Risks of underground methane gas in construction projects

A survey on methane gas concentration in Gothenburg, Sweden

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Abstract

Construction companies in the modern era consider all things, from the precise measurement and placement of the poles to the finishing touches of the facade. Before the commencement of construction work, environmental consultants sample the soil, including soil properties and hazardous contaminants. In part, this is to minimise economic hazards due to unexpected costs regarding the removal of soils, that are not technically appropriate, and reduce the risks of unexpected exposure to harmful substances during the construction process.

Methane, CH_4, is found in nature as it is formed by the decomposition of organic material. The gas is light, allowing it to migrate underground or accumulate in pockets depending on the soil properties and their compositions. When reaching concentrations of 5–15%, the gas is combustible and flammable (CIRIA, 2006). Throughout history, methane gas has been the cause of accidents and fatalities as it has not been adequately acknowledged. In addition to explosions, the gas can intoxicate workers if they inhale excessively (Wisconsin Department of Health Service, n.d.).

The purpose of this thesis is to determine whether methane gas concentration should be considered prior to and throughout construction work. The method is a combined approach of fieldwork, literature study and an interview. The fieldwork took place throughout Gothenburg to measure methane gas concentration and water level in groundwater monitoring wells. Gas concentrations were taken at a parking lot, an industrial area, an old landfill, old properties and a gas station. Previous reports from WSP, a consultant and advisory company in community development, provided information about the soil and its sequence for each location.

Results from the fieldwork show that CH_4 concentrations are 0.0% or 0.1% in regions with clay, man-made ground and gravelly sand. The areas with higher CH_4 concentrations consist of sediments that have been deposited in fluvial environments.

Keywords: Methane, Construction, Methane migration, Remediation, Soil properties

Sammanfattning

Byggföretag har i dagens läge mycket att beakta, från den exakta mätningen och placeringen av pålar till fasadens slutliga detaljer. Innan konstruktionsarbetet börjar tar miljökonsulter prover på marken, bland annat för att ta reda på markens egenskaper och föroreningsnivåer utifrån planerad markanvändning. Det är delvis för att minska risken för oförutsedda kostnader i samband med borttransport av överskottsmassor samt exponering av skadliga ämnen under byggprocessen.

Metan, CH_4, förekommer i naturen eftersom den bildas vid nedbrytning av organiska material. Gasen är lätt vilket gör att den migrerar under marken eller ackumuleras i fickor beroende på jordens egenskaper och sammansättning. När metangas når koncentrationer på 5–15% är den brandfarlig och lättantändlig (CIRIA, 2006). Genom historiens gång har metangas varit orsaken till olyckor och dödsfall eftersom den inte har uppmärksammats ordentligt. Förutom explosioner kan gasen vid inandningen av för stora mängder leda till förgiftning (Wisconsin Department of Health Service, n.d.).

Syftet med det här examensarbetet är att fastställa om metangaskoncentrationer bör beaktas före och under byggnadsarbete. Metoden är en kombination av fältarbete, litteraturstudier och en intervju. Fältarbetet genomfördes på flera platser i Göteborg för att mäta metangaskoncentrationer och vattennivån i grundvattenrör. Gaskoncentrationer togs på en parkeringsplats, ett industriområde, en gammal deponi, gamla fastigheter och en bensinstation. Tidigare fältrapporter från WSP, en rådgivare och konsultbolag inom samhällsutveckling, tillhandahöll information om jordarter och jordlagerföljd för varje plats.

Resultatet från fältarbetet visar att CH_4 koncentrationer är 0,0% eller 0,1% i områden med lera, fyllnadsmaterial och grusig sand. Områden med högre CH_4 koncentrationer återfanns i sediment som avsatts i fluviala miljöer.

Nyckelord: Metan, Byggnation, Metan migration, Åtgärder, Mark egenskaper

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1. Introduction

The worldwide population continues to increase at a rapid growth rate, making it necessary to develop homes and properties to facilitate the citizen's everyday life. Preparations before construction work begins are required due to various factors, particularly from a geologic perspective. Examples include soil stability, bedrock, risk of settlement and landslides (WSP, 2023). In recent decades, awareness of gas concentration in the soil has become more acknowledged due to hazards and health threats. A typical scenario is radon, a radioactive gas that is formed when radium disintegrates in the bedrock. Radon can also be released from building materials, for example the blue lightweight concrete that was manufactured up until 1975 (Swedish Radiation Safety Authority, n.d.). From then on, construction companies were attentive to the harmful emissions from material and below the surface. When developing properties in areas where radon concentrations are known, measurements are taken before the construction work, as well as safety precautions.

Another gas that poses a threat and health risk is methane that occurs naturally from the decomposition of organic material (Nazaries et al., 2013). It is combustible at low concentrations and constitutes a danger to construction workers through gas poisoning and ignition. Environmental consultants' analysis of methane in soil sampling is generally limited to landfills because of the known elevated CH_4 concentrations that tend to appear in such locations. If there is a high level of methane gas during excavation, the gas can combust when an excavator strikes a rock or other hard objects, causing a spark (WSP, 2023). Despite the known consequences of methane gas in soil, it is not monitored as radon prior to construction work.

1.1 Purpose

The purpose of this thesis is to examine whether methane gas measurements should be taken and considered in building projects in the Gothenburg region, as investigations are only performed in areas with known landfills and man-made ground.

1.2 Thesis implementation

In order to identify the impact of methane gas in construction projects, CH_4 concentrations will be analysed in 16 groundwater monitoring wells throughout Gothenburg, however the exact locations will not be given out due to privacy reasons. Fieldwork will take place at a parking lot, a gas station, old properties, an old landfill and an industrial area to examine whether high methane concentrations may be present in areas that are not active landfills. The areas were chosen based on the availability of groundwater wells. The aim is to determine, based on the measured methane concentrations, possible correlations and parameters that may have an influence on methane gas, but also conclude whether it should be measured everywhere prior to construction work or only at specific sites with certain soil properties and content. Parameters including soil type, composition, man-made ground, meteorological factors and water level are considered in this study.

In this thesis, the occurrences of methane in various environments and locations are going to be discussed along with its mobility, treatment, precautionary actions and companies' perspectives on methane gas.

2. Background

Methane is a greenhouse gas (GHG) that contributes to 20% of global warming. However, it does not have a long lifetime in the atmosphere as it remains there for about 8-10 years. Compared to carbon dioxide, the most abundant anthropogenic GHG, methane is 25 times more effective at capturing heat in the atmosphere (Nazaries et al., 2013). Methane is also the main contributor to ground-level ozone, O_3, another harmful GHG. By reducing CH_4 emissions there will be a subsequent decrease in ground-level ozone each year that could prevent millions of tonnes of crop losses, premature deaths and asthma-related hospital visits (UN Environment Programme, 2021).

These hydrocarbons are created in anoxic environments by the decomposition of organic matter in wetlands, landfills and ruminant animals (Nazaries et al., 2013). The microbial process is called methanogenesis, with methane being generated as the final product of metabolism through anaerobic respiration (Lyu et al., 2018). Higher temperatures and organic matter in the ground increase methanogenesis. Even water-saturated soil and moisture conditions increase the production of methane. Less precipitation will fall in some parts of the Earth, a result of rising worldwide temperatures, causing the soil to dry out. This would decelerate methane development while promoting aerobic methane oxidation, eventually reducing gas emissions (Yang et al., 2021). According to the 6th Intergovernmental Panel on Climate Change (IPCC, 2021) report, the observed trends show that there will be an intensification of heavy precipitation in all of Europe, North America and Asia that can increase methane generation with higher soil water content.

Once methane is formed it can either dissipate by migrating or accumulate underground. Coarse aggregates, macadam and sand can transport methane gas at low pressure for longer distances, whereas clay and till have limited transport capacity. Clay can preserve the gas in soil patches and hinder its movement (Avfall Sverige, 2010). If there is peat, loam and organic residues in the soil, there is a high chance of ongoing methanogenesis because of organic degradation (Lyu et al., 2018). According to NHBC (2007), the concentration of methane gas rarely exceeds 0.1% in the soil if there is no active source that generates the gas.

2.1 Climate impact

The largest sources accounting for 63% of the anthropogenic atmosphere methane are ruminants, rice culture, landfills, biomass burning, waste treatment and fossil fuel (Nazaries et al., 2013). Ruminants, such as cows and sheep have a chamber called rumen where methane is produced by the microorganisms, methanogenic archaea. When their food is digested, certain fermentation products, notably methyl-containing compounds, CO_2 and H_2 are not absorbed. These end products are metabolised to CH_4 and its formation is completed by methanogens, a group of microbes. The gas is released by eructation and is called enteric fermentation (Attwood et al., 2011).

2.2 Gas poisoning

Methane gas is colourless and odourless, when it is used for commercial purposes, an odorant is added so that workers can identify gas leaks (Wisconsin Department of Health Service, n.d.). The gas can combine with hydrogen sulphide, which smells like rotten eggs at H_2S concentration < 1 ppm (U.S. Environmental Protection Agency [EPA], 2020). Methane gas is a hazard due to asphyxiation, explosion, flammability and long-term health impacts from prolonged contact. Given that methane is less dense than oxygen, it displaces ambient air and reduces the availability of oxygen. If the oxygen levels are less than 15% in the air, a person may experience headaches, dizziness or fatigue (Wisconsin Department of Health Service, n.d.).

In Sweden there is no limit set for CH_4 concentrations in the air, however countries such as Ireland, Canada and Belgium have limit values of 1000 ppm that can serve as a guideline. There is also no limit value for oxygen at Swedish workplaces, but standard atmospheric air contains 21% oxygen (Swedish Work Environment Authority, n.d.).

2.3 Landfill

2.3.1 Regulations on landfills

Waste that is not recyclable is frequently disposed of at dump sites. This can include industrial waste, household waste, excavation masses, construction waste etc. The biodegradation of organic waste in landfills under anaerobic conditions produces a gas that generally consists of 45-55% CH_4, 25-40% CO_2 and other trace gases (Avfall Sverige, 2010). The composition of landfill gas can vary due to temperature, the site’s age, waste composition and moisture content (EPA, 2020). The gas, especially methane, has a low density that allows it to be moved over greater distances underneath hardened surfaces. Examples include channels, conduit trenches, drainage and in cracks where gas resistance is lowest (Ramboll, 2018). The gas can be utilised for the purpose of electricity generation, industrial energy and district heating. The extraction systems require large quantities of methane gas and are a costly investment, so the market is limited because investors are difficult to attract (Avfall Sverige, 2010).

Precautionary actions against methane and landfill gas at dump sites can be carried out by having a permeable layer in the ground. It is gas dispersive and can consist of macadam, ventilation pipes, drainage pipes and gas drainage shafts underneath a sealing layer. There can also be methane oxidising covers where the gas is passed through oxidising filters. Through microbial decomposition, methane is converted into carbon dioxide (Avfall Sverige, 2010).

2.3.2 Leachate

When rainwater infiltrates material at landfills, it extracts harmful substances and transports them. This is termed leachate and can form at closed dump sites when groundwater and surface water enter the contaminated area. From 8 to 12 million cubic meters of leachate is collected per year from landfills containing commercial and household waste in Sweden. The polluted water fluctuates depending on decomposition, temperature and rainfall in the area. To prevent leachate and other toxic compounds, it is important to seal and cap the landfill (Swedish Environmental Protection Agency, 2008).

The Swedish Geotechnical Institute (SGI, n.d.-a) noted that leachate pump stations at landfills have exploded due to the explosiveness of the gases. In one case, a small building in Gothenburg whose sewage pipes were connected to a leachate pipeline, combusted. Migrating landfill gases have resulted in fires and explosions in buildings within dump sites and explosions in wells at facilities dealing with gases. The risks are greatest at the landfill but occur outside the area as well (Ramboll, 2018).

2.3.3 Suspension of a landfill

The capping of the landfill is composed of various layers with contrasting properties such as levelling, sealing, drainage and protection. The materials used for coverage include bentonite mat, stone flour, drainage gravel and cover soil. In general, a clay layer is applied on top of the waste as its low permeability minimises the percolation of surface water into the ground. A bottom seal can also be placed over a geological barrier, for example, a plastic geomembrane that makes the bottom structure impermeable. The geological barriers provide protection and should consist of continuous layers with properties and durability similar to natural soil (SGI, n.d.-a).

Although old landfills are sealed and covered, it is not advised to build houses on them as there are risks. The settlement potential is extensive because it can take a considerable time for the subsidence to be initiated. This tends to be the case when soil conditions change as oxygen and moisture from construction work are added. If construction work is to continue, the organic material generating gases should in most cases be removed. Pipelines and ditches need to be constructed in an arrangement to prevent gas from entering the buildings. A certain level of soil remediation may be required in the area as there is a degree of remediation depending on the surrounding environment and land use (SGI, n.d.-b).

2.4 Migration of methane gas

2.4.1 Parameters that influence gas migration

Methane gas flows below the surface due to multiple factors including geological parameters, vegetation, tidal effects, meteorological conditions and construction work (NHBC, 2007). As intense precipitation will become more frequent (IPCC, 2021), it will affect groundwater by raising water levels. This will reduce the pore space available for methane gas while increasing the CH_4 concentration in the soil. The enhanced groundwater will over time raise the ambient pressure in the pore spaces, leading to increased gas migration to neighbouring buildings and pipes. Rain and freezing temperatures can temporarily seal a clay-rich soil surface resulting in gas migration or trapping it underground. When the gas has no escape route, the methane generation will continue at the same pace, leading to increased gas pressure (NHBC, 2007).

Atmospheric pressure has a significant impact on gas in the soil. At increasing pressure, air flows into the ground that in turn reduces methane concentrations as they are diluted by air. At lower pressures, the gas will expand, increasing the emission rates. Atmospheric pressure can also influence solubility as high pressures increase the solubility of several gases. Gases are released from water at low pressure and lead to the release of large quantities of gas from the ground to the atmosphere and/or to properties. Solubility is affected by temperature as it increases with decreasing temperatures. It can also affect the amount of gas emitted from the ground. An increase in gas solubility with increasing pressure results in a lower gas concentration as the gas dissolves in water rather than remaining in the ground as a gas (NHBC, 2007).

Another driving force is the rate of pressure fluctuation, although there is little change if there is a gradual decrease over a larger pressure range. There must be a rapid drop over a small pressure range with the potential to produce larger concentrations and flow rates of ground gases. The humidity of the soil affects the magnitude of the pressure effect, if the ground is arid, the reaction to pressure fluctuations will be rapid. If the ground is saturated or moist, the changes in atmospheric pressure are attenuated to an extent. The pressure gradient can be caused by the difference in temperature and wind effect. At low pressure the gas in the soil expands, causing increased emission rates. High pressure dilutes the gas concentration as the pressure causes air to flow into the ground (NHBC, 2007).

2.4.2 Driving mechanisms

Advection, a pressure-driven flow, is one of two mechanisms of gas migration that transfers substances through the flow of air under pressure or a fluid. It requires a pressure gradient from a gas generation at the source, barometric pressure fluctuations or pressurised discharge. The parameters that determine the flow rate are the gas permeability of the rock or soil, the pressure gradient, the water saturation of the soil and the thickness of the flow path. Advection may also happen because of wind-driven pressure gradient, operation of elevators in shafts and the Stack effects (EPA, 2020).

Diffusion, the second mechanism, is the flow and concentration gradient that transfers substances from areas of greater abundance to lower abundance. The kinetic properties of particles are the outcome of diffusion. The parameters that influence the mechanisms are temperature, the thickness of the flow path, water saturation of the soil, the concentration gradient and the diffusion coefficient of ground gas temperature. Migration and intrusion of ground gases are caused by diffusion if there is no active source nearby, but if there is an active source, advection is the cause of the migrating gas (EPA, 2020).

Migration of soil gas into properties also occurs through barometric pumping when the barometric pressure drops rapidly. This results in an enchanted pressure gradient as it takes time for the pressure in the ground to adjust. Thermal convection (Stack effect), mechanical ventilation systems and wind flow surrounding buildings can decrease air pressure at the bottom of the building and generate an inward pressure gradient. Gas pathways are dependent on the structure and condition of the building. The most likely routes for the gas are cracks, service penetrations, poorly filled construction joints and slab-on-ground construction. Other common passages underground is from service channels, trenches, piles, drains and elevator shafts (EPA, 2020).

2.4.3 Gas migration into buildings

During construction work and surface capping, new routes for migrating gas can be established beneath developments and/or off-site. When gases migrate towards buildings it is caused by pressure gradients between the building interior and ground. The negative pressure relative to the atmospheric pressure can occur in construction as a consequence of *Stack effect* and *Venturi effect,* explained below (CIRCA, 2006).

The Stack effect occurs when air is drawn into a facility by a pressure difference that occurs when the internal temperature of the building is hotter than the outside. This can take place through the entrance in the ground floor construction or within the external envelope of the facility. In a heated building, the warm air and gas rise through the Stack effect and spread throughout the facility while in a well-insulated building, air and soil are brought in through the ground floor (CIRCA, 2006). The effect can be applied as natural ventilation in larger buildings by creating an opening that is higher in the building and an opening that is lower. If the outside temperature is lower than the building temperature, the warmer air inside will flow up and out of the higher opening as warm air is less dense than cold air. Cool air will be drawn in due to a vacuum through the lower opening (Moffitt Natural Ventilation Solutions, n.d.).

The Venturi effect occurs when positive air pressure is established on the side of the building exposed to wind pressure. Suction occurs on the leeward side, if there are openings on the wall, the internal pressure decreases as the air is sucked out through the gaps. A pressure gradient is created between the inside and outside and the gas in the ground can be drawn into the facility through entry points in the ground floor. The Venturi effect, like the Stack effect, can be used for natural ventilation in buildings. The pressure difference provides a natural flow that can be utilised by creating natural ventilation in the structures of walkways and properties. To induce natural ventilation, Venturi tubes are installed along the roof line. The air from the outside is drawn in while the air from the inside will be pushed out because the pipework creates a low pressure at the opening of the building (Cadence System Analysis, n.d.).

2.4.3 Consequences of gas migration

When gas intrudes buildings and structures, it is dangerous as it can accumulate in explosive or toxic concentrations, notably in confined spaces and small rooms. It can even gather in storerooms, electrical cabinets, wells and areas with limited ventilation. Of particular concern is that the gas, due to its properties, can migrate through pipelines and end up in descending wells. The mass of new buildings can also prevent gas from escaping the ground, causing it to migrate to nearby properties (Ramboll, 2018).

In addition to a gas-tight foundation, further measurements can be overpressured in the building, ventilation measures and ventilation of lower floors in the compartment can help reduce the migration of methane gas into buildings (Ramboll, 2018).

2.5 Eliminating methane gas from buildings

2.5.1. Active precaution measure

Methane gas accumulation in buildings is common and there are active protection procedures involving systems that incorporate maintenance, mechanical components and inspection. Sub-slab depressurization is a system for vapour intrusion that utilises blowers or fans to maintain the pressure in a sub-slab, beneath the foundation. The pressure created is negative so the gas can not migrate from the underlying floor to the building. It can also be done with a blanket or gas-proof membranes below the construction. The gas is controlled through valves and released into the atmosphere (EPA, 2020). This is a cost-effective and reliable option that reduces moisture and natural radon gas from indoor air (Naval Facilities Engineering Command [NAVFAC], n.d.).
A solution like the sub-slab depressurization is the sub-membrane depressurization, which is more common in residential basement buildings with a soil surface. An impermeable membrane is deployed that seals the exposed earthen area. A suction is applied to reduce pressure in the region under the membrane and the gases are then ventilated to the outside, stated by NAVFAC (n.d.).

Building pressurisation is a different system that combines with sub-membrane depressurization for open spaces and buildings with a requirement for no gas intrusion. The system generates a positive indoor pressure relative to the sub-slab using an air conditioning system (NAVFAC, n.d.). For the system to be effective and no gas migration, the pressure inside must be maintained above the highest ground gas pressure (EPA, 2020). Building pressurisation is not advised to be used in residential buildings as the construction must be relatively air-tight and is therefore more often used in commercial buildings (NAVFAC, n.d.).

Indoor air treatment, another vapour intrusion mitigation system, is based on air pollution management equipment. That means it does not prevent the entrance of gases, rather it extracts them. Filters such as zeolite or granular activated carbon combined with photocatalytic oxidation units can be applied. According to NAVFAC (n.d.) indoor air treatment is considered more of a temporary solution and can be a portable air cleaner or in-duct model.

2.5.2. Passive precaution measure

Passive protection measures require no mechanical components, maintenance or inspection and do not consume as much energy as active systems. One example of a passive action is the excavation and removal of source material that emit natural gas before construction begins. The masses are moved to a licensed landfill, which usually precedes the building process (EPA, 2020).

Vertical barriers, such as bentonite slurry walls, sealed sheet piles or sheet membranes can be used to control gas migration. The barriers are designed to penetrate below the water table or a low-permeability horizon underneath the gas-bearing layer. However, the gas flow can divert around the end of the vertical barrier so a venting system, to counter the gas, is installed at the edges. Vertical ventilation systems are likewise available, as are systems and trenches that can regulate the lateral movement of ground gas. The trenches tend to have a barrier membrane on the descending side and are lined with granular material. These venting systems can be passive or actively pumped. Gas-proof membranes can be installed beneath buildings or floor slabs. To protect and support the membrane, cushion geofabric can be utilised. The membranes should be selected depending on the specified gas permeability, chemical compatibility with the ground gas, soil, long-term durability etc. (EPA, 2020).

2.6 Construction work

2.6.1 Excavation at high methane gas levels

When building in areas where gas contamination is suspected or at decontamination sites, a gas detector is used, according to Ramboll (2018). The gaseous substances that the detector provides data for are molecular oxygen, carbon monoxide, methane, oil/diesel and benzene. If any discoveries are made, work must be suspended whilst a risk assessment is carried out to determine the cause. The framework for a risk assessment is a strategy or analysis that evaluates contaminated soil, deliver public services and develops engineering designs. At low O_2 levels, no work can be conducted as gases including methane, carbon monoxide and carbon dioxide displace or consume the air (Ramboll, 2018).

When working on sites where there is direct contact with contaminated soil, there are certain guidelines to follow. Personnel involved in and around shafts when excavating contaminated landfill materials are required to wear respirator protection with particle filters and protective clothing against fumes. The window must be kept closed in the excavator or truck for the duration of the excavation process. In case of dust in the shaft, the excavator operator is required to wear a respirator with a particle filter, unless the vehicle is equipped with an equivalent filter type (Ramboll, 2018).

In the Ängelholm municipality of Sweden, gas meters are required when performing groundwork five meters below the ground surface. This came about when several well drillers around the local area encountered methane gas while digging. The requirement for gas meters applies to piling work, groundwater drilling and excavation, geotechnical soil investigations, drilling for energy and cooling, geothermal heat pumps and groundwater heat pumps. The gas detectors are portable and provide sound and light indications. The devices are calibrated once a year and have a detection limit set at 20-40% LEL (Lower Explosive Limit). Whenever possible, the detector is positioned near the borehole or at the bottom of the excavation site. Further investigations are conducted to evaluate the presence of CH_4 and to evaluate what precautions in the construction and foundation phase are necessary to minimise the risks of methane gas (Ängelholms kommun, 2021).

2.6.2 Lack of gas meters on site

Thomas Landell, a site manager at Carlbergs, a land and construction company, spoke during an interview for this thesis about methane gas and construction work (full interview in Appendix I). The site manager mentioned that Carlbergs do not use gas detectors. Landell explained that the area is analysed before the building work, therefore the risk of unexpectedly detecting CH_4 during excavation is small. It is highly probable that workers have encountered the gas while digging in underground pockets, although given its low weight, it evaporated and vented on its own. If workers detect a gasoline-type odour, the work is interrupted until an environmental consultant arrives at the site to conduct a risk assessment. In most cases, the gasoline smell will be discharged by default after one day of removing the topsoil cap (T. Landell, personal communication, April 28, 2023). This is due to the evaporation of benzene, the most volatile petroleum agent, and aliphatic compounds, petroleum substances with short coal chains, when they encounter with the atmosphere. There are still substances with longer carbon chains present in the soil that did not evaporate and are odourless (V. Bouvier, personal communication, May 22, 2023).

Not operating with a gas meter and violating workplace safety regulations can cause immense damage. In September 2013, a worker was killed and another injured at the Canastota Wastewater Treatment Plant, USA. The operators were not provided with gas meters to monitor CH_4 concentration in the air. In addition, the methane gas dome where the work was conducted did not have sufficient ventilation or emergency exits (United States Department of Labor, 2014).

2.7 Groundwater monitoring wells

To monitor and sample the groundwater, wells made of plastic or metal are bored into the ground. They can be located near landfills, roads, green areas and parking lots. The most common material for the tubes is PEH-plastics and at the top of the wells there is a cover. This is designed to protect the groundwater monitoring wells from traffic, contamination, weathering and destruction (V. Bouvier, personal communication, May 4, 2023)

To verify the presence of methane gas, carbon dioxide or similar gases in the pipes, it is essential to analyse the pore gas within the tubes. For example, a biogas analyser can be used that provides data of different gases in the unsaturated zone, above the water table. If groundwater is present above the filter section f (Fig. 1), no poregas can accumulate within the well. There will be a failed pump test because there is not enough poregas to measure. If the groundwater level drops, methane gas can transport to new locations or increase in quantity (Avfall Sverige, 2010).

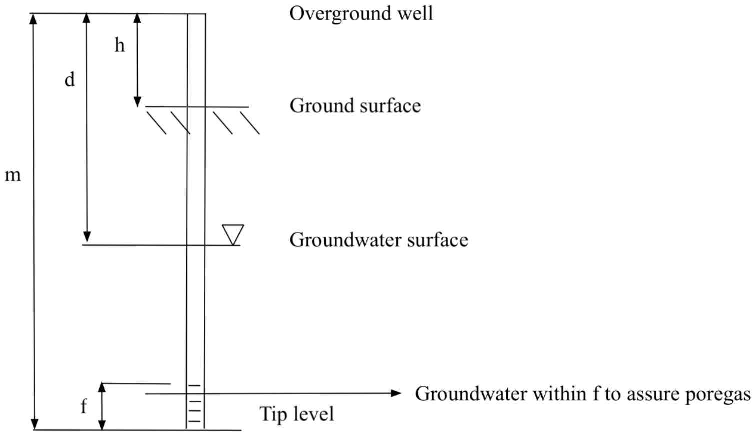

Figure 1. *Description of the different variables and heights of a groundwater monitoring well. The figure is from WSP (2023).*

3. Method

3.1 Fieldwork

The first set of fieldwork carried out April 11th and 12th took place in Gothenburg to measure methane gas from a parking lot, an industrial area, an old landfill, old properties and a gas station. In the second set of fieldwork, carried out on May 10th, the same groundwater wells were analysed for a second time. Precise coordinates and locations of the groundwater monitoring wells will not be given in this thesis because of privacy reasons.

Returning to the sites after a month will reveal whether the values remain the same or if there is a variation due to parameters such as the time of year, temperature, precipitation, atmospheric pressure etc. and the impact they have on methane gas. This is crucial when, or if, methane gas is measured prior to construction work as the gas can increase or decrease that potentially could delay the working process if a risk assessment needs to be done.

CH_4 concentrations are expected to decrease in May. The weather is warmer and sunnier compared to April, which means the methane has presumably dissipated because of higher solubility due to increased pressure.

3.1.1 Guideline for the fieldwork

To estimate CH_4 concentration one needs access to a groundwater monitoring well (Fig. 2) that enables poregas to accumulate in it, and a biogas analyser such as a Geotech Biogas 5000 (Fig. 3) for the analysis of the gas. To open a groundwater monitoring well, a flat screwdriver can be used to unlatch the cover or dexel. One example of a monitoring well cover (Fig. 2A) has a blue dexel, allowing it to be walked and driven over. These types of groundwater wells are common in areas with parking lots, old facilities and industrial areas. Pipe B (Fig. 2B), has a metal cap rather than a dexel and can be located in areas such as old landfills and surrounding gas stations where there is no traffic and pedestrians. The metal tubes are there to protect the pipes from maintenance work and lawn mowing. In this case, the wells are part of a monitoring program that analyses water for a five-year period at a time (V. Bouvier, personal communication, May 4, 2023).

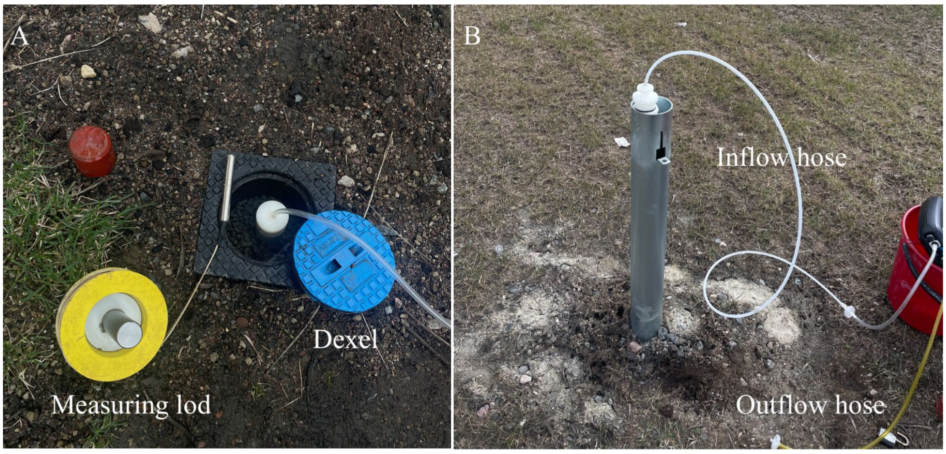

Figure 2. *Groundwater monitoring well's height difference with the Geotech Biogas 5000 and hose for inflowing gas connected. A) Pipe is located at old facilities near a smaller road. B) Pipe is located further away from the gas station.*

When the cap of the pipe is removed it is substituted with a plastic cover and an ID is created for the groundwater well through the Geotech Biogas 5000. The gas pump's system must stabilise before a transparent hose (Fig. 2B) is connected to allow the inflow of gas. A yellow hose (Fig. 2B) is attached to the analyser for the outflow of gas. During an interval of 300 seconds, the poregas from the pipe circulate through the device and out. The biogas analyser will display the concentrations of CH_4, CO_2, O_2, H_2S and Bal in percent (Fig. 3) along with the percentage of the gas at the previous and the highest concentration.

Figure 3. *Data from the Geotech Biogas 5000, only CH_4 concentration is of interest.*

The final step is to obtain the water level in the groundwater well using a lod. In Fig. 2A, the measuring lod is visible with its yellow case and metal end. The tape measure is hoisted down the tube until the metal rod makes contact with water and a signal is activated. For each reading, the rod was wiped with paper to avoid the risk of cross-contamination.

3.2 Interview with entrepreneur

For additional information on construction work and CH_4 concentration, a telephone interview was held with an employee of Carlbergs, a land and construction company. Thomas Landell, the company's site manager, describes the business in the following terms: “Our company is first in, last out as we deal with both the fine planning and functional contracting.” (full interview transcript can be found in Appendix I). Carlbergs works with land contracts, VA facilities and land remediation. Questions regarding methane gas and construction were asked along with a description of how the company starts a construction project.

4. Results

4.1 Industrial area

At the industrial area that was close to a highway, CH_4 concentration was at 0.1% both in April and in May. The WSP field description suggests that the surface consisted of asphalt and/or man-made ground. The subsurface consisted of clay, silt, sand and gravel in various combinations, such as sandy gravel, muddy silty clay, gravelly sand and silty clay (Bouvier, 2023). The map from the Geological Survey of Sweden (SGU, n.d.) Soil types 1:25,000 - 1:100,000 reveals the presence of artificial fill, postglacial clay and crystalline rock/bedrock present in the area (Fig. 4) where the measurements were carried out.

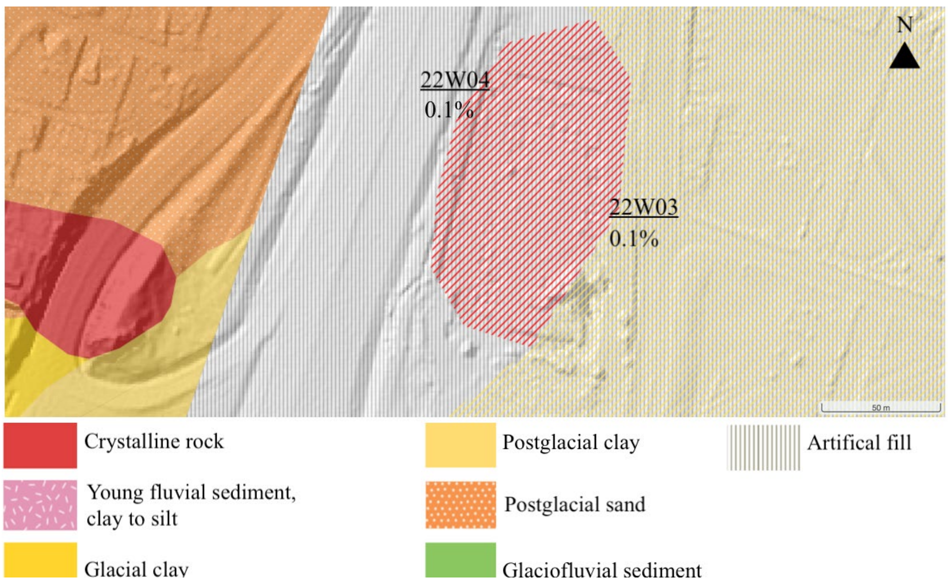

Figure 4. *The IDs for the groundwater monitoring wells with CH_4 concentration (%) underneath from the industrial area measured in April and May that remained unchanged. Map scale is 1:2500 from SGU (n.d.), “Soil types 1:25,000 - 1:100,000”.*

4.2 Old landfill

At the old landfill, CH_4 values varied as the results in April were found to be 0.2% and 2.7% and in May had decreased to 0.1% and 0.4% respectively. The location was an old industrial landfill, previously a gravel pit, that was filled with construction waste, scrap and excavation materials (City of Gothenburg, n.d.). In Fig. 5, glacial clay, postglacial clay, glaciofluvial sediment, crystalline rock and man-made ground are present according to the map from SGU Soil types 1:25,000 - 1:100,000 (n.d.).

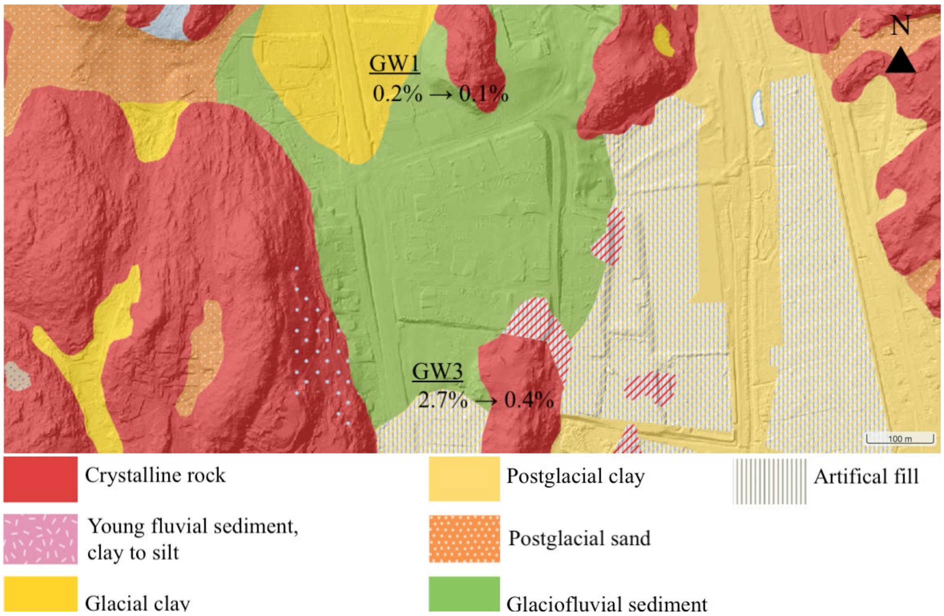

Figure 5. *The IDs for the groundwater monitoring wells with CH_4 concentration (%) underneath from the old landfill measured in April and May. The arrows point to the recent measured values from May. Map scale is 1:5000 from SGU (n.d.), "Soil types 1:25,000 - 1:100,000".*

4.3 Old properties

At the old properties, CH_4 measurements showed varying outcomes. The values in April were 0.1%, 0.2%, 1.2% and 66.3%. In May, most of the wells decreased except for 23W02 and 18W10. The materials underground consisted mainly of man-made ground with gravelly sand and gravelly silty sand underneath. Clay and mud can also be found as well as coal residues and wood residues (WSP, 2022-a ;WSP, 2022-b; WSP, 2023). Big parts of the man-made ground consist of soil, slag, scrap material, black inorganic material, pieces of metal, paper, bricks, glass and a thin layer of cables (WSP, 2022). In Fig. 6, the map from SGU Soil types 1:25,000 - 1:100,000 (n.d.) indicates that the area consists of young fluvial sediment, clay to silt and artificial fill.

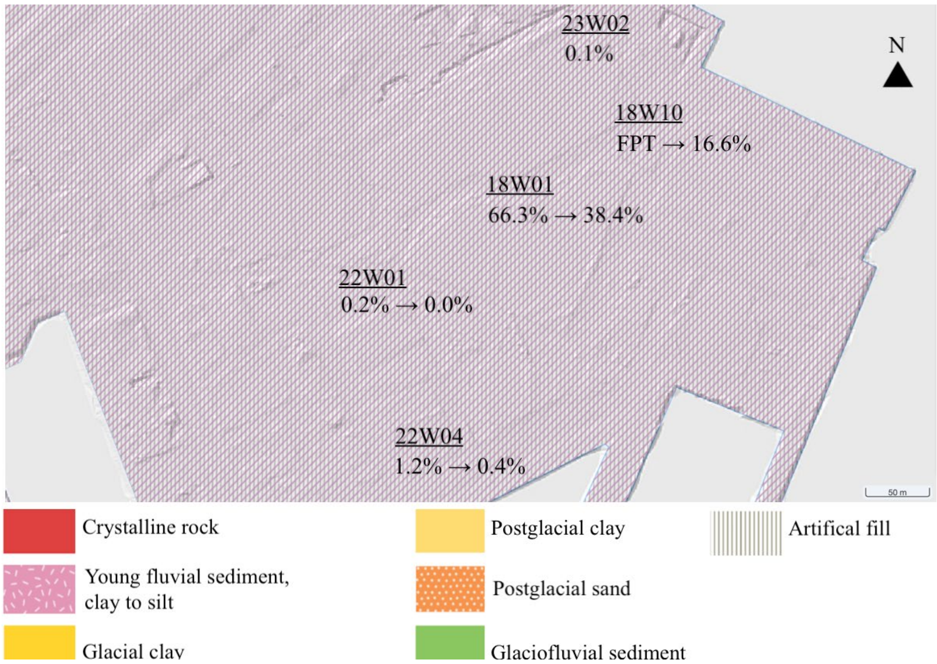

Figure 6. *The IDs for the groundwater monitoring wells with CH_4 concentration (%) underneath from the old properties measured in April and May. The arrows point to the recent measured values from May, no arrow means the value remained the same. 'FPT' stands for failed pump test. Map scale is 1:2500 from SGU (n.d.),"Soil types 1:25,000- 1:100,000".*

4.4 Parking lot

At the parking lot, formerly occupied by various establishments and businesses, all groundwater monitoring wells measured 0.1% on both occasions. Previous field observations carried out by WSP (2020) found that beneath the asphalt there was predominantly gravelly sand and postglacial clay. At specific levels there can be silt, clay, block soil, highly decomposed and regular peat. The man-made ground primarily consisted of gravelly sandy soil however occasionally there were pieces of brick, glass and slag. In Fig. 7 there is predominantly postglacial clay in the area with crystalline rock and postglacial sand further away from the map by SGU Soil types 1:25,000 - 1:100,000 (n.d.).

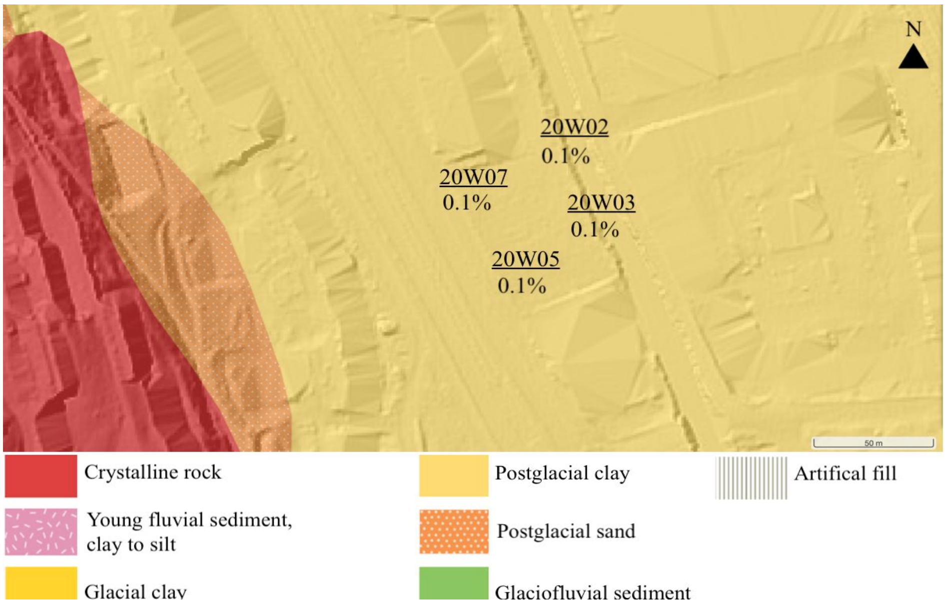

Figure 7. *The IDs for the groundwater monitoring wells with CH_4 concentration (%) underneath from the parking lot measured in April and May that remained unchanged. Map scale is 1:1250 from SGU (n.d.), "Soil types 1:25,000 - 1:100,000".*

4.5 Cleaning and gas station

At the cleaning and gas station the results were 0.1% and 0.0%. The ground was composed of a layer of man-made ground, underneath it was gravelly sand, muddy silt, loam soil, clay, silty and regular peat. During WSP's field observation, it was concluded that the man-made ground contained mull (a form of humus), clay, sand, gravel along with brick remnants, plastic and wood fibres in some places. In the area there are a lot of toxic contaminants, e.g., residual traces of aliphatics, aromatics, ethyl benzene, xylene and benzene (WSP, 2022). According to the map from SGU Soil types 1:25,000 - 1:100,000 (n.d.) the region consisted of glacial clay, postglacial clay, artificial filling and crystalline rock (Fig. 8).

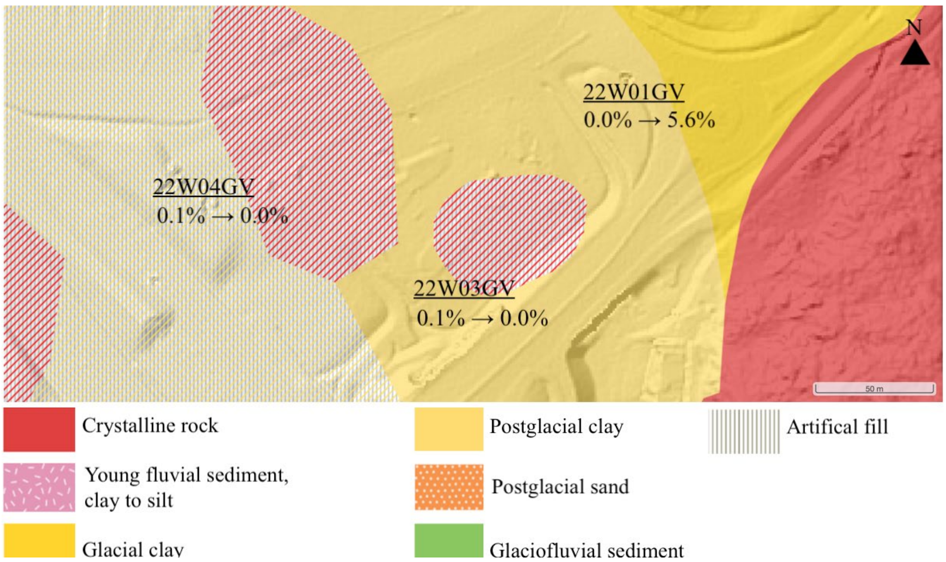

Figure 8. *The IDs for the groundwater monitoring wells with CH_4 concentration (%) underneath from the gas and cleaning station measured in April and May. The arrows point to the recent measured values from May. Map scale is 1:1250 from SGU (n.d.), "Soil types 1:25,000 - 1:100,000".*

4.6 Tables of collected data

Table 1. Weather-related parameters during the days out in the field. The measurements are taken from the Swedish Meteorological and Hydrological Institute (SMHI, n.d.) open database for air temperature (min and max, per day), amount of precipitation (per day), relative humidity (hourly) and atmospheric pressure (hourly).

Date	Weather	Temperature	Precipitation	Relative humidity	Atmospheric pressure
11/4-23	Rain	3.8°C - 13.6°C	1.6 mm	55% - 88%	1002.9 - 1008.6 (hPa)
12/4-23	Clouds	6.9°C - 12.7°C	0.1 mm	40% - 91%	1002.5 - 1008.6 (hPa)
10/5-23	Sun	10.0°C - 22.0°C	0.0 mm	18% - 49%	1013.2 - 1015.5 (hPa)

Table 2. Results of CH_4 (%) during the fieldworks, the values are the concentration that measured when the interval of 300 seconds ended and the value in parentheses is the concentration where it peaked or was the highest by the Geotech Biogas 5000. The measuring lod's value is the groundwater level in the monitoring wells. 'X' means that no values could be measured due to various reasons such as mud, no proper tube etc. 'FPT' is the abbreviation for "failed pump test". '-' means that no values could not be found.

Site	Name	April CH_4 (%)	May CH_4 (%)	Lod (m) April	Lod (m) May	Filter section (m)
Industrial area	22W03	0 (0.1)	0 (0.1)	2.8	2.9	3
	22W04	0.1 (0.1)	0.2 (0.1)	X	2.2	2
Old landfill	GW1	0.1 (0.2)	0.1 (0.1)	1,6	3.1	3
	GW3	0.1 (2.7)	0.0 (0.4)	2	0.9	3
Old properties	23W02	0.3 (0.1)	0.1 (0.1)	2	2.2	3.05
	18W01	0.1 (66.3)	0.1 (38.4)	1.8	2.1	-
	18W10	FPT	1.2 (16.6)	2.0	2.3	-
	22W01	0.2 (0.2)	0.0 (0.0)	2.3	1.6	4.05
	22W04	22.6 (1.2)	0.0 (0.4)	X	2.6	4.05
Parking lot	20W02	0.1 (0.1)	0.0 (0.1)	1.2	1.3	1
	20W03	0.1 (0.1)	0.1 (0.1)	1.3	1.3	2

	20W07	0.1 (0.1)	0.1 (0.1)	1.9	1.9	1
	20W05	0.1 (0.1)	0.1 (0.1)	1.5	1.7	2
Gas station	22W04GV	0.1 (0.1)	0.0 (0.0)	2.1	2.3	0.5 - 1
	22W03GV	0.1 (0.0)	0.0 (0.0)	2.3	2.7	0.5 - 1
	22W01GV	0.1 (0.0)	0.1 (5.6)	2	2.5	0.5 - 1

In Appendix II there are stack diagrams of CH_4 concentration for April and May.

5. Discussion

The information gathered from the fieldworks show a distinct correlation between methane gas and different soil properties. The locations with highest CH_4 concentration were the old landfill and old properties, both of which have sediments deposited from fluvial processes and contain organic material that is likely to be the cause of methane formation. The locations with lowest CH_4 concentration were the parking lot, the gas station and the industrial area. These three sites have clay, gravelly sand, man-made ground and little or no change in water level. The fact that the groundwater levels remain almost the same, apart from one monitoring well, can be the reason why methane measurements were the same despite being one month apart.

When working in areas with large amounts of coarse man-made ground and clay, it may not be as critical to be concerned about methane gas despite the presence of peat or other organic material. The water level can be a factor that needs closer monitoring because as it rises, less methane gas will be collected in groundwater monitoring wells. Despite the high and low concentrations of CH_4 there should be gas meters on construction sites as it is for safety measures.

5.1 Fieldwork in April; areas with the highest methane concentrations

Based on the numbers collected in April, the highest concentrations of CH_4 were found at the old properties (Fig. 7). The area served as repair workshops when the harbour was in operation as a shipbuilding facility in Gothenburg. During the 1800s, the region was a large wetland that decreased over time. There is no wetland today and the location's foundation is man-made (Mark Johnson, personal communication, 22 May, 2023). WSP (2023) reports that there are wood and coal residues in the soil, suggesting active methanogenesis due to decomposition of the organic material. This can explain the high levels of gas measurements at the location. For the groundwater wells that measured 66.3% and 1.2% methane gas, the pipes may have had organic material surrounding them or have been dug in patches of methane. There is a large amount of clay and silt in the region that can retain the methane or prevent its migration underground (Avfall Sverige, 2010). This may explain the elevated and reduced values of CH_4 analysed in some groundwater wells.

In short, it is not only the properties of the young fluvial sediment that store the methane gas or the organic material in the soil, but the combination of the different soil properties, man-made ground and content that are responsible for the high concentrations of CH_4.

The site with the second-most substantial results was the old landfill (Fig. 5). Disposal sites tend to have high CH_4 concentrations because of organic material deposited in oxygen-free environments. The location was, however, a former landfill that stored non-organic waste, notably construction waste and excavation materials (City of Gothenburg, n.d.). The postglacial clay and glaciofluvial sediment can contain organic material that may have emitted methane gas but was naturally vented due to the soil properties of the glaciofluvial sediment. The clay can also be the reason for the measured CH_4 concentrations. The clay properties can collect methane in soil pockets or prevent methane migration and the analysed concentrations were the only methane gas present underground.

5.1.1 Source of methane at the sites

There are various factors that could be responsible for the elevated and lower methane values observed during the fieldworks. The ground at the sites differs with some materials being more porous than others or composed of organic substances. While some locations had similar soil sequences and content, the methane concentrations varied. In some cases, the man-made ground is the factor behind it as it can aerate or retain the gas underground depending on its properties and content.

At the old properties, there are several factors behind the generation of methane gas. The area was a wetland two hundred years ago and there are coal and wood residues in the soil. Throughout the area there is man-made ground including soil, slag, waste material, inorganic black material, paper, metal, glass and layers with cables (WSP, 2022-a; WSP, 2022-b; WSP, 2023). The ground beneath the old properties is composed of young fluvial sediments, clay to silt and man-made ground that are good at retaining gas despite the slightly porous man-made ground. The combination of porous and non-porous material in the man-made ground retains the methane gas. Methane gas was measured in four out of five groundwater monitoring wells (Fig. 6). Near 23W02 there was a layer of man-made ground 2.6-3.2 meters below ground level consisting of bricks and black soil, underlain by silty clay (WSP, 2023). Nevertheless, the result from the Geotech Biogas 5000 was 0.1%, indicating that the man-made ground may have aerated the gas or that the silty clay had mobilised the gas to nearby locations.

The ground beneath the old landfill (Fig. 5) consists of glaciofluvial sediments that can contain organic material, the only source for methane at the location. The content of the man-made ground is unknown but is less important as there are none in the vicinity of the groundwater wells (SGU, n.d). The main soil types are glaciofluvial sediments and glacial clay, which have different characteristics in terms of ground gas. A typical example of this is illustrated in Fig. 5, GW1 had 0.2% CH_4 with clay in the soil while GW3 had 2.7% and was in an area of high porosity. The measured concentration would be expected to be opposite as material with lower porosity retains methane, yet GW1 had lower CH_4 concentration than GW4. There is a chance that GW4 was installed with organic material surrounding it or in a pocket of methane that could explain the higher values of methane gas.

5.2 Fieldwork in May; areas with the lowest methane concentrations

At the industrial area (Fig. 4), there was postglacial clay around the site that may have generated methane gas at one point, yet the measured concentration was at 0.1%. Postglacial clay can contain organic matter as the clay was covered by seawater at the time it was deposited (SGU, n.d.). During the isostatic rebound, most of the postglacial clay had been eroded from the glacial clay. The landscapes, at that time, were more vegetated and organic material was deposited (Mark Johnson, personal communication, 21 May, 2023). However, there was a large variation in grain size in the soil that can promote the movement and ventilation of methane gas because of the high porosity of the gravel and sand. The filter sections of the monitoring wells were also in a layer of gravelly sand that could explain the low methane gas values, if there were methane gas it would have emitted naturally, thus explaining the low CH_4 concentrations.

At the parking space (Fig. 7) there was only glacial clay in the region, despite that the measured methane was at 0.1%. A report by WSP (2020) noted the presence of peat in the soil sequence along with gravelly sand and postglacial clay. Both peat and postglacial clay can generate methane gas, however, if it was formed the clay should have held up the gas migration or accumulated it in underground pockets. It is highly probable that the gravelly sand facilitated the outflow of gas if there were any methane gas.

The measured gas concentration for the cleaning and gas station was 0.0% and 0.1% (Fig. 8). The site consists of postglacial clay, artificial fill and bedrock (SGU, n.d.) with gravelly sand, peat and loam soil in the soil sequences (WSP, 2022). This could be a comparable scenario to the parking lot. The methane gas may have been generated from the peat and postglacial clay but migrated from the site due to the gravelly sand. There are presumably smaller-sized soil under the gravelly sand; it could have trapped the gas in pockets or hindered their movement due to its properties.

5.2.1 The impact of man-made ground and soil properties

At the industrial area (Fig. 4) the content of the artificial fill material is unknown, therefore little can be compared with the other sites. According to observations from WSP (2023), the asphalt was underlain by gravelly sand. The porous composition of asphalt and gravelly sand likely contributed to the release of methane gas, which explains the 0.1%. The location is mostly composed of postglacial clay, and if it generated methane gas, it is reasonable to assume that it vented due to the porous materials or migrated to nearby facilities and trenches. The industrial area was close to a highway, there are likely underground pressure lines for roadside lightning, sewage water and electric pipelines that are ideal for the gas migration.

At the parking lot (Fig. 7) there was expected to be higher methane gas readings as there were peat and postglacial clay in the soil, according to WSP's reports (2020). The reason behind the low values is perhaps due to the man-made ground that consisted of gravelly sandy soil with occasional glass, brick and slag. The gravelly sandy soil exhibits high porosity, brick and slag likewise tend to have a large porosity, depending on their composition and formation. Glass, on the contrary, exhibits very low porosity. As most of the man-made ground is of high porosity, it is probable that it facilitated the release of methane gas. An additional reason for the absence of methane can be related to the installation of the groundwater monitoring wells in the area since the filter sections were established above a clay layer. The low porosity of the clay would make it difficult for the gas to penetrate it and accumulate in the wells. For example, at well 20W03 (Fig. 7) there was a layer of coarse detrital mud or peat present that might have generated methane. The filter section of the groundwater well was at a depth of 2 meters whereas the peat layer was at a depth of 0.3-1.1 meters, therefore, impossible to analyse any methane gas (WSP, 2020).

At the petrol station (Fig. 8) there was an abundance of man-made ground consisting of mull, gravel, sand, bricks, clay and wood fibre. Despite the presence of mull and wood fibre, which are known to emit CH_4, there was no detectable gas concentration. The man-made ground can be found at a depth 0-3.3 meters underneath the ground and the filter section of the wells are placed in the man-made ground above the clay at a depth around 0.5-1 meters. It is possible that the methane vented into the atmosphere due to the gravel and sand. However, methane gas could be present underneath the layer of clay and/or have relocated.
At the site there was a building for car wash where contaminants have been detected. Because gas can migrate through the pipelines and accumulate in the small spaces near the gas pumps, a geological barrier and crawl space were constructed during the building of the gas station. Under the geological barrier is macadam as a gas intrusion barrier (WSP, 2022).

5.3 Fieldwork in May; the impact of meteorological factors

The amount of precipitation has decreased; during fieldwork in April, it rained a total of 1.7 millimeters (Table 1), while in May there was no precipitation. It is, therefore, not unprecedented that the relative humidity had dropped considerably with the numbers almost cut in half. In moist and water-saturated ground conditions, methane production is increased, providing one of many explanations for the higher levels of methane gas analysed in April.

The air temperature and atmospheric pressure have each increased by more than 10°C and 10 hPa (Table 1) respectively within one month. High-pressure weather and temperatures lead to increased methanogenesis. The increased atmospheric pressure will raise the solubility of methane and reduce the additional methane production, which resulted from the increased air temperature and weather. That can be one of many factors behind the overall reduction in CH_4 concentrations in groundwater wells.

The main meteorological factors causing the decrease in methane gas is the combination of higher atmospheric pressure and reduced relative humidity. It can provide an explanation why half of the set of groundwater monitoring wells exhibits a reduced gas concentration.

The other half of groundwater wells tested the same concentration of gas in May, but the reason for the unchanged CH_4 concentration is because their water levels did not change.

5.3.1 Expectations of the general decrease

Nevertheless, there was one pipe, 22W01GV, located at the gas station (Fig. 8), that had a greater CH_4 concentration compared to the first round of fieldwork. In April it had 0.0% while in May it showed 5.6% and the reason for this increase is unknown. Measurement of the water level in 22W01GV indicated that it had sunk by 0.5 meters. As the water level is lowered, it uncovers more of the filter section at the bottom of the groundwater wells, allowing more gas to accumulate in the tube. The warmer temperature could be another factor. The readings are one month apart, meaning that the soil has had time to heat up. There is a possibility that peat and mull lie around 22W01GV, which started its methanogenesis during the warmer days.

Temporal and diurnal variations in methane concentrations are not uncommon, according to Delkash et al. (2022), the average daily flux is 73% and is 23 times greater during the day compared to night. When the atmospheric conditions are neutral and stable, the methane emissions are the most representative that often occurs 11:00-17:00 (Delkash et al., 2022).

In groundwater well 18W10 during April, CH_4 concentration could not be measured due to a failed pump test. The former 'FPT' implied that there was no poregas that could accumulate in the tube due to the water level being too high. As mentioned, when there is water over the filter section of the groundwater wells, no poregas can collect. In May, the lod measured 2.3 meters while in April it was at 2 meters meaning that the water level sunk 0.3 meters and allowed methane gas to accumulate (Table 2).

5.4 Regulations in Sweden

Based on the interview with the Carlbergs site manager, it is evident that certain construction companies do not consider CH_4 concentration when working and digging in areas in general. This is not unexpected as accidents with clear connections to methane gas have not occurred in Sweden. There are likely to be cases of explosions and suffocation due to methane, but with no apparent correlation between incidents and gas.

Construction companies are, however, more cautious when explicitly working in areas where there is a known CH_4 concentration. Ramboll (2018) explained in their MKB detailed building plan, that when conducting remediation work there are gas meters on site, operators wear protective gear, in particular respirator protection when working in shafts with high gas concentration. There is still a potential for explosions at the site or the gas can migrate to nearby facilities, storage rooms and restricted spaces to cause suffocation or combustion. Explosions are not rare in landfill leachate pumping stations due to gas migration and accumulation (SGI, n.d.-a).

The Ängelholm municipality in southern Sweden uses gas detectors when working at a depth of 5 meters (Ängelholms kommun, 2021), whereas Carlbergs, a land and construction company in western Sweden does not use gas detectors on any occasion. The question of whether to use gas meters depends largely on the characteristics and composition of the soil. During the interview with Carlbergs, T. Landell mentioned that in Gothenburg, there is not a problem with CH_4 concentrations but rather pollutants and substances that occur naturally in the clay. Since the city mainly consists of clay, there can be 100 meters until natural bedrock and man-made ground, therefore methane gas is not a threat. As mentioned beforehand, clay can either trap the gas in underground pockets or hinder its migration (Avfall Sverige, 2010). Even if the pockets have been released, the gas quickly evaporates, and the risk of explosion is low as the work site is an open space. However, the risk of accidentally igniting a spark when there is a sudden outburst of methane gas, can never be excluded.

Despite never having an accident with methane, the municipality of Ängelholm still decided to have gas meters as a requirement when digging five meters below the surface. To prevent work-related injuries and accidents (Ängelholms kommun, 2021).

5.5 Links between methane gas and soil

After completing the measurements carried out in May, it is apparent that meteorological factors, grain size of the ground material, placement of filter-section and water level has a great influence on methane gas.

If there is glacial clay and gravelly sand in an area, measuring for methane is not necessary based on the collected field results. The industrial area (Fig. 4), parking lot (Fig. 7) and gas station (Fig. 8) had no significant amount of methane gas and contained clay, gravelly sand and soil with organic material. If there was methane beneath the ground, the clay would retain it by stopping its passageways or store it underground, whereas the gravelly sand does not restrain gas but ventilates it. The presence of methane-generating material does not necessarily lead to a large CH_4 concentration as it can depend on the characteristics of the soil. As an example, at the parking lot (Fig. 7) there was peat in the ground, yet the biogas analyser measured 0.1% methane. The clay at the site might have trapped the methane gas or caused it to migrate.

Another key factor is the location of the groundwater well's filter section (Fig. 1). If the f-section is situated above a clay layer, as in the parking lot, and there is methane gas underneath, the gas can not accumulate in the well because of the clay's low porosity and permeability. There were groundwater wells that had their filter section located within methane-generating soil but still had no significant concentrations. This is observed at the gas station, where man-made ground can be found in the top three meters of the ground, with the filter sections of the wells at a depth of 0.5-1 meters. The filter sections were installed in a layer of man-made ground that included humus and wood fibres (WSP, 2022), yet it had no methane gas. During measurements in May the groundwater well, 22W01GV (Fig. 8) measured 5.6% CH_4 while the rest of wells had no increased levels. This could mean that the man-made ground with organic material eventually started producing methane generation due to the warmer weather.

Water level is important to consider since it has an impact on the CH_4 concentrations. For those sites where CH_4 concentrations remained unchanged, the water level had little or no change. The wells at the old landfill had a more pronounced change in water level. The water level of GW1 dropped 1.5 meters and GW3 water level increased 1.1 meters, so the elevated water reduced its CH_4 concentrations in May. The majority of groundwater wells at the old properties decreased by 0.3 meter from April to May, not as drastic as the old landfill although there was a significant decrease in methane gas at the site. The main factor behind this can be the higher pressure and solubility, either the methane gas migrated to nearby properties, or it diffused.

5.6 Potential source of errors

During the fieldwork conducted in April and May, there are likely to have been errors along the way. The first time using a biogas analyser was out in the field on 11 April, therefore time was needed to get accustomed to it. The device had to calibrate between each reading which could be an error factor as the relative pressure of the system varied between the readings of each groundwater well.

Before starting the gas measurements, the original covers and caps must be removed and replaced with a plastic cover. The diameter of the wells was found in two sizes, and therefore it was important to change from smaller or wider lids and inflow hose. Due to lack of experience, the plastic cap was attached too early so poregas from the inflow hose could escape instead of being connected to the biogas analyser, as no hose were allowed to be connected to the unit during calibration. It also happened that the plastic covers could not be screwed on properly, allowing some poregas to escape through the gaps. With time the preparation work became increasingly effective. In May, the hose and caps were installed in a more convenient way allowing the poregas to immediately pass through the gas analyser and not dispersed in the air. This would not substantially influence the results but can still be considered a source of error.

As with the biogas analyser, the measuring lod had not been used beforehand. Initially, the values of the measuring tape were taken higher than they should have been. While one person was hoisting the lod, the other person stood close by and grabbed the tape when the signal was triggered by water. In the beginning, the measurements were taken with an additional length over a half meter because the measuring lod was intercepted at a normal height. As the fieldwork continued, the lod was captured where the overground well ended (Fig. 1). It does not affect the results but rather the interpretation of the data collected on whether poregas can accumulate in groundwater wells.

With the last two groundwater wells at the old properties, the measuring lod kept giving the constant signal for water even when it was not in the wells. The batteries were replaced before going into the field and the metal rod was always wiped with paper after each groundwater reading. There is a possibility that dirt had gotten on the sensor or a lot of moisture in the groundwater wells caused a drop of water to condensate (V. Bouvier, personal communication, May 12, 2023). It helped temporarily when regular freshwater was poured over the rod, however the signal came back. This may have given water level measurements that were inaccurate, but compared to the first round of fieldwork, no drastic changes were measured after the measuring lod began to malfunction.

5.7 Future solutions and precaution

Prior to construction projects, CH_4 concentration should be measured to be on the safe side. It is of importance to remember that even if methane concentrations are at 0.0%, there is still a chance that it can increase due to atmospheric pressure, temperature, relative humidity, precipitation etc. A case in point occurred at groundwater well, 22W01GV at the gas station that increased 5.6% CH_4 from April to May.

Based on the fieldwork, there is a correlation between man-made ground, clay and gravelly sand that together result in low amounts of methane gas. The sites with that content were the parking lot, the gas station and the industrial area. Despite containing organic material, wood residues and peat, that are known to emit methane, the concentrations were 0.0% and 0.1%. Areas composed of sediment deposited by fluvial processes, e.g., glaciofluvial sediment and young fluvial sediment, clay to silt had higher methane levels due its organic material and soil properties that partially retain the gas. Therefore, the sites with the highest CH_4 concentration were the old landfill and old properties.

Based on the readings gathered from this thesis, if methane gas analyses are to be made before construction work, they should be done in areas of fluvial sediment rather than in areas of clay, man-made ground and gravelly sand even if they contain organic material. If the man-made ground can have such an impact depends on its composition. However, it is not 100% guaranteed that there will be no methane gas in such areas despite the results from the fieldworks as there are discrepancies and anomalies that can not be predicted. This supports the idea that gas meters should be placed on excavation sites or workers should have personal meters attached to them.

6. Conclusion

The conclusion for this thesis is that methane gas should be considered when working in areas other than landfills, with ongoing methane production, porous soil properties and larger grain size. Areas with fluvial sediment, had a higher level of methane gas compared to clay, that had a lower level of methane gas based on the data collected from this thesis' fieldworks.

Methane measurement should be carried out based on soil content and characteristics of the material underground, rather than being limited to landfills, as methane is still a threat outside these sites. The Gothenburg region is composed mainly of clay, yet the threat remains as the clay can accumulate the gas underground or further migrate it. During construction work, having gas meters on the worksite increases the chance of detecting methane in time, before construction-related accidents occur. By installing gas-tight base structures and geomembranes when the foundation of a building are laid can ensure that methane gas can not mobilise and gather at the new properties.

One important consideration is that air temperature, relative humidity, precipitation, groundwater level and atmospheric pressure all affect CH_4 concentrations, which can increase or decrease if these parameters fluctuate.

Acknowledgments

This bachelor thesis is performed at Gothenburg University, Sweden at the Department of Earth Science. Despite starting my university studies amid the corona pandemic, the situation eventually improved. Since excursions were cancelled, I have not been able to spend much time outside and decided to do some sort of fieldwork for my thesis. On that way, I got in contact with my external supervisor, Vera Bouvier from WSP.

I will start by thanking Vera for her tremendous help and guidance, as she always brought new proposals to this report. Mark Johnson, the course manager and my internal supervisor, was the reason I came into contact with Vera, a big note of appreciation to you. Thank you, Thomas Landell at Carlbergs, for the interview regarding construction work, and WSP for lending me the equipment used for this thesis. Thank you Lisa Jörgensen, the opponent for the thesis, and Philipp Wanner, the examiner. To my younger sisters, thank you for being my personal assistants during the fieldwork. It was a unique experience to drive around together in the oldest Toyota minibus to ever exist.

Lastly, I would like to thank my family, classmates and people who have been involved in this project.

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Appendix I

Interview with Thomas Landell (site manager at Carlbergs).

Interviewer: S
Interviewee: T

S: Let's begin with you explaining what kind of company Carlbergs is. What does the company do?

T: Carlbergs is a land and construction that was founded by two men during the 60s. Their names are Kjell and Ronny Carlberg. During the 90s they sold a part of the company and are now one of the three partners. Carlbergs is first in, last out as we deal with both the fine planning and functional contracting. The company can be involved from the initial excavation to the final fine planning. I as a person have been 20 years in the industry and am currently the site manager. You would think that the site manager would be more on site but it is more administrative, a lot of paperwork needs to be done.

S: I see, that is also very important. Before going to the next question I would like to say that this thesis is about methane gas underground and how it can eventually affect construction work. When I was doing research about methane gas, I found out that it can be very dangerous due to its explosiveness as it can combust at concentrations between 5-15%. Another thing I found out was that methane gas in general is not a problem that is regarded by various construction companies. Have you ever encountered problems with methane gas in the ground when doing construction work or even just found methane concentration underground?

T: During my time here at Carlbergs I have never come across methane gas in the ground, therefore there has never been a problem with it. Of course it depends on where the excavation is taking place. If there is humus underground or there has been a very old landfill with household waste then there would be methane gas, however I have never come across it.

S: So you do not have gas sensors around the construction area nor does the construction crew have personal gas sensors on them?

T: No we do not have gas sensors. Before we come to the site there has been analyses done in the area so the chances that we unexpectedly find methane gas in the ground are very low. Miljöförvaltningen/environmental administration are the ones in charge of it, not Carlbergs. However, something that we encounter more often than methane gas is masses from landfill, construction waste, industrial waste, fly ash, oils in the ground that were not found until the excavation started. All of those things can be classified as environmentally hazardous and need to be dealt with before the construction work can continue.

S: OK, interesting. I just want to go back to gas concentration in the ground. So you have never encountered methane gas and have never done anything about it?

T: Yes, correct. Sadly I can not give you information and answers regarding your questions about methane gas as we have never encountered it.

S: It is fine, I will still be able to use this information for the thesis. I am thinking about other gases aside from methane gas, have you encountered gases like radon gas? If so have you done anything in particular to remove it like excavate the mass, top it with filling material or geomembrane?

T: In the case of radon gas there is not much in the ground that we at Carlbergs are concerned about. However there is more radon in the bedrock that we utilise to form crushed material that is used during construction work. There is a possibility that the crushed material contains radon if the bedrock it was taken from contains it which is something we are very careful with.

S: OK let's move on with the remaining questions that unfortunately are all about methane gas so let's just skip them for the time being. Could you briefly explain what your building process looks like from a lawn to a finished building?

T: Absolutely. First of all we contact the ledningskollen/wiring inspection to get information about the whereabouts of wires to protect them against digging. Ground investigations are already done regarding dangerous materials and pollution underground. Despite that when the workers start excavating, they may find avseende/regarding areas containing oil, waste masses that can be arbitrary and environmentally hazardous masses that must be reported. On such occasions we contact Vera and WSP, environmental experts to come check the area. They will come and take samples of the ground to do analyses on. For example we were going to excavate at a playground, when we started digging we found hazardous waste underground in the green area. Our parents did not care where they put their waste in the past but today it is very important. The masses from the playground were classified as IFA which is not good, however the results also show that it is FA waste. So what I would do is use an empty excavation flare to cover the contaminated masses and later on drive the material to a contaminated landfill when given more instructions regarding the hazardous material.

S: So when the material has been driven to a landfill do you do any decontamination in the area afterwards, if so how long does that take?

T: The remediation is done by Miljöförvaltningen/environmental administration and they are the ones that decide how long it takes to sanitise the area. It also depends on what type of area it is, in industry areas you are allowed to leave behind MKM masses. In Gothenburg there is a big problem regarding elevated values of naturally occurring substances in clay such as zinc, chrome, lead and other substances. Due to the fact that they naturally exist and are not of anthropogenic cause, the masses can not be driven to a KM landfill.

S: So what can be done about the clay with these elevated values of substances? Are they sanitised?

T: What you do is limit the contaminated area with a ground cloth that separates the soil layers in the ground. If you put regular soil on top of the contaminated clay then the layers will combine as the clay will push through. With this ground cloth the layers will stay separated making it possible to build on top. After the environmental consultant has taken samples of the ground, Miljöförvaltningen will determine how the clean up will be carried out. The majority of the time, they listen to the environmental consultant like WSP and do exactly as they propose.

S: Is there anything else you can use beside a ground cloth, perhaps a geomembrane or similar material?

T: If you are building a parking lot and there are poor soil conditions, say that there is clay underground. The clay has a low shear strength and needs reinforcement, therefore a geogrid can be used.

S: I understand. Let's move onto another question. You are working on the basis of the planning and building law, how do you communicate risks related to the work environment? Are there any risks involving gas?

T: Before the construction work begins there has to be done a work preparation, risk assessment and a work environment plan. Often the work preparation done at Carlbergs includes the bearing capacity of the ground. Measurements against slope inclination in the excavation are taken and if you need to use sheet piling to be able to excavate. In Gothenburg there is a lot of pollution underground and I have had my workers, both men and women, alarm when there is an unusual smell. There are times when the ground smells like diesel and we have to contact the environmental consults. When the consults arrive the next day, the smell is gone as the gases have evaporated as they have been exposed to the atmosphere.

S: Just like methane gas, when the top layer of the ground is removed the gas can migrate and "disappear".

T: Exactly, therefore there is a chance that the workers have come across pockets of methane but have not noticed it as the methane gas is odourless. Methane is also lighter making it evaporate faster.

S: I know that we have come to the conclusion that methane gas is not something that is really acknowledged during the construction work but has there ever been methane gas accumulated when the building is done? If not methane gas, how about radon?

T: There has not been any methane gas after the building is finished. In the case of radon, if we are aware that there may be radon in the area, we cast a radonstop in the slab of the building. We also put seals in the pipes, an example is a chain seal.

S: That was all of the questions I had for you, as I have to skip some questions due the fact that methane gas is not something you have worked with.

T: Yes I see, I hope the answers I have given you are enough.

S: Absolutely, I will make great use of them. I just have some questions regarding the building sequence we talked about earlier. These are not really gas related questions but I was wondering what the next step is after you have excavated the masses. Do you pile or do something else?

T: Yes so when building we often use piles of either steel or concrete depending on the weight of overlying property. If you are building in bedrock then piling is not needed as you can construct a cliff edge of the bedrock. If you are building in Gothenburg, then you need to pile down to the bedrock which can be 100 m underneath the clay. A rough excavation is done for the piles and when it is finished, the piles are cut to the right height. After that a detailed excavation is done for the concrete as it will cast the form for the building.

S: How does it work when you are digging in the ground for wells and stormwater?

T: The digging needs to be deep enough for the pipes as they need to be frost-free, the depth lands around 120 m. These pipes are mainly for water and sewage, however the water lines lie a little further down the other pipes.

S: When the pipes are so deep underground they could perhaps be in areas where there is high gas concentration. Are the pipes perhaps gas-tight?

T: Yes some pipes are actually gas-tight but it depends on the location. In Gothenburg we have a lot of contaminated areas and masses, so at such places it is good for gas-tight pipes as it is important that the gas does not interfere with the water in the pipes.

S: That was all of the questions I had for you today. Again, I apologise for the trouble with the Teams meeting but I am glad that we worked it out.

T: No problem, you did not get a lot of answers regarding methane gas but I hope you will have some use of the interview.

S: Absolutely, even if it is not what I expected it will be great for the thesis.
[End

Appendix II

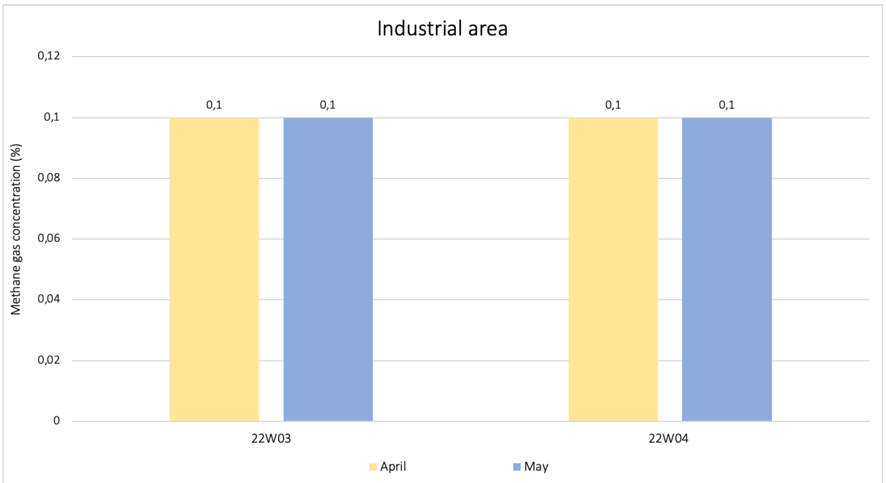

Figure 9. *Column chart of methane gas concentration (%) from April to May at the industrial area. Created in Excel.*

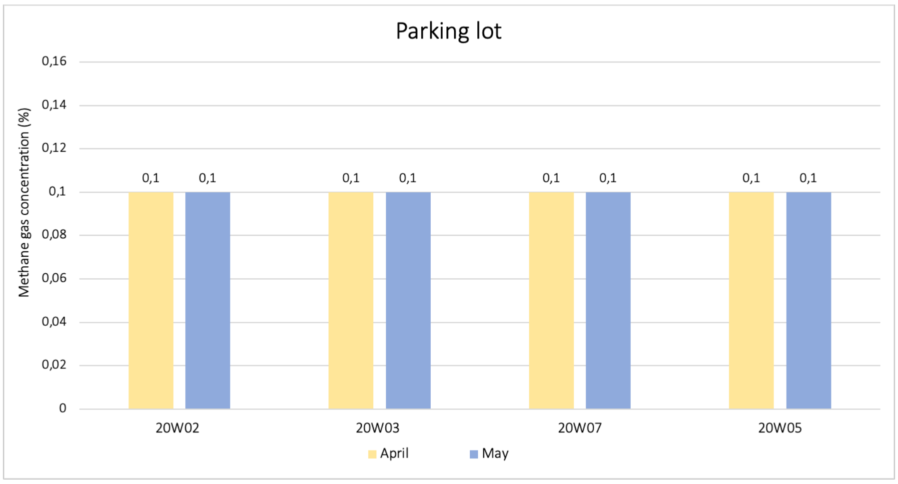

Figure 10. *Column chart of methane gas concentration (%) from April to May at the parking lot. Created in Excel.*

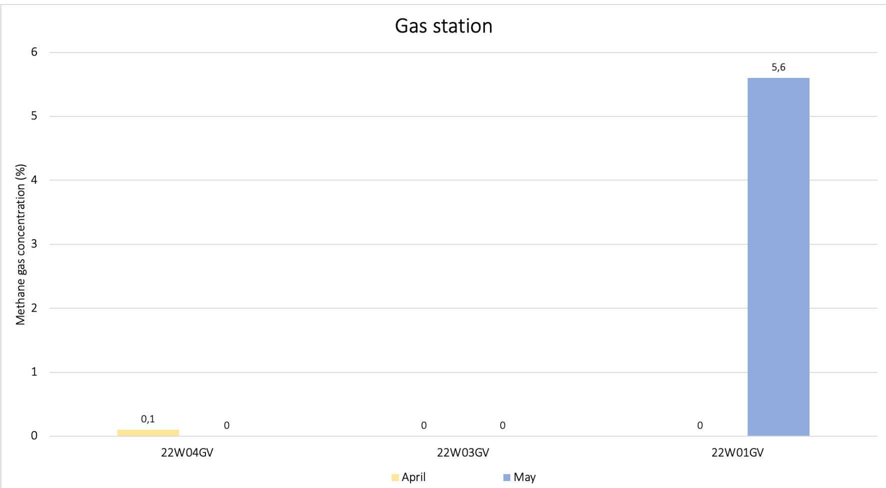

Figure 11. *Column chart of methane gas concentration (%) from April to May at the gas station. Created in Excel.*

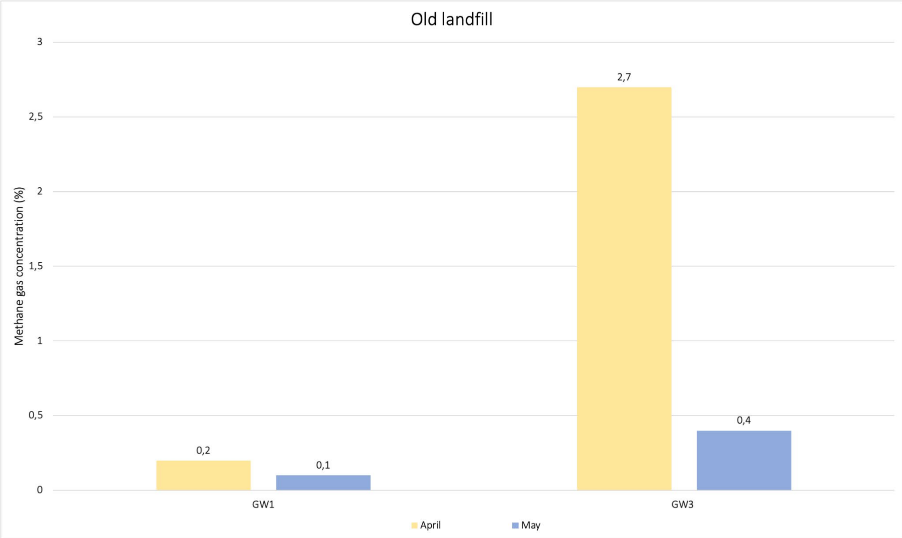

Figure 12. *Column chart of methane gas concentration (%) from April to May at the old landfill. Created in Excel.*

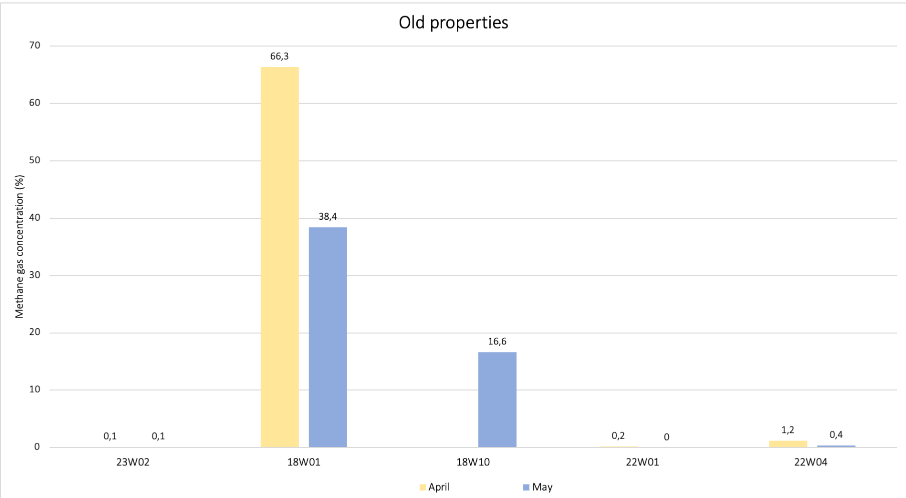

Figure 13. *Column chart of methane gas concentration (%) from April to May at the old properties. Created in Excel.*