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Cliff Reconnaissance Vehicle
test campaign in the Dachstein ice cave

Mars cave exploration simulation

27th of April to 1st of May 2012



Cliff Reconnaissance Vehicle (CRV or « cliffbot ») test campaign in the Dachstein ice cave

Mars cave exploration simulation

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Executive summary

The Österreichisches Weltraum Forum (Austrian Space Forum) or ÖWF has organized from the 27th of April to the 1st of May, a Mars cave exploration simulation campaign. The selected location is an ice cave designated “Rieseneishöhlen” located south of Salzburg near Obertraun in a mountainous area called Dachstein. In the ice cave located at around 1400 m, small glaciers are present all year round. We do not know yet if such ice caves may exist on Mars. Caves have been recently discovered on Mars which are apparently linked to previous volcanic activity, but the presence of ice in this type of caves is only a possibility. Caves on Mars would be an interesting location to search for past or present biological activity because they are protected from ultra violet radiations. And the presence of ice, which means water, would increase the probability of interesting discoveries.

The Dachstein campaign gathered various experiments and various teams representing eleven countries.

One of the most spectacular experiments is the utilization of the ÖWF simulation spacesuit Aouda. This spacesuit, which is not pressurized, has however a sophisticated mechanical system allowing the restitution of pressure effects on the suit tester. It is equipped with measurements and telemetry allowing the transmission of data such as heart rate, CO2 partial pressure, view seen by the tester to a control center remotely located.

The Planète Mars association participated to the Dachstein campaign with two versions of its Cliff Reconnaissance Vehicle (CRV also called Cliffbot). The general objective was to see how such a vehicle could help caves exploration, providing access and information on areas where a man in a spacesuit cannot access.

The main objectives were the following:

First objective was to assess what could be the usefulness of the CRV to explore non reachable areas by a man in space suit in a cave. This implies typically a vertical hole. Also steep to medium ice slopes would fall in this category of non reachable slopes. It appeared during the campaign that Tristan dome was a good representation of vertical non accessible hole but I had no certainty before the campaign that such a hole would be available for experimentation.

Second objective was to operate the vehicle with the Aouda spacesuit and find what are the difficulties linked to operations in a spacesuit. This test has been done numerous times in Utah with the Mars society simulated spacesuits but these are rather easy to operate (no simulation of internal pressure for example). It was clear before the campaign that Aouda spacesuit would be operated by a ÖWF crewmember.

Third objective was to operate the vehicle with the Aouda spacesuit gloves, test which could be done by the cliffbot APM participant.

Fourth objective was to document the difficulties encountered on various all terrain configuration by the vehicle on the way down or up.

Fifth objective was to use the pictures sent by cliffboat on board hazcam to control the vehicle operations.

Sixth objective was to acquire nice pictures of the vehicle in the spectacular ice cave environment.

The main results and lessons learned are the following:

1 The vehicle has demonstrated its **ability to be recovered from two difficult situations** twice, demonstrating again an all terrain capability.

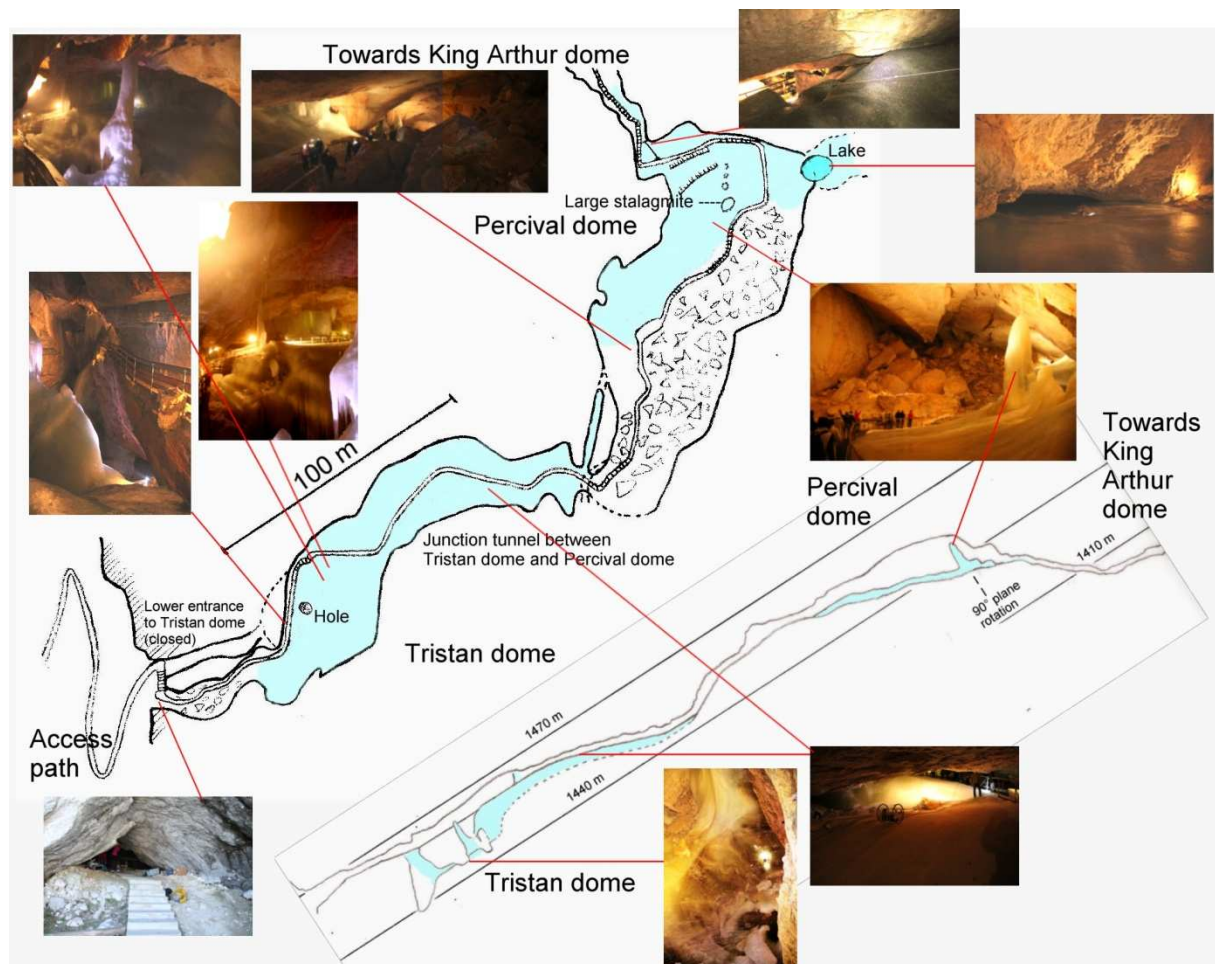
2 The photo **mapping of a typical non accessible hole** (in this case the lower part of Tristan dome) was possible because of a favorable slope configuration (overhanging and vehicle suspended to the rope). This configuration allowed rotation of the vehicle and landscape swapping. **The vehicle was designed to conduct cliffs strata imaging and not 360° panorama. Exploring a hole in a cave requests more 360° views than close up of strata.** The vehicle could have been used 180° from its nominal orientation, with the camera oriented opposite to the wall in order to acquire general views in the case where it was rolling on the slope and not suspended. But a **multiple camera configuration or a rotating camera configuration would be best adapted to a cave hole mapping** than the present configuration.

3 **Guiding and controlling the vehicle without direct view and using only the picture transmitted by the hazcam has proved nearly impossible.** There, also, a **multi camera (or camera swapping the landscape) would be necessary or at minimum a front view and rear view** availability. Also the video signal transmission is a problem in complicated slopes where obstacles can preclude the picture reception up hill.

4 For the first time a **cliffbot was demonstrated using another instrument than a camera** when the LATMOS laboratory used the CRV 5 for the **Exomars ground sounding radar** experimentation. The use of other than camera instruments was foreseen since the beginning of the vehicle design but had never been conducted before by lack of Planète Mars association capability to field more complicated and costly devices than a camera. The CRVs test objectives till now were always more focused on the vehicle all terrain capability than on scientific measurements.

1 Introduction

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Dachstein ice cave map and main locations

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2 CRV development history



Doc. NASA - Pat Rawlings

On Mars as well as on earth or other telluric planets, cliffs and steep slopes are areas where the ground provide direct access to layers and rocks which have been produced by hundreds of millions years of geological , meteorological and biological (eventually) history. With exploration lengths in the order of 100 m in the line of slope, crossing the various layers, a lot of information may be gathered on a planet history.

To be able to observe a ground which is not obstructed by debris, the slopes to be explored have to be between vertical (90°) and around 45°. A rover using wheels for propulsion cannot travel along this type of slope. One solution is to use a cable suspended rover. This rover may be entirely autonomous with a uphill anchorage provided by another rover or be operated with more or less autonomy by astronauts operating on the uphill side. Some Mars exploration artist views are showing astronauts in space suits suspended to ropes

and exploring a vertical cliff. If such a difficult operation is ever attempted, it will be only because a cliff exploration rover will have found a worthwhile feature to be observed, analysed or retrieved!

Starting from the above considerations and acknowledging that the cliff rover problems have seemingly not been addressed by space agencies or organisms, Planète Mars Association decided, in summer 2001, to explore the difficulties of mobility along a steep slope for a cable suspended rover. Main requirements were the ability to operate on slopes between 90 and 45°, the ability to deal with the highest possible obstacles on the way down or up and particularly to be able to be retrieved and brought back up the hill in those obstacles conditions and even in case of overhanging parts in the cliff. A secondary requirement was to test what would be visible with a camera on board and test devices to measure the size of features visible in the camera field.



The CRV 1 before a test in Vernon

CRV 1 general configuration

The Cliff Reconnaissance Vehicle, or CRV in short (VRP in French), is by no way a vehicle designed for actual operations on planetary grounds but only a demonstrator to test the best configurations to fulfil the above requirements. The geometrical configurations experimented as well as the size bear probably a strong similarity to a future operational vehicle but other (lighter) materials would be used as well as smaller space qualified equipments. Also the assembly process to build or deploy in the field the vehicle would be much more simplified. The CRV 1 to 3 have no autonomous mobility and are lowered and brought back up manually suspended to a rope. An operational vehicle would surely be operated with an electric windlass. The operating process implies that the cliff or slope has to be accessible from above. The CRV main payload is a camera although other payloads are possible.

Three different Cliff Reconnaissance Vehicle (CRV) configurations have been tested at the MDRS since 2002: CRV 1 was tested during MDRS 2 by Gilles Dawidowicz (February – March 2002). CRV2 was tested during MDRS 7 by Alain Souchier (November 2002). CRV 3 was tested during MDRS 23 by Anne Pacros (February 2004), during MDRS 26 by Edwin Loosveldt (March 2004), during MDRS 39 by the Leonardo crew (April 2005), during MDRS 40 by Anne Pacros and her Monalisa crew colleagues, during MDRS 43 by Alain Souchier (February 2006) and during MDRS 90 by Pierre-Emmanuel Paulis (February 2010). This was the eight experimentation in Utah for the CRV vehicle family. Naturally other tests, particularly preparation tests for Utah campaigns, have been conducted in France.

The CRV 1 was a 4 wheel configuration, with a mass of 8 kg. When upside down the vehicle was designed to slide on ski type structures. The CRV 2 had the same general configuration with the use of some lighter structures. It was 5 cm larger than the CRV 1 and had a real time video transmission to send to a receiver up the hill the picture taken by a context camera (or hazcam) or by the main camera looking at the ground. The mass was increased to 8.5 kg. The CRV 3 is a totally new design based on 2 big wheels. The vehicle rolls on these wheels even when it is upside down. The vehicle mass is 4.075 kg (including the main camera loaded with video tape and battery). Without the video emission box, the mass is reduced by 0.555 kg. The configuration without the emission box was used for missions MDRS 23 and 26. The

emission box was on the vehicle during MDRS 39 and 40 but was not used by the crews. Missions MDRS 23, 26, 39 and 40 thus concentrated on mobility demonstrations. The CRV objective for MDRS 43 was the context hazcam camera use optimization. In the nominal configuration the context hazcam camera located on the vehicle is looking upwards to give the operators information about the obstacles above. This may be useful to ease the vehicle retrieval. Also the upward view may bring information on the ropes situation (entanglement, twists,...). The context hazcam camera is linked to the emitter by a long wire. Thus the camera can be installed elsewhere on the vehicle looking to other directions. A small container was also provided since mission MDRS 39 to house this camera somewhere along the ropes for example looking downward to the vehicle from a position located some meters above. The search for an optimum location was one of the CRV MDRS 43 mission objectives. The other one about context camera use optimization, was to see how the information from this camera could be used by the operating astronaut to facilitate the vehicle operations. And naturally mobility demonstrations were also an objective. Particularly as the operating crew member had experimented the CRV 2 during MDRS 7, the CRV 3 could be used on exactly the same locations as the CRV 2 to demonstrate improved mobility (or not).



Cliff Reconnaissance Vehicle n°3 main features (CRV test 70 at White Rock Canyon during MDRS 43 in 2006). Small modifications were introduced between this configuration and the CRV 3-3 configuration tested in Dachstein.

During the MDRS 43 mission, tests 68 to 74 were conducted. Tests 73 and 74 were done with a mock up of new very simplified version. This version is devoted only to quasi vertical cliffs and is a simple container to be equipped with a camera. The camera was not on board for tests CRV 73 and 74. The container with a camera on board and a transmission by wire to the CRV 3 was used during the CRV 3 test n°72 linked to the suspension rope and gave images of the CRV 3 from above.

During test 71 the CRV 3 was blocked in the cliff called Stacy's Cake, in the same location as the CRV 2 was blocked in 2002. The blockage was linked to the ropes configuration. In order to retrieve the vehicle from an overhanging without rotation on its side, the rope junction to the vehicle had the following configuration looking from the up side to the down side: one rope, then 2 ropes, then 4 ropes (see the above photo). The transitioning from one to two ropes positions the vehicle either in its normal position or in an inverted position on which it can still roll. Then the transition to 4 ropes prepares the wheel to cross the obstacle. This configuration was the reason why a blockage occurred during test 71: the transition between 1 and 2 ropes and between 2 and 4 ropes blocked the vehicle during its way down on sharp protruding rocks and the vehicle could not be brought up.

A configuration with one rope was experimented during test 72 on the small smooth hill close to the Hab (but the main objective was to test the down looking context camera located in a container one meter behind the vehicle). As expected, the junction between the rope and the vehicle, located at the wheels main axis level, being too close to the vehicle centre of gravity, the CRV experimented large angular yaw oscillations. The final solution had to be a rigid or semi rigid pole linked to the CRV axis which would put the rope attachment point far above the centre of gravity. This has been the CRV3-2 configuration experimented during test 75 in Vernon the 11th of November 2008. As this configuration is not optimal to retrieve the CRV on its way up an overhang, the test was precisely conducted on an overhang to assess the difficulties linked to the new configuration. The test ground was a grassy slope roughly at 20 °, then a vertical cliff 2 m high, then a large overhang with a sharp 90 ° angle. A sharp overhang is the worst configuration because without the one to two ropes configuration which rotates the vehicle either 0° in roll (nominal position) or 180° (inverted position but still "on the wheels"), the vehicle may find itself in a 90° or 270° position (or close to) totally on its side. Reaching the overhang corner, the vehicle may remain stuck. If the overhang corner is rounded enough the vehicle may rotate around its roll axis to reposition itself either in the 0 or 180° position. So it is why a sharp shaped overhang was an interesting difficult proving ground.



Test CRV 75 in Vernon the 11th of November 2008 in order to check the new suspension configuration ability to cross a cliff overhanging part in the up direction. The new suspension configuration were the 2 ropes then 4 ropes suspension is replaced by a semi rigid pole or rod linked to a single rope, is shown on the left. This CRV version is designated CRV 3-2

3 Vehicles configuration and preparation for Dachstein tests

Two vehicles were used during the Dachstein test campaign:

- A CRV 3-3 vehicle directly derived from the CRV 3-2 version discussed in the preceding chapter
- A CRV 5 vehicle with the same general configuration but able to carry higher loads and built to be used with the Exomars ground sounding radar developed by the Latmos laboratory.

The CRV 3-3

The CRV 3 used in the Dachstein simulation campaign is a slightly modified version called CRV 3-3. The previous version CRV 3-2 was tested for the last time in Utah in February 2010 during the MDRS 90 simulation mission were tests 76 to 79 were conducted.

The CRV 3-3 modifications compared to CRV 3-2 are the following:

The plastic hoop wheels have been changed. The diameter is the same: 75 cm. But the torus diameter is slightly higher: 2.0 cm compared to 1.8. The wheels are thus a little stiffer. Distance between the wheels is 57 cm. All the spokes which were rather corroded from last mission in Utah were replaced. A conical reinforcement band was added on the hub on the internal spokes side around the holes

location for spokes attachment. The anti roll rods were rebuilt with an internal side rigid half rod in glass fiber and a rather flexible outside half rod in plastic. Their length is 104 cm.

The camera container porthole which was broken was changed and the circle band around was renewed. The plate used to screw the container on the instruments plate was also repaired. All these damages came from the free fall experienced by the vehicle during the last campaign in Utah. This fall came from a bad fixation of the rope to the vehicle and not from a rope rupture.

The two lasers were replaced by two new more powerful ones. These are green 1mW class 2 lasers, 36.5 g each, with an internal 3V alimentation. The two lasers are adjusted to have parallel beams thus giving by the two spots distance (19 cm) a reference dimension in the camera field of view whatever the distance to the scene. The lasers are installed on deformable supports which allow changes in direction and adjustment of the parallel beams.

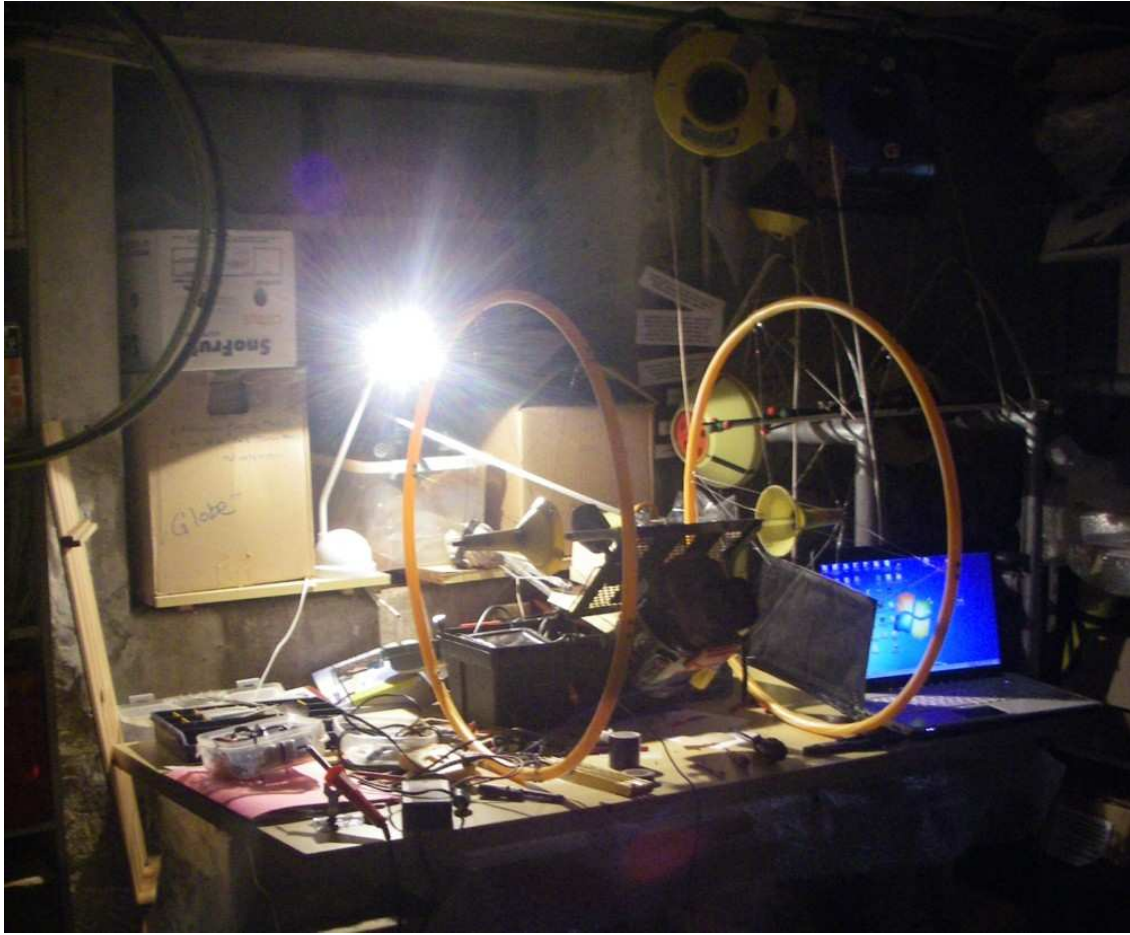
The CRV 3-2 had only one flashlight to illuminate dark locations in the main camera field of view. The CRV 3-3 was equipped with two flashlights (using leds) for the same function in prevision of cave operations. Also a same type third flashlight was added to illuminate the context hazcam field of view. These flashlights are installed on deformable supports which allow changes in orientation.

The two 6V batteries “Pro pack Ni-Cd 600mAh” which aliment the on board hazcam and the emitter were replaced by two 6V batteries “NiMH 2/3 A HUMP-PACK 1500mAh”. As indicated the energy capacity has been increased by a factor of 2.5. The previous small black and white hazcam camera “Velleman CAMZWMLAH 352x288 pixels” has been kept as a back up in the emitter box being very small and light. But a new color camera was installed outside on the instrument plate. This camera could be easily oriented according to the slope explored. During all the Dachstein campaign it was used looking down but could have been (by changing the plate side on which it is bolted) oriented up. This was the configuration for previous campaigns in order to show to the operator the difficulties lying upwards on the way back uphill. The down looking configuration was selected for the Dachstein campaign in order to give information on the obstacles on the down ride, expecting that the vehicle could be sent in areas with no previous visual observations from above.

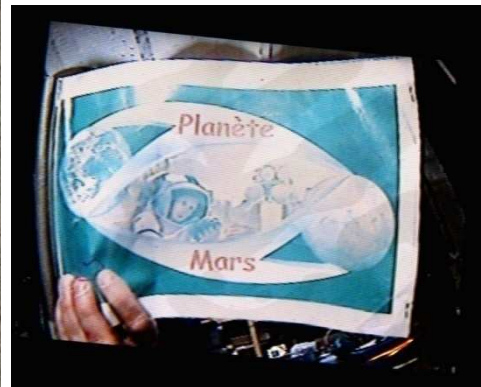
The new color camera is a Sygonix with 752 x 582 pixels with a mass of around 300 g. It is equipped with 24 infrared leds which are automatically powered when the lighting conditions are poor which could be interesting in cave utilization. But this feature was (probably) not used as a flashlight was illuminating the field of view. This camera needs a 12 V alimentation as the previous one and has the same consumption of around 400 mA. The emitter uses a 6 V alimentation and this is why two 6 V batteries are used on board, one for the emitter and the sum of two for the camera. The camera is certified for outside utilization including rain which is also an interesting feature for a cave utilization.

The emitter has not been changed. It is a wireless Mini TX. The Mini TX emitter has a power consumption of 80mA and can operate between 4.8 and 7.2 V. On the receiving box side the 12 V battery has been replaced by a “NiMH Racing-pack 3700 mAh TAMIYA”. The black and white monitor has been replaced by a color TFT Monitor 14.2 cm, 320 x 234 pixels with a 650 mA consumption. A “Velleman TFT LC MONCOLHA 4” color monitor was kept inside the receiving box as a back up. The ALM-2450 2,4 GHZ receiver has a consumption of 180 mA and is using the same 12 V as the monitor. The receiving box total consumption is thus 830 mA.

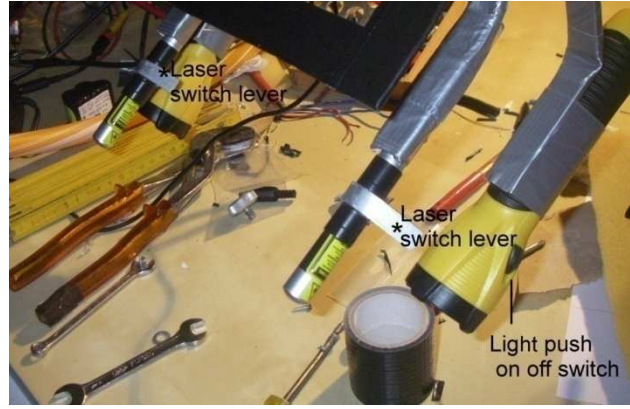
The main camera located in the protective container is a Sony Digital Handycam DCR-TRV480E. This digital camera records on tape. Depending on the tape type the recording autonomy is 60 mn or 45 mn. It has its own battery.



CRV 3-3 preparation in the workshop



On the left the reception box in its operational configuration with the open cover hold in position by the white bar on the right and the monitor on the left; the spare monitor is located under the yellowish foam protection on the left. In front the blue box holds the receiver. This box may be positioned in the slope for a better video reception. On the right is an example of picture on the monitor.



On the left: rear side with the renewed porthole on the camera container, the two flashlights and the two lasers. On the right zoom on the lasers and flashlight.



In the left: front side with the hazcam on the left and the flashlight illuminating the hazcam field of view. On the right: the emitter box and its switches.



Reinforcement conical band on the hub.

Total mass for the CRV 3-3 is 4994 g (including camera, anti roll rods, anti yaw rope fixation rod). This would be 1.9 kg on Mars. The preceding VRP 3-2 configuration had a mass of 4075g.

The rope length in the rope container is 36 m. If needed, 17 m of rope could be added from another container.

The CRV 5

The CRV 5 is a heavier version of the CRV 3. This version was built to provide to the Latmos Laboratory a vehicle able to carry the Exomars ground sounding radar or at least part of the system.

The CRV 5 wheels are bicycle wheels 65 cm in diameter when including the inflatable tube. The vehicle was delivered to Latmos without tubes and tubes added by the Latmos team to increase the distance between the vehicle axis and the ground in order to accommodate the two pyramidal radar antennas with a sufficient safety margin to the ground. The distance between the wheels is also 65 cm. Anti roll rods were provided but not used during the tests, the slope on which the vehicle was used being smooth.

The vehicle mass without the Exomars radar equipment and without the anti roll rods is 3230 g.

The Latmos team purchased an electric winch to operate the vehicle.



The CRV 5 as delivered to Latmos. The Latmos team changed the instrument plate and added tubes on the wheels. The anti yaw rod and rope were replaced by the cable associated with the electric winch which is on the right of the picture.

Preparation steps

The main steps of preparation for the Dachstein campaign were the following:

27th of February: reception of the new hardware (camera, monitor, batteries).

4th of March: first breadboard functional test of the video system.

3rd of April: delivery of CRV 5 to Latmos

16th of April: autonomy test demonstrating 3h 50 mn of video emission and reception for the hazcam system. The limit comes from the batteries on the vehicle and not from the reception box.

22nd of April: end of CRV 3-3 mechanical assembly with the camera container assembly on the vehicle.

4 CRV 3-3 tests in the Dachstein ice cave

4-1 CRV 80

Test 80 was conducted just in front of the cable car station on a 4 m long slope the 28th of april. This test was initially conducted just for fun to see the vehicle operating on snow which was not in the design objectives for the vehicle. The test proved interesting however because in the end one of the spokes bolt was found unscrewed and also all the elements stacked on the main axis were laterally displaced by 2 cm. No large forces are exerted laterally so the two wheels center parts are only glued on the axis. A stronger glue was applied on these elements after the test. Also all the screws on the bolts, holding the spokes, were verified.



Test CRV 80: first one on snow !

4-2 CRV 81

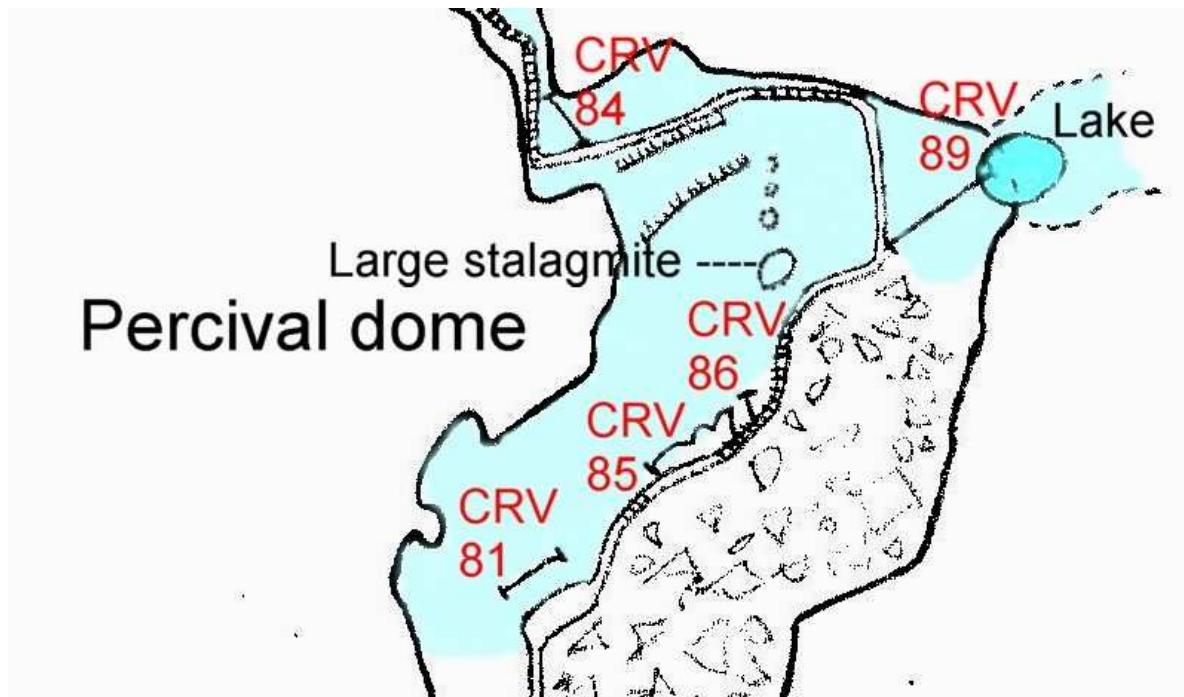
Test 81 was conducted in Percival Dome just before and during the parade for media, the same 28th of april. This was the first test on ice. Five or six runs were conducted on a 10 m length. For information a different test number is given only when different paths are followed. The test has shown that the vehicle slides easily laterally on ice, which is not surprising. During the first run, 4 m from its starting point, the vehicle sled laterally behind a large rock and the right anti roll rod was subjected to a large flexion when the vehicle was brought back. This was the cause of the anti roll tip protective small sphere loss. This sphere was retrieved later on. Nearly the same paths were used for the demonstrations to media with a slightly laterally deported staring point in order to avoid the large rock.

The video transmission was tested and worked well.

For tests 80 and 81, the main recording camera was not inside the vehicle container.



Location of the vehicles parade for the media in the upper part of Percival dome.



Location of CRV test 81 in Percival dome



The CRV 3-3 has 3 flashlights for cave operations (two for the main camera and one for the hazcam) compared to one for the CRV 3-2 configuration.



On the right the rock which was an obstacle on the way back up on the first CRV 81 run but which could be overcome.

4-3 CRV 82

CRV 82 occurred the 29th of April. This was the test conducted by Daniel Föger in the Aouda spacesuit with the help of Luca Foresta.

To prepare the test, a first presentation of the vehicle was conducted the 27th of April evening at the hotel to Daniel Föger and Luca Foresta. Then the 28th of April in the morning at the cable car station, the operations of the reception box and of the main camera remote control were rehearsed by D. Föger.

In the afternoon of the 28 th, D. Föger tested all the operations with the Aouda gloves. One laser was then found inoperative and two spokes bolts had again lost their screws. Changing the batteries in this laser in the evening did not change the situation. The missing screws were replaced. At that time the reason why the screws were lost was not understood. The spoke position tight against the screws normally precludes any screw rotation. Also one T rap used to secure the camera container was found broken. The camera container is fixed to the experiment support plate by a bolt and two safety T raps. The broken T rap was replaced and two more were added.

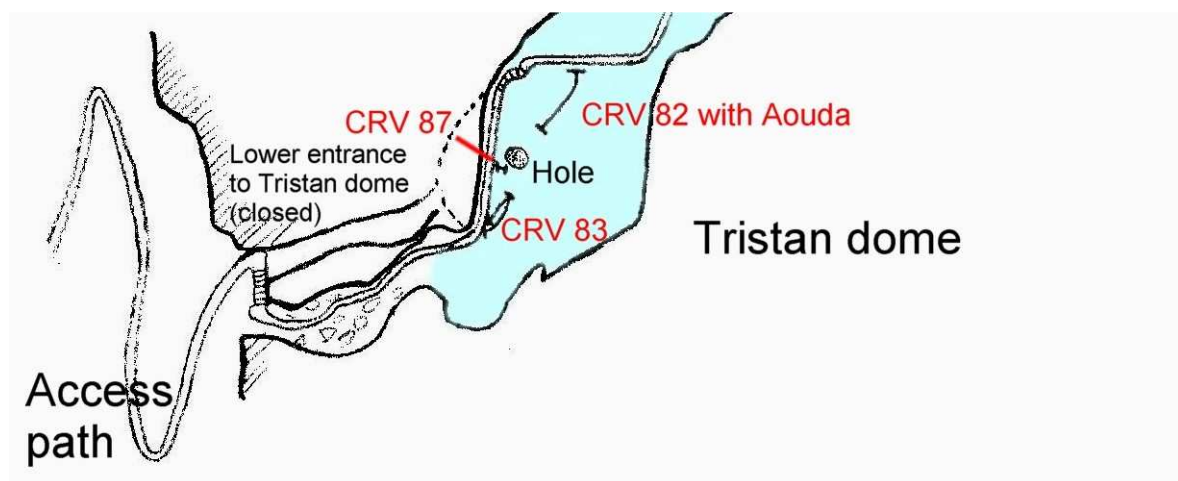
The 29 th of April the CRV 82 test preparation was conducted by Luca Foresta and Alain Souchier.

First the vehicle operations were rehearsed with Luca at the cable car station.

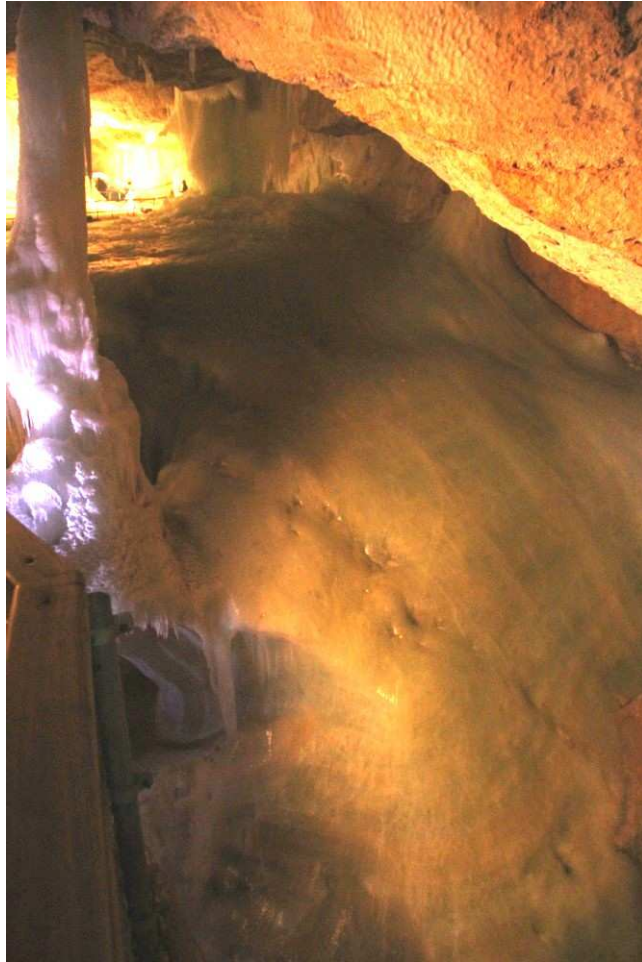
At around 10.30 we were in Tristan dome with Luca and found there Julia Neuner who was planned to participate in helping the operations. We started by a new discussion on the location for the test in order to avoid any difficult test situation which could prove impossible to manage or eventually would lead to the vehicle loss in the bottom of Tristan dome.

The first slope selected during the initial cave visit the 27 th of April was located on the right side of Tristan Dome when looking from the entrance. This was a smooth steep slope, around 70° at maximum and leading to the lower part of the dome. But the 29 th it appeared that, from the pathway the slope was not only oriented down towards the bottom of Tristan dome but also slightly right. The CRV would probably be deviated laterally on the right to a vertical slope ending in stalactites. Bringing the CRV back up the stalactites would probably be impossible.

So another path was selected, left as seen from Tristan dome entrance, some ten meters after the beginning of the ice part on the path way. At mid point to the bottom this slope would also lead to stalactites and the plan was to stop the descent before entering the dangerous area. Luca would have to assess the situation from the pathway in its rocky part towards the entrance and tell to stop the descent before the stalactites.



CRV 82 test location in Tristan dome. Initially a slope located 15m right was planned but would have probably sent the vehicle in stalactites.



This nice slope was initially selected for the test with the CRV tests with Aouda spacesuit but the vehicle would have probably sled left in the hole and stalactites area. Operations were foreseen from the pathway in the left up corner.

For safety reasons the operation in spacesuit were foreseen from the path way and around 10 m of flat surface extended from the path to the slope. Thus the vehicle will have to be “launched” in order to reach the slope. This would be done by Luca. During the preparation we proceeded to this launch twice stopping just before reaching the slope. When retrieved the CRV showed again a lost screw on one of the spokes! This led me finally to understand that the screw losses were not linked to screw rotation but to the bolt rotations. So I started a verification and complementary screwing of all the bolts as we were in test preparation with Luca. As no maintenance was foreseen in preparation I had to use scissors as a screw driver. For information the vehicle accepts one loose spoke but two, if they are close together, would lead to a wheel collapse.

The other steps of preparation (called Initial Condition 1 or IC1 in the procedure) went well. But the IC1 was over at 11.15 whereas 10.45 was planned. However this did not seem to be on the critical path of test owing to the suit preparation operations.

I followed the second step of test preparations (called IC2 in the procedure) and also the test operations from the operation center in the cable car station starting from 11.35.

Hereafter is the description of the tests operations:

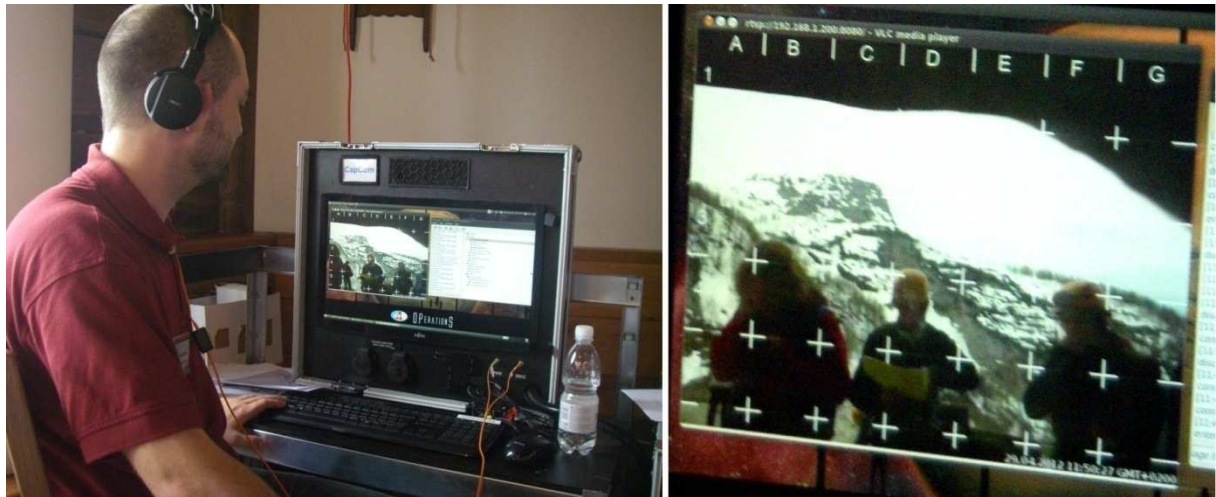
At 12.15 the vehicle is on and the reception box is on, but 3 mn later a simulation hold has to be decided because the suit tester has lost his headset. I suggest then to stop the recording (which is supposedly on) to keep recording autonomy (limited at one hour). This could be normally done by the remote control without opening the container. But it soon appears that Luca or Daniel has opened the container to shut off the camera. May be the recording was not already activated after all. Then, when the operations started again, the camera was set on again and the container closed. This operation was probably conducted by Daniel with the Aouda gloves because he explained me later that this operation which can be a little difficult was astonishingly easy. But this comment could be also related to the first closing. When trying to send the recording command through the remote control, information is sent that the command is not operating. Luca then reopens the container, finds that the camera is off, restarts the camera, manually pushes the recording switch and closes the container. It is then 12.45. I will have this same problem of non operating remote control on a later test, because the camera turns off and this has to be understood. At 12.49 the vehicle is in the upper part of the slope, 10 m from the starting point. At 12.53 the operations are stopped at 15 m and Luca goes back on the pathway towards the entrance to see where the vehicle is located compared to the dangerous stalactites area. He then tells that the vehicle has now to be brought back. Later on he will explain that the vehicle was still around 2 m above the stalactites but that the rope was doing an angle around a small ice peak in the flat part. If this peak would break and free the rope, the CRV could well have gone down by 2 m entering the dangerous area. Some minutes after, the information is sent that the rope is stuck. From the operation center it is difficult to understand how the rope (and not the vehicle) is stuck. Afterwards it is explained that the angle around the small ice peak in the flat part is introducing a supplementary force on the rope. Ulrich Luger then ventures on the ice flat surface with iron boots to free the rope and the vehicle is then easily brought back. At 13.05 it is on the edge and at 13.08 at its starting point. The operations are then stopped and Daniel Föger in the Aouda Spacesuit shifts to another experiment.

Concerning the on board hazcam video signal transmission, the signal was lost when the vehicle was in the slope because of a too large ice layer between the emitter and the receiver located on the upper flat surface. I suppose that the video signal was acquired again when the vehicle came back.

In the post test debriefing it is also indicated that, before reaching its lowest position, the CRV was blocked temporarily on a quasi horizontal part but could be restarted again. Also when the rope was indicated as being stuck, the vehicle was a little sideways with deformations on the wheel and Luca feared that too much forces could be exerted laterally on the wheels.

Sequence of events from the pictures

The photos taken in the operation center have shown that the Canon EOS 7D camera time should be corrected by minus 1 mn 47 s and the small Pentax camera used in the operation center by minus 5 mn 12 s. These corrections have been applied on the photos time there under.



Preparation as seen from the operation center with, on the screen, the view taken by the Aouda helmet camera. Daniel Föger, the suit tester, is still outside in the cave porch.



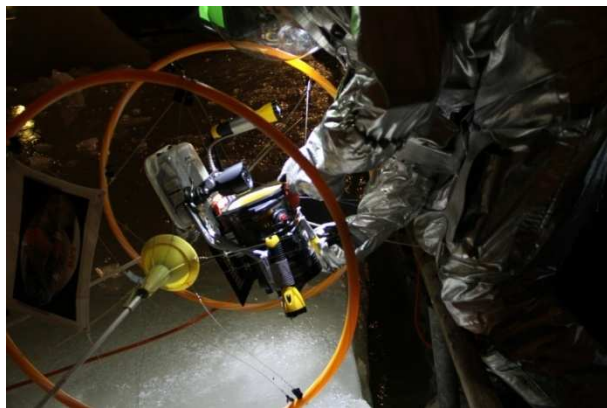
12.09.35 (left): the team is in position.

12.11.10 (right): D Föger set the receiver on.



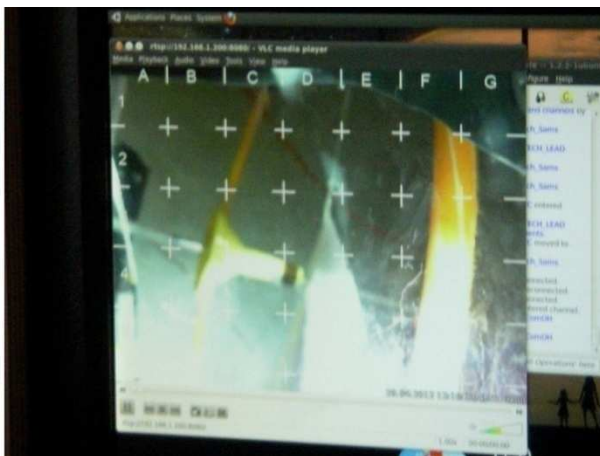
12.14.04 (left): spacesuit camera picture.

12.15.09 (right): CRV picture from the spacesuit camera during operations corresponding to following photos.

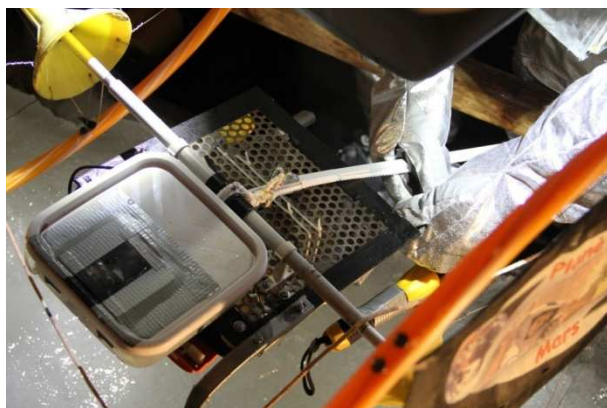


12.15.15 (left): left flashlight set on; the emitter box is on from the position of the two switches. The camera container is open.

12.16.30 (right): still at work.

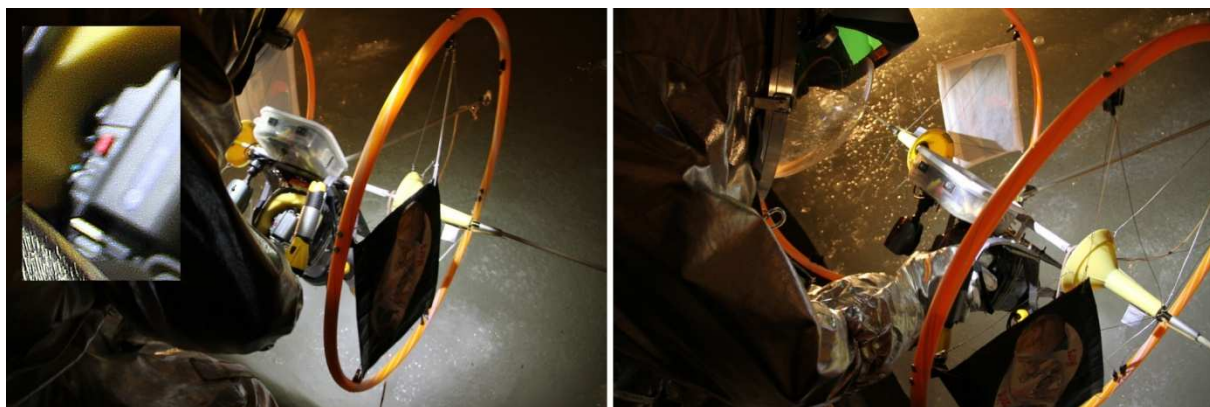


12.16.06 (left) and 12.16.15 (right): CRV views from the spacesuit camera.



12.16.45 (left): laser set on (operating?).

12.18.17 (right): The receiver box is on (green light) and is sent as close as possible from the slope but according to the long horizontal path before the slope this will not improve the reception signal for a long time when the vehicle will go down.



12.25.53 (left): camera container open, camera on (green light).

12.27.00 (right): container closing.



12.28.31: ready to go?



12.36.21(left): The remote recording command is not operating.

12.43.55 (right): Luca opens the container; the camera is found off; the camera is set again on and the recording commanded on the camera directly; then the container is closed again.



12.46.19 (left): launch!

12.46.58 (right): CRV on its way.



12.47.54 (left): CRV on its way.

12.48.47 (right): slow or stop on a small horizontal surface.



12.49.22: still on the flat area.



12.50.32 (right): in motion down again



12.50.44: general view showing why the lower part would have been dangerous to go.



12.51.19 (left): lowest point reached.

12.53.54 (right): general view showing by the vehicle orientation that the rope is not straight between the suit tester and the CRV. The rope does a 60° turn around a small ice peak located somewhere on the flat surface. The descent is stopped there by Luca because, if the ice peak breaks, the CRV could go down suddenly by 2 m entering the dangerous stalactites area.



12.56.56 (left): Daniel Föger the suit tester, feels a high tension in the rope

12.55.09: Not only the rope does a turn around an ice peak but the vehicle is also sideways on a ice bump. The anti yaw rod is probably too flexible. Both circumstances increase the rope tension.



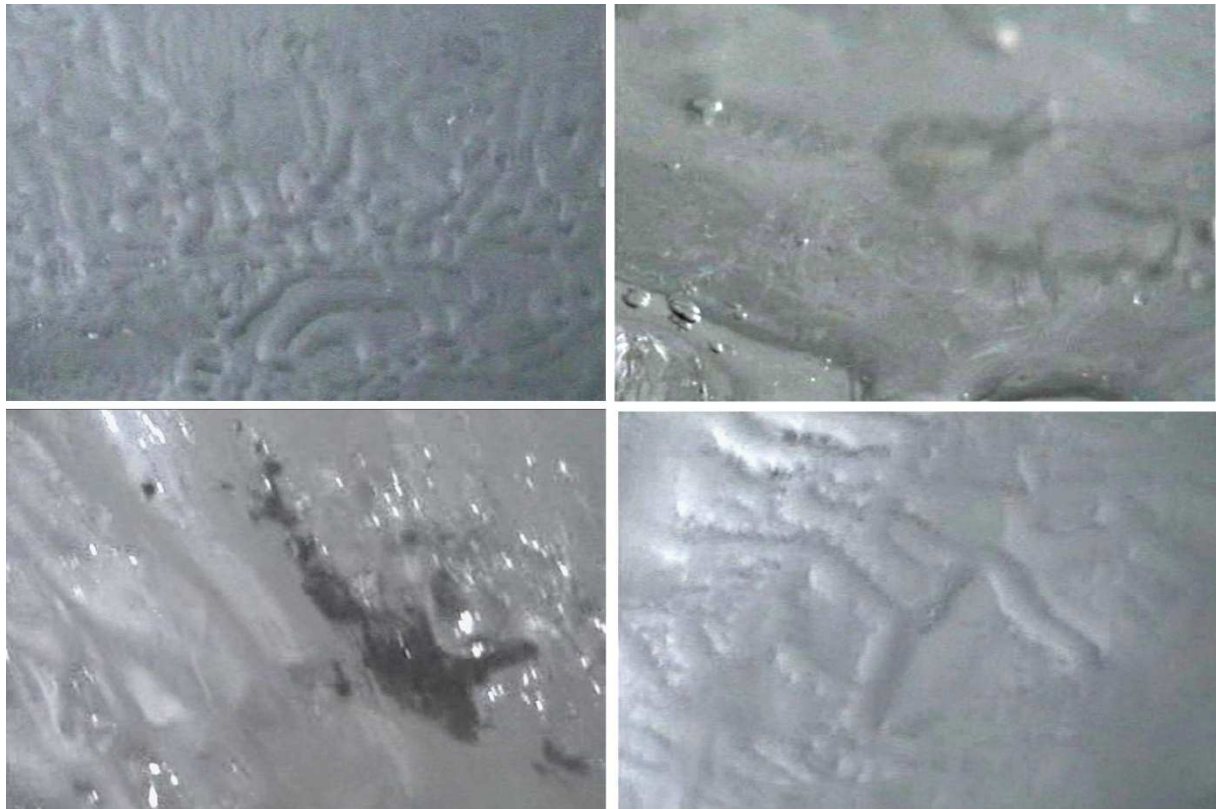
12.57.32 (left): picture received in the operations center when the rope is declared stuck

13.03.54: Ulrich Luger frees the rope from the ice peak.



13.05.54 (left): the CRV reaches the slope edge.

13.06.05: Daniel Föger pulls the CRV back to the pathway.



Views taken by the on board main camera at 8mn 15s, 21mn 09s, 22mn 45s and 23mn 04s after the beginning of recording. Most of the time the pictures are fuzzy and blurred. The autofocus had probably not enough details to focus on or/and the camera was no more on wide angle which seems possible because in wide angle the two bright spots of the flashlight should be visible.

4-4 CRV 83

The test CRV 83 was conducted also the 29 th of April at around 15.00. The location was the ice steep slope towards the entrance of Tristan dome, just before the pathway along the rock wall above the lowest part of Tristan dome. This slope was identified as a promising test field during the reconnaissance visit the Friday. At 15.30, 13m of rope have been unrolled, the rope is attached to the

pathway handrail and photos are taken of the vehicle nearly down to the bottom of Tristan dome. 2 more meters are unrolled. At 15.35 the descent is again stopped and new photos are taken. Then 3 more meters are unrolled, reaching thus 18 m and then the ascent is started. At mid ascent a blockage occurs. Apparently the vehicle is stuck in a vertical crevasse between the ice slope and the rocky part of the cliff. I do not take time to stop the operations and have a look from the other side of the pathway because I am aiming at leaving the cave as planned towards 16.00. The vehicle seems rotated 90° because from the upper part I see the anti roll rod protruding perpendicularly to the wall (and the anti roll rod is the only visible part of the vehicle). I let go one meter then restarts the ascent and the vehicle comes out of the crevasse. When back on the pathway it appears that the main axis is bent by 10° on the right wheel side. It appears also that the semi rigid rod linking the rope and the vehicle is broken at the attachment level to the vehicle. This failure does not matter for the vehicle safety because the rope is also directly tied to the vehicle main axis. This feature is intended to cope with this type of event. The axis deformation raises a question: is it better to have a very stiff vehicle (as the CRV 5 assembled for the LATMOS Exomars radar) or a vehicle which can be deformed when blocking situations occur because the deformation can facilitate the deblocking?

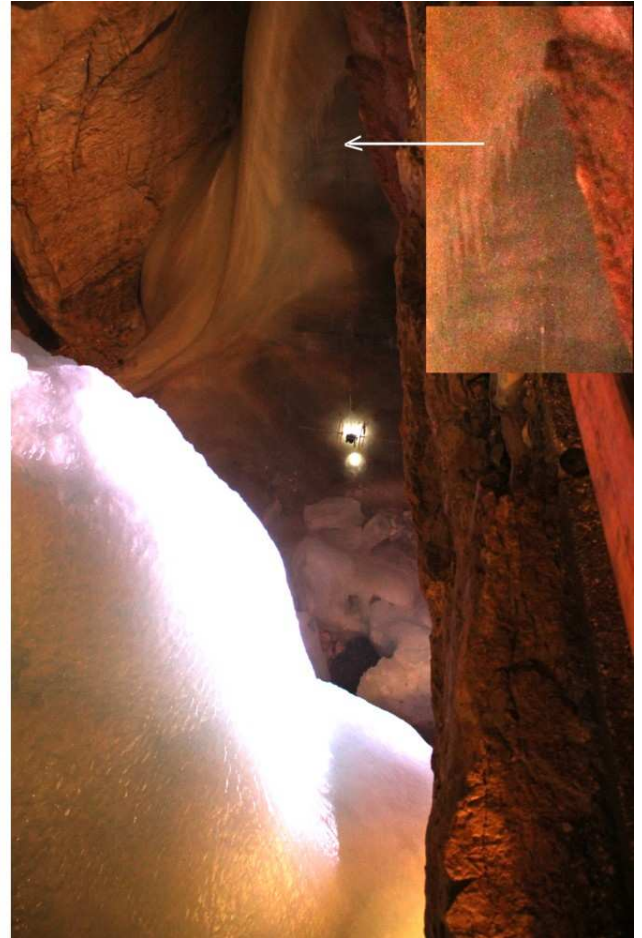
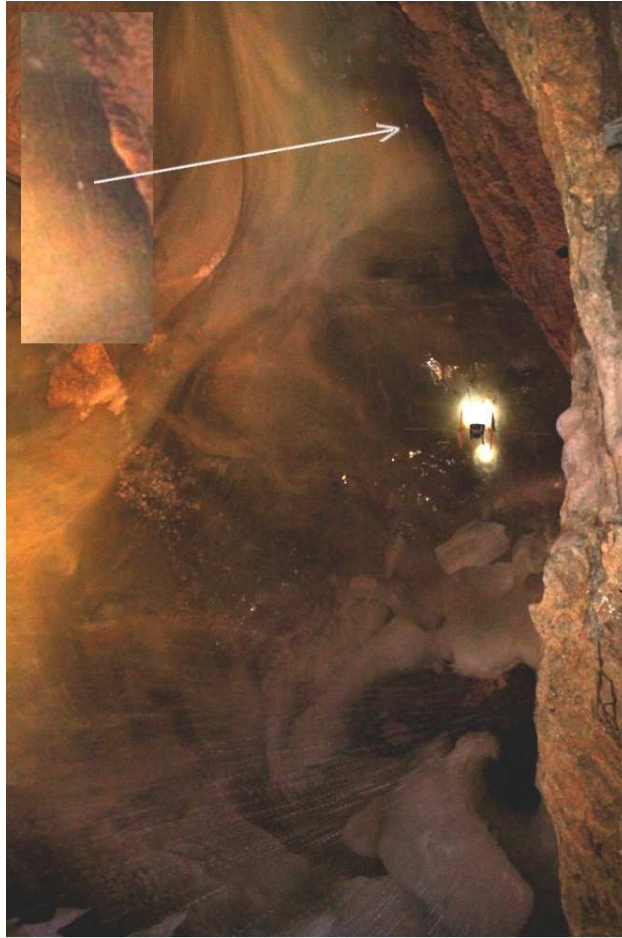
Concerning the hazcam video transmission, a picture was received at the beginning with parasites and vanished quickly. During the checks in the evening the emitter box battery n°2 was found at 5.68 V which is rather low and explains the transmission interruption. Battery n°1 was at 6.68 V. No reloading was conducted after test 82 which lasted may be one hour with the batteries on. This should not have had consequences because a more than 3 hours autonomy was demonstrated during the preliminary tests some weeks before.



15.28.52: first stop at 13 m with brightened photo on the right showing that the vehicle has derived on the right (left as seen from above) on the ice slope on which it went down.



15.29.06: other world....



15.32.33 (left): the CRV at 15 m; the rope is partly visible. The little waterfall coming from the ceiling (lower left) is digging a hole in the ice 15 m below.

15.34.11: the vehicle has deviated on the right (as seen from the photo point of view) and will ascent in the cavity with stalactites close to the rock wall (enlargement in the upper right corner) which will block somehow the ascent. The rope is visible in the enlargement lower part.



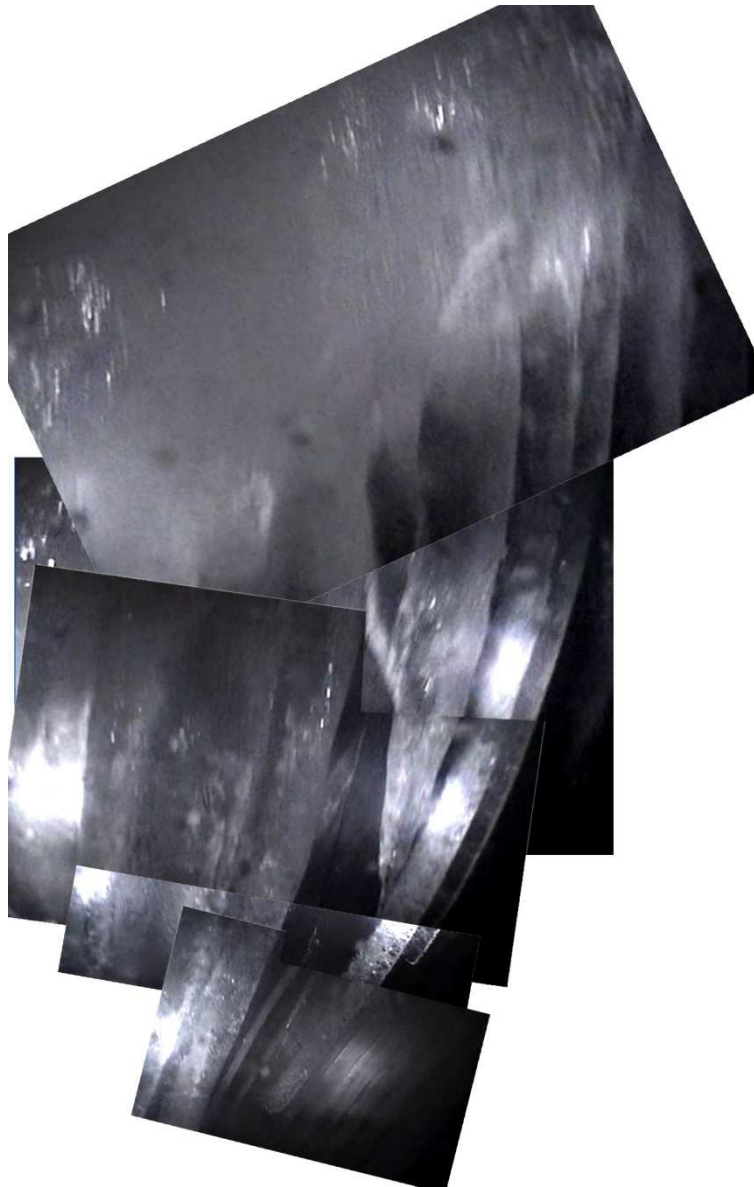
The ice slope as seen from above seemed trap free.



But, as seen from another point on the path way, the trap is clearly visible. These photos were taken the day following CRV 83 test, to better understand the blocking causes.



In the first meters of descent, ice is shown with a mosaic like pattern roughly 1 cm wide. The two flashlight spots are separated by 24 cm.



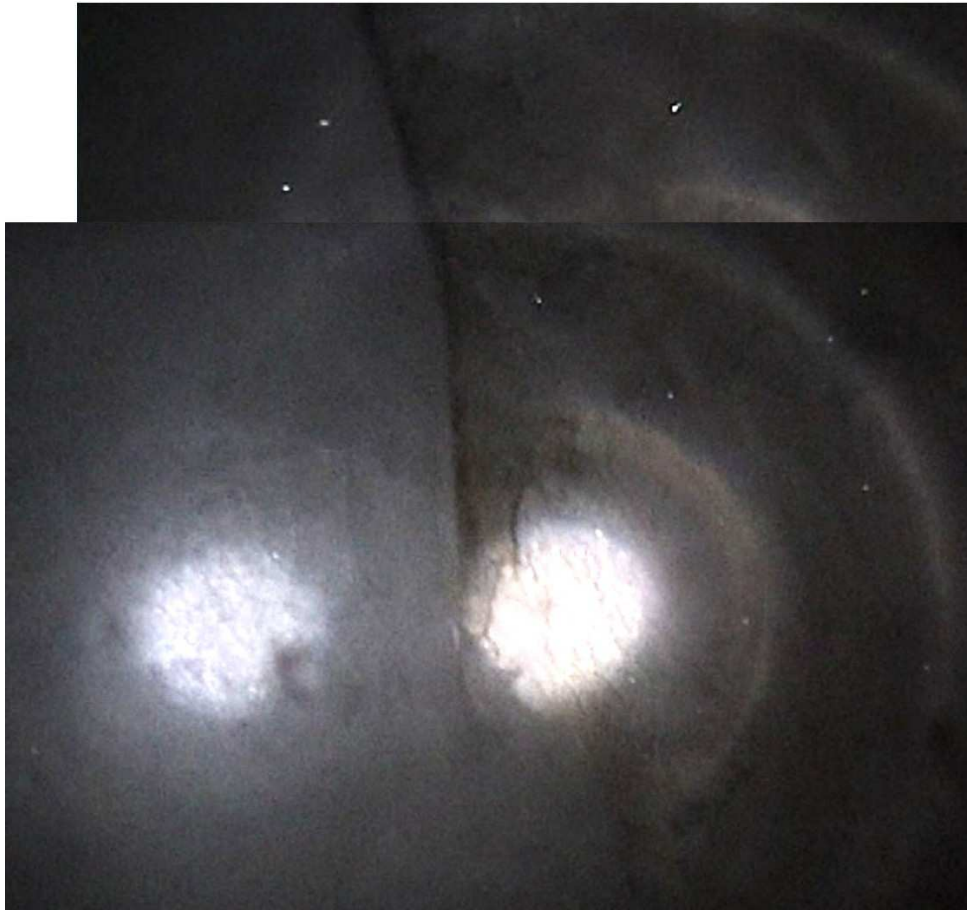
At mid descent the vehicle crosses the field of stalactites which will be an obstacle on the way up and which was not visible from above.



The ice cavity below the stalactites. The vehicle is farther from the icy wall as may be seen by the bright spots seemingly closer and in fact still separated by 24 cm.



Down the slope the vehicle is again rolling on ice and shows, as above, a mosaic like pattern with structures roughly one cm wide.



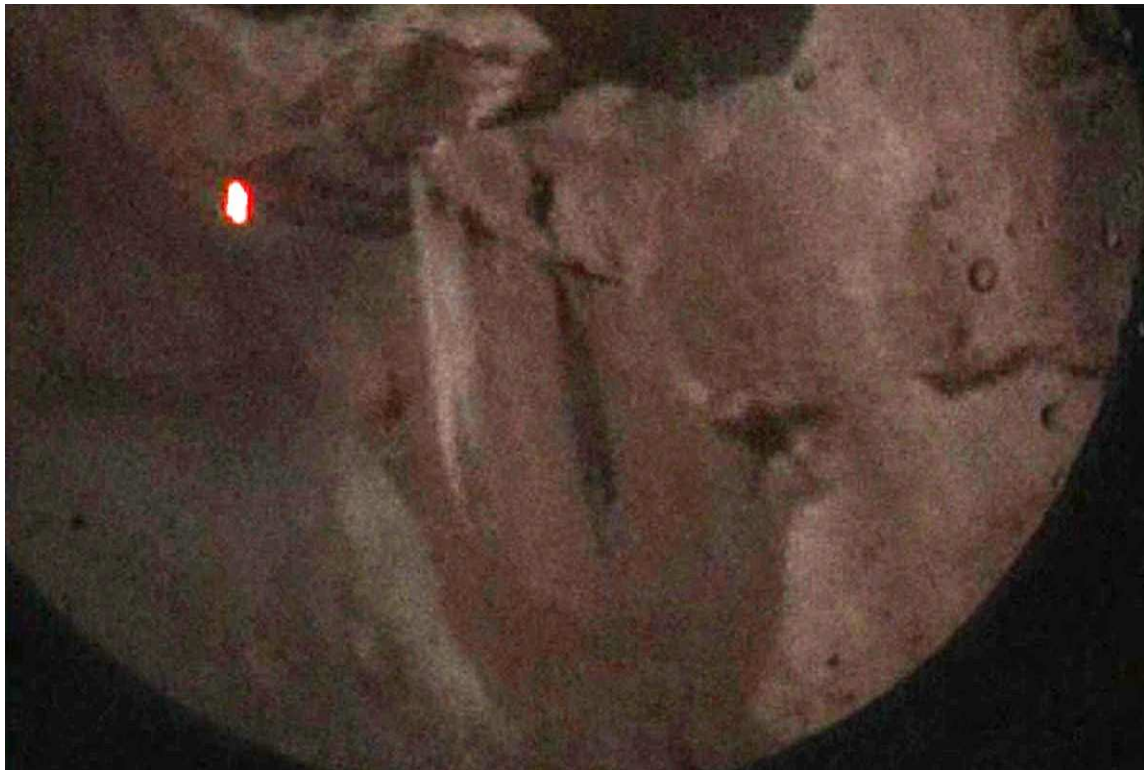
The ascent has started. The vehicle is suspended to the rope and rises exactly at the limit between ice on the left and rocks on the right.



Entering the field of stalactites just before the blockage.



Experiencing the blockage, the vehicle rotates 90°, looking parallel to the rocky wall and towards the central stalagmite.



After successfully clearing the obstacle, the vehicle is now “upside down” (but still on its wheels as the design allows) looking to the other side of Tristan dome.

4-5 CRV 84

Test 84 was conducted the 30th of May in the lower part of Percival dome leading to the entrance door to King Arthur dome. The objective was to assess the difficulties of conducting the test while using the Aouda spacesuit gloves and to use the pictures sent from the on board hazcam to manage the vehicle descent and ascent. As the rope rod attachment to the vehicle was broken the day before the yaw stability is now obtained by a transition from one to two ropes attached on the vehicle main axis. When setting on all the systems, it appeared that no pictures appeared on the monitor screen. A battery test showed that the emitter batteries were for battery 1 at 6.22 V and for battery 2 at -1.21 V! The batteries were fully loaded at the beginning of the morning. Apparently the battery 2 switch was on for a long time. One explanation was that it was inadvertently set on on during the ascent from the cable car station to the cave entrance. This proved the right hypothesis the following day when a check at mid ascent showed that the switch was on on whereas it was off when leaving the station. The switch can be in contact with my leg during the ascent and this triggers it to on. For CRV test 84 then remained the objective of using the Aouda gloves. It was very difficult to push the flash light switches. For one I had to try 4 or 5 times. For the other I succeeded in ten trials. And for the last one I had to use a tool to push the switch. For this test the camera was inside the container for the weight but not switched on. Before sending the vehicle in the slope I secured the rope, with 7 m of free rope, to the hand rail doing the knot with the gloves on. This was a safety measure in case the vehicle would slip from my hands. It would have then stopped after 7 m. naturally doing a knot was possible with the gloves but untying the knot was impossible. The vehicle was not equipped with the anti roll rods because the slope was rather smooth and also I aimed at descending in a narrow pass between two rocks. The descent was conducted with the Aouda gloves without difficulties. A first stop was done at

5 m, tying the rope still with the Aouda gloves, then 7 m were reached. The descent was stopped there because 2 m farther, a small vertical slope had stalactites which could be broken by the vehicle. The ascent was conducted without the Aouda gloves. The active part of the test has extended only between 12.45 and 12.55.



The Aouda three layers of gloves: from left to right and up to down, the comfort glove, the glove restituting the pressure forces from both sides and the outside glove from the palm side.



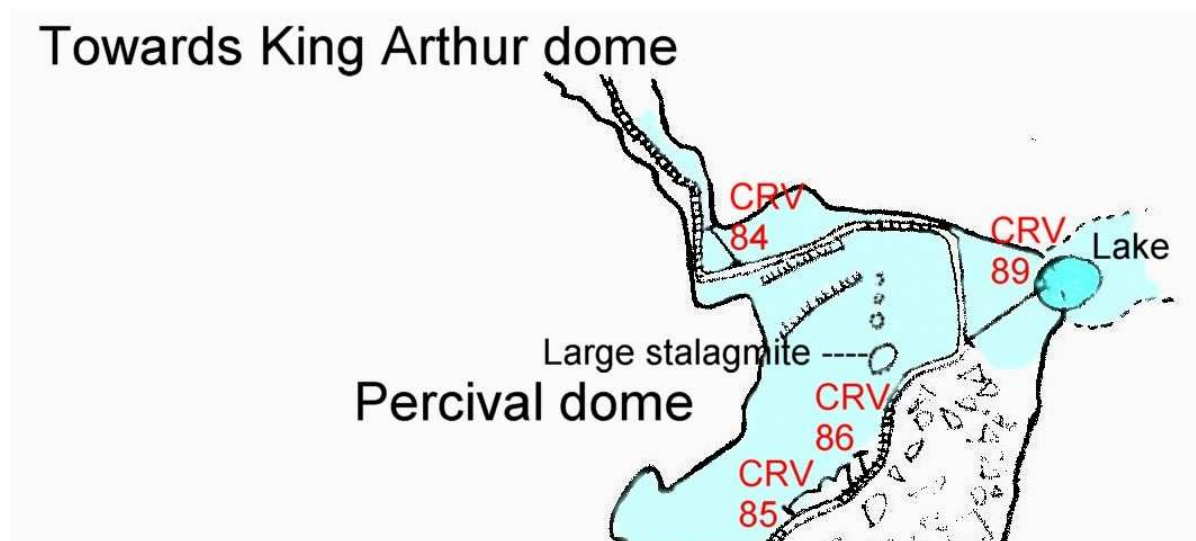
The outer glove from the other side.



Stop after a short 7 m ride.



Stopping before the stalactites (left) and after successfully descending between two rocks (right).



Location of tests 84, 85, 86 in Percival dome.

4-6 CRV 85

Test CRV 85 was conducted the 30 th of April from the pathway in the middle upper part or Parcival dome. The main slope is towards the central stalagmite but the slope is also slightly oriented on the right and the vehicle slide sideways during the descent with the right anti roll rod interacting with the rocks extending between the path way and the ice field. As for the preceding test, the camera is on board but not set on.

In the process the right anti roll rod ends being bent. The vehicle is retrieved from a lower point on the path way climbing directly through 4 m of chaotic rocks.



End of descent during test 85.



Right anti roll rod bent at the end of test 85.

4-7 CRV 86

Test CRV 86 is conducted shortly after 85 from the pathway. In a 4 m ride, the vehicle reaches the ice field and then is brought back. The anti roll rod bent during the previous test has been repaired. The camera is on board but not set on recording. The objective was to demonstrate the vehicle ability to roll on very irregular terrain with rocks reaching around one third of the wheels diameter. And the ride was indeed bumpy.



The repair configuration with transition from one to two ropes after the rod attachment failure the day before is visible there.



Test CRV 86 has been conducted on the very irregular rocks field on the right between the pathway and the ice field.

4-8 CRV 87

Test 87 was conducted the 1st of May. The objective was, once again, to reach the bottom of Tristan dome, explore the central hole and hidden part under the pathway, and make use of the video picture

transmitted to the operator to pilot the vehicle in the interesting areas without entering in dangerous situations. As most of the part of the ride down would be in overhanging conditions, the vehicle being out of contact with the wall, it could be expected that a manually commanded displacement in the lower part of the dome could be done.

The starting point on the pathway was close to the little water fall coming from the ceiling. The objective was to reach the hole border close to the fall but outside of the fall naturally. During this test the camera was recording, the three flashlights were operating but I did not try to activate the lasers which were out of order. The anti roll rods were taped to the main axis in addition to the elastic hook fixation in order to be sure not to loose one of the rods down the dome. At 10.15 the vehicle is down amid ice blocks at 15 m rope length. Before the ride down I have tied the rope to the hand rail at 20 m length as a safety measure. Then I rose the CRV around one meter above the ground to swap the ground around the hole. The transmitted picture was good and I took photos of the monitor (the monitor picture is not recorded) which is not easy being alone holding the vehicle in one hand and taking photos with the other. Photos were also taken of the vehicle down the hole from other parts of the pathway. Then the vehicle was raised till reaching 10 m of rope, meaning that it was hovering 5 m above the ground. Rotating the rope allowed for a slow 360 ° swapping of the landscape. At 10.45 the CRV is back at its starting point.

The following photos are the ones taken on board (extracted from the video). Time is given starting from the beginning of the recording. The beginning of descent is at 1.15. The photos taken from above as well as some photos of the pictures received on the monitor are shown also, trying to present all the pictures in a rough chronological order. The only time link between outside pictures (general pictures or pictures of the monitor receiving the Hazcam views) and on board pictures is the landing time which is 10.15.00 corresponding to 2.50 in on board recording time. To avoid confusion the recording times are given with a R before.



R 2.04 to 2.19: mosaic of pictures taken on board showing the electric installation in the bottom of Tristan dome and the rocky wall under the pathway. These pictures are taken before landing.



R 2.22 to 2.24: ice blocks on the floor around 30 cm wide roughly 25s before final landing.



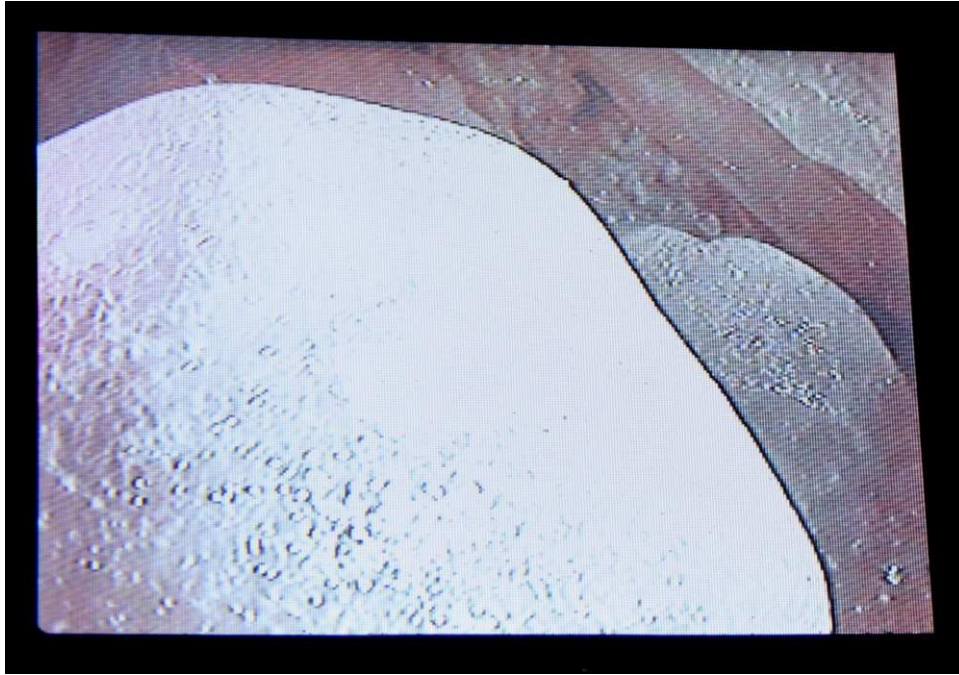
R 2.04 to 2.24: mosaic of 5 photos, the two left ones being however taken closer to the ground than the right ones. These views show the rocky wall under the pathway.



R 2.28 to 2.55: ice blocks on the floor. The final landing is at R 2.50.



Same photos after treatment



10.15.41: first view from the hazcam on the monitor after landing.



10.16.11: the CRV 15 m down in Tristan dome. On the left against the rock, the reception box. This picture correspond to the time 4.00 on the on board camera.



Same picture brightened. The small waterfall is visible on the left.



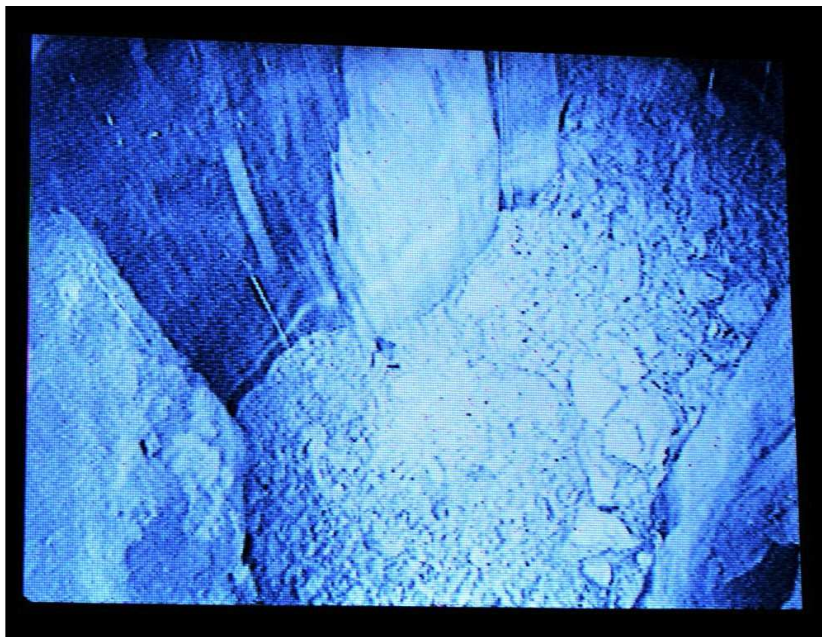
Addition of photo R 6.09 to the R 2.04-2.24 panorama, and treatment.



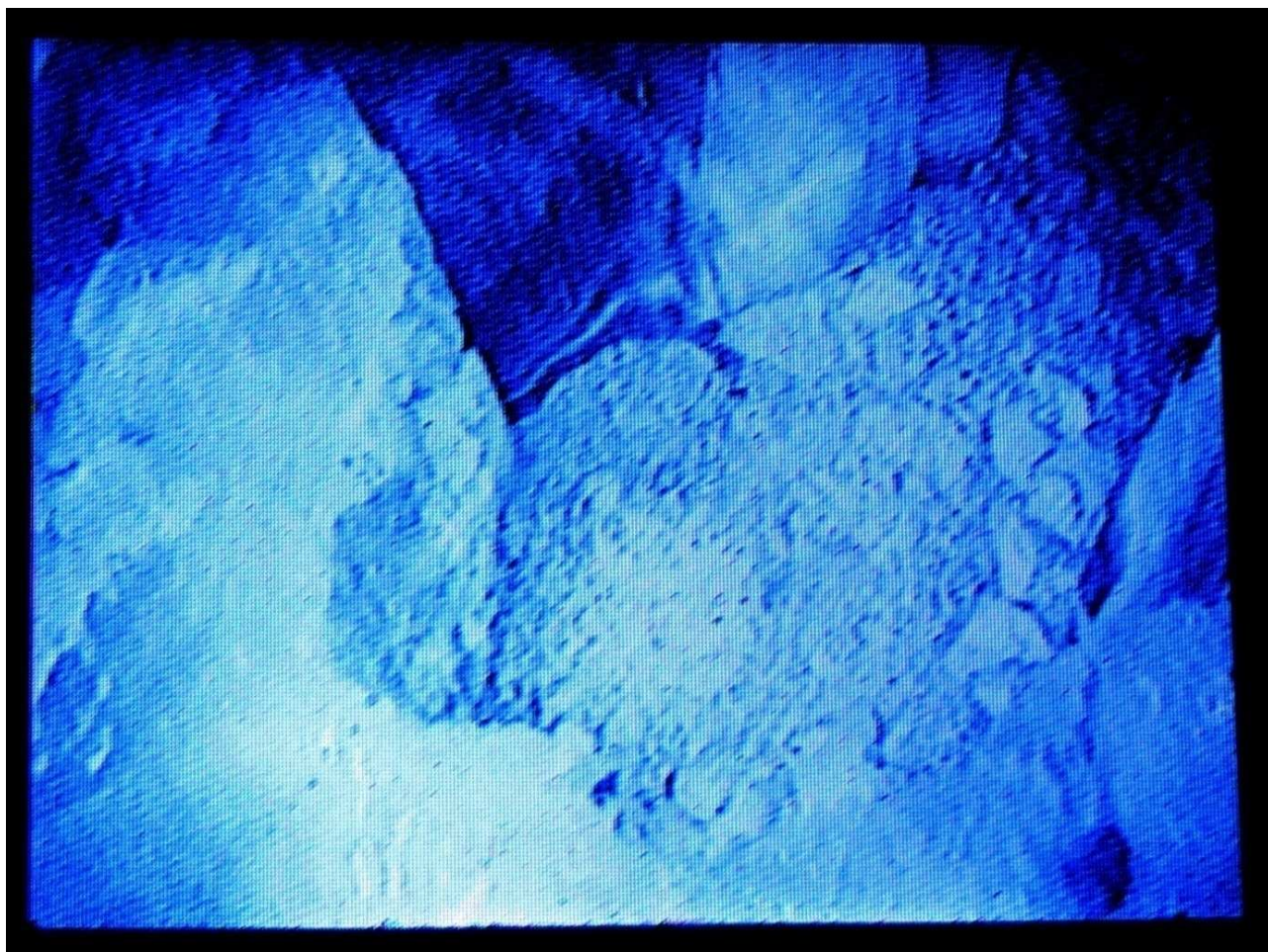
R 6.19 and 6.22



R 6.46: close up on ice (field of view of around 30 cm)



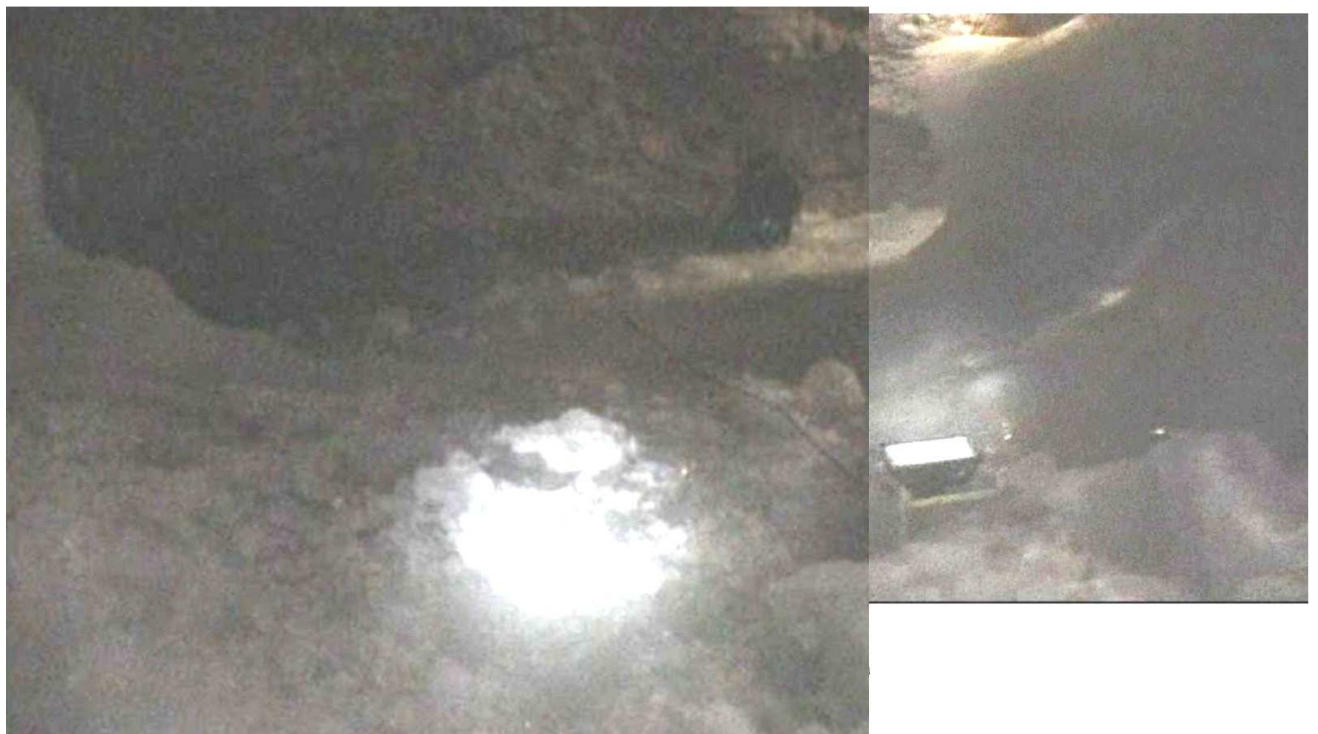
Picture of the central hole taken by the hazcam at 10.18.56 on the right, compared to the view from above. The waterfall is visible on the left of the two photos.



10.18.59: the central hole by the hazcam.



10.20.24: hazcam view.



R 8.13 and 9.10: the rocky wall under the pathway with a hole which may be the lower entrance to Tristan dome.



R 10.24



R 14.11 and 14.13



R 14.32 and 14.39: a stalagmite close to the central hole.



10.28.31: hazcam view showing the hole on the right and the light on the upper left (same one as seen on photos above).



R 16.10 to 16.31: view on the rocky wall opposite to the pathway. The stalagmite close to the central hole is on the middle left. There are no indications on the cave map that the black opening in the cliff is leading somewhere.



R 16.49 and 16.58: the lower part of the rocky wall under the pathway.



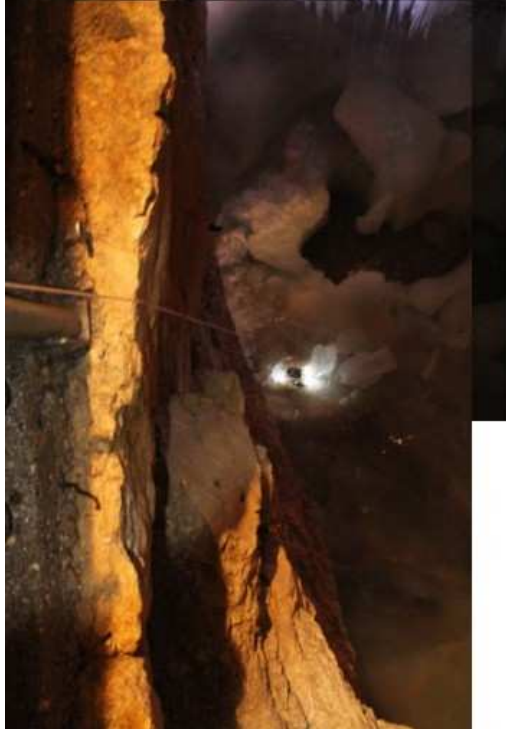
R 16.10 to 16.58: panorama on around 270°. On the left the rocky wall opposite to the pathway; on the right the rocky wall under the pathway. In the middle is the icy slope where test 83 was conducted.



R 18.05 (with background enlightened)



Hazcam views at 10.30.18 (left) with the hole on the right and at 10.31.54 (right).



*10.33.41: panorama from vertical down to horizontal. The CRV is slightly farther from the hole.
The same view brightened is shown on the right.*



R20.38: view by the on board camera in the location shown on next photo.



10.33.45: vehicle still down. 10.33.45 corresponds to 21.35 for the on board pictures.



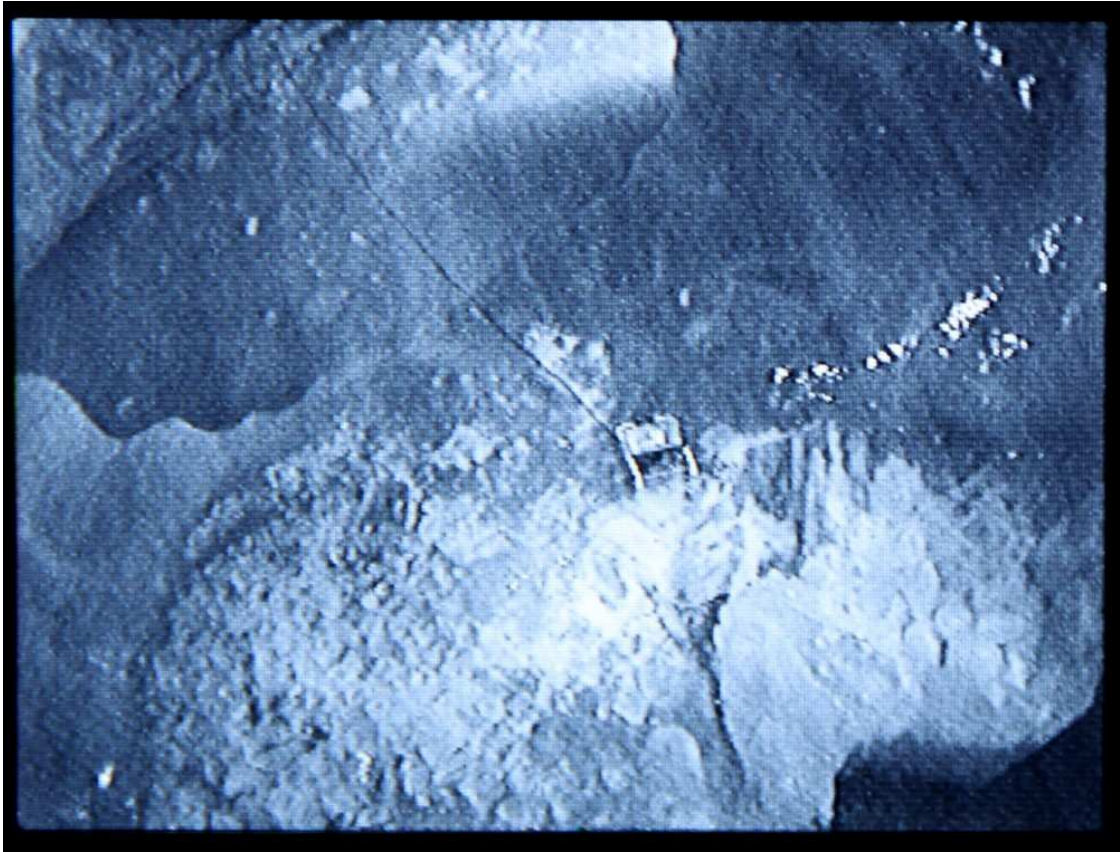
R 22.41 and 23.42: views of the opening on the other side of Tristan dome. The vehicle is now 5 m above the ground (rope at 10 m).



R 22.31 to 24.2: 100° panorama from 5 m above the ground.



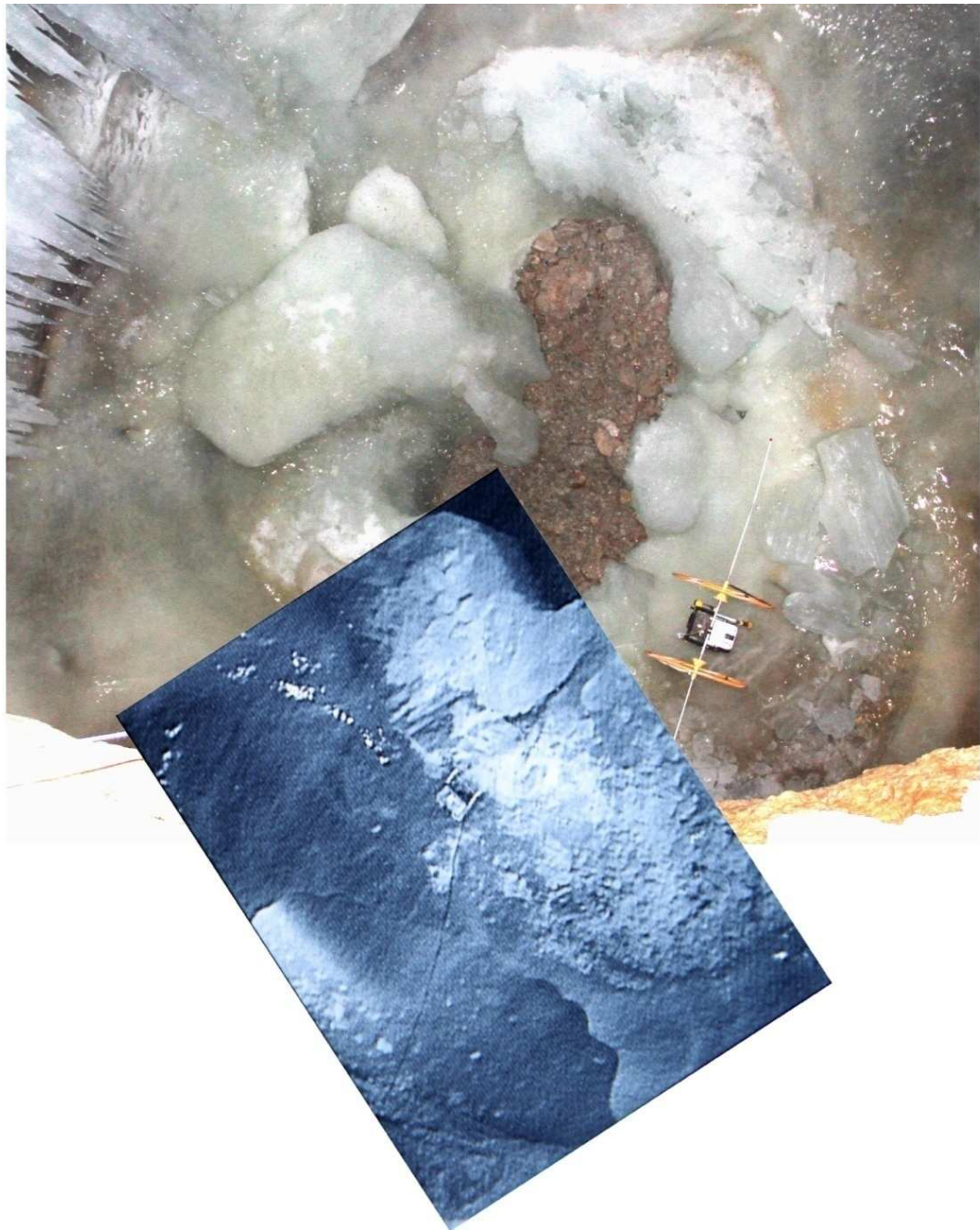
360 ° panorama in the lower part of Tristan dome.



10.37.24: hazcam view showing the hole (bottom right), and a light. The vehicle has now been raised 5 m above the ground. 10.37.24 corresponds to 25.14 for the on board pictures.



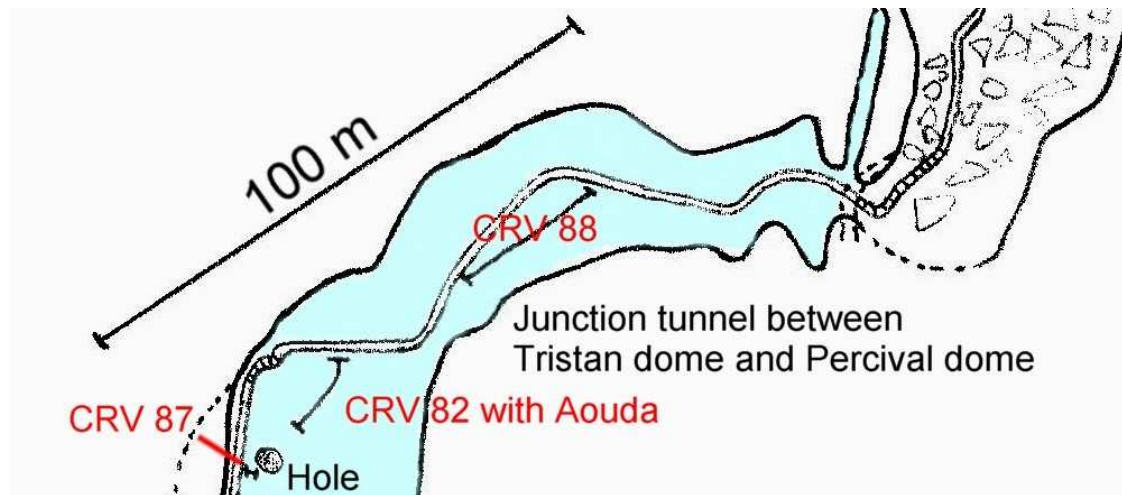
10.39.00 (left) and 10.38.23 (right): the CRV has been raised 5 m above the ground. The receiving box may be seen on the left.



Addition of a view sent by the real time video transmission

4-9 CRV 88

Test 88 was also conducted also the 1st of May. The objective was to conduct the CRV ride with only the information transmitted by the on board hazcam to the monitor uphill and thus without using direct visual observation. For this experiment a long rather smooth ice slope was selected with some rocks as obstacles. Also the slope could be observed, if needed, from the pathway on the whole distance and also, if needed in case of difficulties, every point could be reached by walking on the ice with iron boots. The selected slope was close to Tristan dome in the tunnel connecting Tristan dome to Percival dome as shown in the picture under. The Latmos team tested their Exomars ground sounding radar on this same slope the preceding day. For this test the main camera is on board but not activated (no exploration purposes on this slope).



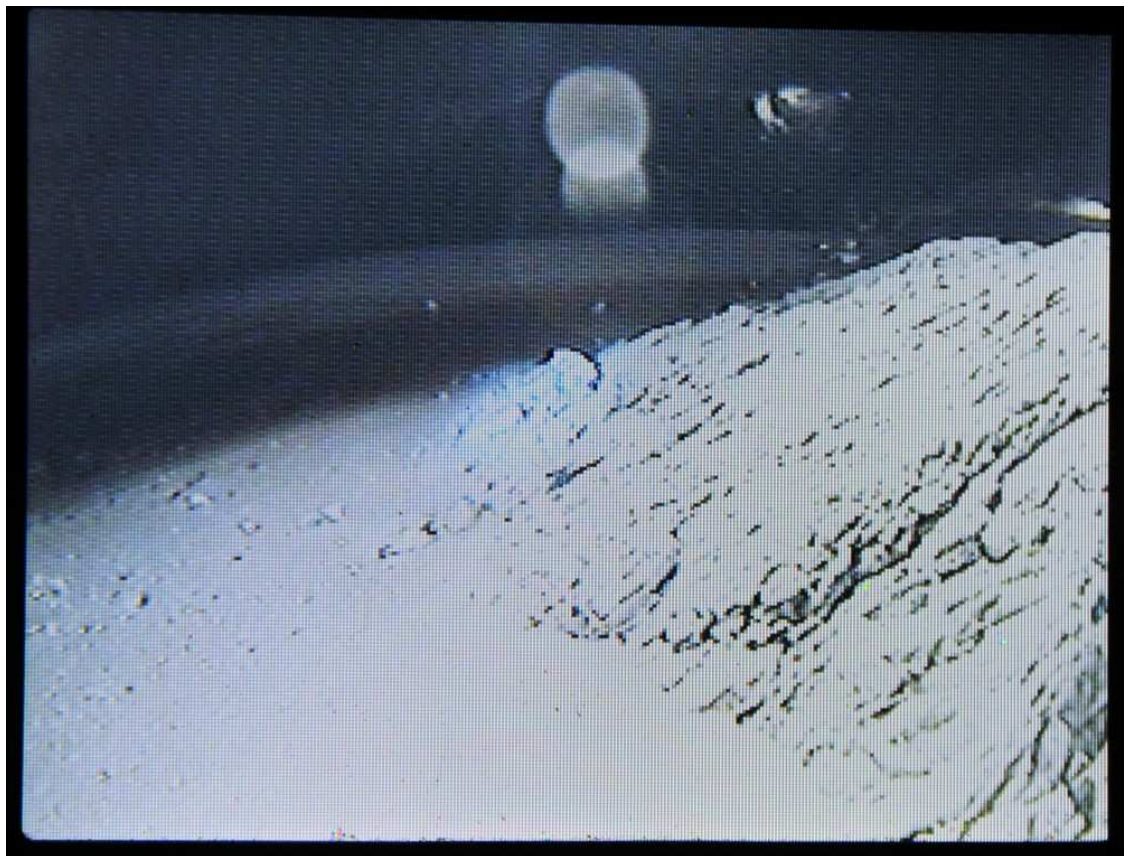
The CRV 88 test was conducted in the smooth slope on the right of the pathway leading to Percival dome from Tristan dome (upper right on the picture).



12.35.28: view transmitted by the hazcam at the beginning of CRV 88 test showing the ice slope and, on the left, the pathway which allows observation on the whole length of the slope.



12.36.34: vehicle still in sight.



12.39.36: one of the last pictures transmitted. The vehicle is no more in line of sight after going down a 2 m ice bank. The rope is at 15 m. A rock stands in the middle of the way but does not seem a large obstacle. The picture is acquired even with a rather high thickness of ice between the emitter and the receiver as seen in the photo under but the signal will be lost shortly after without any more move of the vehicle. Receiving box battery is still at 12.73 V so is the signal lost by ice absorption or because the battery level is low on board after the preceding test?



The vehicle is no more visible behind the bank. The receiver is on the ice on the left. I try to bring back the vehicle by some meters to acquire again the video signal but it appears to be blocked. One anti roll rod appears canted 45° behind the icy slope (not visible on the photo) indicating that the CRV is in a difficult situation. The attempt to pilot a ride only by monitoring the hazcam video transmission has to be stopped there and the situation has to be assessed now visually from the pathway.



12.48.53: understanding the blockage; the vehicle probably crossed the rock on the left side, then came back on the rock on the right side when I pulled the rope. The right anti roll rod is doing its job, avoiding a tip over of the vehicle.



12.51.59: after some pull and release maneuvers of the rope, the vehicle is freed but on a flat surface and at 90° orientation to the general slope.



13.03.47: after a new pull and release maneuver the CRV goes down again. Here at 20 m from the start.



13.07.31 and 13.08.01: rope at 30 m. In the left photo the anti roll rod characteristics are clearly visible: the first half is rigid and the second half flexible. On the other side the anti roll rod fixation has been deformed when the vehicle was stuck behind the rock. On the right photo nearly all the slope is visible. The starting point is on the pathway above the brightly lighted ice bank.



13.14.31: end of the ride at 31 m (longest ride during the Dachstein campaign).



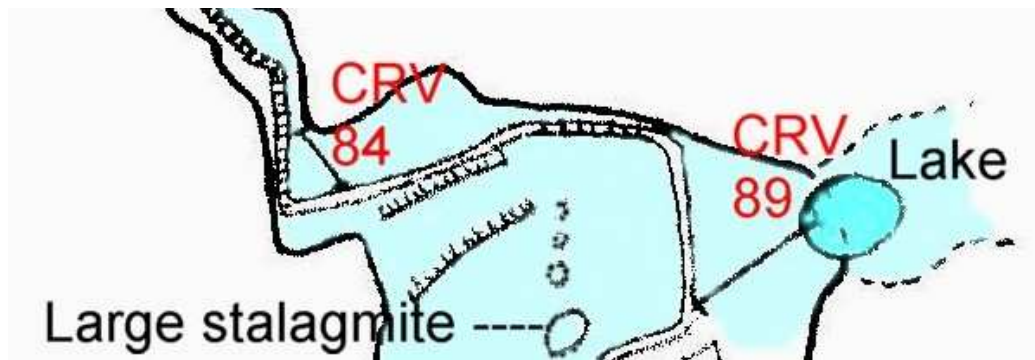
13.19.57: ride up. Back to the ice bank (after avoiding the rock).



13.25.19: right anti roll rod bent during the blockage behind the rock.

4-10 CRV 89

CRV test 89 was also conducted the 1st of May and is the last test of the Dachstein campaign. The objective was to send the vehicle close or in the small lake in the “ice lake” which occupies the lower part of Percival dome where the pathway crosses this “ice lake”. No technological objectives in this final test, the slope being very shallow and very smooth, but mainly the objective of shooting nice photos. Two rides were conducted on the same path, the second one to shoot a video.



Location of test 89 in Percival dome



14.01.20: not yet in the lake.



14.04.15: in the lake. The ride was stopped there, not knowing if the depth was increasing farther in the lake.



14.05.22



14.05.38

5 CRV 5

The CRV 5 was built to allow the Latmos laboratory to test the Exomars ground sounding radar on slopes. To support a higher weight compared to the CRV 3-3, the vehicle is based on bicycle wheels. Initially these wheels were not equipped with tires but the Latmos team added tires in order to increase the height between the instrument plate and the ground. The Latmos team modified the instrument support plate and, as the weight of the vehicle was around twice the weight of the CRV 3, an electric winch was purchased. Antiroll rods were provided to Latmos but were not used, the slopes on which the vehicle was operating being smooth and shallow.

Also it was noticed during the runs that, without the anti yaw rod which is located at the junction between the vehicle and the rope, yaw oscillations did occur. Without the anti yaw rod the distance between the rope attachment point and the gravity center is short and differences in contact forces between the ground and the wheels on left and right sides induce these yaw oscillations.



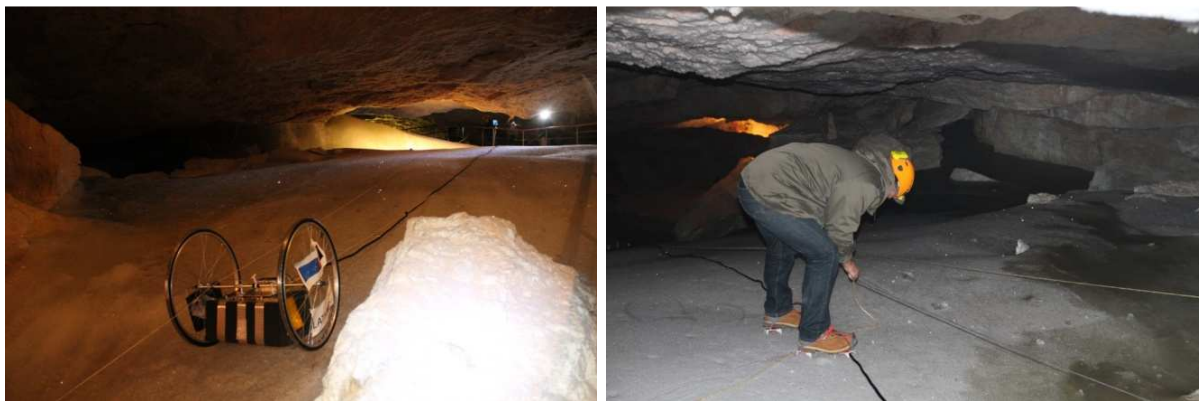
The CRV 5 in the cable car station. The Exomars ground radar antennas are the light yellow truncated pyramids.



CRV 5 utilization by the Latmos team on the ice slope between Tristan and Percival dome the 29th of April.



Close view of the CRV 5 with the Exomars ground sounding radar antennas in yellow with black foam protection around. The signal is sent by the black wire linked to the main rope. The association Planète Mars logo is on the right wheel.



CRV 5 utilization by the Latmos team the 29 th of April.



CRV 5 utilization by the Latmos team on the same slope the 30 th of April.



The CRV 5 from front side with the foam protected antennas (and on the wheel on the left the Association Planète Mars logo)



For these runs the CRV 5 started from below the rock which was the cause of difficulties in the CRV 3-3 88 test.



Operation of the radar on CRV 5 is naturally more complex than the simple camera on CRV 3-3.



On flat surfaces the Latmos team used a traditional cart (left the 30th of April in the junction tunnel between Tristan dome and Percival dome) or the polish rover (right in the upper part of Percival dome).

6 Conclusions

Roughly more than 80% objectives were reached. The objectives before the Dachstein campaign were not totally defined by lack of knowledge on the cave topography. Although I had from ÖWF and from Internet, maps and photos of the cave, it was rather difficult to have a 3D pre-mission mental representation of the cave.

The main objectives were the following:

First objective was to assess what could be the usefulness of the CRV to explore non reachable areas by a man in space suit in a cave. This implies typically a vertical hole. Also steep to medium ice slopes would fall in this category of non reachable slopes. It appeared during the campaign that Tristan dome

was a good representation of vertical non accessible hole but I had no certainty before the campaign that such a hole would be available for experimentation.

Second objective was to operate the vehicle with the Aouda spacesuit and find what are the difficulties linked to operations in a spacesuit. This test has been done numerous time in Utah with the Mars society simulated spacesuits but this are rather easy to operate (no simulation of internal pressure for example). It was clear before the campaign that Aouda spacesuit would be operated by a ÖWF crewmember.

Third objective was to operate the vehicle with the Aouda spacesuit gloves, test which could be done by the cliffbot APM participant.

Fourth objective was to document the difficulties encountered on various all terrain configuration by the vehicle on the way down or up.

Fifth objective was to use the pictures sent by cliffboat on board hazcam to control the vehicle operations.

Sixth objective was to acquire nice pictures of the vehicle in the spectacular ice cave environment.

The main results and lessons learned are the following:

1 The vehicle has demonstrated its **ability to be recovered from two difficult situations** twice, demonstrating again an all terrain capability.

2 The photo **mapping of a typical non accessible hole** (in this case the lower part of Tristan dome) was possible because of a favorable slope configuration (overhanging and vehicle suspended to the rope). This configuration allowed rotation of the vehicle and landscape swapping. **The vehicle was designed to conduct cliffs strata imaging and not 360° panorama. Exploring a hole in a cave requests more 360° views than close up of strata.** The vehicle could have been used 180° from its nominal orientation, with the camera oriented opposite to the wall in order to acquire general views in the case where it was rolling on the slope and not suspended. But a **multiple camera configuration or a rotating camera configuration would be best adapted to a cave hole mapping** than the present configuration.

3 **Guiding and controlling the vehicle without direct view and using only the picture transmitted by the hazcam has proved nearly impossible.** There, also, a **multi camera (or camera swapping the landscape) would be necessary or at minimum a front view and rear view** availability. Also the video signal transmission is a problem in complicated slopes where obstacles can preclude the picture reception up hill.

4 For the first time a **cliffbot was demonstrated using another instrument than a camera** when the LATMOS laboratory used the CRV 5 for the **Exomars ground sounding radar** experimentation. The use of other than camera instruments was foreseen since the beginning of the vehicle design but had never been conducted before by lack of Planète Mars association capability to field more complicated and costly devices than a camera. The CRVs test objectives till now were always more focused on the vehicle all terrain capability than on scientific measurements.

Many thanks to the ÖWF team for a perfect organization and the selection of this very interesting (as well as beautiful) experiment location.