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Oskarshamn site investigation

Refraction seismic measurements in Laxemar spring 2007

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June 2007

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author and do not necessarily coincide with those of the client.

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Abstract

This document reports the execution and interpretation of refraction seismic performed in Laxemar during April 2007. All measurements were conducted by MRM Konsult AB.

The main objective of the investigation was to investigate possible tectonic lineaments and soil depths before planning an industrial area for a possible underground storage of nuclear waste.

Eleven profiles with a total length of 4,900 m were measured. The survey was carried out in a grid with 100 m spacing between the lines. The length of five West-East lines was 500 m and the length of six South-North lines was 400 m. The geophone spacing was 2.5 m for all profiles. A number of (22) usually 2.5 m wide zones with lower sound velocity, from 2,700 m/s up to 3,700 m/s with a mean value of 3,500 m/s were found. The sound velocity of the sound rock is in the range from 5,000 m/s up to 5, 900 m/s. The mean value of the bedrock velocity for compact rock is 5,600 m/s. The bedrock elevation in the area varies between 0 m above sea level and 19 m above sea level and the soil depths varies between 0 m and 10 m.

Sammanfattning

Rapporten presenterar utförandet och resultat av tolkningen av refraktionsseismik som genomfördes i Laxemar under april 2007. Mätningarna genomfördes av MRM Konsult AB som också genomförde tolkningen.

Huvudsyftet med undersökningarna var att undersöka möjliga tektoniska lineament och jorddjup inom ett område för en ovanjordsanläggning för ett eventuellt slutförvar av använt kärnbränsle.

Elva profiler med en total längd av 4 900 m undersöktes. Undersökningen gjordes i ett rutnät med 100 m linjeavstånd. Längden av fem linjer i väst-östlig riktning var 500 m och längden av sex linjer i syd-nordlig riktning var 400 m. Avståndet mellan geofonerna var 2,5 m för alla mätlinjer. Berget verkar vara av mycket god kvalitet men ett antal (22) i huvudsak 2,5 m breda zoner med lägre ljudhastighet framkom vid tolkningen. Ljudhastigheten för dessa varierar från 2 700 m/s upp till 3 700 m/s med ett medelvärde på 3 500 m/s. Utbredningshastigheten i friskt berg varierar mellan 5 000 m/s upp till 5 900 m/s. Medelvärdet av ljudhastigheten i friskt berg är 5 600 m/s. Bergets nivå varierar mellan 0 m över havet och 19 m över havet och jorddjupen varierar mellan 0 m och 10 m.

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1 Introduction

This document reports the results gained by the measurements and interpretation of refraction seismic in Laxemar subarea, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-07-022. In Table 1-1 the controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

Eleven profiles with a total length of 4,900 m were measured. The geophone spacing was 2.5 m for all profiles. The survey lines forms a grid with 100 m line spacing. The grid covers an area of 500 m in West-East direction and 400 m in South-North direction. The area will house buildings for a possible underground storage of nuclear waste. The purpose of the survey was to obtain information about the rock quality and the soil depths in the area for the further design of the industrial area.

The location of the survey lines is shown in Figure 1-1. The delivered raw and processed data have been inserted in the database of SKB (SICADA) and data are traceable by the activity plan number.

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	**Number**	**Version**
Refraktionsseismik under våren 2007 i Laxemar	AP PS 400-07-022	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för refraktionsseimik	SKB MD 242.001	1.0

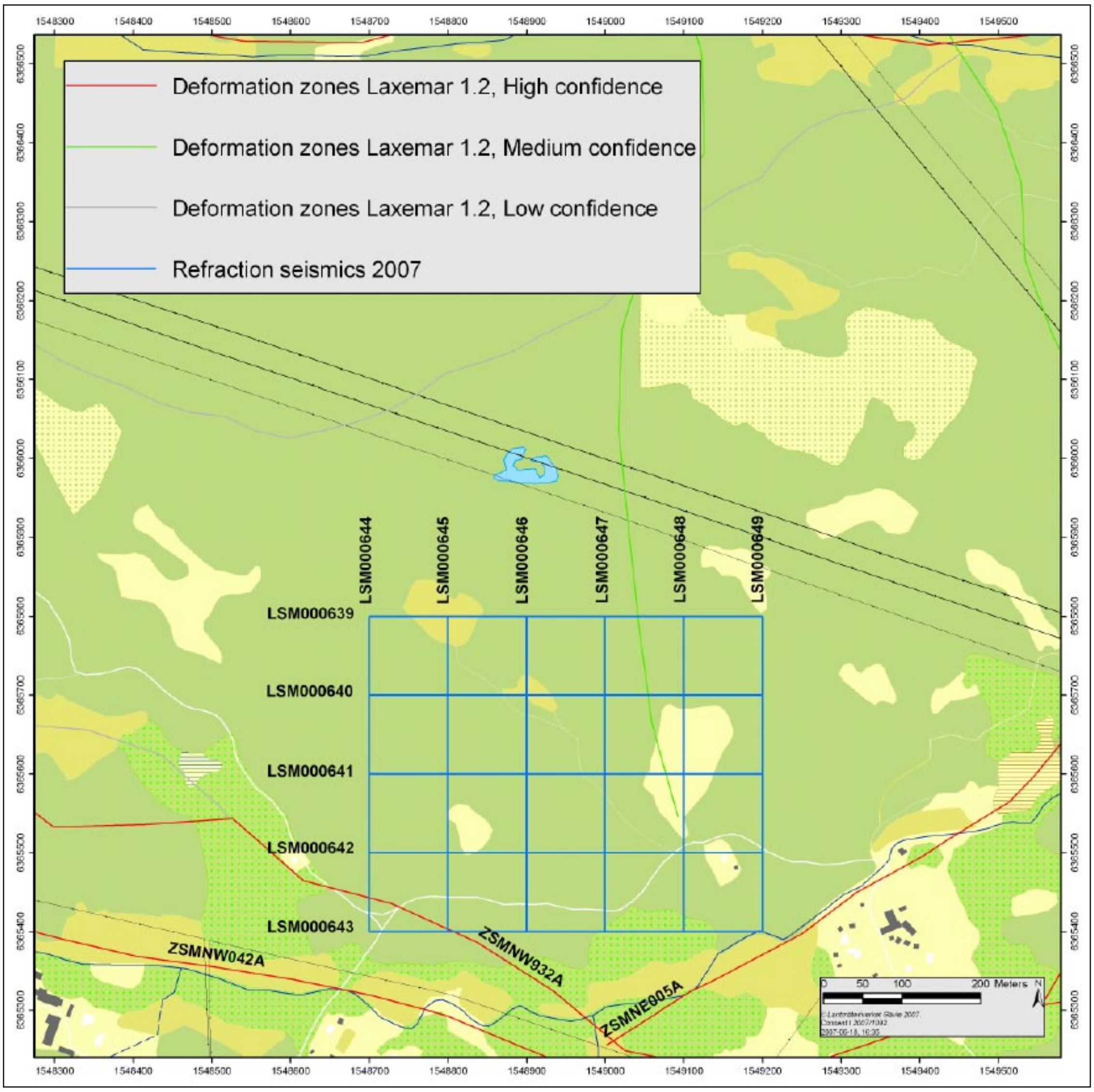

Figure 1-1. *Location of refraction seismic profiles in Laxemar subarea. Interpreted deformation zones with high, medium and low confidence from the preliminary site description of Laxemar are shown with red, green and grey lines respectively /3/.*

2 Objective and scope

The main objective of the investigation was to investigate in more detail the tectonic lineaments and soil depths within the planned industrial area. Background material are possible tectonic lineaments interpreted from laser data and detailed geophysical measurements from ground surface /1, 2, 3/. Eleven profiles with a total length of 4,900 m were measured. The geophone spacing used was 2.5 m for all profiles. The location of the profiles is shown in Figure 1-1.

3 Equipment

3.1 Description of equipment/interpretation tools

3.1.1 Recording instrument

The signals from the geophone cable are recorded digitally in SEG-2 format by a 24-channel instrument, ABEM Terraloc MK6, Figure 3-1.

Figure 3-1. *The recording instrument, ABEM Terraloc MK6.*

4 Execution

4.1 General

The refraction seismic measurements was performed according to the method description for refraction seismic SKB MD 242.001 (SKB internal controlling document).

4.1.1 Refraction seismic measurements

The energy source used was a normal commercial explosive. The charges are buried into the ground. The electrical detonators are ignited with a separate shot cable. The vibrations in the ground are picked up by geophones, Figure 4-1, in this project placed with 2.5 metres spacing along the survey line. The signals from the geophones are carried to the recording instrument by a geophone cable. In this project two cables with a total of 24 outlets were used which means that a full spread covers 57.5 metres in length.

4.1.2 Line survey

Before the seismic measurements the lines were staked and a line survey was performed and the coordinates for geophone points were calculated from the adjusted digital terrain model. The measurements were performed by a Total station, Figure 4-2 and a GPS/RTK receiver. The resolution in X-, Y- and Z-coordinates is better than 0.1 metres in X- and Y-coordinates and better than 0.3 metres in Z-coordinates.

Figur 4-1. *Geophones used during the survey.*

Figure 4-2. *Line survey with Total station.*

4.2 Analyses and interpretation

4.2.1 Data extraction

The shot records were visually inspected and subsequently printed on paper. The arrival times from the different shots were picked manually and plotted as time-distance graphs on paper.

4.2.2 Interpretation

The interpretation was carried out manually with conventional methods. These methods are well described by Sjögren /4/.

4.3 Nonconformities

No changes were made of the survey program defined in the activity plan AP PS 400-07-022.

5 Results

The results discussed in the following section are shown as seismic sections in Figures A-1 to A-11 in Appendix 1. The seismic sections are delivered in .dwg format in the length scale 1:1,000 and depth scale 1:200. In Appendix 1 the scale has been reduced according to the layout of the page in the Appendix. The location of the measured lines is shown in Figure 1-1.

5.1 Interpreted results

In the profiles in Appendix 1 velocities in the uppermost part correspond to the overburden. Velocities from 300 up to 700 m/s correspond to loose topsoil. Velocities from 800 up to 2,200 m/s correspond to moraine above or below ground water table.

Profile LSM000639 (500 m), shown in Figure A-1 in Appendix 1, runs from west to east. The profile is the northernmost one of the west to east running profiles. The soil depth is small along the first part and increases to around 9 m under the hill between chaining 250 m and 420 m. The bedrock elevation is mostly flat around 8 m along the profile. Two minor zones with low sound velocity in the bedrock are found, otherwise the bedrock seems to be of good quality showing velocities around 5,600 m/s.

Profile LSM000640 (500 m), shown in Figure A-2 in Appendix 1, runs from west to east. The soil depth is 2–8 m along the profile. The bedrock elevation is 6–9 m from the start of the profile up to chaining 360 m, thereafter the elevation is 4–6 m. Two zones with lower than normal sound velocity in the bedrock are found. Along most of the profile the sound velocity in the bedrock is 5,500–5,600 m/s.

Profile LSM000641 (500 m), shown in Figure A-3 in Appendix 1, runs from west to east. The topography is fairly flat up to chaining 320 m. The soil thickness varies and the bedrock is exposed or shallow at three short distances along the first 200 m of the profile. Between chaining 200 m and 320 m the soil thickness is 4–5 m and the bedrock elevation is at 8–10 m. After chaining 320 m the terrain slopes gently down to a field around chaining 400 m and from 440 m the ground surface climbs up to outcropping rock with elevation 17–18 m at the end of profile. Below the field the soil depth is a little more than 8 m ad the bedrock elevation is close to 0 m at the same place. Four zones with low sound velocity in the bedrock are found. The most significant one is found under the field.

Profile LSM000642 (500 m), shown in Figure A-4 in Appendix 1, runs from west to east. The first part up to chaining 150 m show a soil depth of 2–7 m. The bedrock elevation is as lowest a little more than 7 m. After 150 m the soil layer is absent or very thin. Along the centre part of the profile the bedrock is outcropping. The bedrock elevation reaches 19 m at chaining 285 m. Two minor zones with low sound velocity in the bedrock are found, otherwise the sound velocity is 5,600–5,700 m/s.

Profile LSM000643 (500 m), shown in Figure A-5 in Appendix 1, runs from west to east. The bedrock is outcropping in the beginning and between chaining 140 m and 255 m. Otherwise the soil depth is less than 5 m. The bedrock elevation is higher than 7 m up to chaining 300 m. Thereafter the terrain and the bedrock level slopes downward and at a stream, where the profile ends, the bedrock elevation is around 0 m. The bedrock quality seems to be good.

Profile LSM000644 (400 m), shown in Figure A-6 in Appendix 1, runs from south to north. The profile is the westernmost one of the south to north running profiles. Outcropping bedrock is found in the beginning and between chaining 170 m and 240 m, otherwise the soil depth is mostly 3–5 m. Along the last 100 m of the profile the top surface layer consists of organic material. The bedrock elevation is around 8 m under the soil covered parts of the profile and higher than 14 m where the bedrock is outcropping. The bedrock seems to be of good quality with the exception of the two minor zones with low sound velocity which is found between chaining 30 m and 45 m.

Profile LSM000645 (400 m), shown in Figure A-7 in Appendix 1, runs from south to north. Outcropping bedrock is found at chaining 30 m, 120–155 m and 205–245 m. In between the soil depth is commonly 4–6 m. The soil depth is at most 7–9 m under the hill at chaining 300–350 m resulting in an almost flat bedrock elevation around 6 m. Two zones with lower than normal sound velocity in the bedrock are found. The most prominent one at chaining 95 m is located at a local depression in the bedrock surface. Otherwise the bedrock seem to be of very good quality with sound velocities in the range 5,600–5,800 m/s.

Profile LSM000646 (400 m), shown in Figure A-8 in Appendix 1, runs from south to north. The first 140 m of the profile show outcropping bedrock or shallow soil depths. The bedrock elevation is 12–15 m in this part of the profile. The centre part of the profile is dominated by a small hill where a plateau with dimension 40 m by 40 m is built for drilling operations. At the drill site no attempt was done to shoot which means that the soil depth is more uncertain than usual at that place. Along the last 100 m of the profile the soil depth is 3–5 m showing a very flat bedrock surface at an elevation around 8 m. Two zones with low sound velocity in the bedrock are found.

Profile LSM000647 (400 m), shown in Figure A-9 in Appendix 1, runs from south to north. The first 170 m is made up of a hill with outcropping bedrock or shallow soil depths. The bedrock elevation varies there between 10 m and almost 19 m. Along the later half of the profile the soil depth normally increases with the ground surface elevation showing a fairly flat rock elevation of 7–10 m. Two narrow zones with low sound velocity in the bedrock are found, otherwise the sound velocity is in the range 5,500–5,800 m/s.

Profile LSM000648 (400 m), shown in Figure A-10 in Appendix 1, runs from south to north. Between chaining 30 m and 105 m there is a hill with outcropping bedrock. The bedrock elevation increases from 4 m at the beginning of the profile up to more than 14 m at chaining 80 m. From chaining 150 m up to chaining 280 m the profile crosses a cultivated field. Under the field the soil depth is 4–8 m showing a bedrock elevation in the range 1–4 m. From chaining 320 m and up to the end of the profile the bedrock elevation is around 7–8 m. Two zones with low sound velocity in the bedrock are found at chaining 195 m and 298 m. The one at 195 m is interpreted to be broader than 5 m. The normal sound velocity in the bedrock is 5,600–5,700 m/s.

Profile LSM000649 (400 m), shown in Figure A-11 in Appendix 1, runs from south to north. The profile begins in a stream under which the bedrock elevation is about 0 m. From chaining 20 m up to 295 m the profile runs across a ridge with outcropping bedrock or thin soil layer. The bedrock elevation is 16–18 m between chaining 125 m and 220 m. From 300 m an up to the end of profile the soil depth is 4–6 m showing a bedrock elevation in the interval 4–6 m. The sound velocity in the bedrock is 5,200–5,700 m/s with exception of two narrow zones with low velocity.

5.2 Location of low velocity zones

The location of low velocity zones is shown in Figure 5-1.

In this survey the sound velocities in the bedrock varied between 5,000 m/s up to 5, 900 m/s. The mean value of the sound velocity for solid rock was 5,600 m/s. A number of (22) usually 2.5 m wide zones with lower sound velocity were found. The sound velocity for most of these

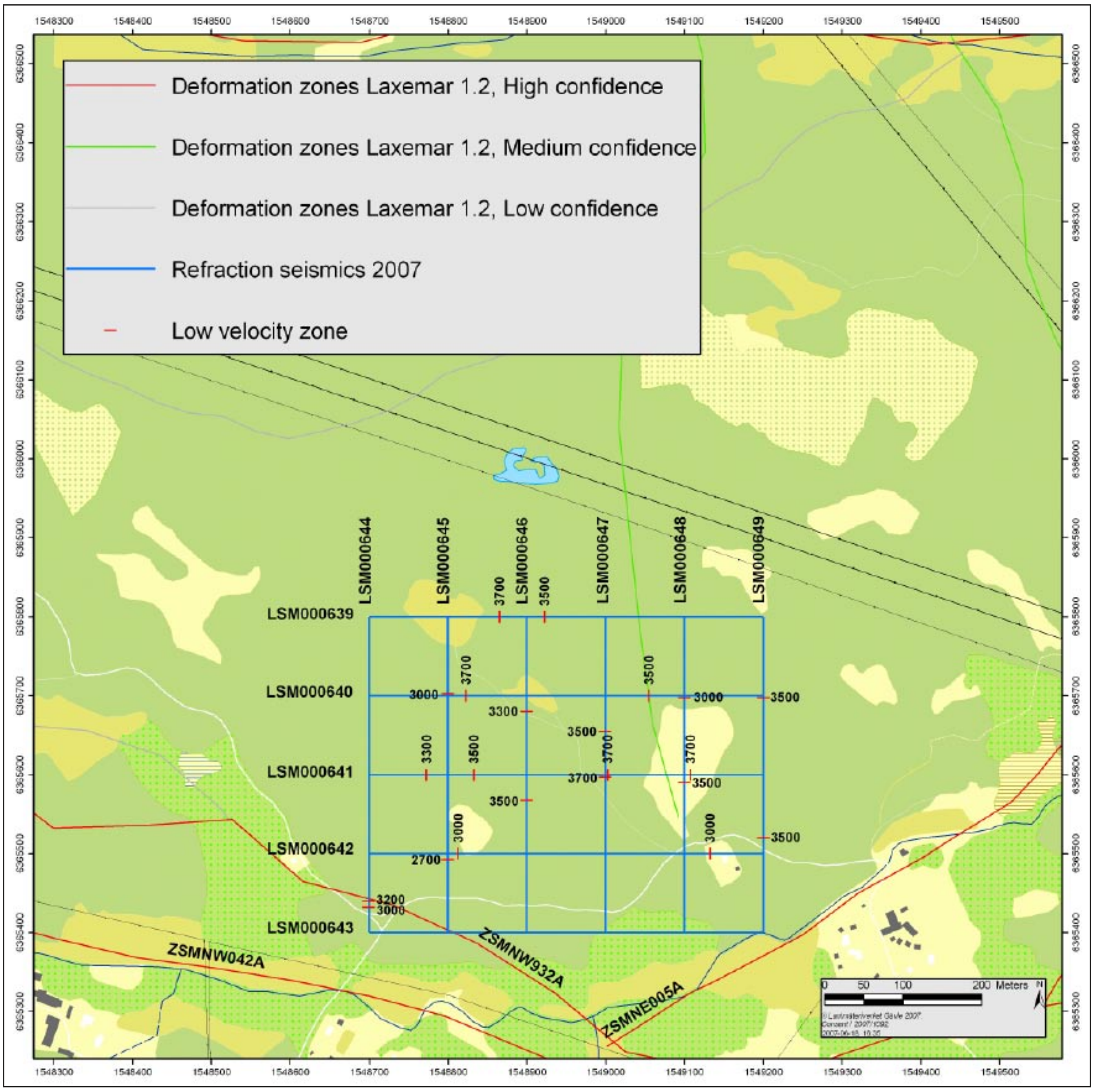

Figure 5-1. Location of low velocity zones in the bedrock interpreted from this refraction seismic survey. The low velocity zones are marked with tic-lines along the profiles. Interpreted deformation zones with high, medium and low confidence from the preliminary site description of Laxemar are shown with red, green and grey lines respectively /3/.

zones was in the interval 2,700–3,700 m/s with a mean value of 3,500 m/s. When calculating the sound velocity for the bedrock the lower limit of the width of a low velocity zone is given by the distance between the geophones, in this case 2.5 m. This means that a zone with fractures that show up during the interpretation can be less than 2.5 m. One final remark regarding low velocity zones in the bedrock is that a 2.5 m wide zone with a sound velocity of 3,500 m/s corresponds to an extra delay of the signal with about 0.25 milliseconds, which is close to or even lower than the resolution for the method, see method description MD 242.001.

5.3 Data delivery

Raw data from the measurements were delivered directly after the termination of the field activities and the delivered raw and processed data have been inserted in the database of SKB (SICADA) and data are traceable by the activity plan number.

Data delivered directly after termination of the field activities were:

- Field log for record numbers and shot and geophone geometry.
- Seismic raw data recordings in SEG-2 format.

Together with this report the following data are delivered:

- Seismik Laxemar våren 2007.dwg (drawings in Appendix 1).
- EG170_Line surveying_Laxemar_Refraktionsseismik_2007.xls (listing of line coordinates).
- GP320_Refraction seismics_Laxemar_våren_2007.xls.

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/1/ **Berglund J, Nyborg M, Triumf C A, Thunehed H, 2006**. Oskarshamn site investigation. Coordinated presentation of topographic and geophysical lineaments in selected areas, including field assessment – Laxemar area. SKB P-06-15, Svensk Kärnbränslehantering AB.

/2/ **Thunehed H, Triumf C A, 2006.** Oskarshamn site investigation. Detailed ground geophysics at Laxemar, autumn/winter 2005/2006. Magnetic total field and resistivity. SKB P-06-137, Svensk Kärnbränslehantering AB.

/3/ **SKB, 2006**. Preliminary site description. Laxemar subarea – version 1.2. SKB R-06-10, Svensk Kärnbränslehantering AB.

/4/ **Sjögren B, 1984.** Shallow refraction seismics. ISBN 0-412-24210-9.

Appendix 1

Interpretation of refraction seismic sections in Laxemar

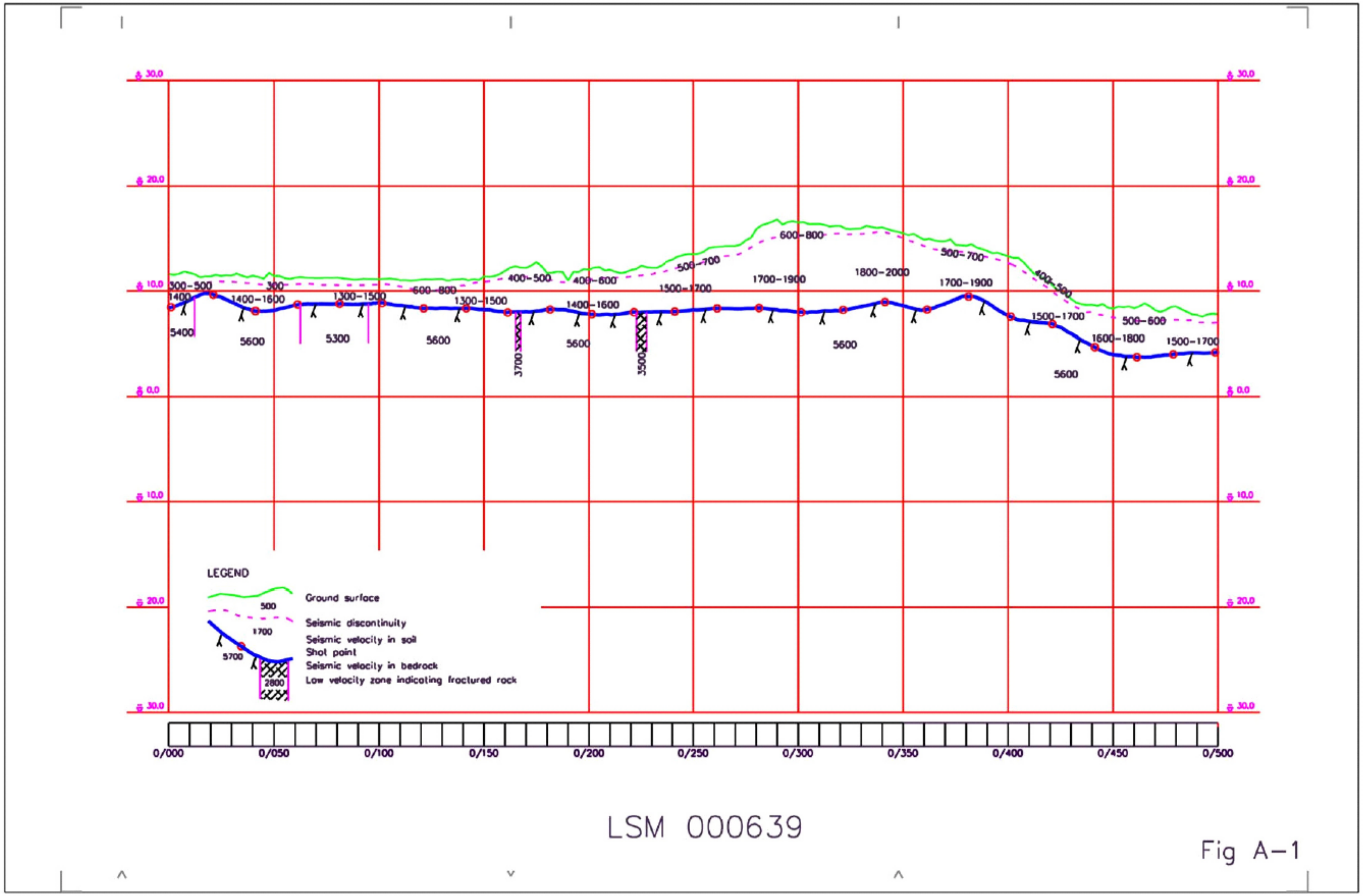

Figure A-1. *Refraction seismics in Laxemar during spring 2007. Profile LSM000639.*

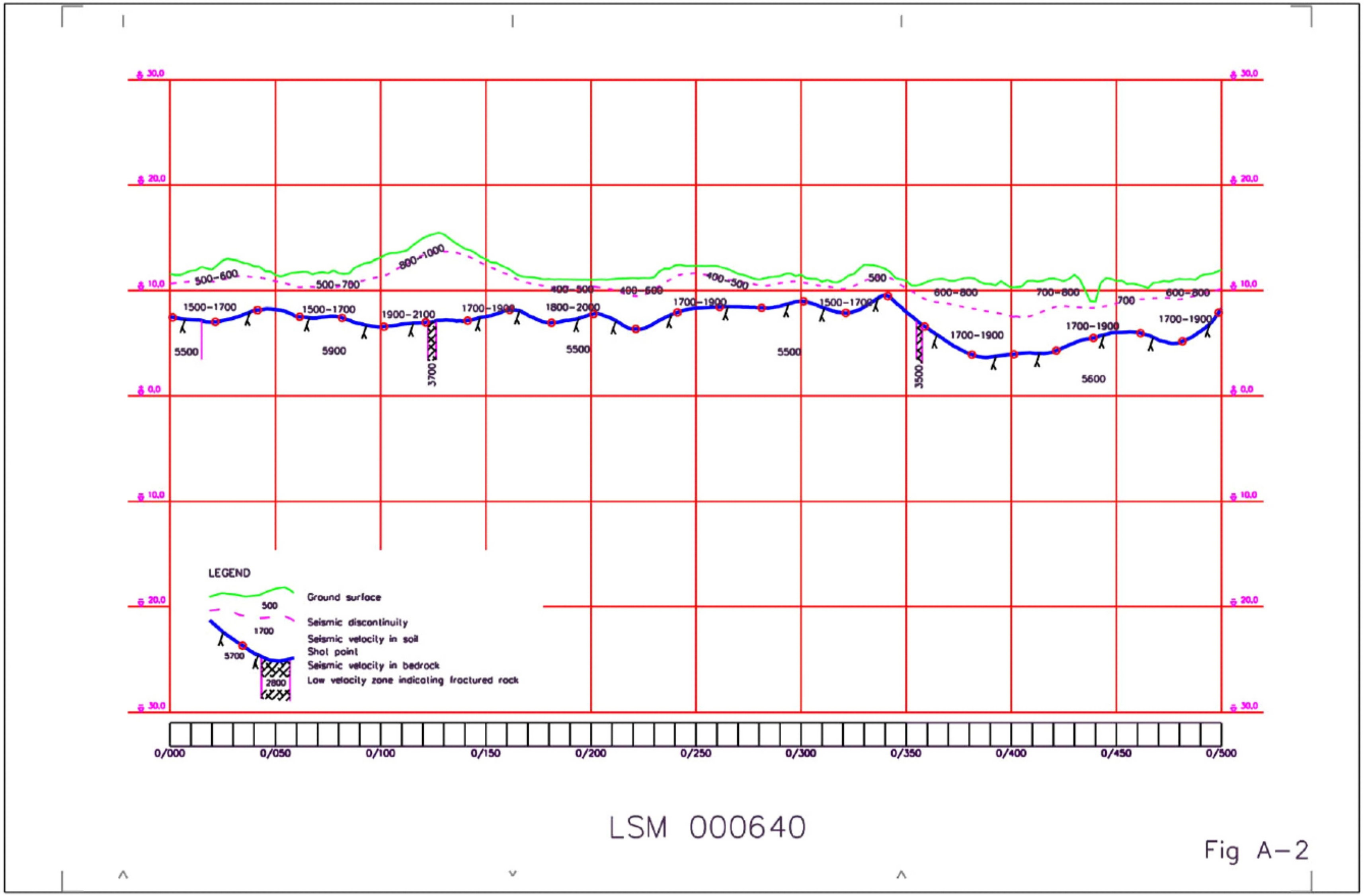

Figure A-2. Refraction seismics in Laxemar during spring 2007. Profile LSM000640.

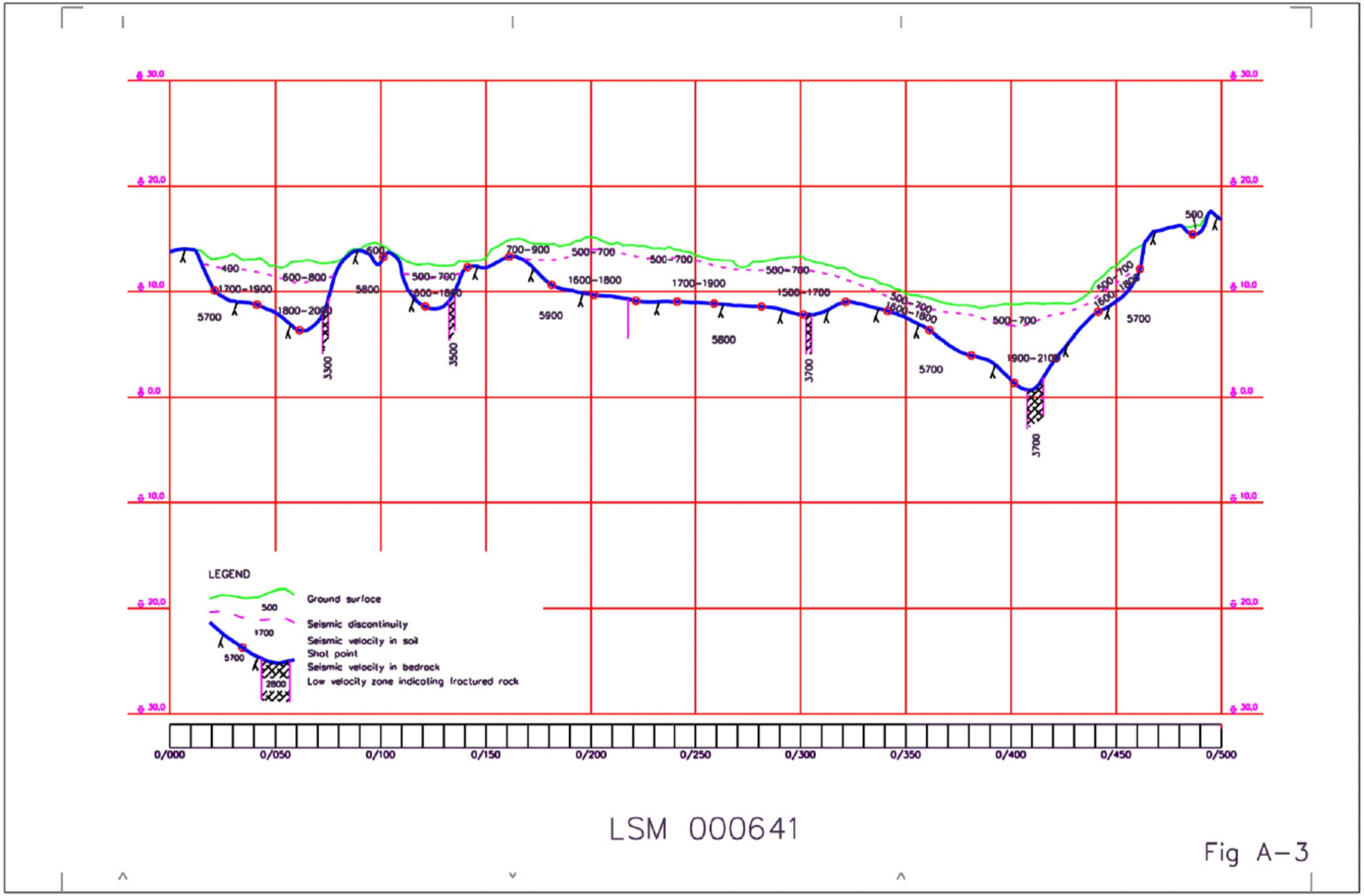

Figure A-3. Refraction seismics in Laxemar during spring 2007. Profile LSM000641.

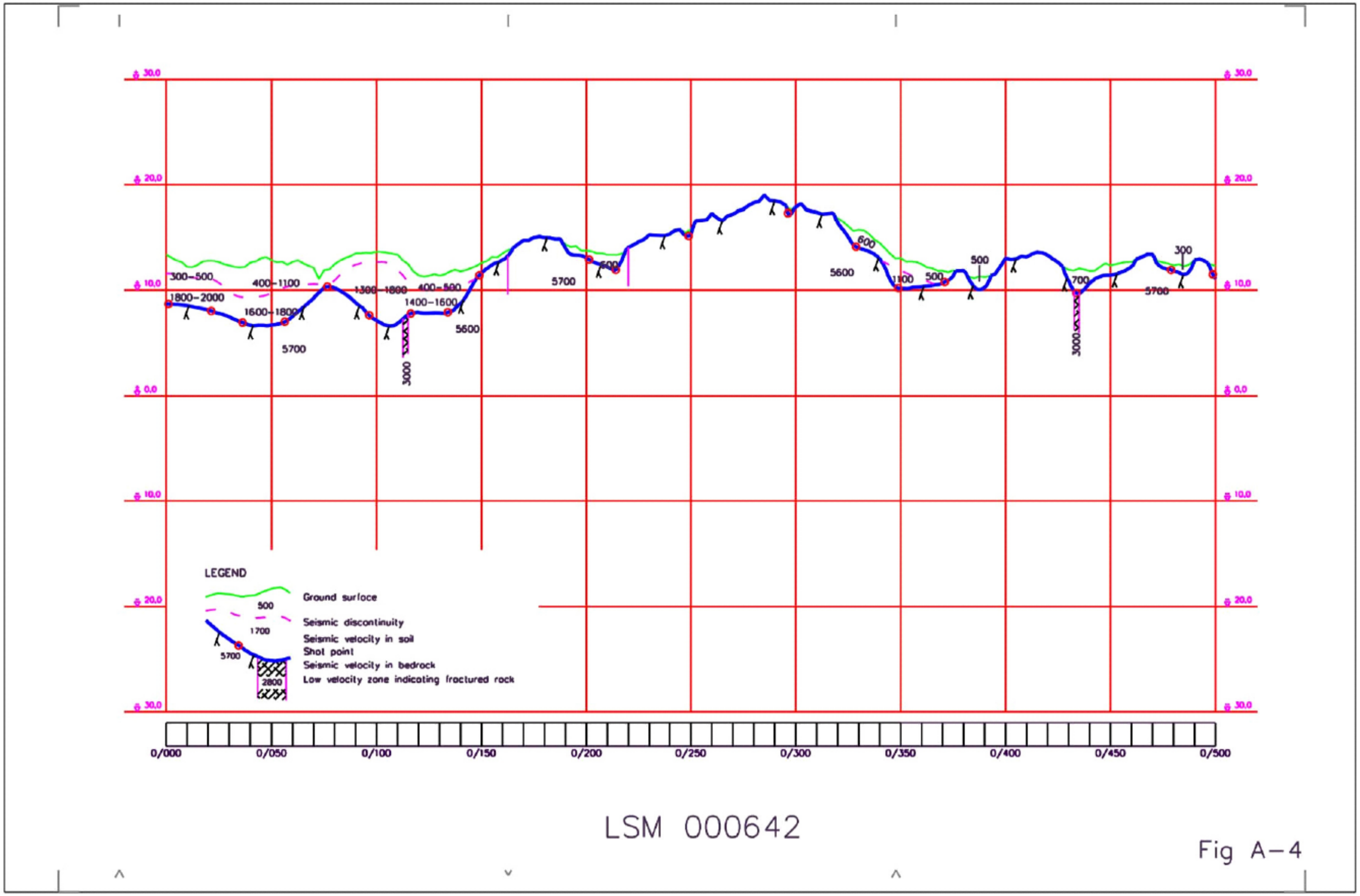

Figure A-4. *Refraction seismics in Laxemar during spring 2007. Profile LSM000642.*

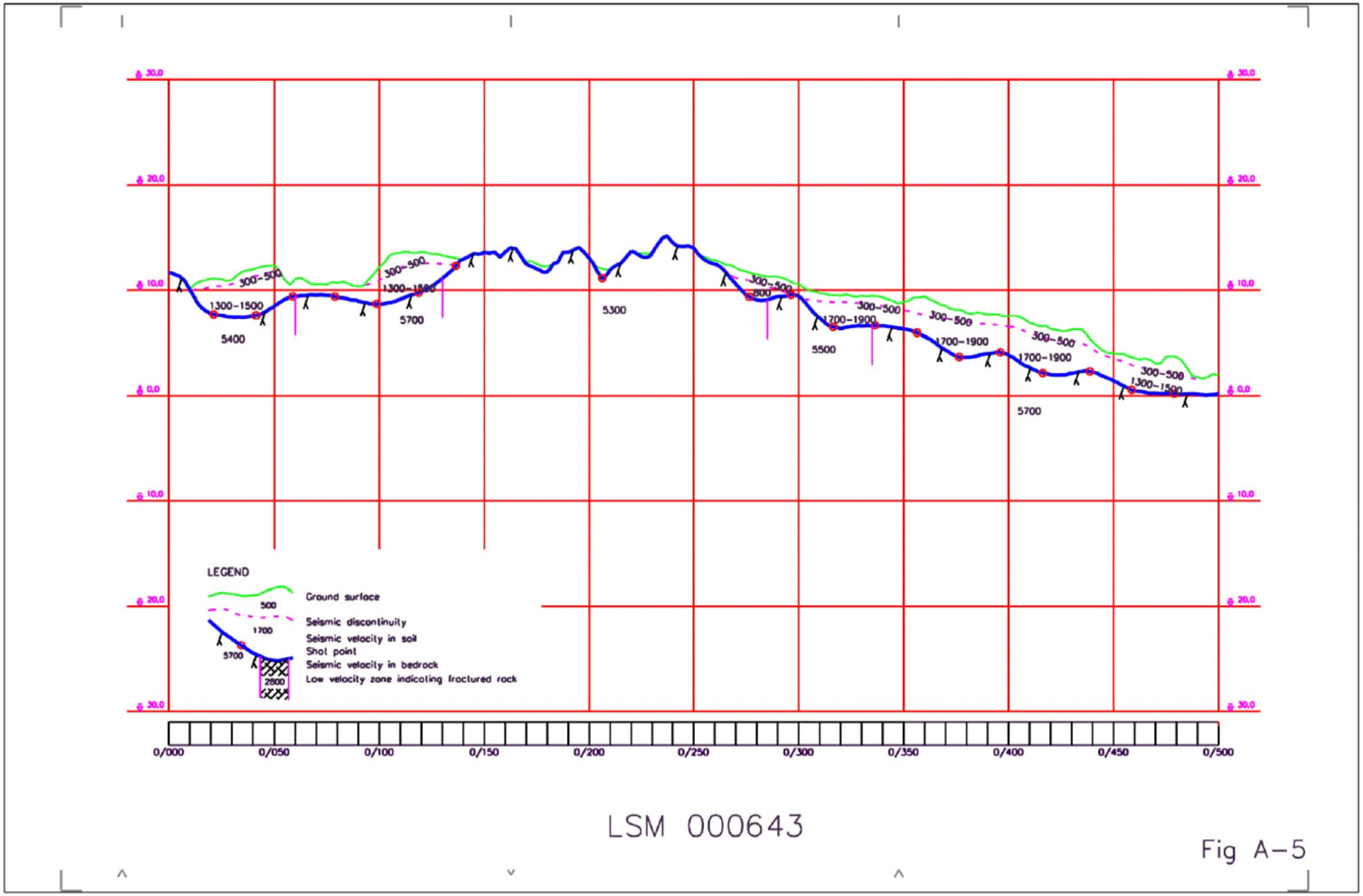

Figure A-5. *Refraction seismics in Laxemar during spring 2007. Profile LSM000643.*

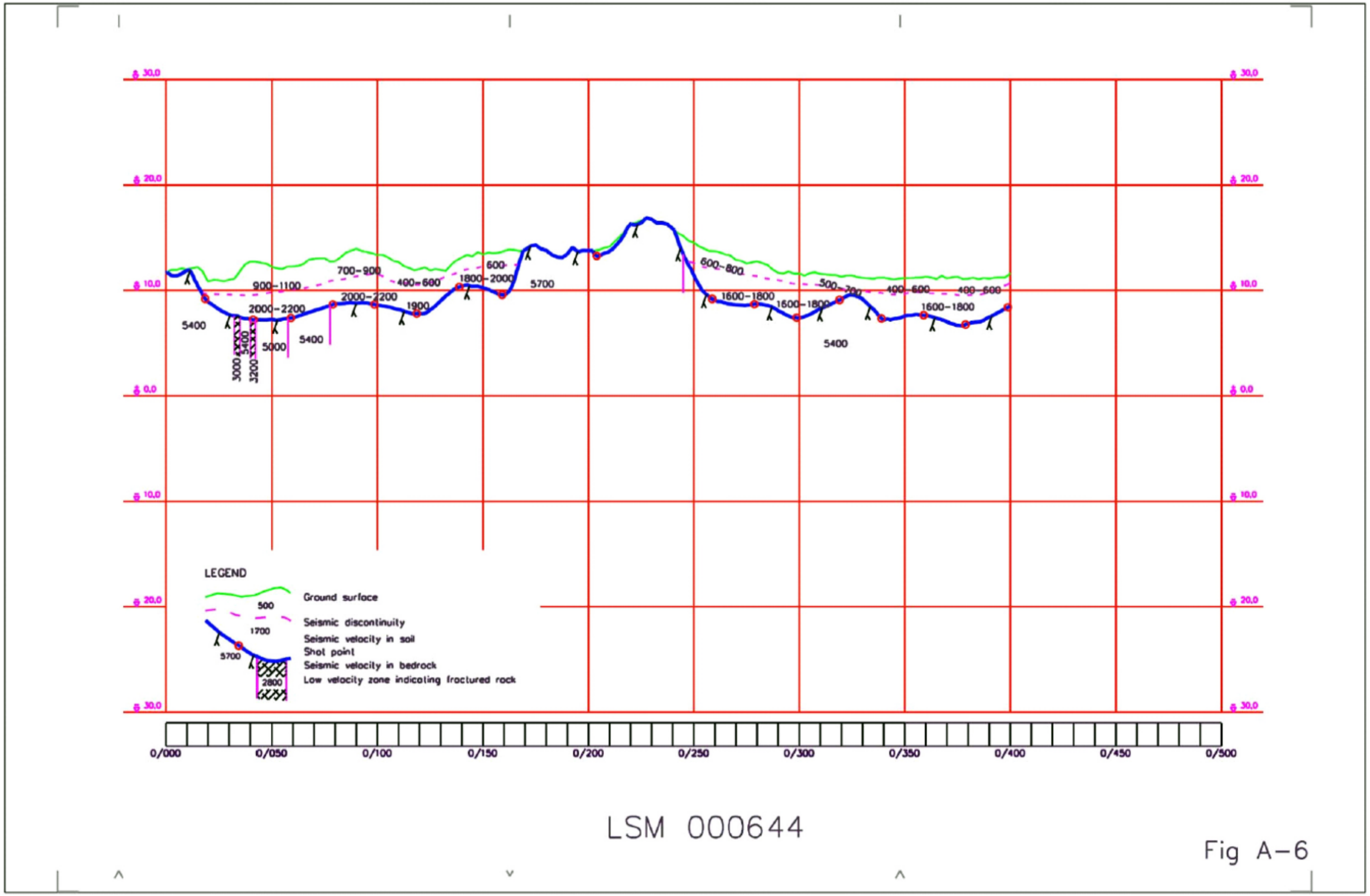

Figure A-6. *Refraction seismics in Laxemar during spring 2007. Profile LSM000644.*

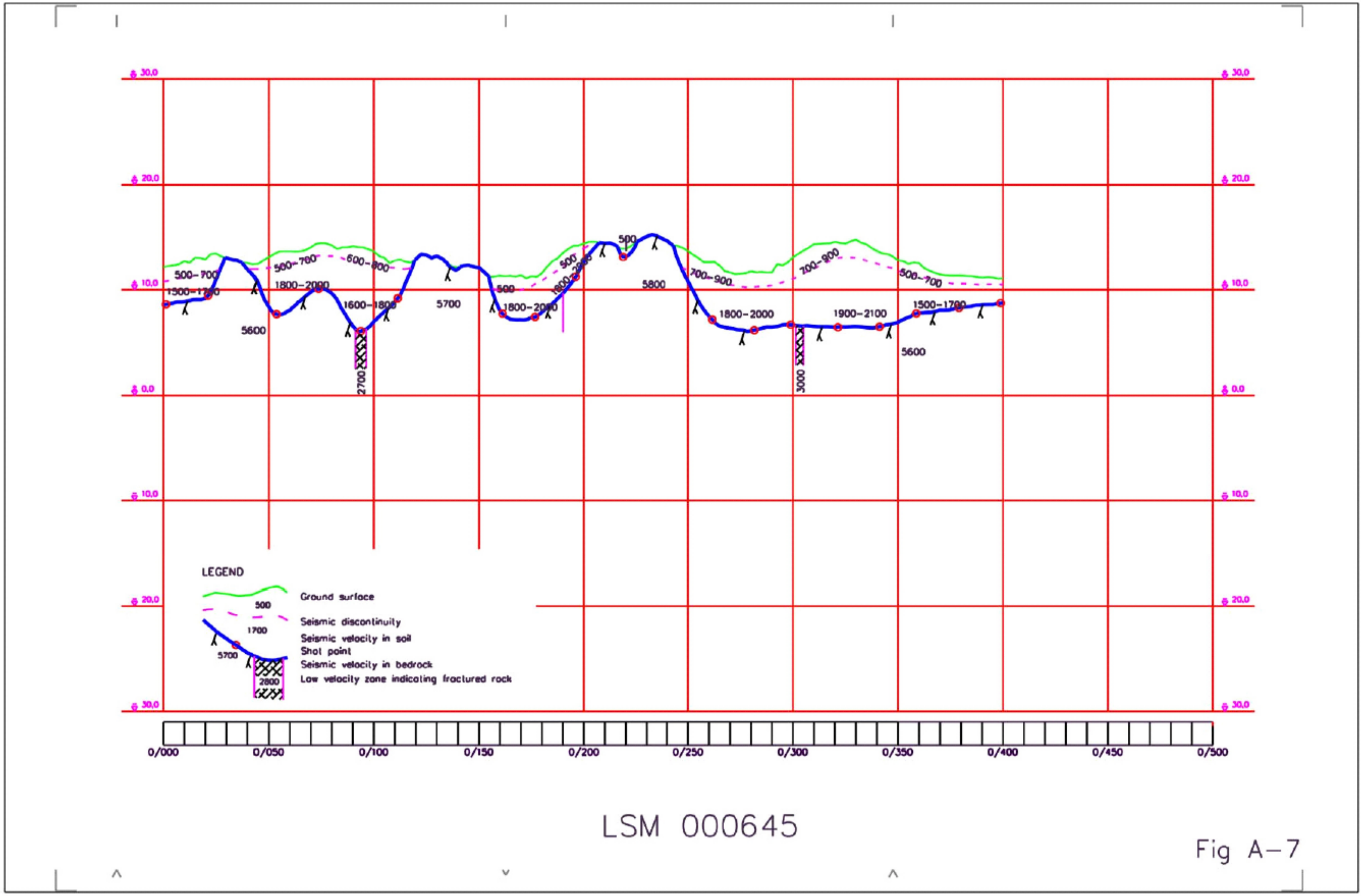

Figure A-7. *Refraction seismics in Laxemar during spring 2007. Profile LSM000645.*

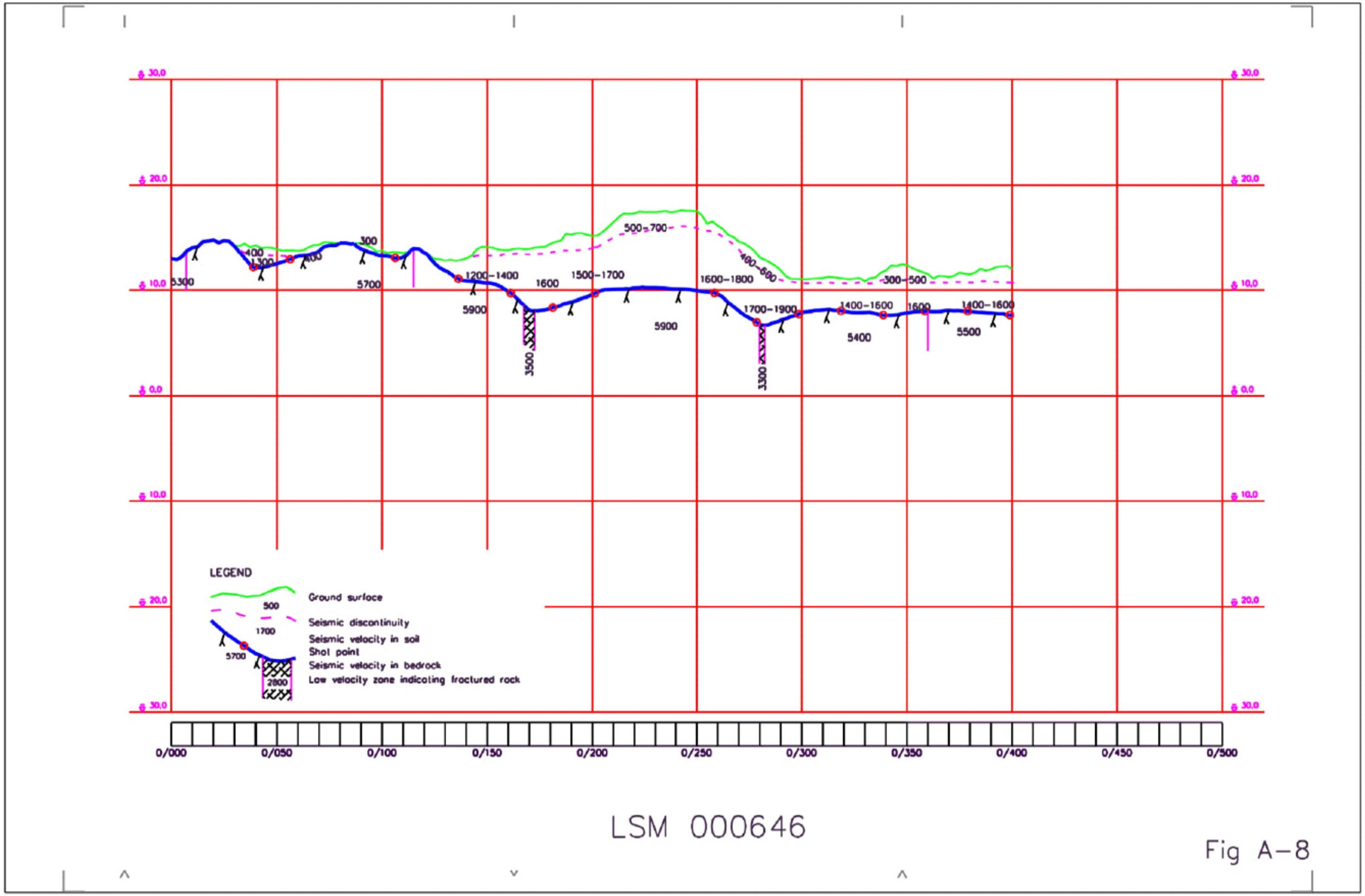

Figure A-8. *Refraction seismics in Laxemar during spring 2007. Profile LSM000646.*

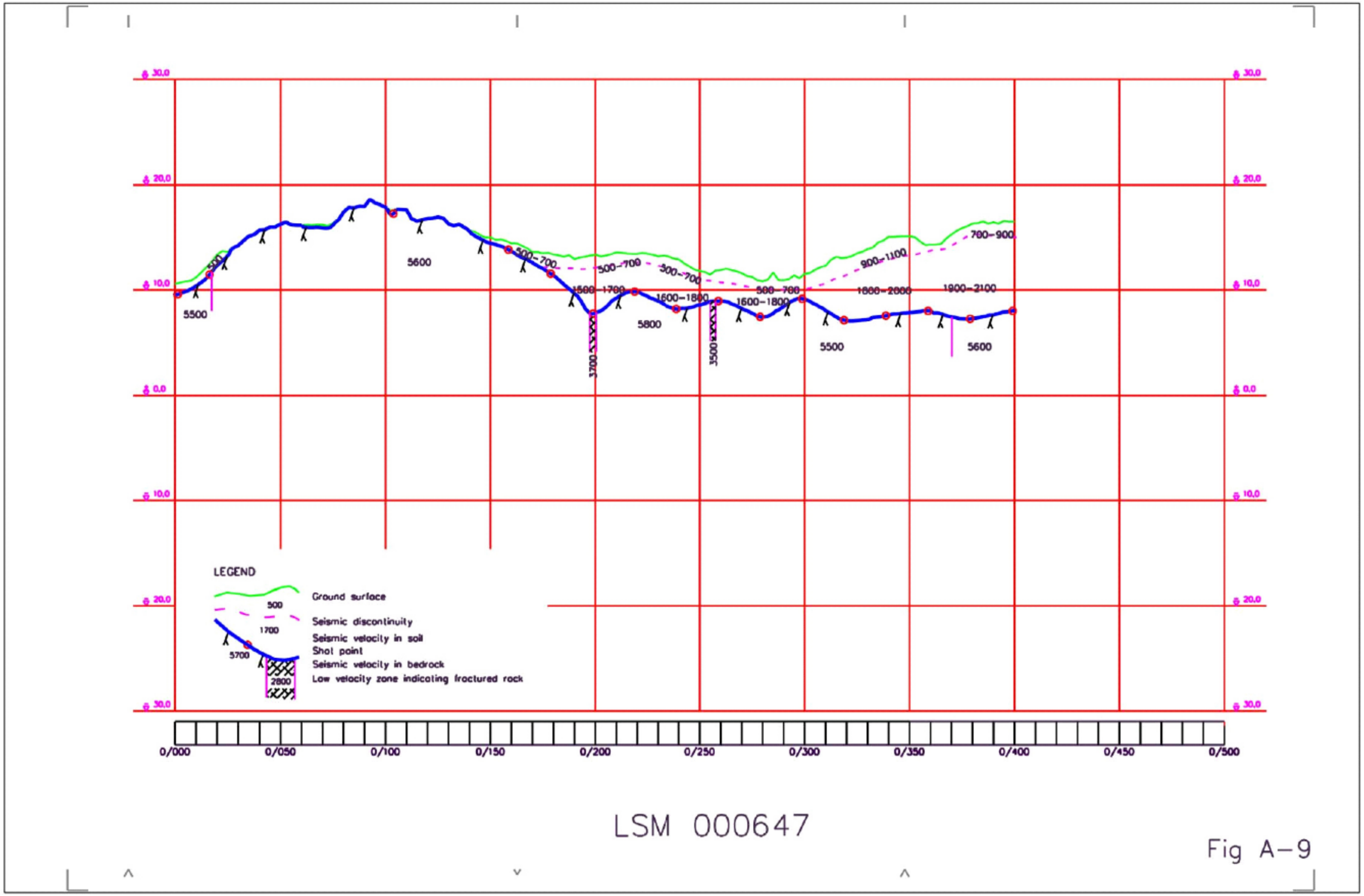

Figure A-9. *Refraction seismics in Laxemar during spring 2007. Profile LSM000647.*

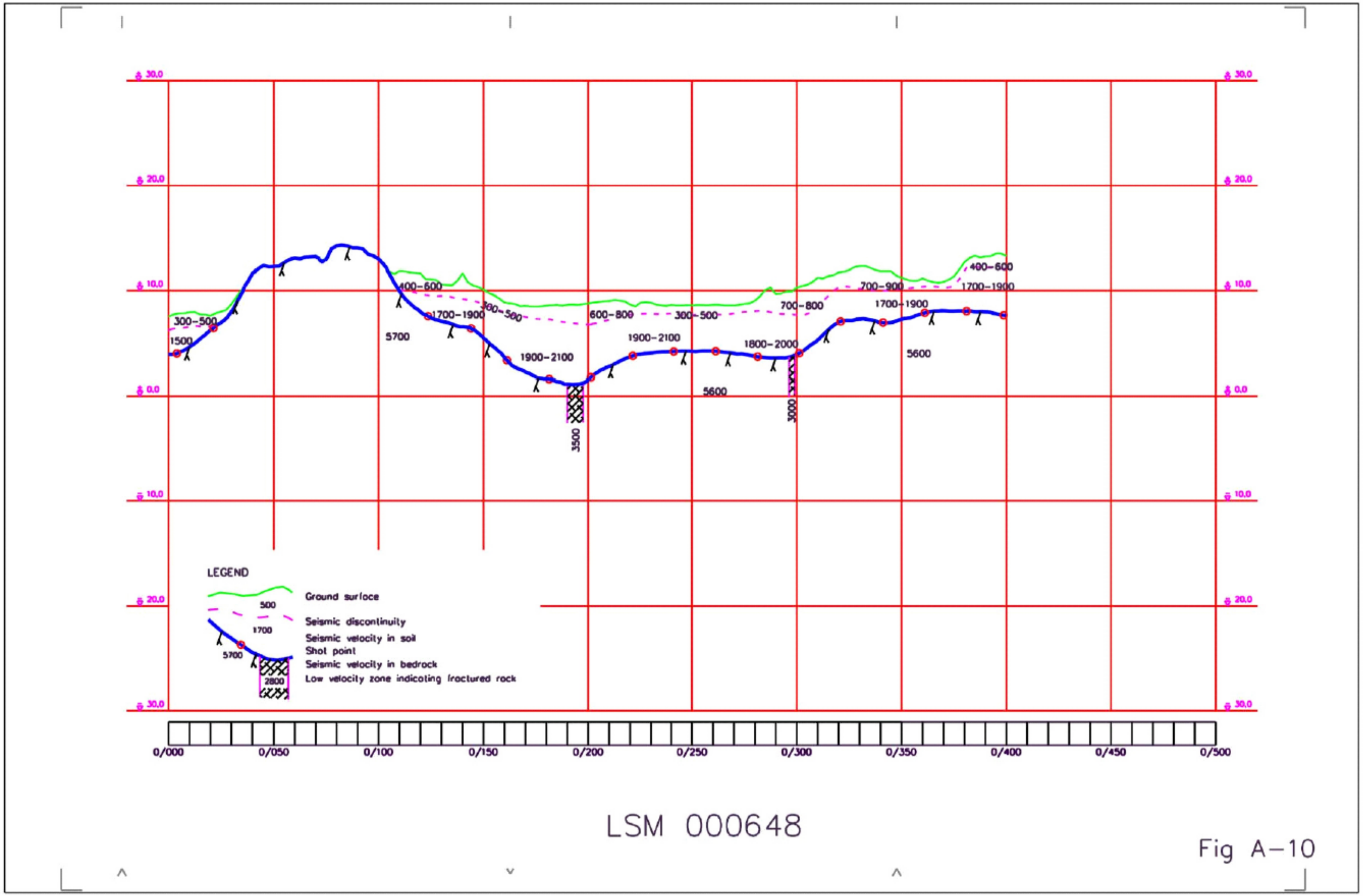

Figure A-10. Refraction seismics in Laxemar during spring 2007. Profile LSM000648.

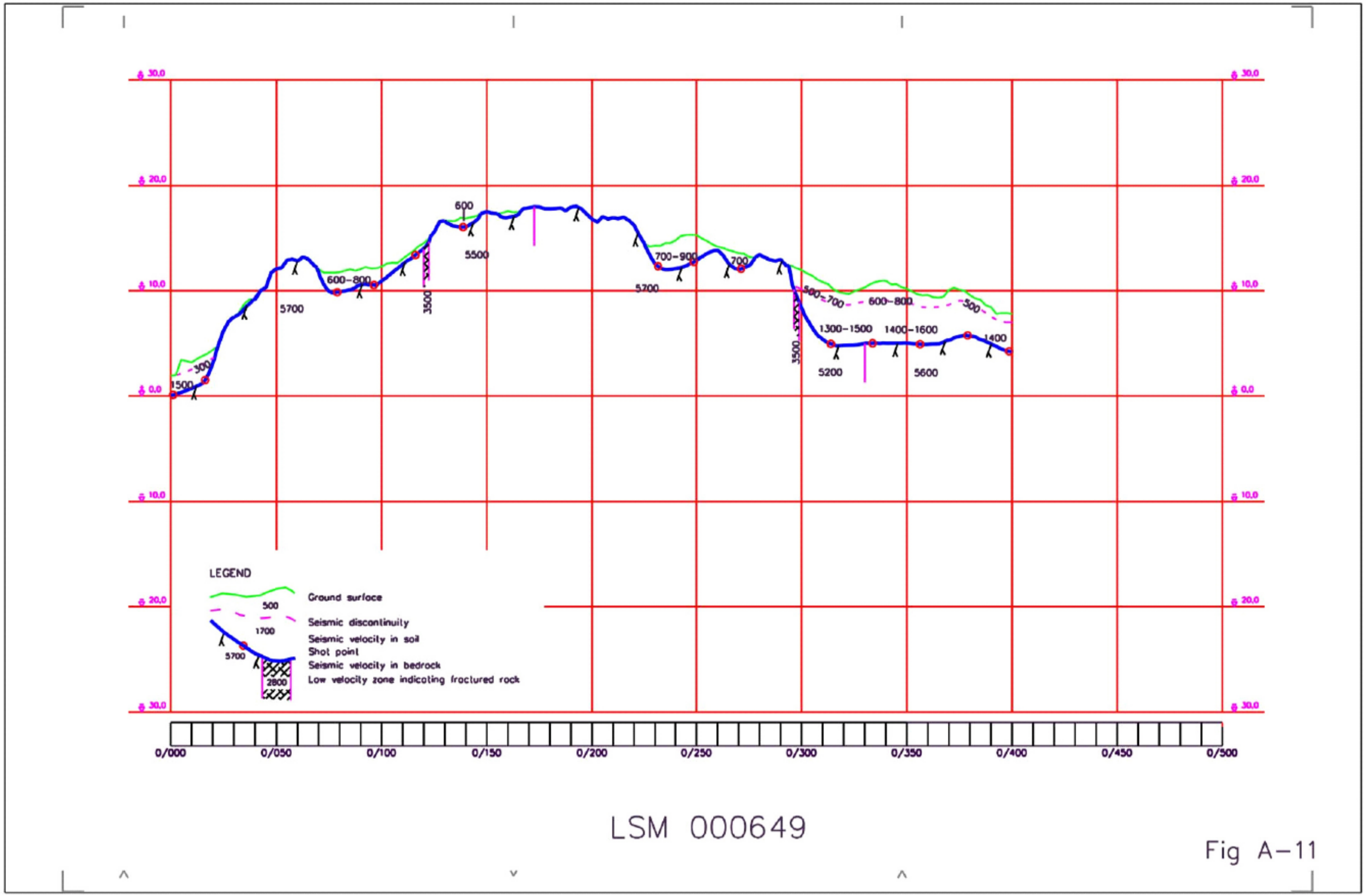

Figure A-11. *Refraction seismics in Laxemar during spring 2007. Profile LSM000649.*