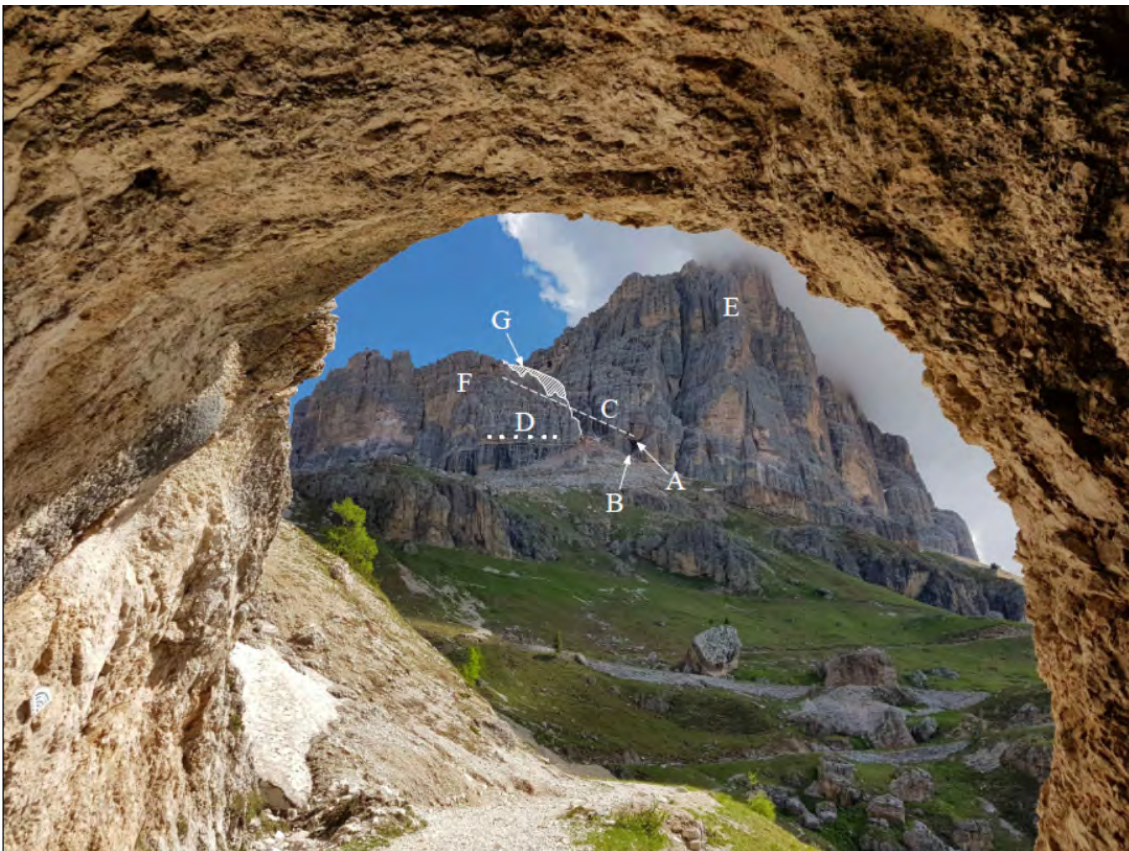


The First World War Military Tunnels of the Italian-Austrian Front

S. Pedemonte
Military history enthusiast

E.M. Pizzarotti
Pro Iter, Milan, Italy

ABSTRACT: During World War I, particularly in the years 1915-1917, all along the Austrian-Italian Front spreading from eastern Lombardy to the Gulf of Trieste, many intense tunnel works were on going for diverse military purposes. Some of these underground activities, many of which are nowadays well preserved and can be visited thanks to the constant effort in conservation and restoration by the local Authorities, are impressive if one thinks of the difficult environmental conditions in which they were built and the technical challenges of the operations. A remarkable literature exists on this subject from the historical and biographical point of view. This paper, instead, focuses on technical and technological aspects, on material resources, manpower, design and construction means and methods used to build tunnels that today seem extraordinary in relation to the period in which they were completed and to the difficulties encountered during the execution.



A = Tunnel adit, B = Ladder to tunnel adit, C = Castelletto Tunnel, D = Austrian Embra-sures, E = Tofana di Rozes, F = Castelletto, G = Ridge destroyed by Italian Mine.

World Tunnel Congress & Exhibition



WTC 2019

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NAPLES 2019

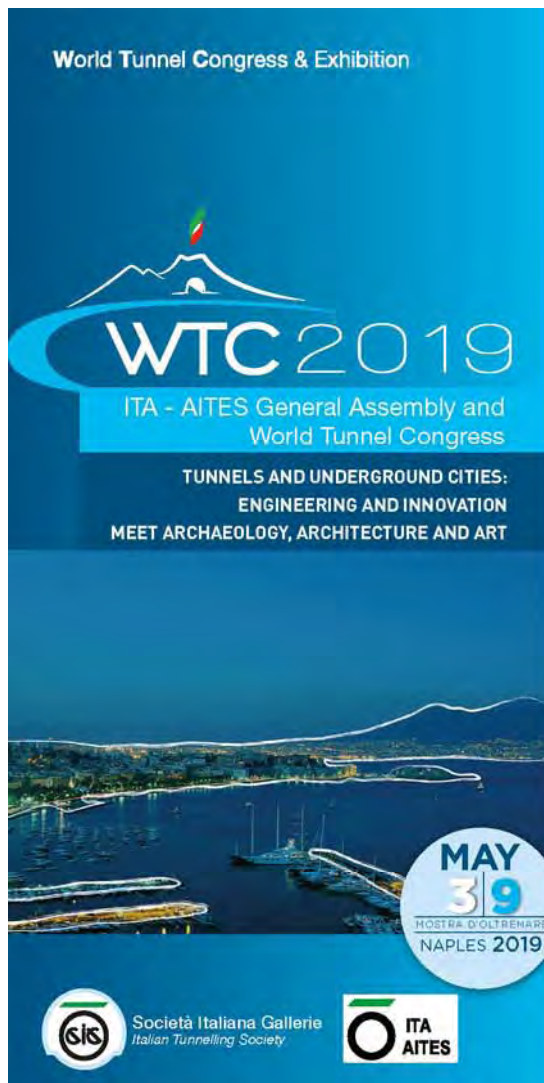
ITA - AITES General Assembly and World Tunnel Congress

**TUNNELS AND UNDERGROUND CITIES: ENGINEERING
AND INNOVATION MEET ARCHAEOLOGY, ARCHITECTURE AND ART**



Società Italiana Gallerie
Italian Tunnelling Society





Archeology, Architecture and Art in underground construction

THE FIRST WORLD WAR MILITARY TUNNELS OF THE ITALIAN-AUSTRIAN FRONT

Author: S. Pedemonte

Military History Enthusiast, Isola del Cantone (Genoa), Italy

E.M. Pizzarotti

Pro Iter, Milan, Italy

Presenting Author: E.M. Pizzarotti



**PRO
ITER**
Progetto
Infrastrutture
Territorio s.r.l.

VIA SAMMARTINI 5

20125 MILANO

SEGRETERIA@PROITER.IT



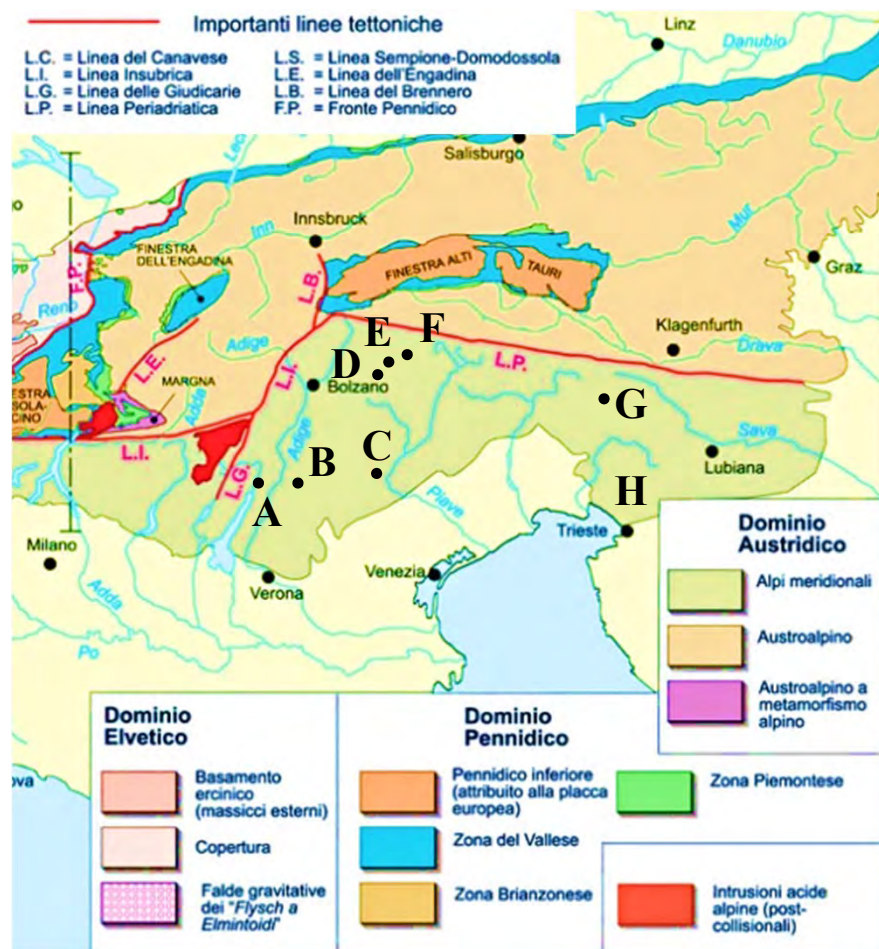
24TH MAY 1915: ITALY ENTERS THE FIRST WORLD WAR

500 km LONG ACTIVE FRONT FROM THE BORDER WITH SWITZERLAND TO THE GULF OF TRIESTE

MOSTLY MOUNTAINOUS, UP TO 3200 m a.s.l. (ADAMELLO MASSIF)

MAIN UNDERGROUND OPERATIONS

- A. MONTE ZUGNA
- B. PASUBIO
- C. MONTE GRAPPA
- D. MARMOLADA
- E. COL DI LANA
- F. LAGAZUOI AND CASTELLETTO DI ROZES
- G. MONTE ROSSO AND MONTE NERO CHAIN
- H. CARSO



THE FRONT IS ENTIRELY INCLUDED IN THE SOUTHERN ALPS, SOUTH OF THE PERIADRIATIC FAULT

- A. **MONTE ZUGNA:** DOLOMITE AND LIMESTONE, OFTEN WITH IMPORTANT KARST PHENOMENA
- B. **PASUBIO:** CARBONATE, DOLOMITIC AND, IN THE UPPER PARTS, ALSO PARTLY CALCAREOUS MASSIF)
- C. **MONTE GRAPPA:** SEDIMENTARY ORGANOGENIC CARBONATE ROCKS, COMPACT AND FINE-GRAINED; SOME OUTCROPS CONFIRM A LARGELY GRAINY TEXTURE AND TEND TO FLAKE APART
- D. **MARMOLADA:** MASSIVE GRAY LIMESTONES, DEBRIS AND STROMATOLITES
- E. **COL DI LANA:** MIXED VOLCANIC CARBONATE (TUFFITE) DEPOSITS WITH MASSIVE TEXTURE
- F. **LAGAZUOI AND CASTELLETTO DI ROZES:** WELL-LAYERED LIGHT GRAY DOLOMITE
- G. **MONTE ROSSO – MONTE NERO CHAIN:** MASSIVE LIMESTONES, WITH REGULAR AND MASSIVE LAYERS, SOMETIMES IN BANKS
- H. **CARSO:** WHITE BIOCLASTIC MASSIVE LIMESTONES OR RUBBLES WITH DOLOMITE CLASTS

EXPLOSIVE

DIFFERENT TYPES OF EXPLOSIVE: GUNPOWDER, DYNAMITE, EXPLOSIVE GELATIN, OTHERS (ECHO, CHEDDITE, SABULITE, NITRANITE, SIPERITE)

DRILLERS

- FIRST PHASE: MANUAL EXCAVATION, RESULTING IN SHORT AND LOW CHARGED HOLES
- FOLLOWING PHASE: MECHANICAL DRILLERS
 - 45 HP AQUILA-SULLIVAN (CASTELLETTO, LAGAZUOI),
 - 30-40 HP SULLIVAN (CASTELLETTO) AND 75 HP SULLIVAN (LAGAZUOI)
 - 15 HP ALFA-INGERSOLL (LAGAZUOI) AND 15 HP DIATTO (LAGAZUOI)
 - ROMEO, SULLIVAN AND CONSOLIDATED PNEUMATICS TOOLS

ROCK TYPE	EXPLOSIVE FOR 1 m ³ OF ROCK	
	GUNPOWDER	EXPLOSIVE GELATINE
GRANITE	1.0 kg	0.25 kg
HARD LIMESTONE	0.6 kg	0.18 kg

(FROM *MANUAL FOR OFFICIALS OF MILITARY ENGINEERING IN WAR*, 1915)

TUNNEL	SECTION [m x m]	ADVANCEMENT [m/DAY]	NOTES
MONTE CIMONE	1.1 x 0.8	3.2	MECHANICAL DRILLERS
COL DI LANA	-	1.2	BY HAND
MONTE SIEF	-	4.0	47 MEN, 4 DRILLERS, 4 SHIFTS PER DAY
LAGAZUOI	1.9 x 1.9	5.0 – 6.0	MECHANICAL DRILLERS
CASTELLETTO	2.0 x 1.8	5.0 – 6.0	120 MEN, 4 SHIFTS PER DAY
MONTE PIANA	2.0 x 1.8	-	LISTENING TUNNEL
MONTE ROSSO	-	1.2 – 1.5	MECHANICAL DRILLERS
CARSO	1.5 x 1.0 – 1.0 x 1.8	0.37 – 1.5	BY HAND

ADVANCEMENT

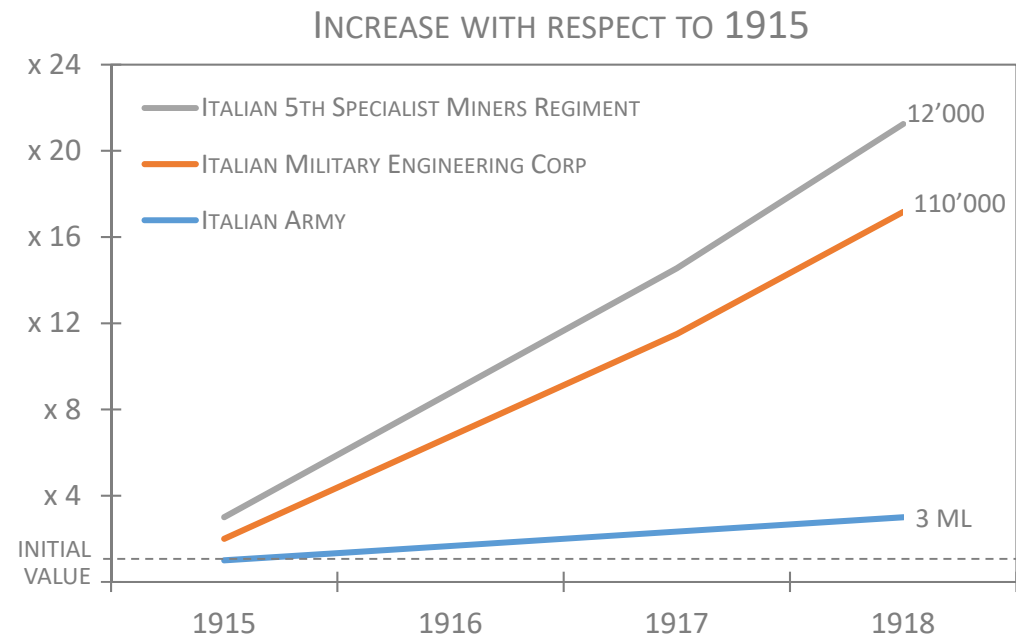
DISCRETE TO GOOD ROCK MASS PROPERTIES; IN ARMY REPORTS, ROCK MASS CHARACTERISTICS OR THE NEED FOR SUPPORTS ARE ALMOST NEVER MENTIONED. THE MAIN OBSTACLES WERE THE MECHANICAL RESISTANCE TO THE DRILLING, TOGETHER WITH THE THREATS OF ENEMY, INCLUDING COUNTER-MINE TUNNELS, AND HOSTILE MOUNTAINOUS ENVIRONMENT.

AFTER 100 YEARS, ONLY SMALL SECTIONS HAD MINOR FALLS IN RARE, PARTICULARLY FRACTURED AREAS, MOSTLY AT ADITS.

DURING WWI NO OTHER CORPS UNDERWENT AN INCREASE SIMILAR TO THAT OF MILITARY ENGINEERING, A CLEAR SIGN OF THE IMPORTANCE OF ENGINEERING AND, ABOVE ALL, OF UNDERGROUND WORKS.

PEOPLE INVOLVED IN MILITARY ENGINEERING:

- 170'000 (ARMY)
- 110'000 (CENTURIAE = CIVILS DIRECTLY DEPENDENDING ON THE ARMY)
- 650'000 (CIVILIAN WORKERS)



THE FIRST WORLD WAR MILITARY TUNNELS OF THE ITALIAN-AUSTRIAN FRONT

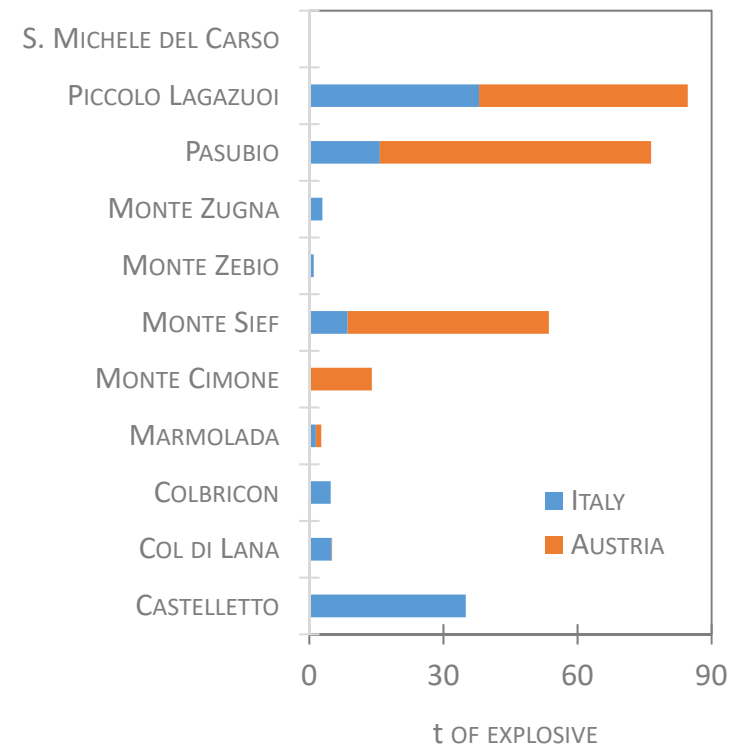
MINES AND COUNTER-MINES

IN ADDITION TO BUILDING UNDERGROUND SHELTERS AND COVERED SUPPLY ROUTES FOR THE ARMY, BOTH SIDES ALSO ATTEMPTED TO BREAK THE IMPASSE OF TRENCH WARFARE BY **TUNNELING UNDER ENEMY'S POSITIONS AND CREATE A BREACH BY BLASTING HUGE AMOUNTS OF EXPLOSIVES (= MINE TUNNELS)**.

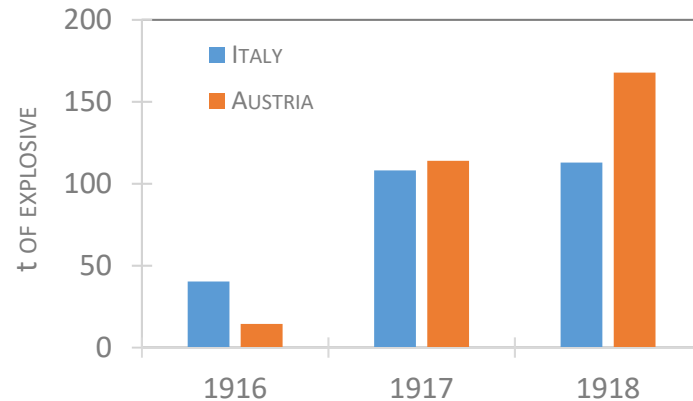
OBVIOUSLY, THE OPPONENT WAS EQUALLY BUSY DIGGING TUNNELS AND CAVERNS AIMING TO STOP OR DISTURB THIS ACTIVITY (= COUNTER-MINE TUNNELS).

MINE AND COUNTER-MINE TUNNELS ARE AMONG THE MOST COMPLEX AND DEMANDING WORKS CARRIED OUT.

EXPLOSIVE CONSUMPTION IN EACH WAR THEATER
(ESTIMATE)



GLOBAL EXPLOSIVE CONSUMPTION
(ESTIMATE)



CARSO

THE ITALIAN ARMY FIRST CONSIDERED THE OPPORTUNITY OF UNDERGROUND MINE WORKS ON THE CARSO IN JULY 1915. IN JANUARY 1916, THE HIGH COMMAND GAVE BROAD TO MINE WORKS FOR OFFENSIVE PURPOSES. THE FIRST PROJECT CONCERNED CIMA 4 OF SAN MICHELE DEL CARSO, WHERE TWO 80 m TUNNELS HAD CHAMBERS LOADED EACH WITH 125 kg OF EXPLOSIVES EACH.

THE WORKS PROCEEDED SLOWLY EVEN FOR THE LACK OF SPECIALIZED MEN: IN THE 1ST UNIT OF THE 5TH SPECIALIST MINERS REGIMENT, ONLY 10 SOLDIERS WERE MINERS BY PROFESSION.



TUNNEL OF
S. MICHELE
DEL CARSO

MONTE ZUGNA

ON THE MONTE ZUGNA (UP TO 2000 m a.s.l.), THE MINES AND COUNTER-MINES WARFARE CONTINUED UNTIL SEPTEMBER 1918 THROUGH WELLS AND TUNNELS.

AS AN EXAMPLE, AS OF 31ST DECEMBER 1917 THERE WERE:

- A STEEP SLOPE TUNNEL OF 20 m FOR HEARING OUT THE AUSTRIAN WORKS
- A 8 m DIAMETER SHAFT, FROM WHICH A 14 m TUNNEL AND ANOTHER 24 m TUNNEL WITH A 25% GRADIENT START

THE FIRST WORLD WAR MILITARY TUNNELS OF THE ITALIAN-AUSTRIAN FRONT

PASUBIO

ON THE PASUBIO (2239 m a.s.l.), AROUND 10 km OF TUNNELS AND 500 km OF ROADS WERE BUILT, 1500 EXPLOSIVE CHARGES WERE BURNED EVERY DAY, 100 km OF COMPRESSED AIR PIPES AND 60 km OF WATER PIPES WERE LAID.

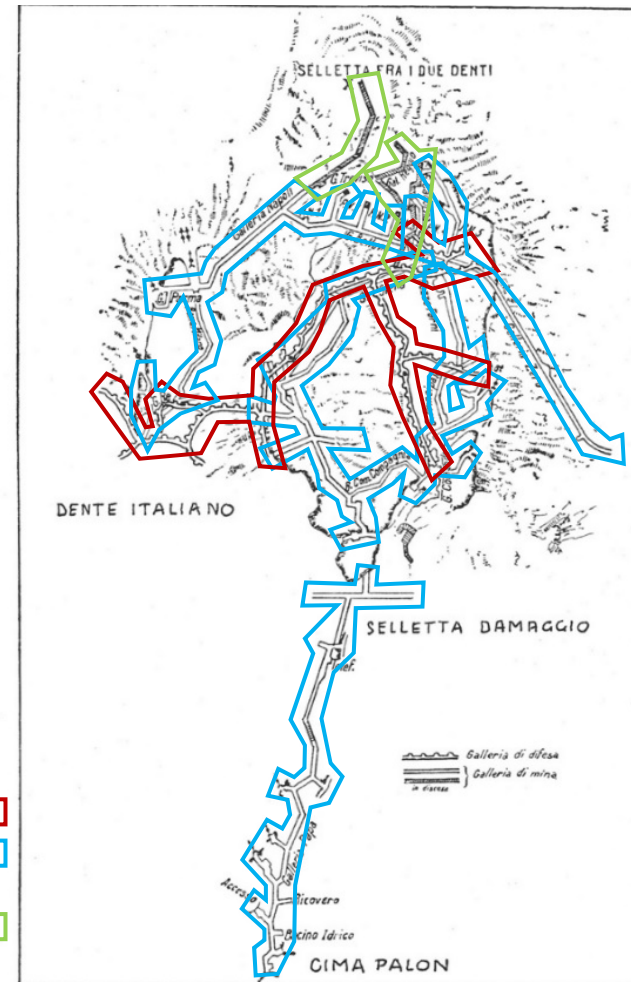
AMONG OTHERS, THE WORKS INCLUDED ALSO A 110 m LONG HELICAL TUNNEL WITH A 2.2 x 2.5 m SECTION, A 190 m LONG TUNNEL WITH A 2.0 x 3.0 m SECTION AND ANOTHER ONE OF 140 m WITH A 2.5 x 2.5 m SECTION.

EXCAVATIONS WERE CARRIED OUT WITH AN AVERAGE PRODUCTION OF 6 m³ PER DAY. 5 HAMMER DRILLS WERE USED, WHILE ELECTRICITY WAS SUPPLIED WITH BALLOT GENERATOR, TOGETHER WITH A PORTABLE GENERATOR FOR VENTILATION.



ROAD OF 52 TUNNELS
31TH TUNNEL
"GENERALE PAPA"

- DEFENSIVE TUNNELS ▭
- OFFENSIVE (MINE) TUNNELS ▭
- ASCENDING EXCAVATION ▭
- OFFENSIVE (MINE) TUNNELS ▭
- DESCENT EXCAVATION ▭



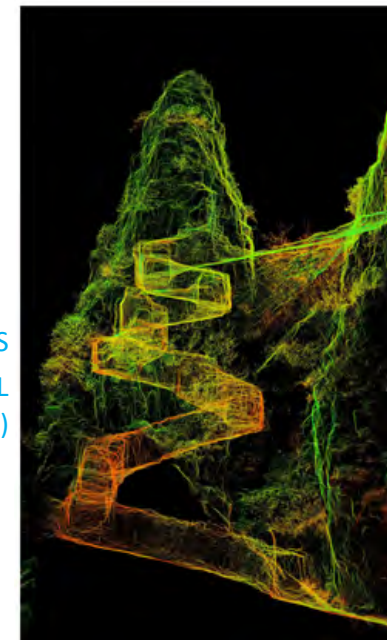
PASUBIO IS FAMOUS IN PARTICULAR FOR THE **ROAD OF 52 TUNNELS** WHICH STARTS AT 1216 m a.s.l. AND ENDS AT 1928 m a.s.l., WITH A TOTAL OF **2335 m OF TUNNELS** ALONG A 6300 m LONG PATH.

- MINIMUM WIDTH 2.2 – 2.5 m
- MINIMUM BEND RADIUS 3.0 m FOR CARRIAGES
- MEDIUM SLOPE 12 % (SHORT STRETCHES 22 %)
- FOUR HELICAL TUNNELS, OF WHICH THE 19TH IS 320 m LONG AND THE 20TH TWISTS FOUR TIMES INSIDE A ROCK TOWER



ROAD OF 52 TUNNELS
20TH TUNNEL

ROAD OF 52 TUNNELS
SCHEME OF 20TH TUNNEL
(IMAGE FROM REGIONE DEL VENETO)



THE FIRST WORLD WAR MILITARY TUNNELS OF THE ITALIAN-AUSTRIAN FRONT

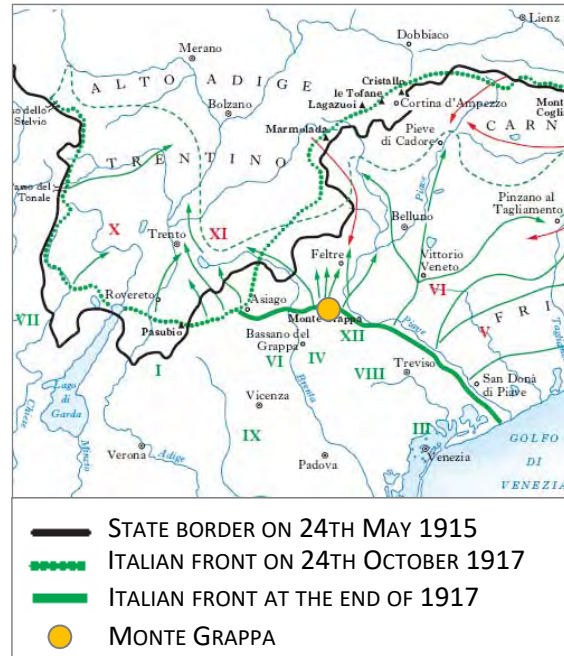
MONTE GRAPPA

MONTE GRAPPA (1775 m a.s.l.) IS FURTHER SOUTH OF STATE BORDER BEFORE THE WAR.

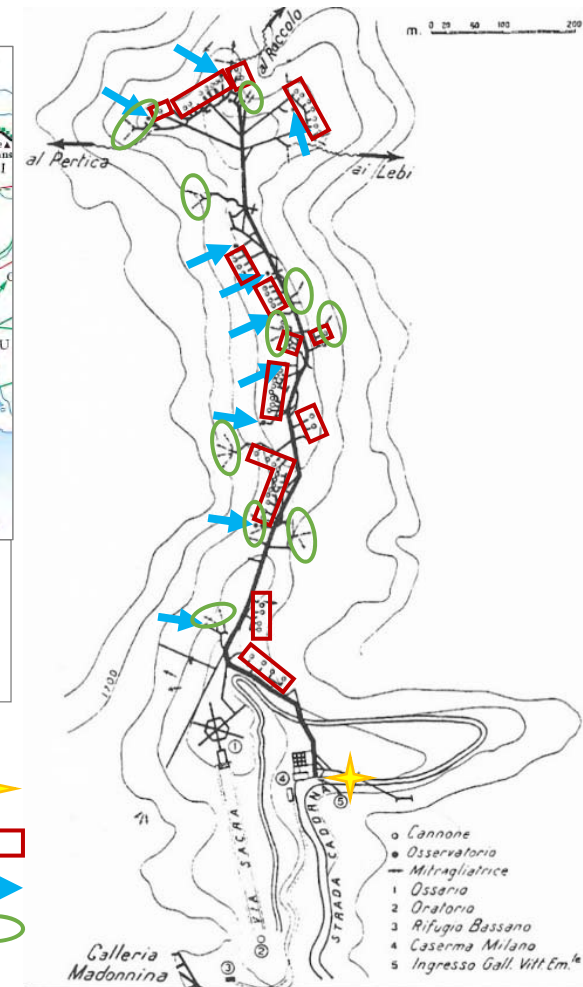
THE DEFENSIVE SYSTEM WAS BUILT WELL BEFORE THE ADVANCE OF THE AUSTRIAN ARMY IN OCTOBER 1917 AND CONTRIBUTED TO STOP IT, TOGETHER WITH THE PIAVE RIVER.

IT HOSTS THE **VITTORIO EMANUELE III TUNNEL SYSTEM**

- BUILT IN JUST 10 MONTHS
- MAIN BRANCH 1400 m, TOTAL LENGTH 5152 m
- HOUSED 23 ARTILLERIES, OF WHICH SIX 105 mm CANNONS, PLUS MACHINE GUNS, FOOD STORAGES, WATER AND AMMUNITIONS
- COULD HOUSE 1500 SOLDIERS
- THE DEPOSITS, WITH 50 TO 200 m³ WATER TANKS, GUARANTEED 15 DAYS OF ENDURANCE



- ★ ADIT OF VITTORIO EMANUELE III TUNNEL
 CANNONS
➔ OBSERVATION POST
 MACHINE GUN



THE **PICCOLO LAGAZUOI** (FANIS GROUP ON THE DOLOMITES, WEST TO CORTINA) HOSTS A **MINE TUNNEL**, EXCAVATED BY THE ITALIAN ARMY TO DESTROY AN AUSTRIAN STATION LOCATED ON LAGAZUOI FORESUMMIT.

TO LOAD THE MINE WITH 33 t OF EXPLOSIVE (GELATINE AND ECHO), ITALIAN SOLDIERS DUG A **HELICAL TUNNEL ABOUT 1100 m LONG WITH A DIFFERENCE IN HEIGHT OF 250 m AND A GRADIENT UP TO 60 %** THAT REQUIRED THE USE OF STEPS (REACHING 2660 m a.s.l.).

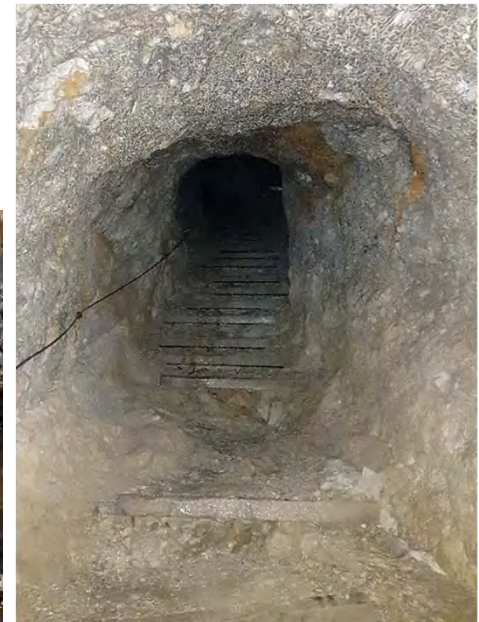
THE TUNNEL IS **1.90 m HIGH AND EQUALLY LARGE** AND THE EXCAVATIONS ADVANCED AT A RATE OF **5.5 m/DAY**.

IN JUNE 1917 THE MINE WAS LOADED AND BLASTED.

ONE OF THE ENTRANCES OF LAGAZUOI TUNNEL SYSTEM



LAGAZUOI TUNNEL



LAGAZUOI TUNNEL
(PHOTO BY GIACOMO POMPANIN)



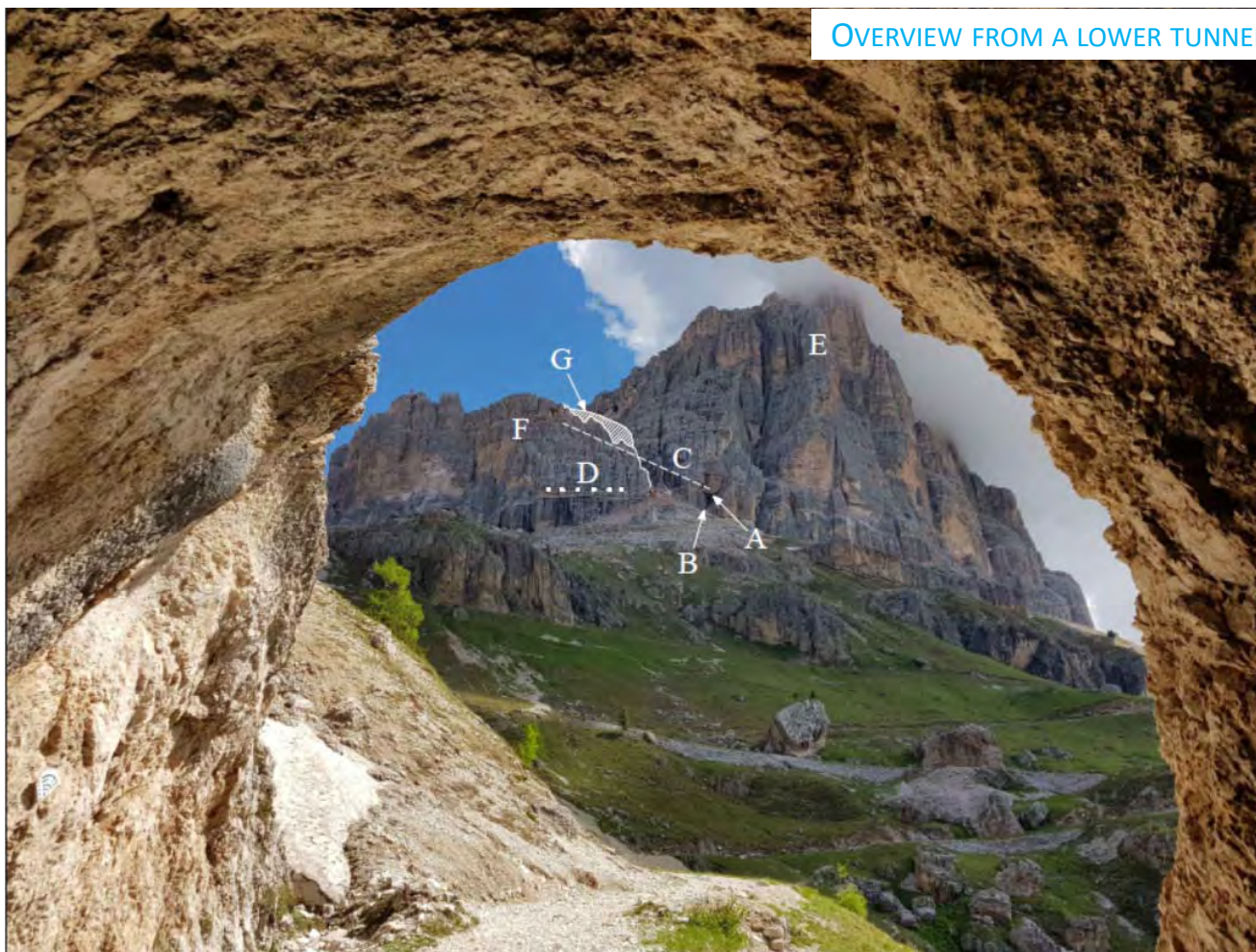
LAGAZUOI TUNNEL
(PHOTO BY GIACOMO POMPANIN)



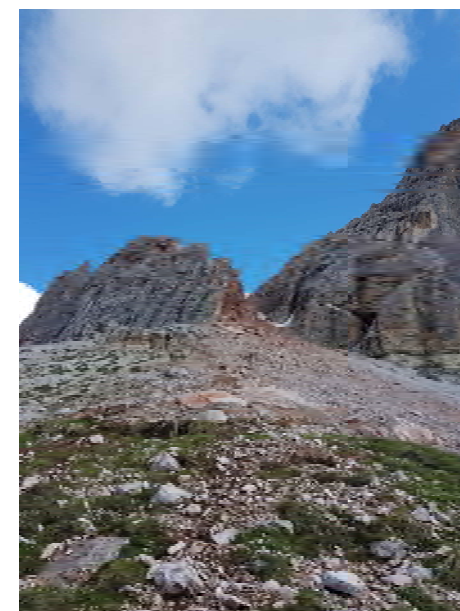


LAGAZUOI TUNNEL
(PHOTO BY GIACOMO POMPANIN)

OVERVIEW FROM A LOWER TUNNEL



- A. TUNNEL ADIT
- B. LADDER TO TUNNEL ADIT
- C. CASTELLETTO TUNNEL
- D. AUSTRIAN EMBRASURES
- E. TOFANA DI ROZES
- F. CASTELLETTO
- G. RIDGE DESTROYED BY ITALIAN MINE



AT CASTELLETTO OF TOFANA DI ROZES (2657 m a.s.l.) A 500 m LONG, VERY STEEP TUNNEL WAS EXCAVATED (2200 m³ TOTAL ROCK MASS).

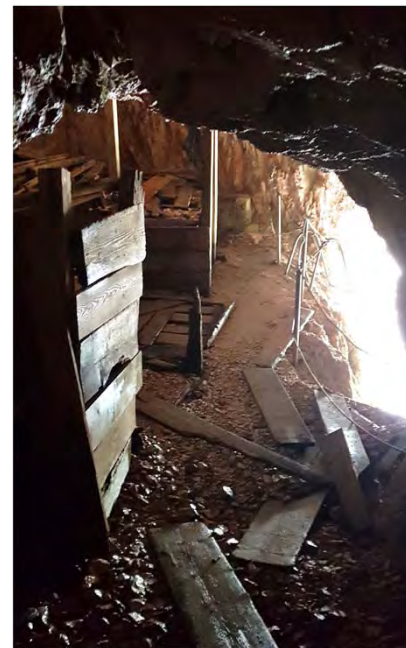
GIVEN AN ENEMY SHOOTING LINE ON THE TOP OF CASTELLETTO, THE TUNNEL ADIT WAS PLACED IN A SHELTERED POSITION WITHIN A NATURAL RAVINE AND REQUIRED THE OVERCOMING OF SIGNIFICANT LOGISTICAL DIFFICULTIES.

IN THE LARGE MINE CHAMBER PLACED AT END OF THE TUNNEL, 35 t OF EXPLOSIVE WERE BLASTED ON 11 JULY 1916.

CHAMBER OF SULLIVAN DRILLER



ACCESS TO THE TUNNEL



CASTELLETTO TUNNEL



TUNNEL ADIT

LOWER ORIGINAL WOODEN LADDER



UPPER LADDER



MILITARY EXPLOITATION OF UNDERGROUND DURING FIRST WORLD WAR MOVED FROM LIMITED AND PUNCTUAL CASES TO IMPRESSIVE AND TECHNICALLY CHALLENGING WORKS, THUS PUSHING UP THE DEVELOPMENT OF A DEDICATED INDUSTRIAL SECTOR.

UNDERGROUND EXCAVATIONS BY THE ITALIAN ARMY ARE:

- STILL LARGELY VISITABLE
- A HERITAGE, BOTH HISTORICAL AND AS REGARDS THE LANDSCAPE
- APPRECIATED BY TOURISTS, ATTRACTED BY THE CHALLENGE OF THEIR CONSTRUCTION

SUCH A HERITAGE WOULD DESERVE GREATER ANALYTICAL SCIENTIFIC COMMITMENT, IN TERMS OF LISTING AND CLASSIFICATION BUT ALSO FROM A GEOMECHANICAL POINT OF VIEW.

THE IMAGE PRESENTED ON THE RIGHT SHOWS AN UNDOUBTEDLY EXCELLENT ROCK MASS, THAT IN PRESENT DAYS NO ENGINEER WOULD EVER TRY IN A SIMILAR WAY: WOULDN'T IT BE USEFUL TO INVESTIGATE ITS STATE OF EFFORT BY MEANS OF IN SITU TESTS AND TO PROVIDE A BACK-ANALYSIS?

HUNDREDS OF KILOMETERS OF UNLINED TUNNELS ARE AVAILABLE FOR STUDYING GEOMECHANICAL ISSUES. WHY NOT TRANSFORM SOME OF THESE WORKS INTO TRUE GEOMECHANICAL LABORATORIES?



ACCESS TRAIL TO MONTE CENGIO (ASIAGO)

THE FIRST WORLD WAR MILITARY TUNNELS OF THE ITALIAN-AUSTRIAN FRONT

AS IT AS BEEN SAID, MILITARY TUNNELS OF FIRST WORLD WAR DESERVE A VISIT, ESPECIALLY THE ONES IN [DOLOMITE REGION](#).

THEY OFFER THE CHANCE TO EXPERIENCE ASTONISHING ENVIRONMENTS, ON ITINERARIES OF ALL LEVELS OF DIFFICULTY FROM SIMPLE HIKING TO CHALLENGING *VIE FERRATE*.

IF YOU ARE INTERESTED PLEASE CONTACT [GRUPPO GUIDE ALPINE CORTINA](#).

I WOULD BE GLAD TO MEET YOU FOR A FIELD TRIP TO THE TUNNELS I KNOW BETTER, [CASTELLETTO AND LAGAZUOI](#).

GRUPPO GUIDE ALPINE CORTINA

SCUOLA D'ALPINISMO

CORSO ITALIA, 69/A

I - 32043 CORTINA D'AMPEZZO BL

TEL +39 0436 868505

CELL +39 335 1705672

INFO@GUIDECORTINA.COM

WWW.GUIDECORTINA.COM



THANKS FOR YOUR ATTENTION!