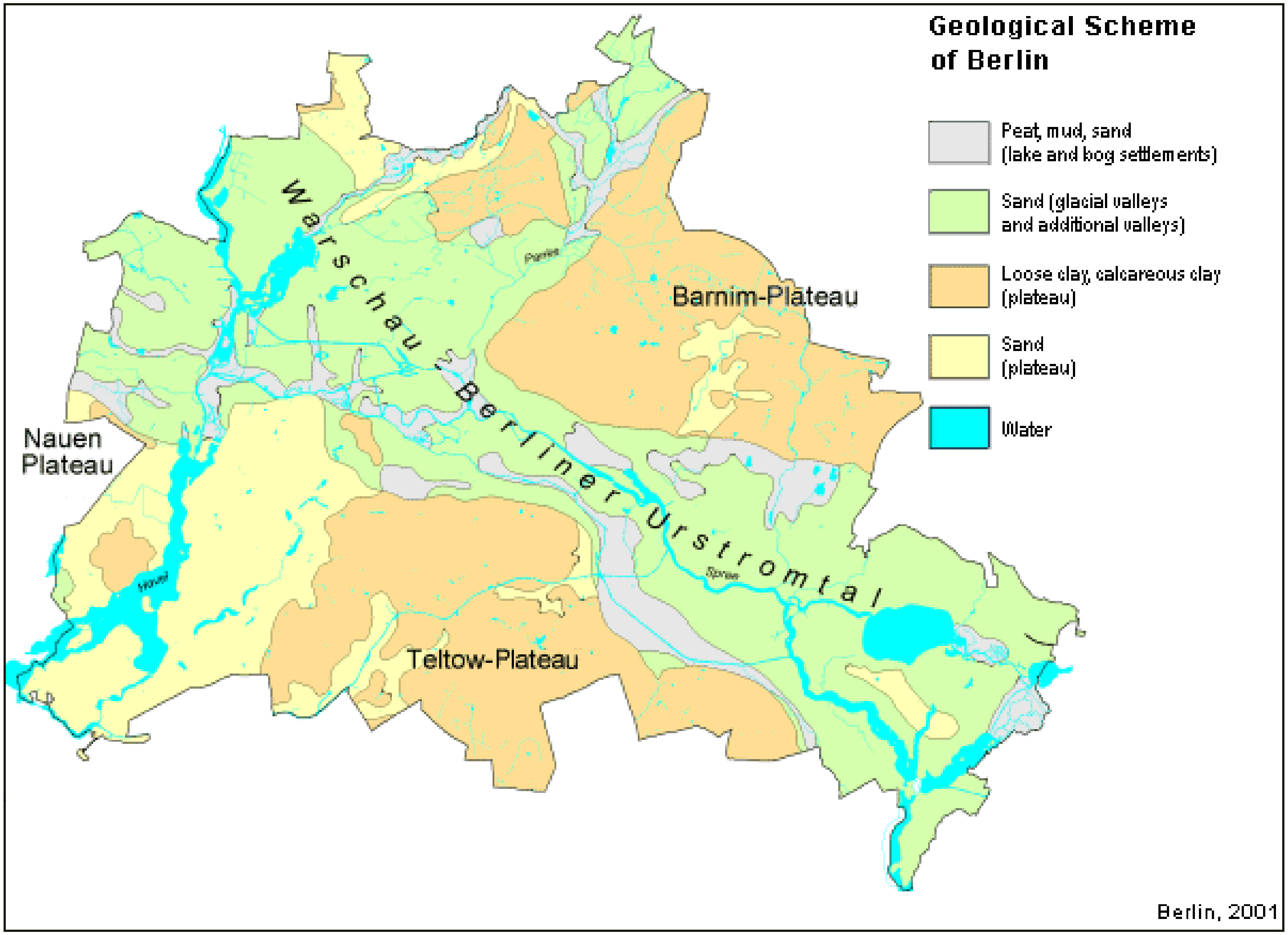
2008: Present network



2008: Present network



On the next page, a geological scheme of Berlin can be found.


Geological Scheme of Berlin
Peat, mud, sand (lake and bog settlements)
Sand (glacial valleys and additional valleys)
Loose clay, calcareous clay (plateau)
Sand (plateau)
Water
Barnim-Plateau
Nauen Plateau
Teltow-Plateau
Warschau-Berliner Urstromtal
Berlin, 2001