Medieval Gunpowder Research Group

Report number 2 - August 2003

The Ho Experiments

Middelaldercentret, Nykobing, Denmark

Introduction

In 1999 the Middelaldercentret in Nykøbing, Denmark, made a replica of the small gun in the Historical Museum, Stockholm, the Loshult gun, and carried out a series of test firings. The purpose of these experiments was to test the effectiveness of this small cannon and to investigate just what it was capable of. A range of different projectiles was used and the gunpowder was acquired from a commercial company and made to two formulae (Hansen 2001).

This work was the inspiration for the formation of the Medieval Gunpowder Group in 2002 which conducted further experimental work with gunpowder made by the Group (Medieval Gunpowder Research Group, Report number 1, 2002). These experiments, though useful and very productive, highlighted the need for a great deal of further work on such areas as different types of powder, different compositions and constituents. The Group met again in August 2003 and the following report outlines the results of their work.

Powder types

A fundamental problem in the study of early gunpowder is that of our understanding of contemporary names and nomenclature, such as serpentine powder or *knollen* powder. At the meeting of the Group in 2002 that the following terms for the physical state of gunpowder were agreed:

Table 1

Proposed and agreed terms used for gunpowder types

Rough powder	*Gunpowder made by the simple mixture of powdered saltpetre, sulphur and charcoal.*
Meal powder	*Gunpowder made by first mixing the dry, powdered ingredients. These are then dampened by adding water or other liquid, for example alcohol, and further ground together. The resultant paste is then dried and finally ground up into a fine powder*
Fine incorporated powder	*Gunpowder made as for meal powder but when wet it is formed into small granules or corns before it is dried*
Coarse incorporated powder	*Gunpowder made as for meal powder but when wet it is formed into large granules or corns before it is dried*

Gunpowder constituents

Charcoal and sulphur

The charcoal and sulphur used in the 2003 experiments were the same as those used in 2002. The charcoal was made at the Middelaldercentret from alder wood and the sulphur was collected in Iceland and refined by the Group (Medieval Gunpowder Research Group, Report number 1, 2002).

Saltpetre

Of the three constituents of gunpowder, saltpetre is the most problematic as we cannot easily replicate the medieval manufacturing process. Calcium nitrate saltpetre made in as traditional way as possible was tried in 2002 but proved to be ineffective and the gunpowder made with it did not work. Future plans for the group include trying to make saltpetre in a medieval method.

Figure 1. The members of the group standing in front of the chicken house from which we hope to collect enough material to make our own saltpetre some time in the future

For the experiments in 2003 we used saltpetre made from sodium nitrate mined in Chile. Vast deposits of sodium nitrate are a feature of parts of the west of Chile and these have been exploited over the years. This material is mined and refined in Chile. The resultant refined sodium nitrate is then converted to potassium nitrate in Spain and this Spanish refined saltpetre was used in these experiments (see Appendix 1, below, for full details of the refining and making of this material).

Loshult gun and ammunition

The gun used in the 2003 work was another, different, casting of the Loshult gun from the National Museum in Stockholm. Though similar to that used in 2002, it had a slightly smaller bore which fitted the prepared lead ball ammunition more closely.

Experimental work

Following the work carried out in 2002 it was agreed that the following experiments would be undertaken.

1. An attempt to assess the accuracy of the gun. For this purpose a target consisting of a plastic screen 2 metres square set at 200 paces from the gun would be erected and 5 attempts made at trying to hit it. The powder for these experiments would be a medium incorporated powder of composition 75:15:10
2. To look at the effect of the proportion of saltpetre on the effectiveness of the gun. For this we would use rough powder with the following compositions:

Table 2

Proportion of saltpetre

3:1:1	*60% saltpetre*
5:1:1	*71.7% saltpetre*
15:3:2	*75% saltpetre*
7:1:1	*77.8% saltpetre*

3. To look at the effect of the grain size of the powder and its effect on the velocity of the projectile. For this we would make incorporated powder in 3 different sizes, fine incorporated powder of approximately 1mm, medium incorporated powder of about 3mm and coarse incorporated powder of about 5mm size. For each of these powders we would fire 5 shots.

Powder making

The powder was made as in the 2002 and we tried to be as consistent as possible in the actual process.

Rough powder

Measured amounts of the three constituents were mixed together on a large sheet of paper. The mixture was then put through a fine grade sieve, mixed briefly on the paper again and this process repeated three times (figure 2).

Figure 2 Lars Barfod making rough powder by simple mixing on a large sheet of paper

Figure 3 Detail of stamping in a wooden mortar using the copper alloy pestle

Incorporated powder

Approximately 10 ml of alcohol (40%) was added to rough powder, made as above, and the wetted mixture divided into three equal parts. Each was then ground by hand in a wooden mortar for 20 minutes. One of the three pestles was made from a copper alloy, and was much heavier than the other two which were made from wood. Therefore each portion of the powder was given a third of the time with the heavy pestle. It was found that the best action for this part of the process was actually a stamping motion, hitting the powder mixture vertically with the pestle slightly to one side of the centre of the mortar. The resultant action not only broke up the powder and beat it together but circulated the powder mixture around the inside of the mortar ensuring that all of the contents were stamped evenly and preventing it sticking to the inner surface of the mortar (figure 3).

It was found, by trial and error, that to ensure consistent grains were produced, the mixture needed to be quite wet before it was pushed, in a sliding motion, through the sieve. After 20 minutes of stamping the contents of the three mortars were combined, more alcohol added and the whole mass 'kneaded' by hand to a smooth consistency. It was then pushed, by hand, through a sieve. The resultant incorporated powder was then spread out in a thin layer on a sheet of paper and left to air-dry in a warm room for between 24 and 48 hours. When dry the grains were hard and difficult to break. As some had stuck together they were then re-sieved.

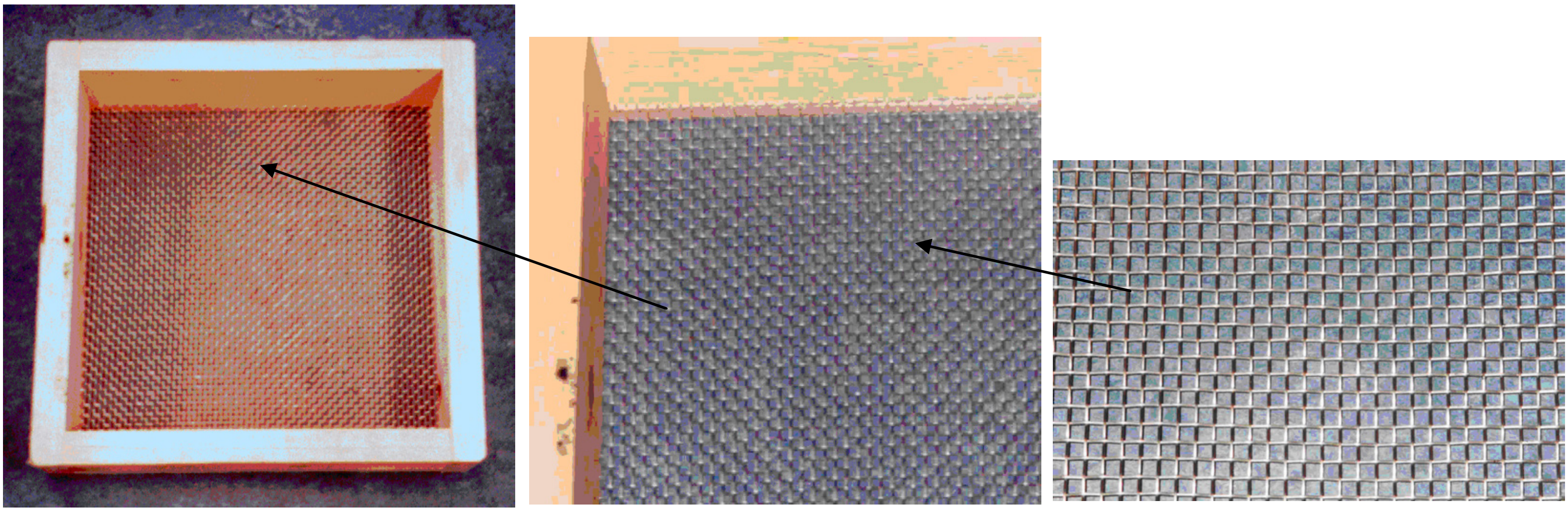


Figure 4. Left – the sieve. Centre – detail of sieve. Right – detail of sieve showing square mesh

Figure 5 Left, the wetted powder prior to being pushed through the sieve (centre). Right, the resultant powder

Powder preparation

Enough of each powder type was made to provide enough finished powder for 5 shots each of 50g. Normally 280g of rough powder was prepared before further processing. In the case of the incorporated powder we found that this only provided us with 250g of finished powder. Once dry 50g of powder was weighed out for each shot into small plastic containers and labelled ready for the actual firing trials.

The trials

As in 2002 the actual trials were hosted and run by the Artillery School in Varde at Oksbøl in western Denmark under the guidance of Jorgen Svender. Radar tracking equipment was used to measure the velocity of the projectile during flight and its range as well as give us information about the trajectory.

Loading

For each test the following loading procedure was carried out:

1. The prepared powder charge was poured into a simple funnel, made from a tapered cylinder of polythene sheet
2. A piece of commercial priming fuse was inserted into the touchhole and held in place.
3. The polythene funnel was then inserted into the bore of the gun and the powder allowed to fall down the ‘funnel’ so that it went right down to the end of the bore.
4. The ball was inserted into the bore and, using a wooden dowel, was hammered home onto the top of the powder charge

Figure 6. Left, filling the funnel with powder. Centre the ball. Right the ball being hammered home onto the powder charge

Results

Target shooting

For this series of tests a polythene screen, 2 metres square, was set up at 200 paces from the gun. For each shot 50g of medium incorporated powder was used in the proportion of 75:15:10. The gun was aimed by eye and the elevation measured using a clinometer, initially 2.2° above the horizontal, though this was adjusted for each shot (figure 7). We did not manage to hit the target with any of the 5 shots.

Figure 7 Left, taking aim. Right setting and measuring the elevation of the gun using a clinometer

Table 3
Results of target shooting experiments

Shot no	*Elevation*	*Velocity ms^{-1}*	*Notes*
1	*2.2°*	*216*	*Ball went 4-5 metres over the target. Range approximately 285 metres*
2	*1.1°*	*240*	*Maximum elevation of ball approximately 1 metre. Range approximately 185 metres. Gun fell over backwards*
3	*1.7°*	*209*	*Maximum elevation of ball approximately 3 metres. Range approximately 240 metres. Radar indicated that ball flew to the right*
4	*(1.4°)*	*238*	*Radar not able to fully record flight*
5	*1.6°*	*238*	*Maximum elevation of ball approximately 5 metres. Range approximately 435 metres*

From these test firings it would appear that the gun was fairly inaccurate at this range – 200 paces. It was also clear that the trajectory of the ball was erratic as would be expected by the Magnus effect. It should also be noted that setting the elevation of the gun was difficult even using a modern clinometer

Effect of the proportion of saltpetre

For this series of experiments rough powder with increasing saltpetre content was used. 50 g of powder was used for each shot, the gun was set at 36° and for each powder type, 5 shots were fired. The initial velocity and range for each shot is given in Table 4.

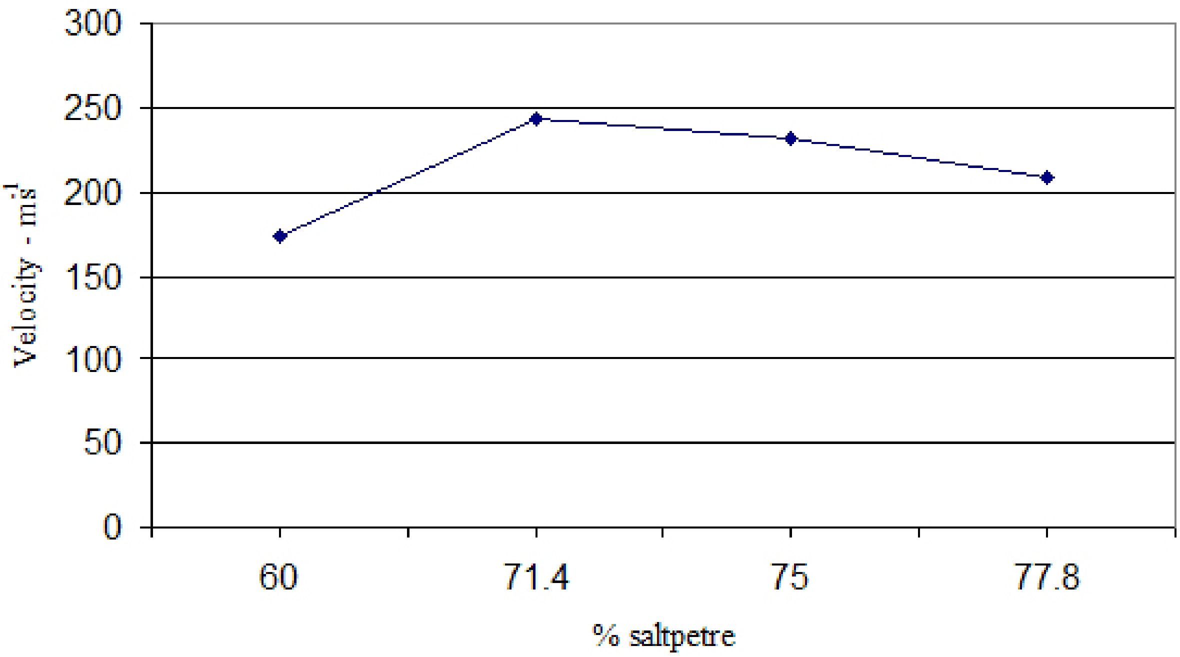
Table 4
Results of increasing saltpetre content

Shot number	*Powder*	*Velocity* ms^{-1}	*Range m*
6	*Rough 3:1:1 (60%:20%:20%)*	*189*	*1125*
7	*Rough 3:1:1*	*167*	*945*
8	*Rough 3:1:1*	*173*	*840*
9	*Rough 3:1:1*	*178*	*1060*
10	*Rough 3:1:1*	*161*	*970*
	MEAN	*174*	
11	*Rough 5:1:1 (71.4%:14.3%:14.3%)*	*241*	*1210*
12	*Rough 5:1:1*	*-*	*-*
13	*Rough 5:1:1*	*245*	*1300*
14	*Rough 5:1:1*	*239*	*1270*
15	*Rough 5:1:1*	*247*	*1280*
	MEAN	*243*	
16	*Rough 7:1:1 (77.8%:11.1%:11.1%)*	*214*	*-*
17	*Rough 7:1:1*	*218*	*1260*
18	*Rough 7:1:1*	*203*	*1150*
19	*Rough 7:1:1*	*200*	*1150*
20	*Rough 7:1:1*	*-*	*-*
	MEAN	*209*	
21	*Rough 15:3:2 (75%:15%:10%)*	*235*	*1190*
22	*Rough 15:3:2*	*215*	*1170*
23	*Rough 15:3:2*	*239*	*1220*
24	*Rough 15:3:2*	*256*	*1165*
25	*Rough 15:3:2*	*215*	*1051*
	MEAN	*232*	

Table 5
Summary of results

% Saltpetre	*Mean velocity of 5 shots –* ms^{-1}
60%	*174*
71.4%	*243*
75%	*232*
77.8	*209*

The results indicate that an increasing proportion of saltpetre, up to approximately 72%, results in increasing velocity, but that increasing it above that level results in a decrease in velocity.



Graph of % saltpetre versus velocity

Effect of grain size on velocity

The final series of experiments looked at the effect of grain size on the velocity of the projectile. Powder of 4 types was prepared as above in the following sizes:

Table 6

Powder grain size

Powder type	*Grain size*
Meal powder	*Very fine*
Fine cornpowder	*Approx 1 mm*
Medium cornpowder	*Approx 3 mm*
Coarse cornpowder	*Approx 5 mm*

Five shots, each of 50 g, of each size of powder were completed and the results are summarised below:

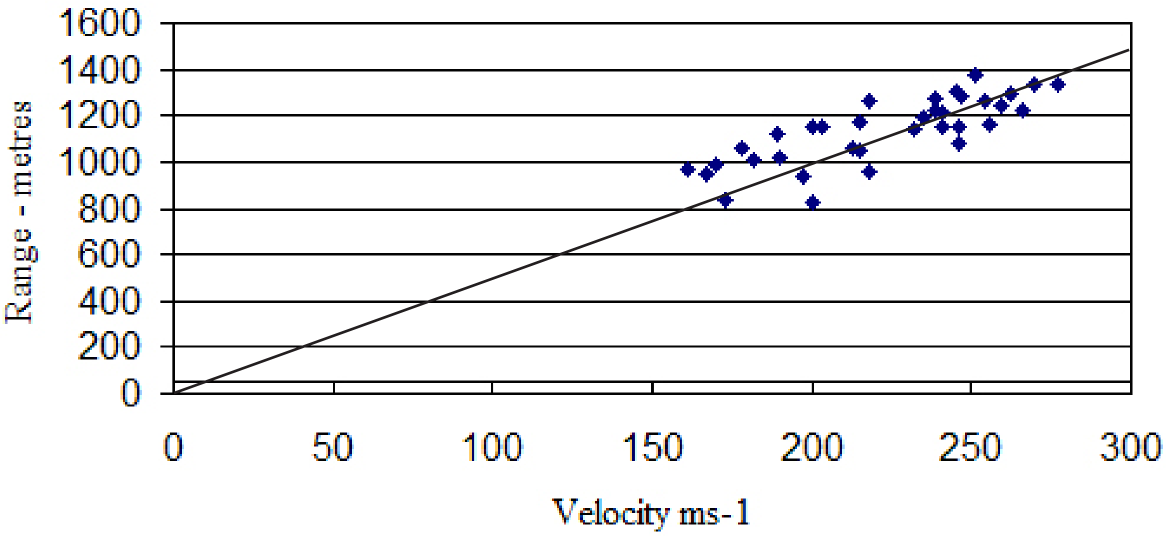
Table 7
Effect of grain size on velocity

Shot number	*Powder type*	*Velocity ms^{-1}*	*Range metres*
26	*Meal powder 75:15:10*	*213*	*1056*
27	*Meal powder 75:15:10*	*251*	*1373*
28	*Meal powder 75:15:10*	*262*	*1290*
29	*Meal powder 75:15:10*	*254*	*1261*
30	*Meal powder 75:15:10*	*241*	*1149*
		MEAN 244	
31	*Fine incorporated 75:15:10*	*270*	*1340*
32	*Fine incorporated 75:15:10*	*232*	*1142*
33	*Fine incorporated 75:15:10*	*259*	*1248*
34	*Fine incorporated 75:15:10*	*266*	*1220*
35	*Fine incorporated 75:15:10*	*277*	*1332*
		MEAN 261	
36	*Medium incorporated 75:15:10*	*246*	*1154*
37	*Medium incorporated 75:15:10*	*244*	*-*
38	*Medium incorporated 75:15:10*	*246*	*1080*
39	*Medium incorporated 75:15:10*	*228*	*-*
40	*Medium incorporated 75:15:10*	*197*	*942*
		MEAN 229	
41	*Coarse incorporated 75:15:10*	*190*	*1015*
42	*Coarse incorporated 75:15:10*	*170*	*992*
43	*Coarse incorporated 75:15:10*	*182*	*1013*
44	*Coarse incorporated 75:15:10*	*200*	*828*
45	*Coarse incorporated 75:15:10*	*218*	*963*
		MEAN 192	

Table 8
Summary of results

Powder type	*Mean velocity ms^{-1}*	*Range of velocity highest minus lowest*	*Range - m*
Meal powder	*244*	*49*	*1056 - 1373*
Fine incorporated powder	*261*	*45*	*1142 – 1332*
Medium incorporated powder	*229*	*49*	*942 – 1154*
Coarse incorporated powder	*192*	*48*	*828 - 1015*

These results show that fine incorporated powder was the best type of powder to use in this gun. This is probably due to the effect that as grain size increases the rate of burning of the powder decreases. The result of this is that for short-barrelled guns the projectile will be ejected from the end of the barrel before the powder has completely burned with the result that the full force of the powder has not been transferred to the ball.



Graph of velocity versus range for the Loshult gun

What is also worth noting is that the effect of grain size is not that large – certainly not the great increase in power that is usually noted for changing the size of grains. Indeed this is further marked by the result obtained from rough powder of the same composition – 232 ms^{-1} – not very different from the results for the incorporated powders. One explanation for this may be that the gun we used had a small bore and was relatively short – very different results may result from using a larger cannon. What is also worth noting is that the results from the various tests are reasonably consistent; the range of the results for type of powder is not large and is very similar between the various powders. This tends to refute the argument that incorporated powders give more consistent results than rough powder.

Conclusions

The results of the experiments can be summarised:

- This small gun is not very accurate when shooting lead balls. This must be due to both inherent inaccuracies in the bore of the gun, in its aiming and elevation as well as the Magnus effect which randomly affects the trajectory of spherical objects.
- Increasing the saltpetre of the powder has an effect on the velocity of the projectile up to an optimum of around 72-73%. After this figure is reached there is a drop in the velocity.
- The best powder for this small gun was fine incorporated powder, both rough powder and the coarser incorporated types performed less well. The results of the various compositions were surprisingly consistent.

These conclusions must be treated with care however as they are based on a small sample of results. It is very likely that the results may have been very different for a gun of a larger size.

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October 2003

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Figure 8 The participants on the range at Oksbøl

Acknowledgements

A project such as this involves a great many people to make it work. We would like to thank the Artillery School in Varde and the Oksbøl Camp for hosting the test firings and engineer Jorgen Svender for enabling all this to happen. We want to thank Jacob Jensen who for a second year provided technical support at Oksbøl. The Medieval Center for hosting the group and preparing the seminar. We are particularly grateful to Martin Dornseifer who supplied the Chile saltpetre and the information in Appendix 1. We would like to thank the anonymous German tourist who took the picture of us all at Oksbøl.

References

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Appendix 1

Chile saltpetre– information supplied by Martin Dornseifer
Introduction
Before the discovery of modern methods of making saltpetre, potassium nitrate, it was produced from organic deposits found in stables, dovecots and the like and it is from this raw material that the 14th century gunner would have obtained his saltpetre. Another source of saltpetre are the huge deposits of sodium nitrate to be found in the coastal region of Chile, South America. For the experiments conducted by the Medieval Gunpowder Research Group in 2003 saltpetre derived from this source was used.

The raw material
Sodium nitrate is found in large quantities in the coastal region of western south America. This arid region stretches for about 2350 km (1300 miles) from 4o to 26o south. There are 4 zones in this region which run parallel to the coast figure 9):

- a steep, 65 km wide coastal mountain range which rises to a height of 1500 m.
- a 25 km wide plateau, the saltpetre fields, which stretches up to;
- the foothills of the Andes
- the Andes mountains rising to a height of 4500 m which act as a barrier against the hot moisture laden winds from the Amazon Basin.

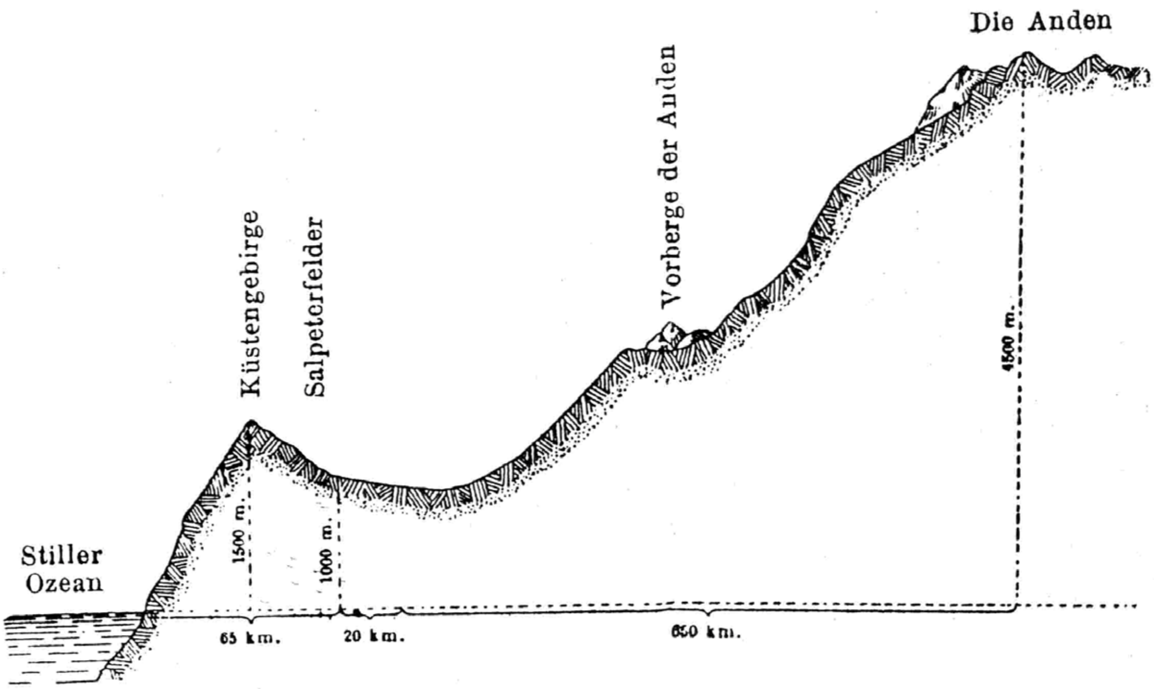

Figure 9 Cross section of west coast of Chile

The winds from the east, from the Pacific Ocean, rarely bring rain and then only in winter. Daily fog and cloudbanks form above the arid plateau which vanish with the rising of the sun without any precipitation forming. The area is also subject to high electrical tension which disturbs radio communication.

Pure sodium nitrate only occurs in small quantities and generally it is found mixed with sulphates, chloride earth and stone, a material known as 'caliche'. A typical cross section of the deposit is shown in figure 10. 'Chuca' is the loose covering layer beneath which is the 'costra', a conglomerate of rocks, common salt and small quantities of sodium nitrate. The 'caliche' below is of similar composition but has a much higher sodium nitrate content. The 'congelo' is a layer of sulphates and chlorides of calcium, magnesium and sodium which are also found in much smaller quantities in the 'coba', a loose earth.

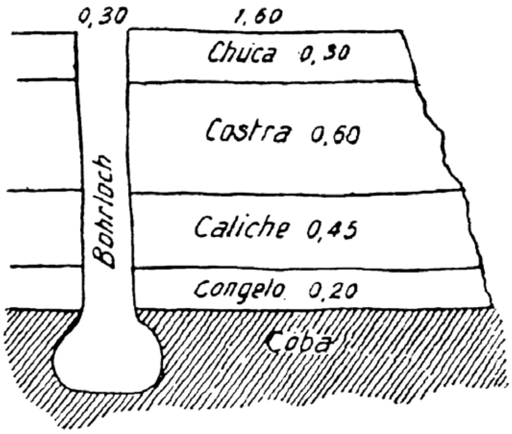

Figure 10 Cross section of 'saltpetre plateau' showing method of mining

The deposits are traditionally mined by sinking a number of boreholes close to each other which widen out at the bottom into which a charge of between 100 and 300 lbs (45 – 140 Kg) of locally produced black powder is placed. After detonation the 'caliche' is picked out, broken up and loaded into steam heated leaching tanks (usually 6) and the salts leached out in a counter-current extraction set-up. The problem is that the solubility of sodium nitrate ($NaNO_3$) is different when in a mixture with other salts than on its own. In general the solubility of sodium nitrate rises with increased temperature while the solubility of other salts goes down (Table 9 and figure 11).

Table 9

Solubility in water

Solubilty in 100 parts water	*O°C*	*10°C*	*100°C*
Potassium chloride	*28.5*	*32.0*	*57.0*
Sodium chloride	*35.5*	*35.7*	*39.6*
Sodium nitrate	*71.0*	*78.0*	*178.0*
Potassium nitrate	*13.0*	*22.0*	*246.0*

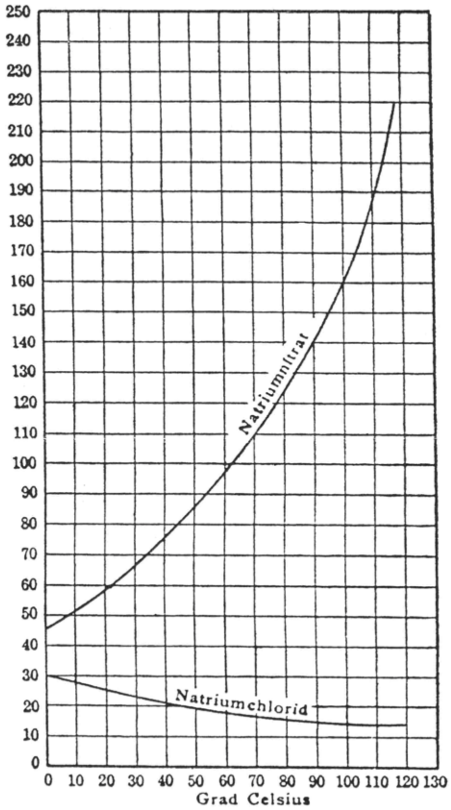

Figure 11 Solubility of a solution of sodium nitrate and sodium chloride

Before the nitrate liquor is ready for crystallisation, in the last leaching tank, soluble impurities start to crystallise and muddy impurities are allowed to settle out. While settling the temperature falls and more dissolved impurities, especially sodium chloride crystallise out. After settling the liquor is moved to crystallisation tanks where it remains for 5 days before the mother liquor is drawn off. The resultant material is trade quality, about 95% pure, raw Chile saltpetre. The raw saltpetre is then usually refined in Chile by dissolving it in the mother liquor of the preceding operations at concentration of up to 50 degrees on the Baumé scale (specific gravity 1.5263), hot filtering followed by crystallisation. The resultant export quality product is white sodium nitrate of 96% to 98% purity.

Conversion of the saltpetre

Probably the oldest industrial method to convert sodium to potassium nitrate is that of Longchamp, of 1818, based on the use of sodium nitrate and potassium chloride. This method did not come into wide use quickly due to the scarcity of pure potassium chloride but later, as it became widely available, it became the normal procedure. The reaction is:

100 parts $NaNO_3$ + 87.65 parts KCl = 118.82 parts KNO_3 + 68.83 parts NaCl

The reactants are dissolved in water and heated for 30 minutes in an iron reaction vessel of about 2.5 m diameter and 2 m height equipped with heaters and stirrers. The solution is then run off into an iron salt filtration apparatus which has a holed, cloth-covered double bottom.

Figure 12 The iron reaction vessel

Figure 13 Detail of reaction vessel

It stays here for 2-3 hours while the sodium chloride settles out onto the filter cloth on top of the double bottom. The hot potassium nitrate solution (at around 95°C) is then run off into crystallisation pans where it is left to cool for between 30 and 38 hours.

Figure 14 The crystallisation pans

Figure 15 Potassium nitrate saltpetre

This raw saltpetre, which contains 7-9% sodium chloride, is separated from the mother liquor as well as possible and washed in a washing-churn apparatus. In the literature another re-crystallisation step and another washing is described. After this the remaining water is allowed to drip off until the water content is down to 2-3% when the crystal cake is removed and dried in an oven before being broken up and sieved. The result is 99% pure powdery conversion saltpetre.

Addendum

Towards the end of the 19th century the ships carrying the saltpetre from Chile to Europe were the fastest and most beautiful sailing vessels that ever sailed the oceans. The world consumption of Chile saltpetre rose from 100 metric tonnes in 1831 to 2,274,000 tonnes in 1910. The export tax on this trade accounted for 40% of the Chilean state's budget.

In the early years of the 20th century the idea of reacting the enormous quantities on nitrogen in the atmosphere with oxygen in electric furnaces started a new chapter. In 1903 the Norwegians Birkeland and Eyde founded the basis of the synthetic saltpetre industry and following the discovery of the Haber-Bosch process, basically the oxidation of ammonia synthesized from hydrogen and hydrogen, artificial saltpetre conquered the World.

The saltpetre operations in Chile subsequently closed down and the town-like building in the desert were left to the vagaries of nature. However this was not their final use. After the democratically elected government of Salvadore Allende was shot and bombed into history by foreign intervention and the dictator Augusto Pinochet brought to power, the workers' barracks of the saltpetre towns were used as terror camps for tens of thousands of political prisoners.

Today the ruins in the desert are left to nature again as monument to Chilean history which are visited by the occasional tourist for a fee collected by a lone Chilean lady in a small ticket booth.