Chapter 17
Geological Considerations for Military Works in the Afrin Battlespace, Syria

M. H. Bulmer

Contents

Abstract To defend against the Turkish Armed Forces (TAF) in the newly formed Afrin Region, Kurdish parties and militias constructed trenches, observation towers (OTs), cut-and-cover hardened tunnels (CCHTs) and underground facilities (UGFs) along the border between Turkey and Syria and throughout Afrin. The Kurdish militia was a light infantry force with limited artillery, improvised armoured vehicles, no combat engineers and no air power. The use of subterranea was a direct response to the increasing need for concealment and protection to improve survivability against munitions used by the Syrian Government Forces, TAF, the Islamic State of Iraq and Syria, and their affiliates. Defences were constructed in mountains of limestone, sandstones and marls and in valleys in alluvial terraces and conglomerates, lithologies very favourable for digging and tunnelling. The scale of Syrian Kurdish works represents significant defensive construction projects, which required financing (US$400,000 for a 300-m long CCHT), experienced and skilled works teams with project managers, site foreman, plant operators and construction crews. Materials used were rebar, forms and concrete, all needed in large volumes. At the start of Operation Olive Branch in January 2018, Turkish airstrikes and artillery targeted OTs, CCHTs and UGFs. Their use of combined arms overmatched Kurdish defensive positions in the Afrin Region.

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17.1 Introduction

Afrin, located in northwest Syria on the border between Syria and Turkey, consists of the Syrian part of the Kurd Mountains (Fig. 17.1), the autonomous region of the Shabha area and a large part of the Manbij plain. The Afrin Region is bordered by the Euphrates Region to the east, Kilis Province of Turkey to the north and Hatay Province of Turkey to the west. Kurd Mountains are part of the Limestone Massif of northwest Syria. The mountains are a southern continuation into the Aleppo plateau that is in turn a continuation of the highlands on the western part of the Aintab plateau. The River Afrin surrounds Kurd Mountains from easterly and southerly directions (Fig. 17.2a). It drains south between the plain of A'zaz to the east and Mount Simeon to the west. The River Aswad separates Mount Kurd in the Kurd Mountains from Mount Amanus in the Nur Mountains to the west.

The Afrin Region for Syrian Kurds had two subordinate cantons, the Afrin Canton and the Shahba Canton. The Afrin Region was first declared autonomous under the name of Afrin Canton in January 2014 (Firat News 2014) but was later

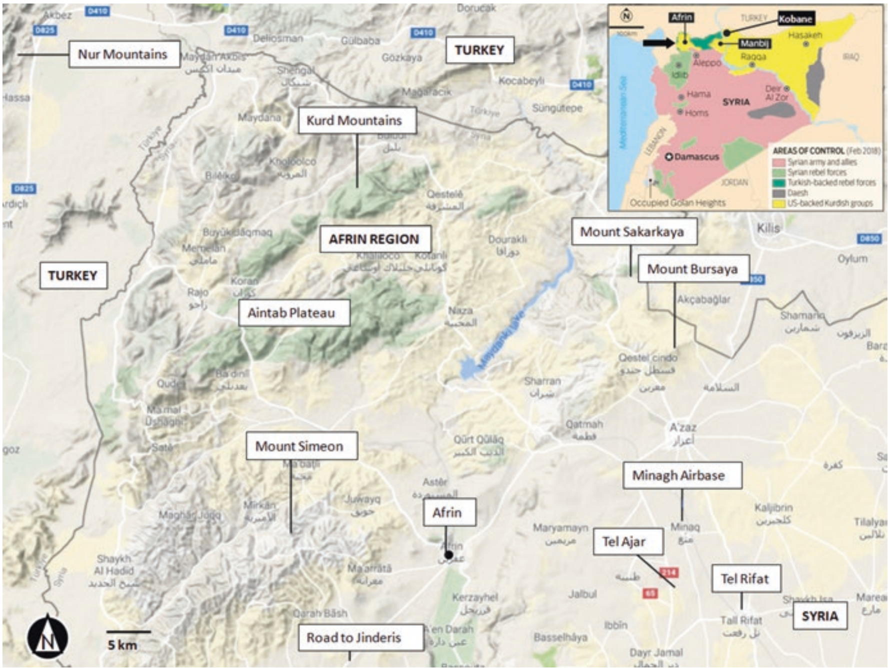

Fig. 17.1 Topography around the Afrin Region. The inset shows areas of control in February 2018. (Modified from Gulf News 2019)

renamed the Afrin Region during the subdivision congresses held in July and August 2017. The administrative centre of the region was the city of Afrin.

17.2 Background

The Arab Spring was a series of anti-government protests, uprisings and armed rebellions during 2010. It began in Tunisia and spread to Libya, Egypt, Yemen, Syria and Bahrain. In Syria, public protests against the Assad regime by the Syrian opposition were initially minor; the first large demonstrations began in March 2011 (World Bank 2017), and in the following months, they spread and increased in size within the country. By the summer of 2011, armed conflict had started between the Ba'athist Syrian Arab Republic led by President Assad, supported by domestic and foreign allies, against the domestic rebel Free Syrian Army (FSA) and foreign forces along with terrorist groups opposing the Assad regime, and each other, in

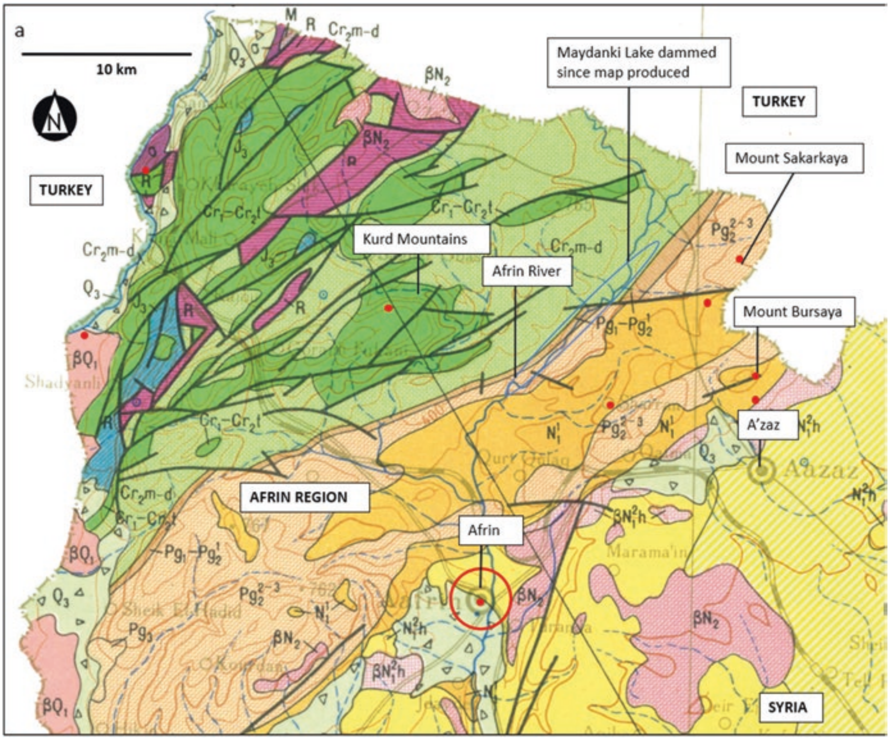

Fig. 17.2 (**a**) A portion of the 1:500,000 scale geological map of northwest Syria Afrin Region. (Modified from Sheet 1, SMI 1964) on which known subterranean military works locations are shown (red dots). (**b**) Legend for the 1:500,000 scale geological map

Fig. 17.2 (continued)

varying combinations.[1] After the Syrian Government Forces (SGF) pulled out of Afrin in 2012, Kurdish People's Protection Units (YPG) militia and Women's Protection Units (YPJ), founded in 2011 as a light infantry force with limited military equipment and few armoured vehicles, took responsibility for its defence.[2] The administrative centre of the region was the city of Afrin. Afrin became the westernmost of three regions of the Syrian Kurdish Autonomous Administration of North and East Syria, also known as Rojava. The YPG/YPJ did not initially take an offensive posture in the Syrian Civil War and were able to maintain trust with both the SGF and its neighbouring rebel groups. That same year, Syrian refugees were attempting to cross the Syrian border into Turkey to flee the advance of SGF against the rebel FSA. SGF attempted to block the flow of refugees and supplies for

[1] By April 2013, tensions between Al-Qaeda and Islamic State of Iraq and Syria heightened when the Da'esh caliph Abu Bakr al Baghdadi instructed his fighters to expand from Iraq to Syria to reclaim control over Jabhat al-Nusra. Over the summer and fall of 2013, IS's aggressive posture toward other jihadists led to heightened tensions, which escalated into infighting in January 2014 and ignited the so-called jihadi civil war. The following month, al Zawahiri officially expelled IS from his AQ network.

[2] In July 2012, the YPG/YPJ had a standoff with Syrian government forces in the Kurdish city of Kobane and the surrounding areas. After negotiations, government forces withdrew and the YPG took control of Kobane, Amuda and Afrin.

insurgents coming across from Turkey (Oweis and Sezer 2012). As a result, the Afrin Region and YPG/YPJ, as its fighting force, were threatened by SGF (and possibly Russia), the Turkish Armed Forces (TAF), the Islamic State of Iraq and Syria (IS) and their affiliates.

IS, who did not recognise the Syrian Kurdish Afrin Region, gained control of large parts of northern Syria in 2014 and advanced into Iraq. On 13 September 2014, IS advanced into Kobane to capture the autonomous region of Kobane Canton and the city of Kobane, capturing over 350 Kurdish villages and towns by 2 October 2014 and displacing 400,000 Kurds. In early 2015, the YPG/YPJ defeated IS and affiliated terrorist groups during the Siege of Kobane, where they received air and ground support from the United States and other Combined Joint Task Force (CJTF) – Operation Inherent Resolve militaries. At the end of August 2015, the al-Nusra Front (the official Syrian branch of al-Qaeda[3] made up of Syrian jihadists fighting against the SGF and its affiliates) shelled the Syrian Kurdish villages near Jindires town in the Afrin countryside (Fig. 17.1; ARA News 2015). The YPG/YPJ held that ground and returned fire into northern Aleppo even though a truce had been reached between the YPG/YPJ and al-Nusra seven months prior and al-Nusra was attempting to engage the SGF and its affiliates located in the same area. This exemplifies how fluid fighting was with numerous actors pursuing their own objectives, which at times meant they engaged groups that they had previously been fighting. An additional actor was created in October 2015 with the founding of the Syrian Democratic Forces (SDF) composed primarily of Kurdish, Arab and Assyrian/Syriac militias, as well as some smaller Armenian, Turkmen and Chechen forces. The SDF fought under the leadership of the YPG/YPJ. In February 2016, in response to the Battle of Aleppo, the SDF moved east out of Afrin to secure supply routes and captured the Menagh Military Airbase and the town of Tel Rifaat (Fig. 17.1). In response, TAF shelled SDF positions across the border to protect the city of A'zaz. In 2017, Russian troops stationed themselves in Afrin as part of an agreement to protect the SDF and YPG/YPJ[4] from further Turkish attacks. This now included an additional actor, the Turkish-backed Free Syrian Army (TFSA)[5] formed 30 December 2017. At the same time, Russia and Turkey planned airstrikes on Idlib (Fig. 17.1, inset) to drive out al-Nusra (TRT World 2017). According to a Pentagon spokesperson, in November 2017 a verbal agreement was made between Washington and Moscow to create an air space deconfliction zone (BBC News 2017). Under the

[3] Its goals were to overthrow Bashar al-Assad's government in Syria and to create an Islamic emirate under sharia law. The tactics of al-Nusra Front differed from IS; whereas IS alienated local populations by demanding their allegiance and carrying out beheadings, al-Nusra Front co-operated with other militant groups and declined to impose sharia law where there had been opposition. Al-Nusra presented itself as moderate in comparison to IS.

[4] The updated December 2016 constitution of the Autonomous Administration of North and East Syria names the SDF as its official defence force.

[5] The TFSA is different from the FSA. The official aims of the TSFA are to assist Turkey in creating a 'safe zone' in Syria. At its formation in A'zaz, it proclaimed itself a National Army. The FSA fought against the TSFA.

agreement, the US considered the area to the north and east of the Euphrates River US designated, whereas Russia had the freedom to patrol west of the river.

To try to defend the Afrin Region against TAF, SGF, IS, al-Nusra as well as other terrorist groups, the Syrian Kurds constructed trenches, observation towers (OTs), cut-and-cover hardened tunnels (CCHTs) and underground facilities (UGFs) along the border with Turkey and throughout the region. The construction of military works in the Syrian Kurdish Afrin Region may have been undertaken by Kurdish parties (KCK/PKK/PYD[6]) and militias (SDF/YPG/YPJ), IS (plus affiliates) as well as al-Nusra, all of whom had previous experience constructing them. At the start of Turkey's Operation Olive Branch[7] in January 2018, the Russian Defence Ministry withdrew its troops and military police from the Afrin Region to avoid conflict with TAF.[8] The US and CJTF militaries that supported the SDF/YPG/YPJ in its fight against IS[9] did not provide air power over Afrin to counter that of the TAF. In 2021, the conflict remains active and the SGF has regained control of much of Syria except for the northern Syrian Kurdish-controlled region (Court and Hond 2020), part of which was occupied by TAF and TFSA during the Turkish offensive Operation Peace Spring, which began on 9 October 2019, after US forces withdrew east (McKernan 2019) on 6 October 2019.[10] This has forced the Kurds to negotiate with the Assad regime (Gulf News 2019). TAF and their proxies occupying the Afrin Region are now frequently targeted by insurgent groups.

[6] The Kurdistan Communities Union (KCK) is a Kurdish political organisation that serves as an umbrella group for all the democratic confederalist political parties of Kurdistan, including the Kurdistan Workers' Party (PKK) and Democratic Union Party (PYD). The PKK and all its affiliates are considered as terrorist organisations by Turkey with evidence of deliberate targeting of civilians. NATO refers to the PKK as a terrorist entity. In the United States a case had been made for removing the Kurdistan Workers' Party (PKK) from the State Department's list of Foreign Terrorist Organizations (FTOs) would create conditions for greater security cooperation between the United States and the PKK in the fight against the Islamic State in Iraq and Syria (ISIS) (https://www.lawfareblog.com/case-delisting-pkk-foreign-terrorist-organization). In 2020, the supreme court of Belgium ruled that the PKK was not a terrorist organisation, instead labelling the group as an actor in an internal armed conflict (https://www.brusselstimes.com/belgium/92787/belgian-government-defies-ruling-of-its-supreme-court-on-pkk/).

[7] Operation Olive Branch was a cross-border military operation conducted by the TAF and TFSA in the Afrin Region. The air war and artillery barrages ended as the TFSA entered the city of Afrin on 18 March 2018.

[8] The Russian Foreign Ministry expressed concern at the assault and called for restraint. (Gall 2018).

[9] Turkey recognises the YPG, YPJ and SDF as an extension of the PKK however other nations such as the UK have not proscribed the YPG as a terrorist organisation (https://www.gov.uk/government/publications/proscribed-terror-groups-or-organisations-2).

[10] The Trump administration ordered American troops to withdraw from northeastern Syria, where the United States had been supporting its Kurdish allies (BBC News 2019).

17.3 Geology Around Afrin

Syrian Kurdish military works were constructed in mountains of limestone, sandstone and marl and in valleys in alluvial terraces and conglomerates (Fig. 17.2; SMI 1964). These lithologies are very favourable for digging and tunnelling. The Kurd Mountains are composed mainly of hard rock, Upper and Lower Cretaceous sandstones, limestones and dolomites; and chalky limestones and marls. The Afrin Valley is underlain by softer rock, Middle and Upper Eocene soft chalk-like and hard nummulitic limestones. Mount Bursaya (855 m asl), Mount Sakarkaya (774 m asl) and mountains southwest to Afrin are composed of Lower Miocene marine limestones, marls, clays, conglomerates and sandstones. The city of Afrin sits astride Tortonian limestones, marls, conglomerates, sandstones and Quaternary alluvial terrace pebble beds and conglomerates. The geology and climate around Afrin are favourable to the formation of dolines, caves and sinkholes. Dozens of Palaeolithic caves have been identified in the Afrin valley (Akazawa and Nishiaki 2017).

17.4 Military Works

Military works in the Afrin Region were constructed on both the Turkish side of the border and on the Syrian-Kurdish side. Using handheld images, media reports, drone as well as satellite imagery, it has been possible to determine how these military works were constructed as well as how and why they evolved. The factors of shape, size, shadow, tone, associated features and movement in images were used to interpret design features, characteristics and activities (Hamshaw Thomas 1920). Associated features were often critical to interpreting the function and signature equipment, such as excavators, and allowed distinctions between different combatants (TAF, TFSA, SGF, IS, al-Nusra, Russians, rebels and YPG/SDF/YPJ) to be identified. Where identifiable, Hamshaw Thomas factors have been used for dimensional analysis to determine the time, materials, volumes and costs needed to construct military works.

Turkey utilised the full resources of the state controlled by President Erdogan in its programme of military works. The Syrian Kurds threatened by Turkish invasion into the Afrin Region, as well as from SGA forces, IS and al-Nusra terrorist groups, undertook their own programme of military works. However, as a newly autonomous region, it did not have the structures, organisations or levels of finances of its opponents. Despite these imbalances, the Syrian Kurds carried out significant defensive construction projects of defensive trenches, OTs, CCHTs and UGFs, which required financing and experienced and skilled work teams with project managers, site foreman, plant operators and construction crews. Given the size and number of UGFs being constructed across Afrin by the Syrian Kurds, there was a critical need to tunnel faster driven by the need for concealment and protection to increase survivability. As observed in the IS tunnel programme in Iraq (Bulmer 2019), moving from hand tools to tunnel machines is a logical progression to meet this necessity. These machines required even more financing and more experienced and skilled tunnel teams with project managers, tunnel foreman, tunnel machine operators, along with construction crews experienced in shoring and lining the tunnels creating hardened UGFs. Materials used in defensive trenches, OTs, CCHTs and UGFs were rebar, wooden forms and concrete with large volumes of each required, as well as water. The costs to the Syrian Kurds, when applied across the military works undertaken, add up to 10s to 100s of millions of dollars. This was not being generated within the autonomous Afrin Region, indicating outside financial support. The Turkish media interpreted the US Defense Department 2019 assistance for Syria as allocating $550 million[11] to the YPG, and this went to covering costs of the military works (Gurses and Butler 2018). They also claimed that the concrete used by the Syrian Kurds was being supplied from the French-owned Lafarge Cement Syria Factory in the Province of Aleppo (Ahval News 2018). Examinations of the costs and availability of materials associated with construction, therefore, provide an insight into an aspect of the ongoing conflict that has received limited attention (Bulmer 2021). However, these costs, which resulted in tangible defensive trenches, OTs, CCHTs and UGFs for Syrian Kurds, provided only a short-term gain in concealment and survivability when matched against TAF state-funded expenditure on armour, artillery and air power to damage or defeat these structures during Operation Olive Branch. There was a considerable increase in Turkey's 2018 budget for Defence, taking it to an estimated $10.6 billion (Defence Turkey 2018). Financially, Turkey's actions in Afrin were not without consequence: on 7 March, Moody's Investors Service downgraded Turkey's debt (Financial Times 2018), warning of erosion of checks and balances under the leadership of President Recep Tayyip Erdoğan and saying that the Afrin offensive, having strained relations with the US and drawn the country deeper into the Syrian civil war, had added an extra layer of geopolitical risk.

17.4.1 Turkey

In 2016, Turkey began constructing a wall along the border with northern Syria to stop IS bombing teams crossing into Turkey, as well as to block the flow of refugees from Syria and stop supplies for insurgents and terrorist groups coming across from Turkey (Fig. 17.3; Chohan 2018; Ozturk 2018). An examination of satellite imagery at visible wavelengths shows a road following the border and a band of "no-man's" land on the Turkish side marking the eastern border with the Afrin region (Fig. 17.3a). The contract to build 828 km of concrete wall was awarded to TOKI, Turkey's state-owned construction enterprise. The wall (Fig. 17.3b) is composed of 7-tonne concrete segments, each 3 m high and 2 m wide delivered by rail and on flat-bed

[11] All $ figures in this paper refer to US dollars.

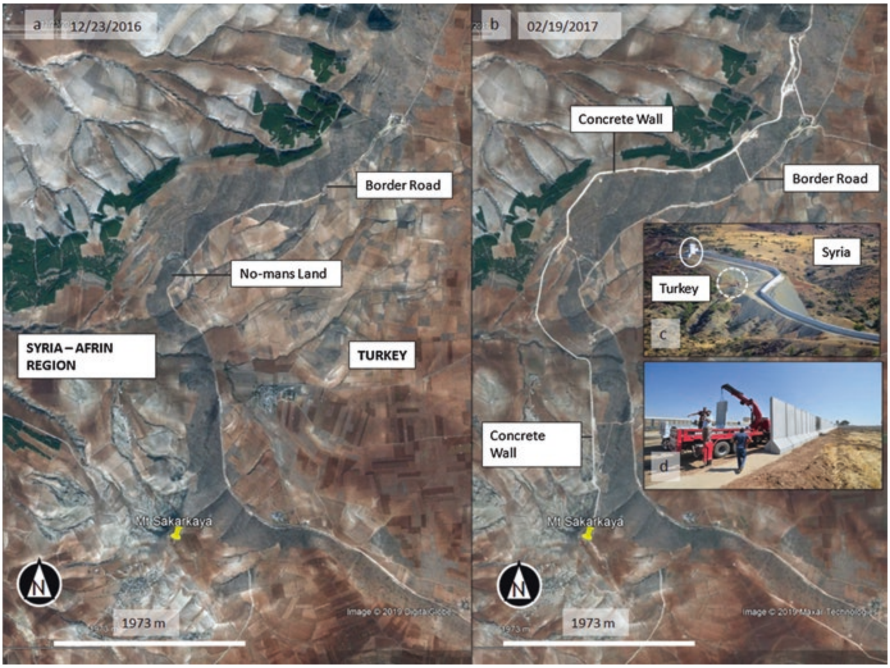

Fig. 17.3 (**a**) WorldView EO image acquired 23 December 2016 over the border between Syria and Turkey around Mount Sakarkaya in northwest Syria. (**b**) WorldView EO image acquired on 19 February 2017 over the same area as image (**a**) showing a concrete wall built by Turkey. (**c**) A section of the concrete wall built on a gravel embankment. (Modified from Ozturk 2018). The white oval indicates an automated OT and the dashed white oval, a flat-bed tractor-trailer with a crane. (**d**) A flat-bed tractor trailer off-loading a concrete block. (From Daily Sabah 2016)

tractor-trailers and lifted into position with a crane (Fig. 17.3c, d). By December 2017, 781 km of wall had been constructed requiring 390,500 concrete segments. In spring 2018, the wall was finished, comprising 414,000 segments (Bulmer 2021). To first order, costs for 414,000 segments, using the global concrete pricing of \$120/0.76 m^3, ranged from \$39.2 million for 0.1-m thickness to \$196.1 million for 0.5-m thickness. This rises to \$65.3 million for 0.1-m thickness then \$326.8 million for 0.5-m thickness calculated using the concrete pricing of \$200/0.76 m^3 (Bulmer 2021). Included in the border wall construction were 120 border OTs (Fig. 17.3c), each of a standard design 15 m high with a diameter of 7 m, each computerised with an alarm and automated firing systems for the weapon systems contained in them (Turkey News 2016). In November 2017, as the border wall construction continued, TAF had excavated trenches on limestone slopes up Mount Bursaya and Mount Sakarkaya, angling up to the Syrian Kurdish defences as part of the preparations for the launch of Operation Olive Branch at the start of 2018. The US military and anti-IS coalition monitored but did not intervene.

17.4.2 Autonomous Afrin Region

The YPG/YPJ was a light infantry force with limited artillery, improvised armoured vehicles, no combat engineers and no air power to counter TAF. Initially, defensive positions on the Syrian side of the border with Turkey, constructed by the Syrian Kurds on the crest of the limestone ridge along the Turkey/Syria-Afrin Region border, were much less sophisticated than on the Turkish side (Fig. 17.4) but underwent rapid design and material improvements to attempt to incorporate lessons learned from the blast and impact effects of weapon systems used by TAF, TFSA, SGF, IS, al-Nusra and their affiliates. Unlined and unsupported defensive trenches collapsed if an artillery round or missile struck near them, burying defenders. The use of concrete and rebar reduced collapses and meant that TAF air and artillery strikes had to hit a trench directly. Roofing over the trenches to create CCHTs also concealed the defenders from TAF and made targeting more difficult. Changing angles, alignment and dimensions in trenches and CCHTs were all measures introduced to advantage the defenders and disadvantage the attackers in face-to-face trench warfare, features reminiscent of the World War I trenches (Jones 2010; Doyle 2017). The increasing use of subterranea was a direct response by the Syrian Kurds to having no air power, needing to avoid detection from Turkish air assets and increase survivability from air and artillery strikes. At the start of TAF Operation Olive Branch in January 2018, many of these Syrian Kurdish military works were still under construction, as evidenced by the photos taken by Turkish media from captured positions.

Fig. 17.4 View from the Turkish side of the border over a defensive wall to the Syrian side on 17 January 2018. Defensive positions constructed on the crest of the limestone ridge can be seen on the Syrian side. (Modified from Chohan 2018)

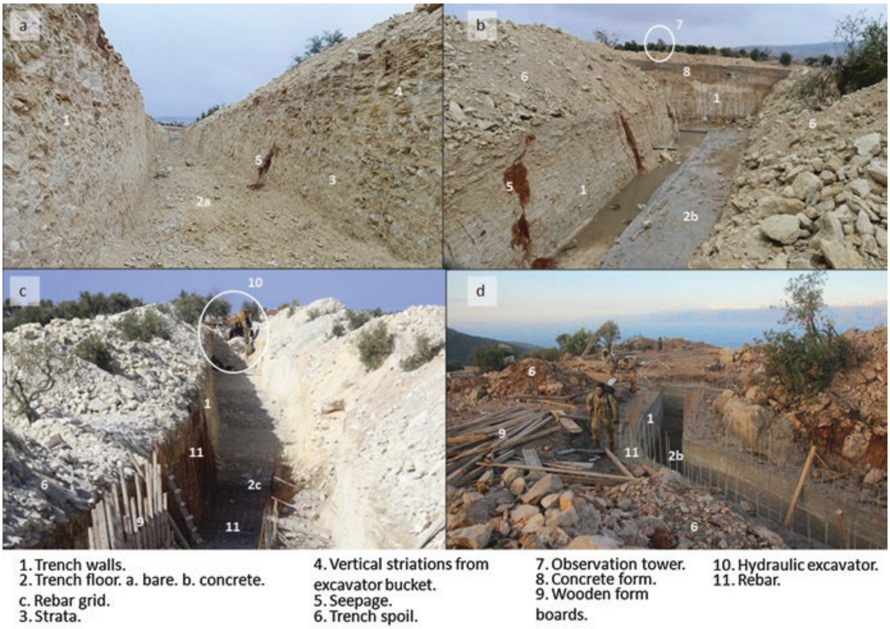

Fig. 17.5 (**a**) Syrian Kurdish trench excavated in horizontally bedded limestone with marls using a machine. (Modified from Vatan 2018). (**b**) Syrian Kurdish trench in chalky limestone with marls dug using a mechanical excavator prior to a concrete floor being poured. The white oval shows an OT. (Modified from Yeni Safak 2018b). (**c**) The white oval shows a tracked excavator digging a Syrian Kurdish trench with a small 305-mm bucket. (Modified from Takvim 2018). (**d**) Concrete-lined Syrian Kurdish defensive trench in limestone on Mount Bursaya. (Modified from Southfront.org 2018)

Cut-and-Cover Trenches

Digging in the different lithologies by the Syrian Kurds was undertaken using hand tools and machine excavators. Defensive trenches excavated on Mounts Sakarkaya and Bursaya (Fig. 17.2) show the horizontally bedded limestone with marls to be coherent enough to support near-vertical walls (Fig. 17.5a). The 5-m-deep dig in Fig. 17.5a appears to be fresh when captured by TAF in 2018, with only minimal water seepage (Fig. 17.5a component 5) and no ponding. Within trenches 5–7 m deep and 3.5 m wide (Fig. 17.5a, b), reinforced concrete was used to construct hardened tunnels 1.5 m wide and 2 m high with sides 0.9 m thick. This started with pouring a concrete floor (Fig. 17.5b component 2b), then the walls and finally the roof. These defensive trenches and hardened tunnels, which ran for tens, hundreds and thousands of metres (Fig. 17.5b–d), had raised OTs (Fig. 17.5b component 7) and changes in trench line angles as part of the defensive design (Fig. 17.5d). Horizontal rebar pieces were wired to vertical pieces in the walls once wooden form boards were installed (Fig. 17.5c, d components 9 and 11), and a concrete roof was poured to provide overhead protection. The hardened walls and roof were then

Fig. 17.6 (**a**) Unlined Syrian Kurdish defensive trench in chalky limestone with a rock floor and reinforced concrete overhead protection. (Modified from Yeni Safak 2018a). (**b**) Syrian Kurdish CCHT with multiple firing points. (Modified from Yeni Safak 2018c). (**c**) View of Syrian Kurdish CCHT combined with an OT on Mount Bursaya. (Modified from Southfront.org 2018). (**d**) Syrian Kurdish pillbox at Mount Bursaya. (Modified from Prima News 2018)

back-covered with spoil (cut-and-cover (C&C)), creating CCHTs (Fig. 17.6a, b). Design evolutions can be observed in the same Syrian Kurd trench locations where the trench looks hand dug and the rock floor follows the topography (Fig. 17.6a components 1a and 2a). The dimensions are 1.0 m wide at the floor and 1.5 m deep with an additional 0.5 m of reinforced concrete having been added, enabling defenders to stand rather than crouch (Fig. 17.6a, b component 3). In several locations, Syrian Kurds constructed "double-deck" CCHTs. Figure 17.6b shows a Syrian Kurdish CCHT with dimensions 2 m high and 1.5 m wide with multiple firing points. The design enables defenders to move easily through the tunnel network unseen with much-improved protection compared to earlier designs. Syrian Kurdish OTs and pill boxes, constructed of reinforced concrete (Fig. 17.6c, d component 5), were connected to CCHTs and had ventilation, electrical wiring and living areas. CCHTs have been identified linked to UGFs with command centres, hospitals, dormitories, weapons, ammunition and vehicle storage areas reminiscent of World War I (Jones 2010; Doyle 2017).

Using images, such as Figs. 17.5 and 17.6 and satellite imagery such as WorldView (Fig. 17.3), it has been possible to determine how Syrian Kurdish trenches were constructed as well as how and why they evolved to CCHTs connected into fixed defensive lines. Where identifiable, Hamshaw Thomas factors have been used to undertake dimensional analysis to determine the time, materials,

Table 17.1 Calculated volume (*V*) of material (without bulking) to be excavated for 5-m- and 7-m-deep trenches over lengths (*L*) of 50–1000 m

Trench *L* (m)	Removal for 5-m deep *V* (m^3)	Removal for 7-m deep *V* (m^3)
50	875	1225
100	1750	2450
500	8750	12,250
1000	17,500	24,500

Table 17.2 Calculations for the number (*N*) of bucket removals for 5-m-deep trenches 50–1000 m long using different standard sizes of excavator buckets. *L* is length, and *V* is volume (without bulking)

Trench *L* (m)	*V* (m^3) for 5-m-deep trench	*N* of 305-mm buckets	*N* of 406-mm buckets	*N* of 508-mm buckets	*N* of 619-mm buckets	*N* of 762-mm buckets	*N* of 914-mm buckets
50	875	10,658	8349	6060	4829	3635	2915
100	1750	21,315	16,698	12,119	9658	7270	5829
500	8750	106,577	83,492	60,596	48,289	36,352	29,147
1000	17,500	213,155	166,985	121,191	96,578	72,705	58,294

volumes and costs needed by the Syrian Kurds to construct CCHTs (Hamshaw Thomas 1920). The dimensions of a Syrian Kurdish trench line (5–7 m deep and 3.5 m wide; Fig. 17.5) can be used to calculate the volume of material to be excavated from lengths 50–1000 m (Table 17.1) with spoil banked on either side (Fig. 17.5b, c).

In operational planning, rates of machine excavation are an important metric and of great significance to determining where any plant available to the Syrian Kurds was best utilised given the threat of Turkish invasion. Excavation rates for a range of bucket sizes can be used to calculate the number of bucket fills required for 5-m-deep trenches over distances of 50–1000 m (Table 17.2). The excavator visible in Fig. 17.5c (component 10) has a small, 305 mm bucket. To dig a 5-m-deep trench, 3.5 m wide along a 300-m length, such as one at Mount Sakarkaya (Turkey News 2018a), using this bucket (0.0821 m^3 capacity) would have required 63,946 individual bucket lifts. The number of individual bucket lifts for the same trench depth and length reduces to 36,357 for a 508-mm bucket (0.1444 m^3capacity) and to 17,488 for a 914-mm bucket (0.3002 m^3 capacity).

Using the rates of machine excavation (Table 17.2), the total time required for digging a 5-m-deep, 3.5-m-wide trench using rates of 4.8 m^3/hour (slow), 6.1 m^3/hour (average) and 7.1 m^3/hour (fast) can be calculated, as well as the time taken using an eight- or 10-hour work shift per day (Table 17.3).

Calculations of the time required to dig (Table 17.3) can then be matched to the different bucket sizes (Table 17.2) to determine the excavation time required. This is a critical consideration for the construction being undertaken with the constant threat to the Syrian Kurds of being attacked (Table 17.4). For an excavator

Table 17.3 Total time required to dig a 5-m-deep, 3.5-m-wide trench using a 914-mm bucket. Tr is trench; *L*, length; *V*, volume (without bulking); *T*, total; H and Hr, hours; and *e*, excavation rate

Tr *L* (m)	*V* (m^3) for 5-m-deep Tr	*T* Hrs $e = 4.8$ m^3/hour (s)	*T* Hrs $e = 6.1$ m^3/hour (av)	*T* Hrs $e = 7.1$ m^3/hour (f)	*T* 8 H shifts $e = s$	*T* 8Hr shifts $e = av$	*T* 8Hr shifts $e = f$	*T* 10Hr shifts $e = s$	*T* 10Hr shifts $e = av$	*T* 10Hr shifts $e = f$
50	875	182	143	123	23	18	15	18	14	12
100	1750	365	287	246	46	36	31	36	29	25
500	8750	1823	1434	1232	228	179	154	182	143	123
1000	17,500	3646	2869	2465	456	359	308	365	287	246

Table 17.4 Total time required to dig a 5-m-deep, 3.5-m-wide trench using a 305-mm bucket at three different excavation rates and over an eight-hour shift. Tr is trench; *L*, length; *V*, volume (without bulking); Hrs, hours; and *e*, excavation rate

Tr *L* (m)	V (m^3) for 5-m-deep trench	Hrs $e = 4.8$ m^3/hour (s)	Hrs $e = 6.1$ m^3/hour (av)	Hrs $e = 7.1$ m^3/hour (f)	Total eight-hour shifts $e = 4.8$ m^3/hour (s)	Total eight-hour shifts $e = 6.1$ m^3/hour (av)	Total eight-hour shifts $e = 7.1$ m^3/hour (f)
50	875	2220	1747	1501	278	218	188
100	1750	4441	3494	3002	555	437	375
500	8750	22,204	17,472	15,011	2775	2184	1876
1000	17,500	44,407	34,943	30,022	5551	4368	3753

(Fig. 17.5c) to dig a 5-m-deep trench, 3.5 m wide along a 300-m length using the small 305-mm bucket (rated capacity = 0.0821 m^3) would have required 13,322 hours excavating at 4.8 m^3/hour (slow rate); 10,483 hours, at 6.1 m^3/hour (average rate); and 9007 hours, at 7.1 m^3/hour (fast rate). It is clear that using a bucket this small was not optimal but may reflect the urgency under which the Syrian Kurds were constructing them, making use of what was available. Examining working hours per day for this same bucket translates to 1665 eight-hour shifts excavating at 4.8 m^3/hour; 1310, at 6.1 m^3/hour; and 1126, at 7.1 m^3/hour. If two eight-hour shifts were run per day, this is 833 days excavating at 4.8 m^3/hour; 655 days, at 6.1 m^3/hour; and 563 days, at 7.1 m^3/hour. Two eight-hour shifts in a single day would have required two excavator operators to sustain the pace of working.

Operating after dusk requires lighting that would have revealed the Syrian Kurdish position to TAF, making it vulnerable to an airstrike or artillery, but if that risk were taken, then operating two ten-hour shifts per day, a total of 666 days would be required for excavating at 4.8 m^3/hour, 524 days for 6.1 m^3/hour and 450 days for 7.1 m^3/hour. These calculations highlight not just the need for skilled excavator operators but also the significance of access to the biggest bucket (Table 17.2) suitable to the task, as well as more than one excavator. These calculations (Table 17.3) highlight the significance of having skilled excavator operators and raises the question as to how many such individuals existed in the autonomous Afrin Region.

Once the trenches were excavated, rebar was installed and tied on the floor (Fig. 17.5b) and then on the walls (Fig. 17.5c) prior to concrete being poured to create the reinforced sides and bottom to the HTs (hardened tunnels). Lastly, the ceiling rebar was tied (Fig. 17.5d component 11) and then concrete poured on it to make a reinforced top to the HT (Fig. 17.6a, b). Costs of single-bar rebar ($0.75/0.3 m based on the 2019 global price) range from $5917 for a 50-m single-bar reinforced CCHT and $35,500 for a 300-m single-bar reinforced length (Bulmer 2021). The total volume of concrete needed to complete two walls, ceiling and floor for a 50-m CCHT, is 315 m^3; for 300-m, 1890 m^3; and for 1000-m, 6300 m^3. The costs of concrete at a global average price at the time of $120/0.76 m^3 range from $49,737 for a 50-m length of tunnel; $298,421 for a 300-m length; and $994,737 for a 1000-m length. At a concrete cost of $200/0.76 m^3, 50 m of CCHT costs $82,895; 300 m, $497,368; and 1000 m, $1.65 million (Bulmer 2021). The use of dimensional analysis to determine the time, materials, volumes and costs needed by the Syrian Kurds to construct CCHTs reveals the large infrastructure investment undertaken using modern construction techniques. The costs, when applied across the construction of trenches, CCHTs and OTs, reveal millions of dollars in expenditure.

Underground Facilities

In addition to C&C techniques, the Syrian Kurds also constructed UGFs as part of the defence around Afrin (Fig. 17.7) using tunnelling techniques to increase overhead protection by increasing the depth below ground. The use of subterranea in Afrin, as well as in Kobane and Manbij (Fig. 17.1) in Rojava (Turkey News 2018b;

Fig. 17.7 (**a**–**c**) Entrances to Syrian Kurdish UGFs in the mountains around Afrin constructed in a chalky limestone. (**a** and **c** modified from NTV 2018, **b** modified from Syria Call 2018). (**d**) Room in a Syrian Kurdish UGF in the mountains around Afrin with 100-m tunnels. (Modified from Syria Call 2018).

Seligman 2019), increased as a direct response to having no air power and needing to avoid detection and increase survivability against munitions used by SGF, TAF, IS, al-Nusra and their affiliates. Entrances to Syrian Kurdish UGFs in the mountains around Afrin (Fig. 17.7a–c) constructed in chalky limestone (Fig. 17.2) show that the spacing between vertical and horizontal rebar is small, indicating weak rock (Fig. 17.7a, b component 1b). Wooden forms need to be added before the concrete pour unless it was to be sprayed on. The floor appears to be concrete (Figs. 17.7a component 2a and 17.7b component 2b). UGFs incorporated design features such as camouflage and concealment, reinforced portals, defensive hard points and thick burster layers (Fig. 17.7a–c), all features of 1914–18 European trench warfare (Doyle 2017) and the 1930s French Maginot Line (Kaufmann et al. 2011). The most sophisticated UGFs had dormitories, hospitals, armouries, kitchens, latrines and command centres complete with CCTV, solar panels, computers, phones, electricity, respirators and ventilation, all of which facilitated underground occupation for long periods. Rooms in one facility (Kar 2018a), likely a command centre, are 100 m long with additional tunnels emerging off them connecting to rooms for offices, dormitories, kitchens, medical centres, weapons and vehicle stores. The dimensions are big enough for Syrian Kurdish forces to store vehicles and artillery. One room has marble tiles on the floor and concrete-reinforced arches (Fig. 17.7d components 6 and 7), possibly designed as an alternate centre of government for the leaders of the Autonomous Region. A large underground hospital was built in Afrin city centre with a 50-m access tunnel (Daily News 2018b).

As with the trenches, OTs and CCHTs, the scale of the UGFs represents significant defensive military work construction projects undertaken by the Syrian Kurds. Images in media reports of UGFs captured by TAF and TFSA during Operation Olive Branch show that many were still under construction (Fig. 17.7a, b, c) but did not reveal how those subterranean spaces had been excavated. Given the size and number of UGFs being constructed across Afrin, the need for the Syrian Kurds to tunnel faster was critical, and moving from hand tools to tunnel machines is a logical progression to meet this necessity. Images and media reports were therefore examined to identify signature tunnelling equipment. The existence of tunnel boring machines (TBMs) being used by the Syrian Kurds was to be expected, given that others had been captured from IS in and around Mosul in 2016 (Bulmer 2019).

Improvised Tunnel-Boring Machines

On 20 March 2018, a series of 400-m Syrian Kurdish tunnels around Afrin were captured by TAF and TFSA (Kar 2018b). One tunnel complex (el Homsi 2019), situated mid-slope in an area of olive grove below CCHTs on the ridge top (Fig. 17.8

Fig. 17.8 (**a**) View of a tunnel entrance in the mountains around Afrin. (**b**) Inside the tunnel entrance are a Bobcat, a BMCH and an ITTBM. (**c**) View of the wheeled part of the BMCH. (**d**) View of the extendable and multiaxial boom-mounted cutting head. (Modified from Nsubuga 2018)

components 7 and 8), contained a Bobcat front loader, a boom-mounted cutting-head machine (BMCH) and a tracked tunnel boring machine (TTBM) (Fig. 17.8 components 10, 11, 12). The ramp down to the tunnel entrance was camouflaged with a sewn disruptive pattern sheet (Fig. 17.8a component 3). Inside the tunnel entrance (Fig. 17.8b), the hard limestone ceiling is unsupported, indicating a strong, stable rock mass (Hoek et al. 2000) that would provide good overhead protection from attacking artillery and airstrikes. The Bobcat, BMCH and TTBM work in a combined manner. The main function of the Bobcat is spoil removal (Fig. 17.8b component 10). The low profile BMCH (Fig. 17.8c component 11) has an extendable boom arm with a multiaxial, rotating, cutting head with teeth and is used to move around a tunnel face (Fig. 17.8d components 11 and 14). It creates a rectangular, arched or trapezoidal tunnel profile (Fig. 17.8b, c, d) and can work in either hard or soft rock (Gagne and Fuerst 2016). The motor on the BMCH is powered by an umbilical cable that runs to a three-phase generator identified outside the tunnel entrance that eliminates engine emissions in the tunnel (Fig. 17.8a, b component 6). The wheeled part of the BMCH (Fig. 17.8c component 11) does not look like standard mining machines and is thus likely improvised. However, the actual boom-mounted cutting head (Fig. 17.8d component 14) is likely to be commercial.

Based on an analysis of images and video, the TTBM is improvised (ITTBM) with a design very similar to ITTBMs captured from IS outside Mosul, which

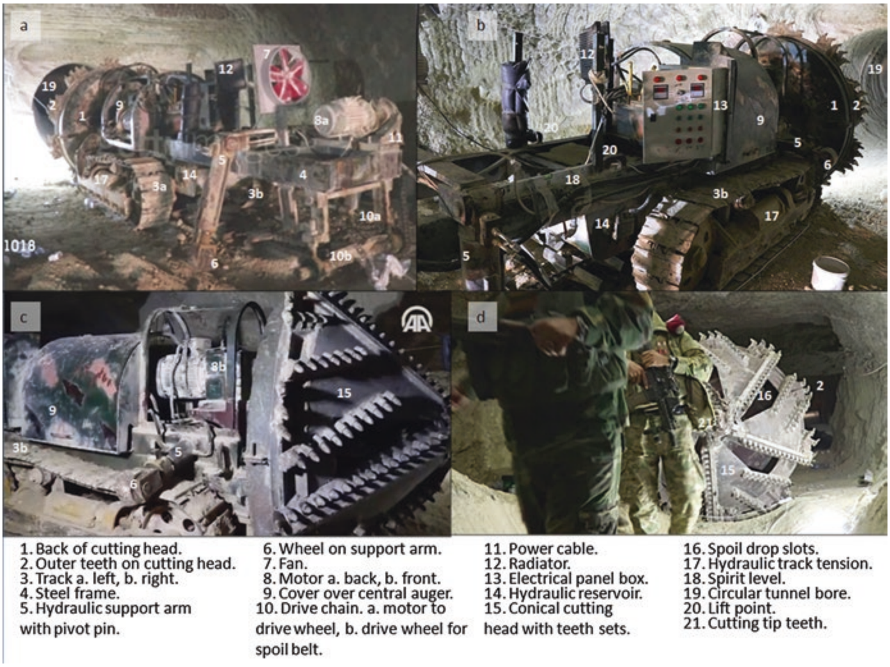

Fig. 17.9 (**a**) Rear left-side view of the ITTBM in situ in a tunnel in Afrin. (**b**) Rear right-side view. (**c**) Forward right-side view. (Modified from Antonopoulos 2018). (**d**) Front view of the cutting head. (Screenshot from Son Kale Twitter.com 2018)

tunnelled in poorly consolidated materials (Bulmer 2019). Design differences reflect improvements making it likely to be more effective in the soft rock geology of Afrin. The existence of the ramp into the tunnel (Fig. 17.8a component 1) shows that the ITTBM was driven to the rock face rather than lowered down a shaft. Electric motors on the ITTBM are powered by an umbilical cable that runs to a three-phase generator outside the tunnel entrance that eliminates engine emissions in the tunnel (Fig. 17.8a–c component 6). The ITTBM bores a circular tunnel (Fig. 17.9a, b component 19) using a conical cutting head (Fig. 17.9c component 15). This shape is a commercially available "Christmas tree'" design with 216 individually replaceable tooth sets that come in sets of five on the cone with 12 sets on the perimeter of the head (Fig. 17.9d component 21).

Using TAF soldiers for scale (Fig. 17.9d), the cutting head radius appears to be approximately 1-m, and an examination of the teeth angles as well as orientation (Fig. 17.9c component 15) shows that the direction of cut rotation is from the operator in a clockwise direction. The nose of the cutting head has four large teeth (Fig. 17.9d component 21) with a central auger running back through the ITTBM. Seven vertical spoil drop slots, each positioned between rows of cutting teeth along the head (Fig. 17.9d component 16), empty the spoil into the central auger. The teeth (Fig. 17.9c component 15) appear to be set up for use in poorly consolidated material and are thus well suited for tunnelling in the soft rocks of Afrin (Fig. 17.2). The design appears less suitable for the greater hardness and higher compressive strengths of the Lower and Upper Cretaceous rocks in the mountains.

The ITTBM is mounted on two metal tracks (Fig. 17.9a components 3a and 3b). There are drive sprockets on either side at the front closest to the cutting head for better traction and control as well as a hydraulic track tension system (Fig. 17.9a, b component 17). Spoil created at the cutting head dropped from a short central auger (Fig. 17.9a component 9) onto a spoil conveyor (Fig. 17.9a components 3a and 3b) that runs to the rear of the ITTBM. The spoil is then moved away by the Bobcat. The auger is chain driven by a motor-powered flywheel (Fig. 17.9a components 10a and 10b). Based on conditions in the tunnel (Fig. 17.8), the spoil would have been dry. There are four hydraulically controlled arms, each with a wheel at the end, that pivot from the frame of the ITTBM (Fig. 17.9a, b, c components 5 and 6). One pair is located just behind the cutting head and the other at the back of the ITTBM. The function of these arms in the horizontal position is to provide lateral stability as the ITTBM advances, controlling for roll and yaw. In the vertical position, they control pitch. A standard builder's spirit level on the right side of the ITTBM (Fig. 17.9b component 18), set horizontally on the steel frame behind the main control box, provides pitch control during tunnelling. The control panel (Fig. 17.9b component 13) has an ignition switch and colour-coded indicator lights that connect to a circuit panel. Two motors, one at the front, which drives the cutting head (Fig. 17.9c component 8b), and one at the back, which drives the spoil conveyor (Fig. 17.9a component 8a), have wiring that runs back from three-phase terminal boxes to the circuit panel. The cover over the central auger is painted in the camouflage pattern of the YPG (Fig. 17.9c component 9).

Table 17.5 Volume (without bulking) and tonnage of spoil generated by the ITTBM with a 1-m radius cutting head over tunnel lengths (*L*) of 25–500 m and the number of dump trucks required for removal. *V* is volume without bulking, and mt is metric tonnes. The tonnage is based on dry coarse sand

	L (m)	*V* (m^3)	Tonnes mt	16 m^3 trucks
(I)TTBM	25	78	125	8
	50	157	251	16
	100	314	502	31
	200	629	1006	39
	300	942	1508	59
	400	1257	2011	79
	500	1571	2514	98

The circular bores (Fig. 17.9a, b, d component 19) are tall enough to walk in and large enough for a small vehicle. The rock mass class (Bieniawski 1976) appears to be I – very good rock - with a rock mass rating of 81–87. This estimate of rock quality is based upon the apparent absence of tunnel support. The geology is ideal tunnelling rock, weak enough to use the ITTBM but strong enough to be self-supporting. Dryness is the key to stability. The tunnel is a clear demonstration of Syrian Kurdish expertise in geology, mining and tunnelling.

Tunnelling Rates

The advance rates for tunnelling by the BMCH at Afrin are unknown, but those from a commercial roadheader MT270 Tunnel Miner (hard-rock conditions), which has a comparable boom-mounted cutting head, can be used to provide a first-order estimate. Used in limestone (Gagne and Fuerst 2016) similar to the hard nummulitic limestones of the Afrin valley, tunnelling rates averaging 8 m/day provide a reasonable estimate for a rate of advance, giving 40 m for a five-day week and 56 m for a seven-day week.

Using a 1-m estimate for the radius of the cutting head on the ITTBM and the 400-m length of one of the tunnels captured on 20 March 2018 (Fig. 17.8), 2011 metric tonnes of spoil would have been generated (Table 17.5). Moving this volume off-site would have required 79 trucks each with a capacity of 16 m^3 (Table 17.5). The Bobcat (Fig. 17.8b component 10) would have been able to take the spoil out of the tunnel for loading. Loading dump trucks would have been a signature activity that TAF air assets would have looked for to detect tunnel construction. Loading at night would have reduced the chances of detection but would still have been detectable to sensors at infrared wavelengths.

As with the advance rates for the BMCH, those for the ITTBM at Afrin (Fig. 17.9) are also unknown, but rates from a Robbins Small Boring Unit with a comparable cutting head and dimensions (Anon. 2017) can be used to provide a first-order estimate. Given the nature of the soft rocks present in Afrin (Fig. 17.2) and at the site of the captured ITTBM (Fig. 17.8), advance rates of 24 m/day for the ITTBM seem

Table 17.6 Rates of boring advance for the ITTBM captured in Afrin based on rates of a Robbins SBU with a comparable 1-m radius cutting head. Volume (without bulking) and tonnage of spoil generation by the ITTBM over lengths (*L*) of 25–500 m and the number of dump trucks required for removal. *V* is volume without bulking; mt is metric tonnes. The tonnage is based on dry coarse sand

Advance rate m/day	Advance rate m/week	Tunnel *L* (m) in 1 year	*V* (m^3)	Tonnes mt	16 m^3 trucks
6	30	1560	4903	7845	306
12	60	3120	9806	15,689	613
18	90	4680	14,709	23,534	919
24	120	6240	19,611	31,378	1226
30	150	7800	24,514	39,223	1532
42.2	211	10,972	34,876	55,802	2180
45	225	11,700	36,771	58,834	2298

realistic (Table 17.6). Using this rate and assuming two ten-hour shifts for each of five days each week, leaving four hour/day for maintenance, it would have taken 23 days to bore a 400-m tunnel. Its effectiveness in hard limestone is uncertain. This first-order estimate shows that although an ITTBM is faster than the BMCH, they have different capabilities that complement each other and provide a very effective combination for tunnelling in hard and soft rocks.

As with the construction of the trenches, OTs and CCHTs, running multiple tunnelling teams at the same time to construct UGFs would have required knowledgeable, skilled and competent project managers to oversee them. The level of training for tunnel workers would be related to the tunnel construction methods. Crews working in a tunnel would have probably endured heat, dust, noise, poor visibility and machine breakage, with constant risks of tunnel collapse, all of which necessitated discipline and teamwork. No evidence has been found that they had to deal with high water flows from the rocks in which they were tunnelling (Figs. 17.8 and 17.9). Images of the tunnel interiors of Syrian Kurdish tunnels captured by TAF (Figs. 17.7, 17.8 and 17.9) indicate that the tunnel face operators were skilled, with the most skilled being the operators of the BMCH and ITTBMs (Figs. 17.8 and 17.9). If these machines were operated in two shifts a day, then two teams of trained operators were required. Where the highly skilled manpower originated is unknown, but thousands of western volunteers brought relevant skills to support the Syrian Kurds (Hall 2019). Based on an examination of the Bobcat, BMCH and ITTBM, a team likely consisted of an operator for each machine, tunnel engineer, mechanic and on-call geologist. In addition, these machines would have needed a robust supply of spares, oils, lubricants and fuel for the generator. Similar to the construction of trenches, OTs and CCHTs, the use of dimensional analysis to determine the time, materials, volumes and costs needed by the Syrian Kurds to tunnel to create UGFs reveals large infrastructure investment undertaken using modern construction techniques. The costs related to creating tunnels and UGFs reveal millions of dollars in expenditure in addition to that on trenches, CCHTs and OTs.

17.5 Fighting in the Mountains

Turkey, having completed the concrete border wall in December of 2017, launched the military incursion Operation Olive Branch across the Syrian border into Afrin on 20 January 2018. The aim was to defeat the Syrian Kurdish forces, which had been fighting IS with the backing of the anti-IS coalitions but whom Turkey now saw again as terrorists. Heavy Turkish shelling and airstrikes forced many Kurdish villagers to flee to natural caves in the mountains. Many of these caves belong to local residents who built their homes at the entrance, incorporating them. Locals took in those fleeing the shelling (Sheikh Ali 2018). TAF combat engineers used armoured tracked excavators (Fig. 17.10a components 1 and 2) with drill attachments (Fig. 17.10a white oval) and large buckets (Fig. 17.10a white dashed oval) at least 914 mm wide (see Table 17.2) to excavate trenches on the limestone slopes of Mount Bursaya and Mount Sakarkaya to assault the Syrian Kurdish defences. Armoured fighting vehicles provided protection as the excavators worked

Fig. 17.10 (**a**) Trench excavated by TAF 10 November 2017 on a limestone slope using armoured tracked excavators. (Modified screenshot from https://www.youtube.com/watch?v=5UajSoNxMwI). (**b**) Syrian Kurdish concrete reinforced cylindrical OT on Mount Sakarkaya destroyed by either an air or artillery strike, revealing the rebar mesh. (Modified from Yeni Safak 2018b). (**c**) Entrance to a Syrian Kurdish CCHT at Mt Bursaya captured by TAF and TFSA. (Modified from Prima News 2018). (**d**) TSFA fighter in a Syrian Kurdish CCHT at Mt Sakarkaya. (Modified from Daily News 2018a)

(Fig. 17.10a component 4). The loose limestone rocks made the going on the slope difficult for infantry (Fig. 17.10a), so once Operation Olive Branch was launched, these trenches were extended to provide protection for TAF and TFSA forces as they advanced up to the Syrian Kurdish fixed trenches, OTs, CCHTs, and UGFs. TAF, a NATO member supported by TFSA, attacked the Syrian Kurdish positions using German-made Leopard2A4 Main Battle Tanks, American-made 203-mm M110A2 and 155-mm M52-Ts self-propelled howitzers, and Turkish-made TR-122 Sakarya multiple launch rocket systems, with airstrikes by American-made, multi-role fighter aircraft F-16C/Ds with American-made AIM 120 advanced medium-range air-to-air missiles, all - monitored in real time by drones. The US military and another NATO member in the CJTF, Germany, watched as the TAF weapon systems bought from them were used against the YPG/SDF/YPJ, their foremost ally in the fight against IS. They monitored but did not intervene to support the Syrian Kurds in Afrin by countering TAF air superiority. This was in part due to the air space deconfliction zone with Russia, since Afrin is west of the Euphrates and in the Russian zone, and the complexity of Turkey being a CJTF member.

At the start of Operation Olive Branch, the primary targets for Turkish airstrikes were Syrian Kurdish OTs, CCHTs and UGFs (Fig. 17.10b–d). Assaulting the rocky mountain terrain proved difficult for TAF armour, but artillery and airstrikes supported infantry fighting to the summits. The use of counter-trenching enabled the infantry to remain protected until they were close enough to climb out and assault the Kurdish defensive positions. This trench warfare was reminiscent of World War I (Jones 2010; Doyle 2017). Against this combined assault, and with no air power, armour or sufficient heavy weapons, the light infantry force of the YPG/SDF/YPJ and its defensive positions were inadequate, and on 28 January 2018, TAF and TFSA captured Mount Bursaya (Fig. 17.10c); Mount Sakarkaya was captured on 1 March 2018 (Fig. 17.10d). The use of combined arms by TAF and TFSA overmatched Syrian Kurdish defensive positions and their light infantry weapon systems. Once these had been captured, TAF and TFSA moved down from the mountains into the Afrin valley and urban spaces.

17.6 Fighting in Urban Spaces

Syrian Kurdish trenches and CCHTs constructed in and around villages, towns and cities in Afrin utilised the existing urban infrastructure, adapting it to create obstacles, blocks, hazards and kill zones. In the city of Afrin, a ditch network (Fig. 17.11a, b component 2), was excavated in the alluvial terrace pebble beds and conglomerates using front-end loaders and excavators (Temizer 2018). The spoil bunds were on the city side of the ditches just inside the main road along the edge of the city (Fig. 17.11b component 2). The 7-m-wide ditches likely served as hasty tank obstacles and were overlooked by high-rise buildings on the edge of the city (Fig. 17.11a, b component 1), enabling defenders to target advancing forces with interlocking fields of fire (Fig. 17.11). Similar to other cities where fighting

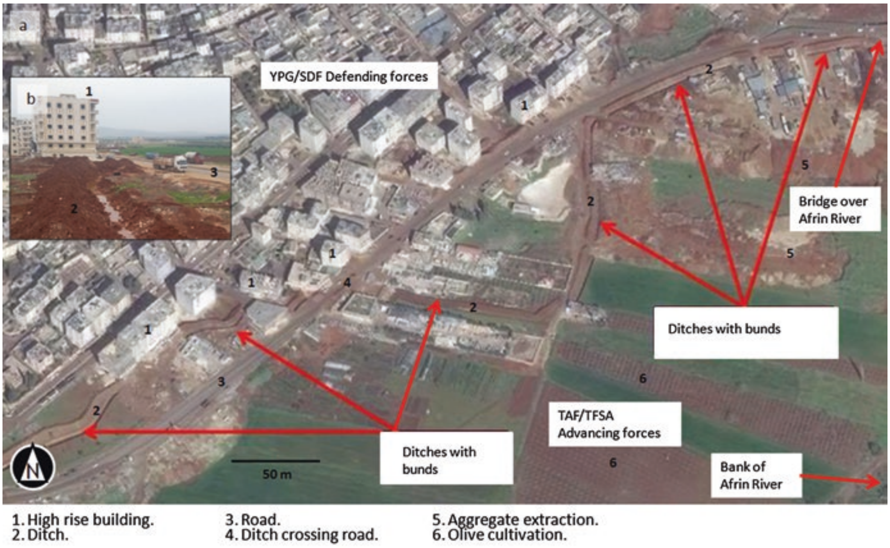

Fig. 17.11 (**a**) Defensive works on the east side of Afrin River in the city of Afrin. (**b**) Ditch and bund on the eastern edge of Afrin city. (Modified from Syria Live Map 2018)

occurred in Syria and Iraq, these buildings were connected by tunnels (Bulmer 2019), allowing defenders to move under protection and without being observed. TAF and TFSA ground forces attacked Syrian Kurdish towns and cities in the Autonomous Afrin Region using the same weapons as were used in the mountains. Again, the US, CJTF militaries and Russia monitored but did not intervene to support the Syrian Kurds. In the city of Afrin, the Afrin River formed a natural obstacle, and the bridge over the river was a critical choke point. But again, the defensive measures and light infantry force of the YPG/SDF/YPJ proved inadequate, and on 18 March 2018, TAF and TFSA captured the city centre of Afrin (Gall and Barnard 2018).

17.7 Conclusions

To meet the threats from the SGF, TAF, and TFSA, as well as from IS, al-Nusra and their affiliates, an extensive programme of military works was undertaken by the Syrian Kurds across the Autonomous Afrin Region as a core part of their military defensive measures. In the mountains, these were constructed between 2016 and 2019 in limestones, sandstones and marls and in valleys in alluvial terraces and conglomerates. These lithologies are very favourable for digging and tunnelling, and the construction incorporated lessons learned from the effects of weapon systems used by TAF, TFSA, SGF, IS, al-Nusra and other terrorist groups. Defensive trenches, OTs, CCHTs and UGFs enabled Syrian Kurdish forces to avoid detection from TAF air assets; provided protection from artillery and air munitions, plus potential chemical fallout; and allowed them to attack, delay and defend against ground forces.

Syrian Kurdish military works in the mountains defended the main high ground on the border with Turkey. In the valleys, these were constructed to defend the villages, towns and cities in Afrin, making effective use of the geology. They demonstrate that the Syrian Kurds possessed geological, engineering, construction and tunnelling knowledge. The scale of their military works programme and demand for plant as well as materials would have necessitated co-ordination with the wider economic activity in the Rojava as well as in Iraqi Kurdistan. This mirrors the IS tunnel programme in Iraq that was co-ordinated across the "caliphate" (Bulmer 2019). Undertaking the military works at the same time that the YPG/SDF/YPJ was fighting IS, al-Nusra, SGF, TAF and TSFA required knowledgeable, skilled and competent project managers to complete them. Costs calculated for the military works undertaken by the Syrian Kurds constructing defensive trenches, OTs, CCHTs and UGFs add up to 100s of millions of dollars. Such finance was not being generated within the Autonomous Afrin Region, indicating outside financial support that Turkish media attributed to the United States and France.

In the construction of defensive trenches, OTs, CCHTs, and UGFs, moving from hand tools to machines, can be seen as a logical progression driven by the need for the Syrian Kurds to create concealed and survivable spaces from TAF air and artillery strikes. Similar to IS, the Syrian Kurds demonstrated engineering and mechanical skills, including making weapons and up-armoured vehicles (Bulmer 2019). These, when combined with geological knowledge, enabled them to fabricate tunnel boring machines. Therefore, the capture of Syrian Kurdish tunnelling machines should not have been unexpected, given the extensive use of tunnelling in both Syria and Iraq by IS, al-Nusra their affiliates and anti-Assad rebels, all of whom lacked air power and needed protection and concealment to improve their survivability. Based on similarities in the designs of tunnel boring machines captured from IS in Mosul, rebels in Douma (Muraselon 2018) and YPG/SDF/YPJ in Afrin, it is possible that fabrication expertise moved between different rebel and terrorist groups across Syria and Iraq. Although not on the scale of IS, the Syrian Kurds could purchase parts and expertise from around the world (CAR 2016), either on the open or black market.

Trenches, OT, CCHTs and UGFs enabled the YPG/SDF/YPJ and unarmed Syrian Kurdish civilians to survive underground for long periods against air and artillery strikes. Fighters were able to defend from hardened positions and to surface behind, in flanking positions, or amongst advancing enemy forces. This proved effective in an insurgency, but during Operation Olive Branch, when fighting a modern military, this was insufficient to overcome TAF and TSFA combined airstrikes, artillery, armour, combat engineering and ground assaults. Unlike the Peshmerga and Iraqi forces that fought IS in Iraq (Bulmer 2019), TAF and TFSA were equipped and trained to find, secure and deny or destroy trenches, OTs, CCHTs and UGFs. Images from Turkish media of positions captured by TAF and TSFA during Operation Olive Branch show that many were still under construction. The light infantry force of the YPG/SDF/YPJ and designs of fixed military works could not be modified fast enough to effectively defend against TAF and TSFA.

Trenching and tunnelling expertise that came into the Syrian uprising from conflicts in Gaza and Lebanon (Cohen et al. 2017; Bulmer 2019) has been enhanced by IS, al-Nusra and affiliates in Iraq and Syria and by anti-Assad forces, as well as by Syrian Kurds, as the conflict has continued. Inputs have also come from Russian, Syrian, Iranian, Turkish and US militaries, as well as from commercial construction and tunnelling machines already in Syria but manufactured around the globe that were claimed by combatants for their use. It should be anticipated that military works and TBMs plus BMCHs, and the accompanying expertise, will continue to develop in current and future battlespaces.

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