Kingswood 5th Grade MSIP Final Project

"Is it Possible to Predict Dust Storms Based on Sand Patterns?"

Science Question

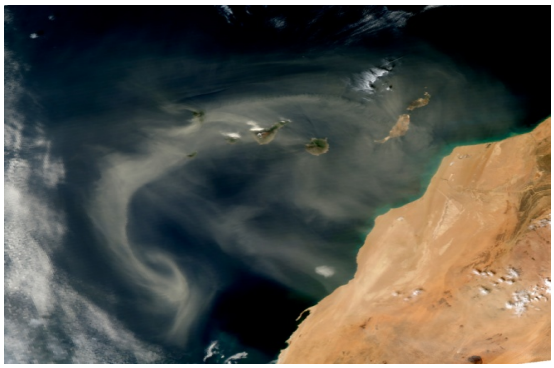
"Is it Possible to Predict Dust Storms Based on Sand Patterns?"

- We were interested in this topic due to its importance. This project is crucial for the better understanding of regional and global dust storm development. These storms can cause tremendous damage and even death to the future astronauts if not properly prepared. We feel that we can track the data and be able to see a pattern in the global dust storm development. We feel this can be done by using qualitative data.

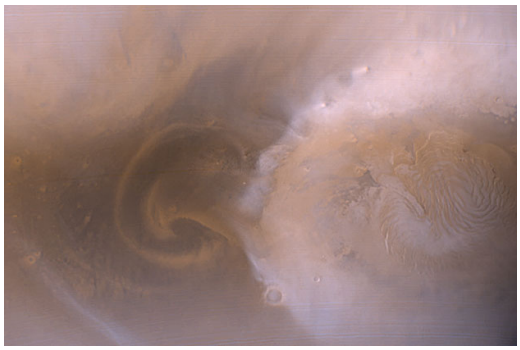
Background Information Used to Formulate Our Hypothesis

- **What are dust storms?**
- **How are they formed on Earth?**
- **How are they formed on Mars?**
- **Types of sand: Earth and Mars.**
- **Comparing the similarities and differences.**

- **First, What Are Dust Storms?** These can be defined as a weather related event which can be found in arid and semi-arid regions. In simple terms, they start when a wind gust blows loose sand and dirt from a dry surface. These winds move the sand from one place to another and can grow quite large. It also lowers visibility.



- **How Are They Formed on Earth?** Dust Storms are formed in the same way on Earth as the definition just stated. Here on Earth, The Sahara and the Arabian Peninsula are the main sources of airborne sand and dust. The above picture illustrates this.



- **How Are They Formed on Mars?** The same way as here on Earth and are powered by the sun. The sun's heat warms the atmosphere on Mars and causes air to move, lifting sand and dust off the ground. The picture above shows a dust storm.

- **Types of Sand: Earth and Mars -** Earth and Mars both have sand. It does look much different than the sand we have in Florida. We just researched where the Mars Rover Curiosity found the soil on Mars to be similar to the soil found near the volcanoes of Hawaii.

- **Comparing the Similarities and Differences -** Mars sand is different than Earth's sand in one important way, its size. Over the past billion years or so, the sand on Mars has been blowing and as a result, being beaten down. It is more like what we can relate to as dust than sand. It is more than 100 times finer than Earth's sand. Mars sand contains metals like iron which causes it to rust and turn reddish in color. Mars is like our sand on Hawaii and does contain similar properties such as feldspar and olivine which is found near volcanoes. It causes sand storms like we have here on Earth. It also forms into dunes which we are familiar with here on Earth and in Florida.

After doing our background research, we were more comfortable in making our hypothesis.

Hypothesis

When we see increasing black surfaces and the formation of sand dunes, a dust storm will soon be created. This is because the exposure of rock will increase the surface temperature, thus creating wind and leading to dust storms.

Our next step was to find out what scientists have been saying about dust storms on Mars. We wanted to get a wide variety of sources to make sure we a good understanding of a Mars Dust Storm.

- **NASA -** We actually started our research off with NASA and did a lot of reading. NASA was able to fill in the history of dust storms on Mars and give us dates as a reference. We saw dust storms happening in the following years: 1796, 1909, 1911, 1922, 1939, 1941, 1943, 1956, 1958, 1971, 1973, 1977, 1979, 1982, 1994, 1997, 2001, 2003, 2007, & 2012. We saw a pattern develop where large dust storms would seem to happen after a lull of a few years. The dust storm would then fire up again two years later and then everything would seem to rest again. From this, we thought we could see patterns develop on the surface which would lead to the formation of the large dust storms.

  NASA provided quite a bit of background information needed to complete a study about Mars. We learned that Mars is far too dry for a lot of clouds to form, but thin, wispy clouds are there, and like Earth, consist of ice. The atmosphere is too thin for carbon dioxide to hold in heat like here on Earth. Mars is heated only by incoming solar heat. Mars storms do not contain water or snow, they have dust, which is what our project is about! The Mars dust storms happen when the Southern Hemisphere is having summer and that is the main reason for our site locations. The dust actually traps the heat and warms up Mars. We also saw that the summer in the Northern Hemisphere is often with no dust. We learned about different missions as well to Mars as well. From these we learned that Mars is cold but does heat up in the summer. In summary, the sun drives Mars climate and weather much in the same way as here on Earth.

- **Jet Propulsion Lab (JPL) -** The JPL website was an awesome website that we referred to often. When we saw the video of the dust devil, we were hooked!

We learned they are the Mars version of a tornado but can be much worse. On Earth, we actually have small dust devils in the desert. Dust Devils leave behind a

dark track exposing the rock behind. They form when the ground heats up during the day, warming the air. As warm air rises, it spins. It will then pick up any loose dirt and sand that is around. They also can grow quite tall and be much bigger than tornadoes on Earth. JPL explained that as cold air from the South Polar Cap moves north towards the warmer equator, dust storms will start to happen.

We learned that the Hellas Basin was often the place where dust storms began. When the dust becomes thick enough during a storm, it reflects the sun's rays back out which allows the surface to cool back down and for the storm to dissipate. Dust Storms affect the seasonal frost and control local and regional weather patterns. The current dust storm (2012) seemed to have originated in the Hellas Basin and quickly became a regional storm.

The final piece from JPL was about sand dunes. The most common sand dune found on Earth and Mars is the crescentic. These sand mounds are wider than long. They form from winds that blow in one direction. These type of sand dunes can move very fast on both planets. Sand Dunes that are longer than wide are called linear dunes. They may be up to 160 kilometers long. An example can be seen her in the Mojave Desert.

- **Universe Today -** This is a website we found and it gave us a lot of information on dust storms. It confirmed the information we found on the NASA and JPL websites on how dust storms are created, when they happened, and all in easy to read stories. It also had very interesting pictures that we have used in this study.
- **Ann Melnichuk -** We found a good online report from Ms. Ann Melnichuk. Her study focused on the local development of dust storms on Mars. In her study, she also used the THEMIS cameras and focused on the Hellas Basin as we did. She, in

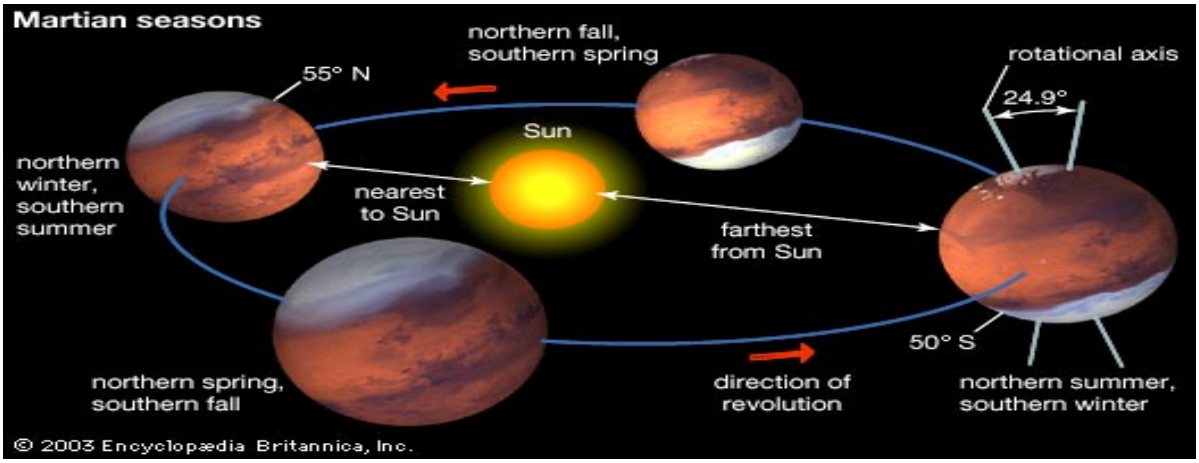
particular, looked at cloud formation and their ice content within the Hellas Basin on Mars. She found that clouds were present during a storm. This study gave us an idea of what happened during a dist storm.

- **Arizona State University -** Arizona State University provided the background talks we watched for our project by Mr. Jonathon Hill. He provided crucial information in understanding how JMARS worked and how to get started on our project. It would not have been possible without this knowledge to accurately do our study on Mars.

- **European Space Agency -** This source provided good information on Mars but not as good as the JPL or NASA websites. On ESA we learned about dust devils, sand dunes and everything was in agreement with what JPL and NASA had said earlier. All of their findings were consistent with previous research.

- **Science Daily -** This site provided a very good article on Mars dust storms. It explained the dust storm in July 2007 and its effect on the Mars rovers. We learned that this storm blocked 99% of the direct sunlight on Mars. Science Daily also explained that the Mars weather repeats itself more often than here on Earth. The summer on Mars in the Southern Hemisphere is when dust storms can start, but not every year.

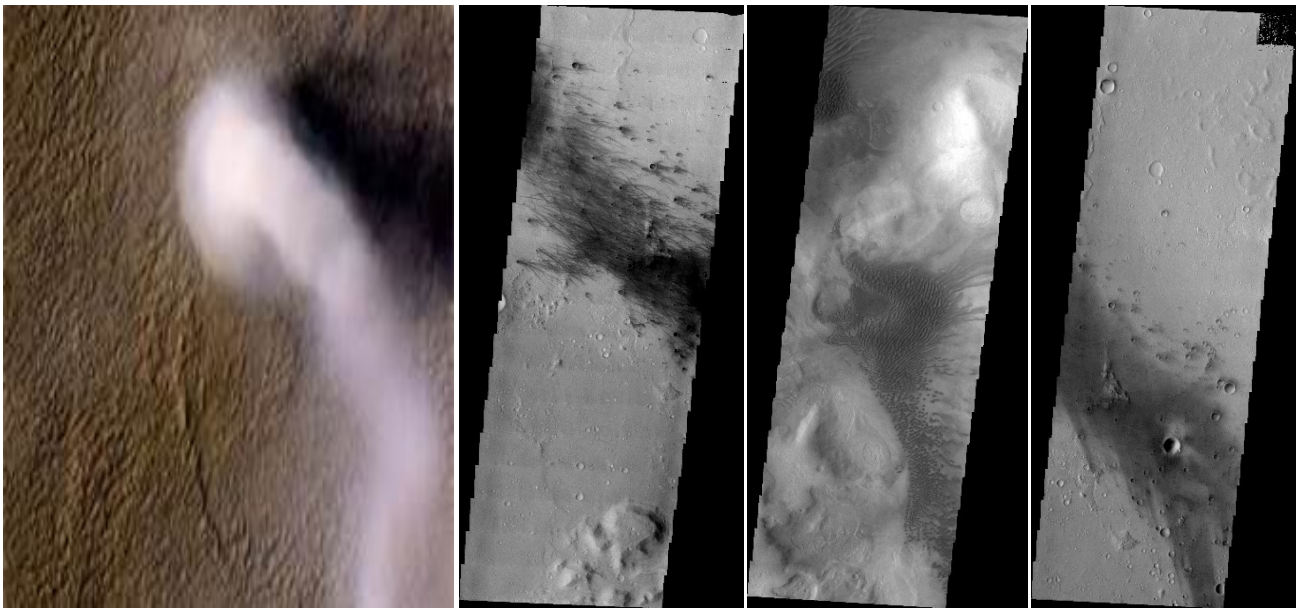
- **Facts About Mars -** This website is more like an encyclopedia version than a website publishing news event after news event. This site provided numbers and facts about Mars's orbit, seasons, and temperatures. It showed us how the orbit



allows the Southern Hemisphere to be closer to the sun, which causes the uneven heating of the surface on Mars. The site agreed that dust storms do not happen every year and they seem to build up strength. We could see this in the previous NASA dates of dust storms.

Data Criteria

Shown below are examples on Mars of what our project was in search of.



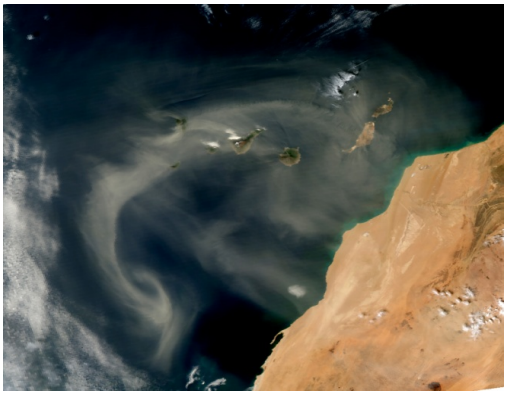
Mars Dust Devil **Dust Devil Tracks** **Sand Dunes** **Bare Rock**

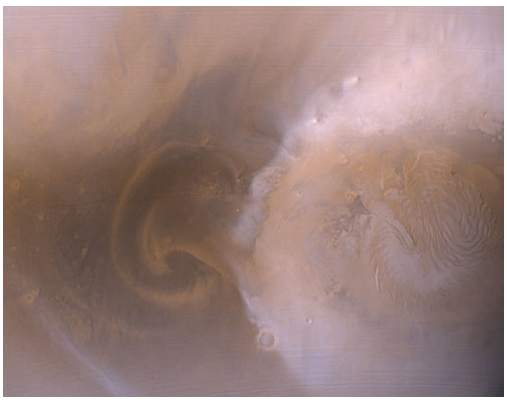
The picture is a Mars Dust Devil or tornado of sand. We can tell when these happen because they have been caught on camera by one of the Mars rovers. We were more interested in the next picture of the Dust Devil Tracks because this is the evidence a dust devil leaves behind. As you can see, the track is a black single line which the Dust Devil has removed the sand from the surface of Mars and exposing the black rock underneath. The Sand Dunes on Mars are very similar to those on Earth as the picture illustrates. One can easily see the similarity with the Mojave Desert photo of earlier. Sand Dunes are easy to spot on the THEMIS images as well as track. The last photo is of bare rock and one of the most important. It is this exposed black rock that causes the wind on Mars and starts the dust storm. Wind strips the surface of sand which leaves behind the bare rock. The more of the bare rock we see on the THEMIS images, the greater chance for wind / dust storms.

Mars & Earth: Winds Cause It All!

The weather on Earth and Mars has one thing very much in common, wind. Wind is caused by heating of the land, as heated air rises, air must replace the air that is rising. The air that comes in to replace it is what causes that wind, due to pressure differences. Air always travels from an area of high pressure, to an area of low pressure. This wind on Mars is what causes and drives the dust storms.

What Are Dust Storms?





Earth **Mars**

As we mentioned earlier, a dust storm is a weather related event which can be found in arid and semi-arid regions. In simple terms, they start when a wind gust blows loose sand and dirt from a dry surface. These winds move the sand from one place to another and can grow quite large. It also lowers visibility. We wanted to show you just how similar dust storms are on Earth and Mars. The pictures of how it looks on the ground during a dust storm and then the satellite photos are hard to distinguish from one planet to another. We were amazed by the closeness of the photos and is hard to tell apart. We do know that the Mars storms can be much more intense than those here on Earth.

Sand Differences

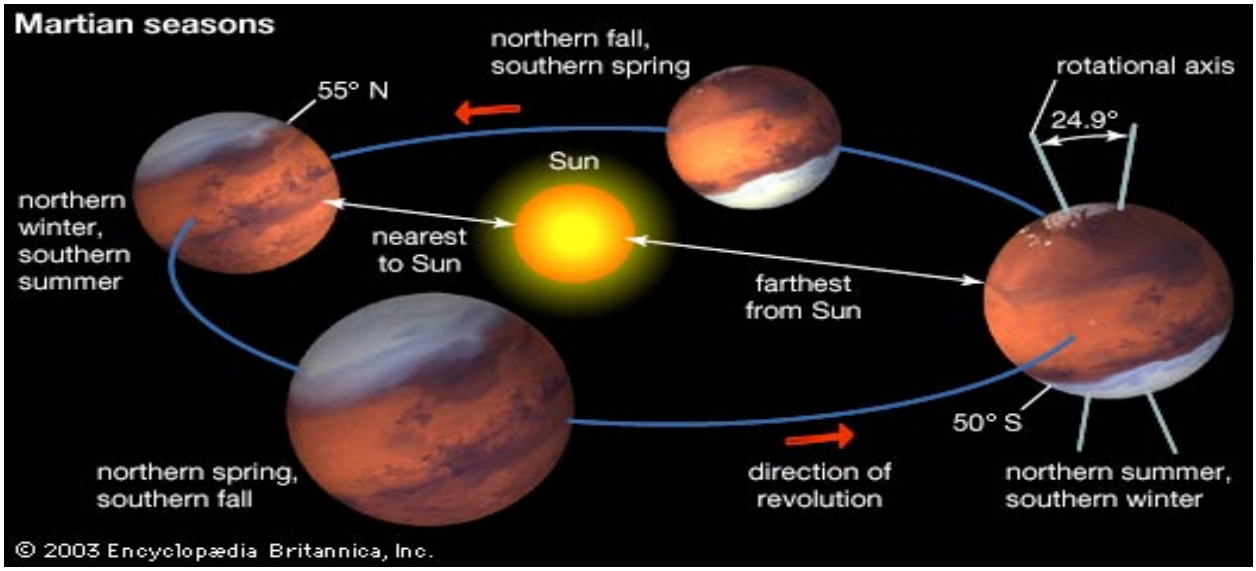
Mars Sand

Florida Sand

Mojave Desert Sand

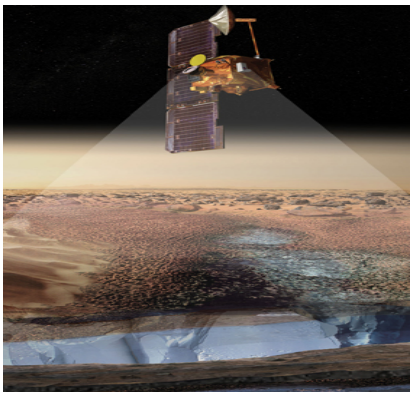
Once again, we show you the differences in the sand we researched and the sand we know first-hand. As you can see, pictures are worth a thousand words! Our Florida sand looks very different as it is white in color. The Mojave Desert and the sand at Mars does look similar, but we know that the Mars sand is much smaller and finer. We also found out that it has similar characteristics to the sand near the Hawaiian volcanoes in general makeup.

What We Know



We refer back to this illustration again as it provided some good background information. Our 5th Grade National Geographic science books also say that the Mars orbit is elliptical and is tilted much the same way Earth is. Mars tilt is around 25 degrees and Earth is tilted at 23 degrees. The Martian day is just a little bit longer than ours by less than an hour. Due to the tilt, Mars also has a change in seasons just like Earth experiences, though they last much longer as a Mars year is 687 days. The tilt and the closer position of Mars allows the Southern Hemisphere to receive hotter temperatures during the summer months. This heat increase causes temperature differences and creates the wind we talked about earlier.

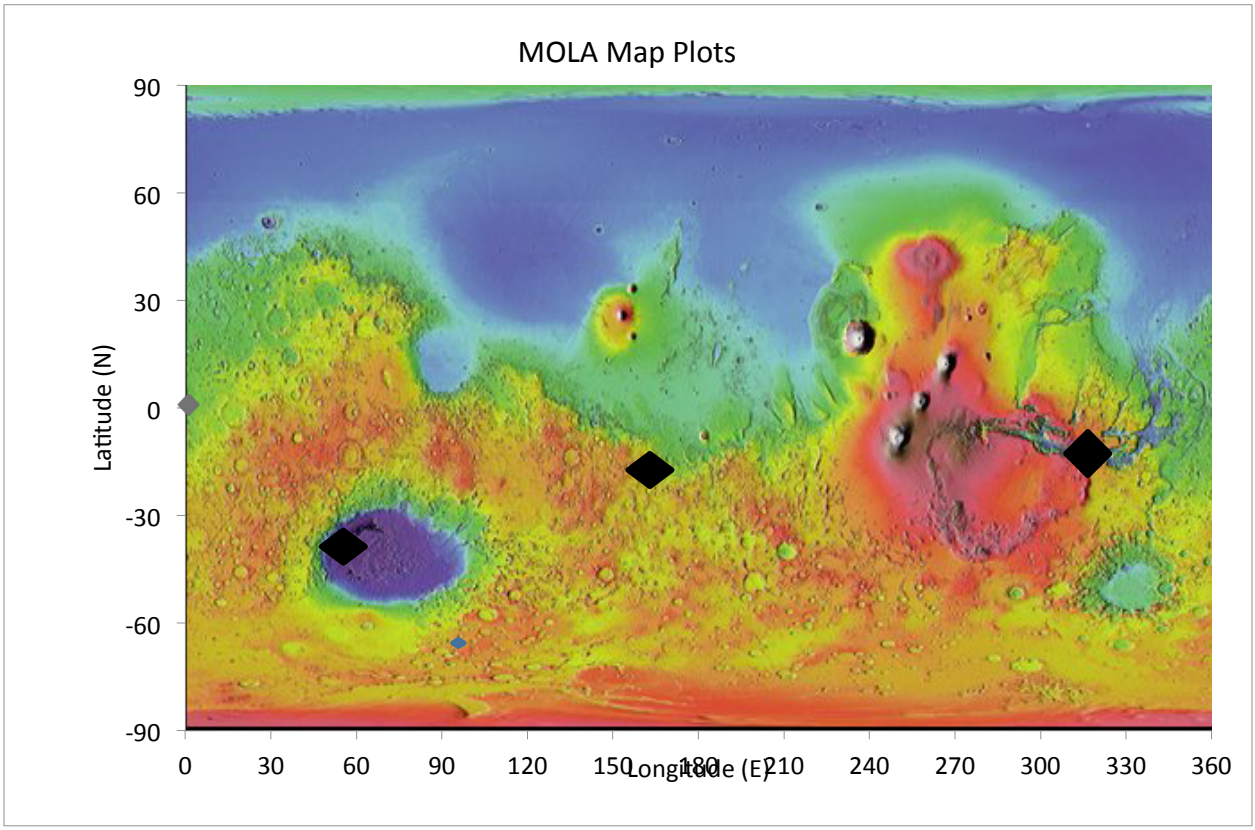
Data Collection Methods



We solely used the THEMIS camera found onboard the Odyssey satellite. The satellite was launched here in Florida back in 2001. Odyssey has been taking pictures

since 2002 and it takes two hours to go in one orbit around Mars. THEMIS is a thermal imaging system and is controlled by Arizona State University. We used JMARS to locate the needed images for the study.

Site Selection



We apologize for not plotting our points on the provided MOLA map, but we could not get the data to save. Instead, we showed our selections by black diamonds. We tried to stay in the close approximate area of each diamond so we could receive consistent data. We looked for sites that showed history of dust devils, bare rock, and sand dunes. We also tried to keep the same elevation to minimize this variable. We chose the Gusev Crater and the edge of the Hellas Basin. We examined over 200 images of these areas. Unfortunately, the chosen Southern sites were experiencing a regional dust storm and could not be photographed by THEMIS. As a result, we chose the Valles Marineris area ad a backup based on elevation and appearance of sand dunes.

Measuring Data

- **Themis Camera Observations**
- **Qualitative vs. Quantitative**
- **Graphing**

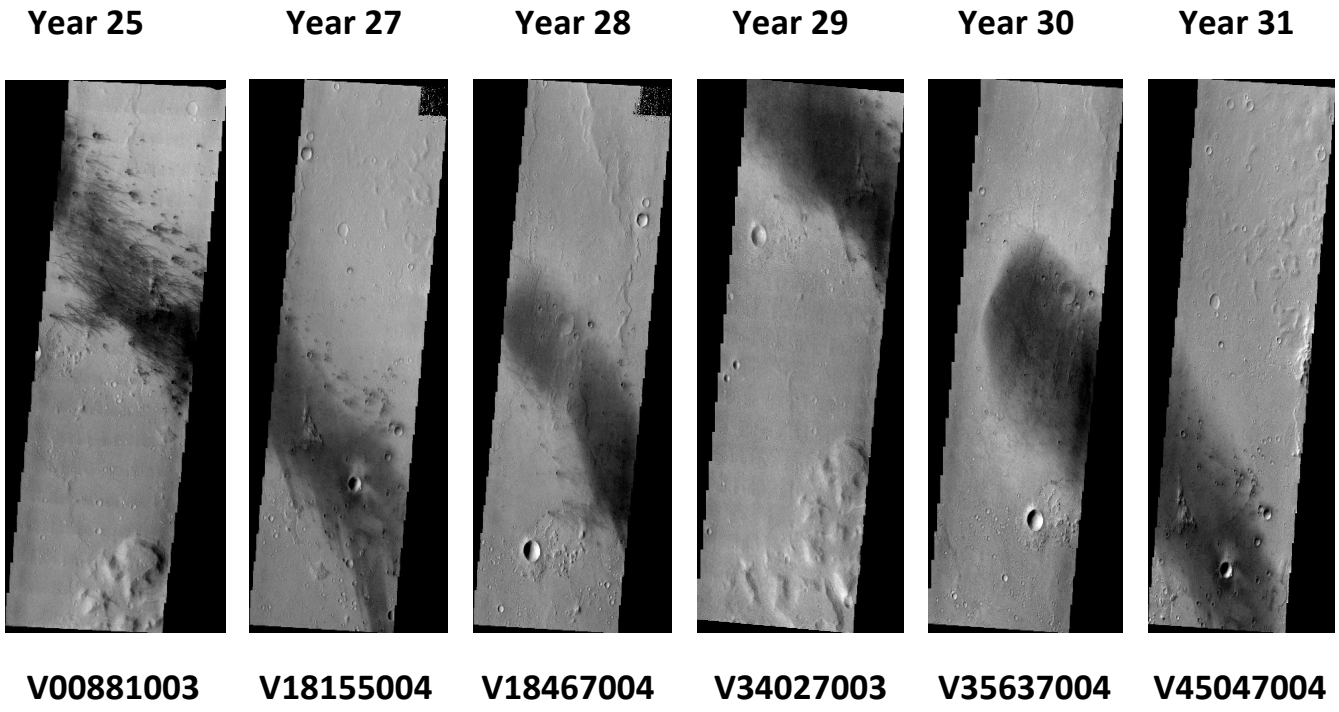
We solely used the THEMIS camera for images. JMARS and the THEMIS camera website was used to acquire and examine the images. We had a difficult time in determining qualitative versus quantitative data. In the end, we voted to qualitative data and described what we saw in each of the photos. We assigned a percentage value to the images in regards to amount of area covered by dust devils, sand dunes, and bare rock. We used a triple bar graph to best show the results of each comparison.

THE STUDY OF THEMIS IMAGES

Gusev Crater

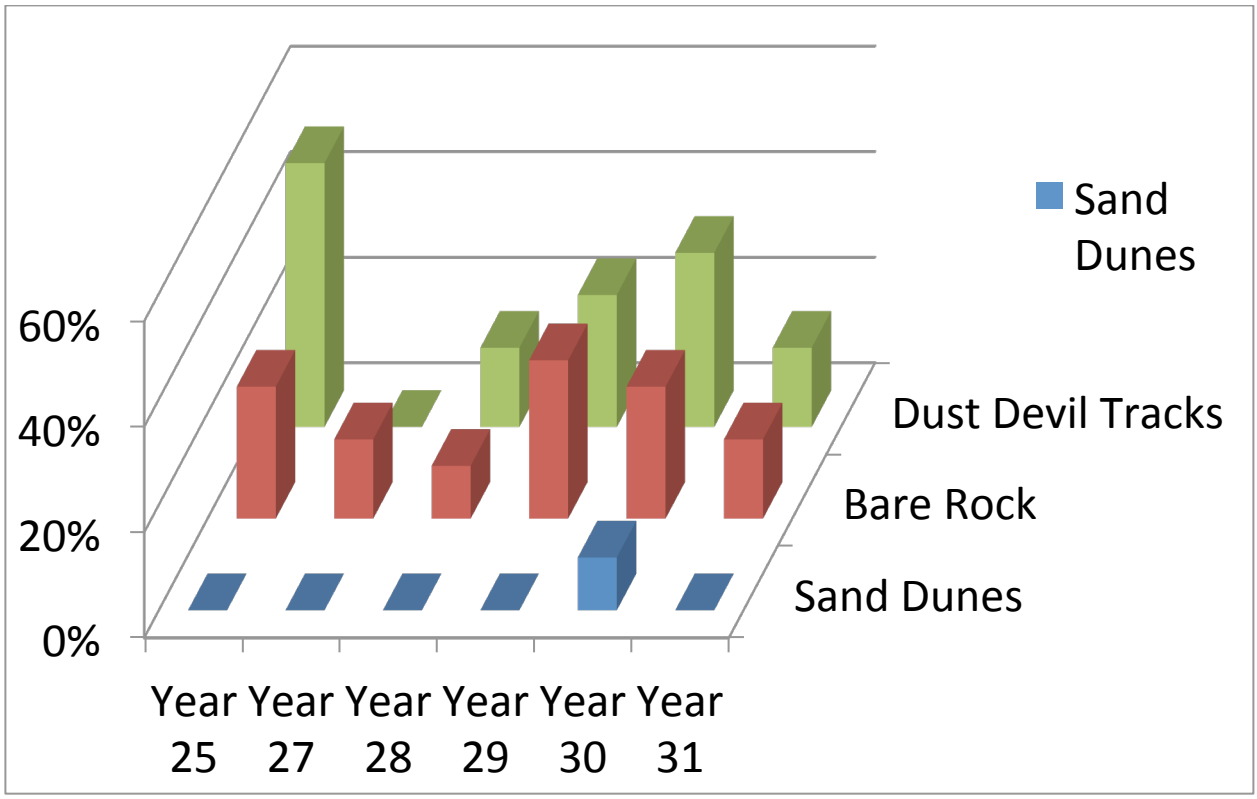
The Gusev Crater will be the first mentioned. Of the 67 images we examined, we provided one for each year that best illustrated what we saw. We started with Mars Year 25 but failed to find any image captured for Year 26. We finished with the last year available at Mars Year 31. We saw examples of all three items we were looking for. Mars Year 25 best shows examples of dust devils. We found numerous images taken this year showing dust devil tracks which we concluded there was a lot of wind activity and temperature variations. In Year 27, all of the dust devil tracks are gone and more of the images examined show evidence of bare rock. Unfortunately we could not find any images for Year 26, possibly due to dust storm activity. We concluded and research showed that a regional dust storm did indeed take place at this time. Our findings in Years 27, 28, 29, and Year 30 showed increasing levels of bare rock exposure, which we concluded that this area would have increased heating during the summer months. Year 31 is not as dark as the previous years' which is leading up to sand accumulation.

Gusev Crater THEMIS Images



Gusev Crater Data Collection

Observations Based on 67 Themis Images



Analysis of Gusev Data

- **Signs of Wind**
- **Evidence of Dust Devils & Bare Rock**
- **Sand Dunes vs. Dust Devils**
- **Possible for all three in one area?**
- **Regional Sand Storm Dates**

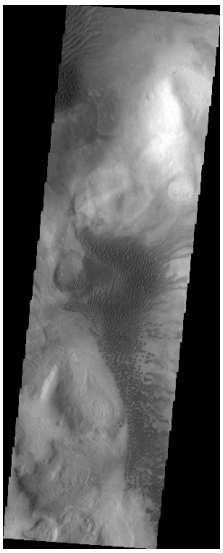
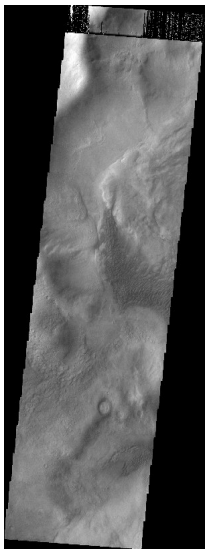
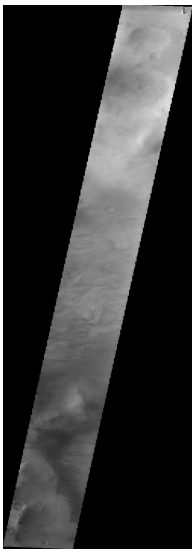
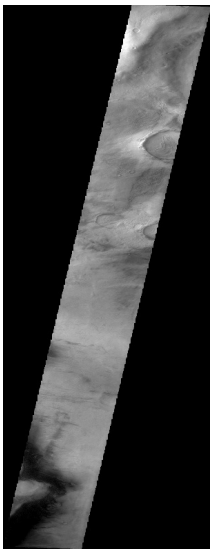
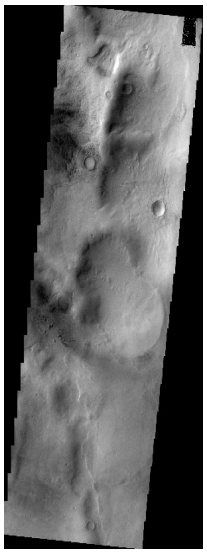
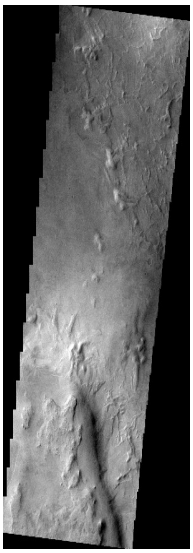
As mentioned earlier, there is a lot of evidence of wind in the Gusev Crater during the observed years. We also observed that having all three target objectives (dust devils, sand dunes, and bare rock) in one area is not very likely. If you think about it, the wind caused by dust devils and exposing bare rock would probably push the extra sand out of the area making sand dunes unlikely. We also saw when a regional dust storm hit the area and it was consistent with our hypothesis. It hit right after Year 25's image was taken and after Year 30's image. This confirmed our hypothesis that when the surface has increased levels of bare rock and dust devils, a dust storm is not too far off. The problem would be the exact timing of the storm but one could see the conditions becoming favorable for dust storm occurrence.

THE STUDY OF THEMIS IMAGES

Hellas Basin

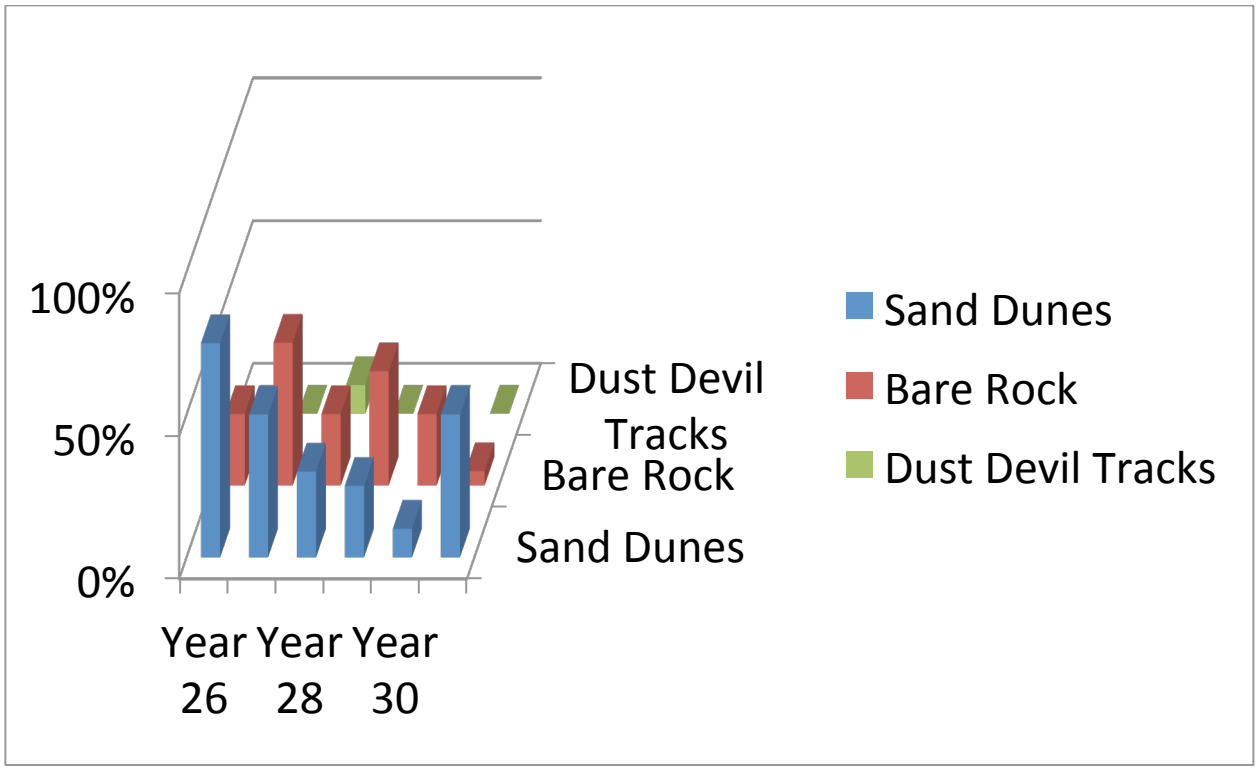
Our next location is the edge of the Hellas Basin. This region has long been known for the origin of regional and global dust storms. We were amazed at the size of this area and felt there would be more variables out of our control due to the size. We examined a total of 158 images and represented the best typical image for each year. In Year 26 images, we observed numerous / build-up of sand dunes in the area. In Year 27, the numbers were less. This is consistent with the Gusev Crater findings in that there was increased activity immediately before a dust storm. A dust storm did take place in Year 27. As a result, we observed fewer sand dunes during this year and the resulting years until Year 31. Year 31 saw a dramatic increase of sand dunes from Year 30. Bare rock was consistent with our hypothesis for Year 26 and 27 but inconsistent for the remaining time. There was little to no evidence of dust devil activity in this particular area.

Hellas Basin THEMIS Images

Year 26	Year 27	Year 28	Year 29	Year 30	Year 31
					
V08862013	V10397004	V18671005	V27182009	V35529007	V43291002

Hellas Basin Data Collection

Observations Based on 158 Themis Images



Analysis of Hellas Basin Data

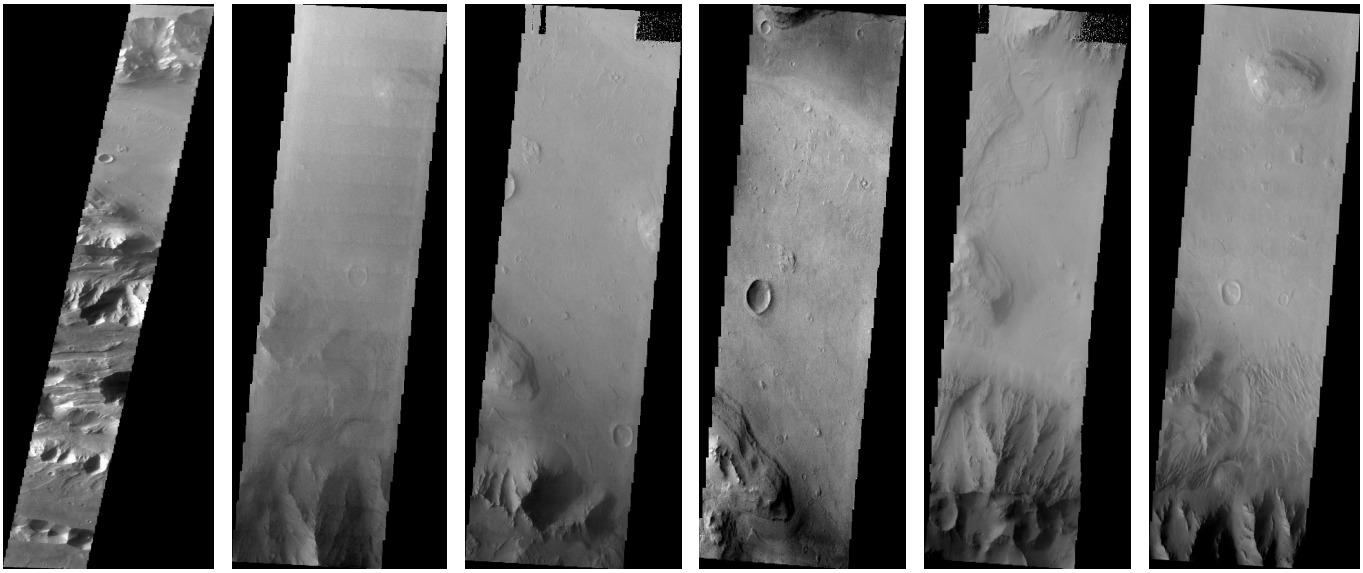
- **Signs of Wind**
- **Evidence of Dust Devils & Bare Rock**
- **Sand Dunes vs. Dust Devils**
- **Possible for all three in one area?**
- **Regional Sand Storm Dates**
- **Consistent with Gusev Data?**

In our analysis of the Hellas Basin, we saw inconsistent data at best. We observed the percentage of sand dunes grow smaller ear year until the dramatic rise in the last year - 31. The percentage of bare rock fluctuated and there was very little evidence of dust devils. When comparing Hellas to know dust storm activity, the results were mixed as well. Only in a few pictures did we notice dust devil tracks along with the sand dunes. In our final analysis of the Hellas images, there was much more activity in this area when compared to the Gusev area. The data did not support our hypothesis as we feel the area might be too big to look at in isolation and be able to predict when a dust storm will generate. The increased activity supports what all previous studies had said about the Hellas Basin area. This area receives strong, consistent blowing of wind.

THE STUDY OF THEMIS IMAGES

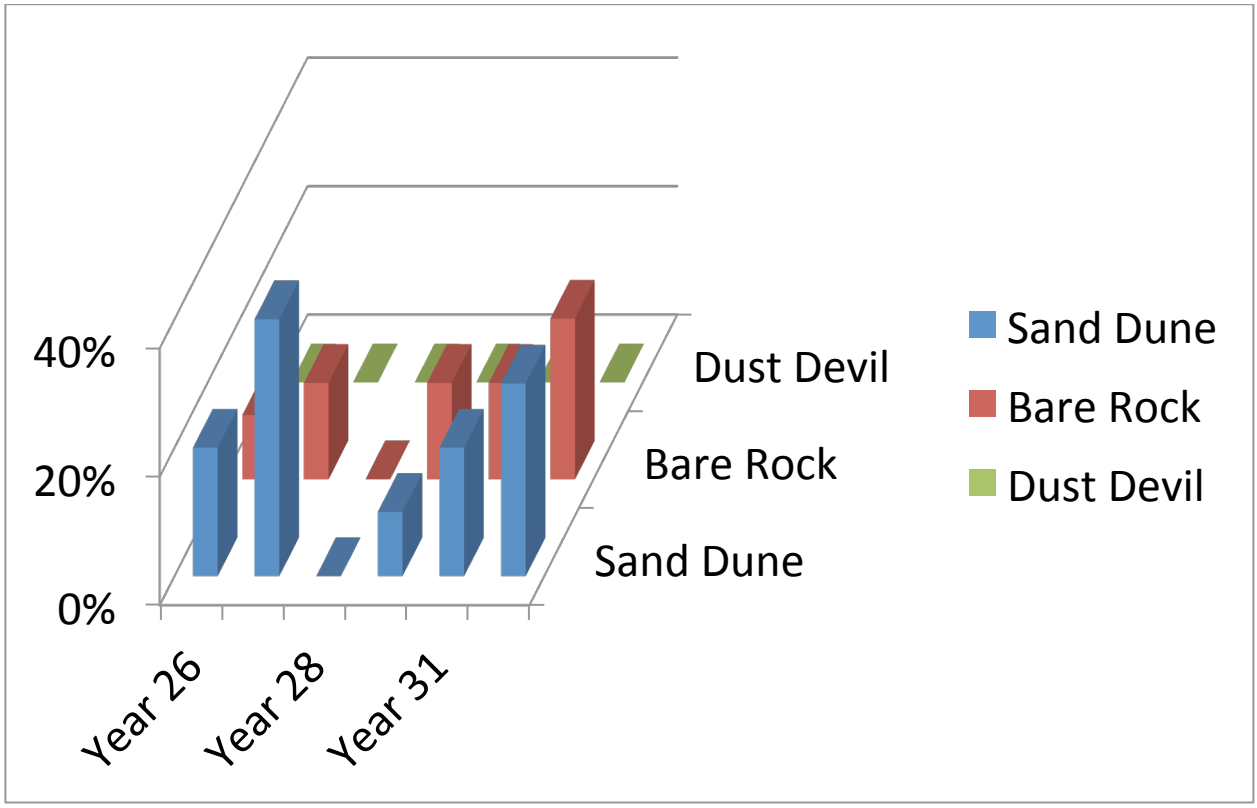
Valles Marineris of the Tharsis Bulge

Our final location are images of the Valles Marineris of the Tharsis Bulge Region of Mars. This was added to our study since that is the only location we could get a THEMIS image of that still met our elevation criteria. As a result of time restraints, we only examined 9 images and 6 of them are shown in this report. Since we kept elevation similar to that of Gusev and Hellas, we thought we would see similar examples in the images. We thought wrong! This particular area had more landforms present and as a result, probably greatly affected the wind patterns. We observed sand dunes in the lower portion of the area along with some exposed rock.

Year 26	Year 27	Year28	Year 30	Year 31	Current Year
					
V04659002	V14856001	V26487004	V3538300	V442810010	V48688001

Valles Marineris Data Collection

Observations Based on 9 Themis Images



Analysis of Valles Marineris Region Data

- ✖ ***Signs of Wind***
- ✖ ***Evidence of Dust Devils & Bare Rock***
- ✖ ***Sand Dunes vs. Dust Devils***
- ✖ ***Possible for all three in one area?***
- ✖ ***Regional Sand Storm Dates***
- ✖ ***Consistent with Previous Data***

Our data chart clearly points out zero dust devil activity. Sand Dunes were much more common at the bottom of our images where the canyon wall is. This makes sense the more we thought about it. We saw in a lab in class that as we blew sand up against a wall, the sand would build up and create dunes. The unfortunate part is that we did not see enough of this area as it looked very interesting with its numerous landforms. The data was consistent with similar numbers of sand dunes and bare rock. There was no evidence of dust devil activity. The data also supports the hypothesis in regards to know dust storm activity. We saw a buildup, regional dust storm and then less evidence immediately following. Since then, there has been a consistent buildup of both bare rock and sand dunes. This would suggest increased wind activity.

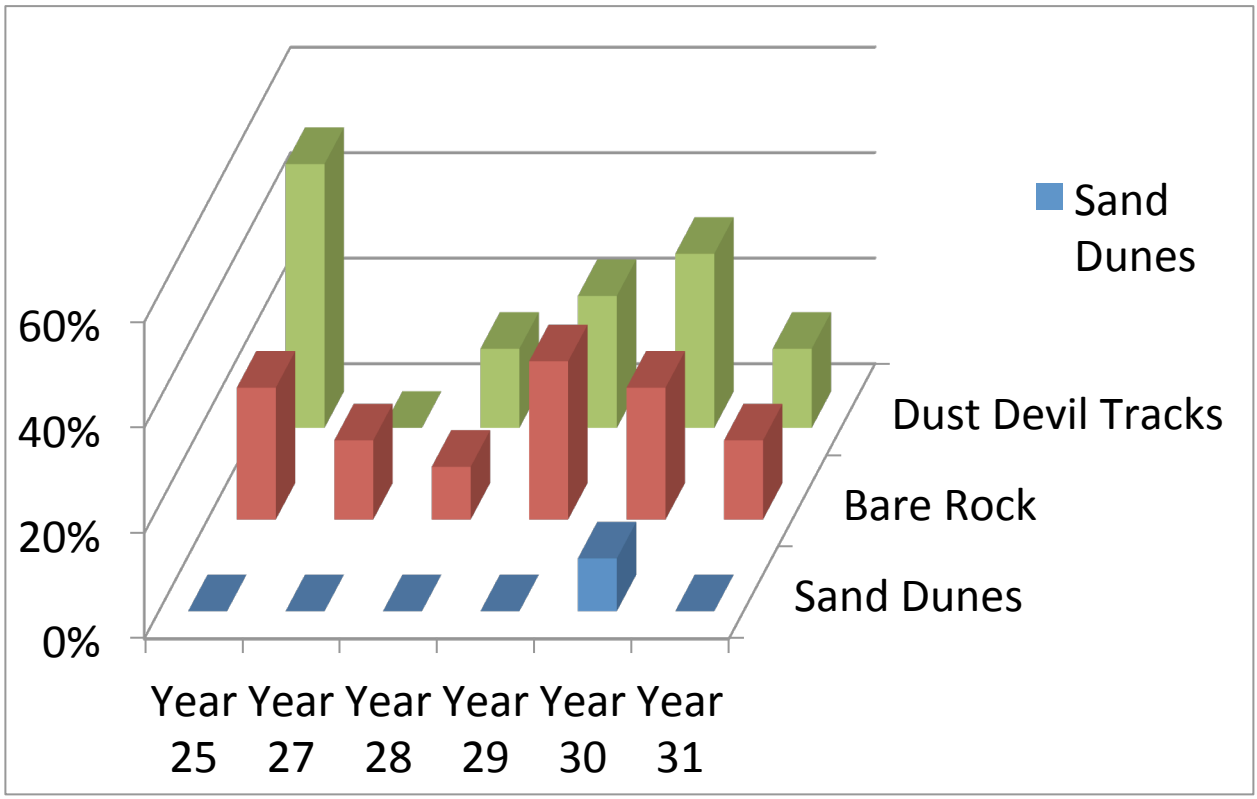
RESULTS AND HOW THEY ARE RELATED TO THE SCIENCE QUESTION

GUSEV CRATER

As we look back at our science question in regards to the Gusev Crater, “Is it Possible to Predict Dust Storms Based on Sand Patterns?”, our data is consistent and the answer would have to be yes. We feel that it was evident that a dust storm would soon be coming. The more exposed rock surface would create more heating form the sun and thus increase the wind amount. However, you would be hard-pressed to just look at a Gusev image and exactly predict when a dust storm is coming. The images do show signs that the conditions are right for the build-up of a dust storm.

Gusev Crater Data Collection

Observations Based on 67 Themis Images



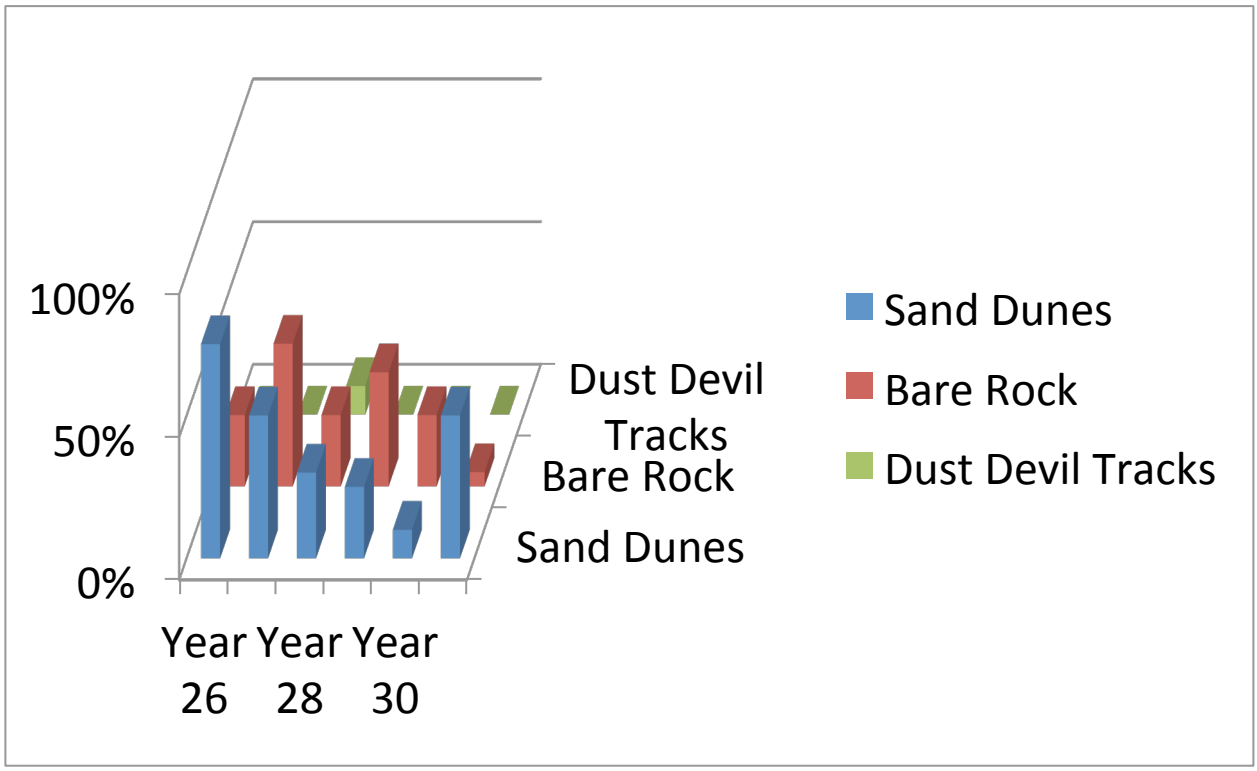
RESULTS AND HOW THEY ARE RELATED TO THE SCIENCE QUESTION

Hellas Basin

When looking at the science question in regards to the Hellas Basin data, we are a bit more unsure. We saw a gradual decline in the number of sand dunes from year 26 to 30 but we do know that a regional dust storm did take place in this particular area. As a result, we are unsure of our findings and being able to predict a dust storm as we could with Gusev. We feel the reason is because the Hellas Basin is so big and its sheer size plays a big part with the formation of dust storms. We can see that the wind is very active here but a bigger picture would be needed to better tell the future. Hellas cannot be analyzed without looking at it as a whole instead of in isolation as we did.

Hellas Basin Data Collection

Observations Based on 158 Themis Images



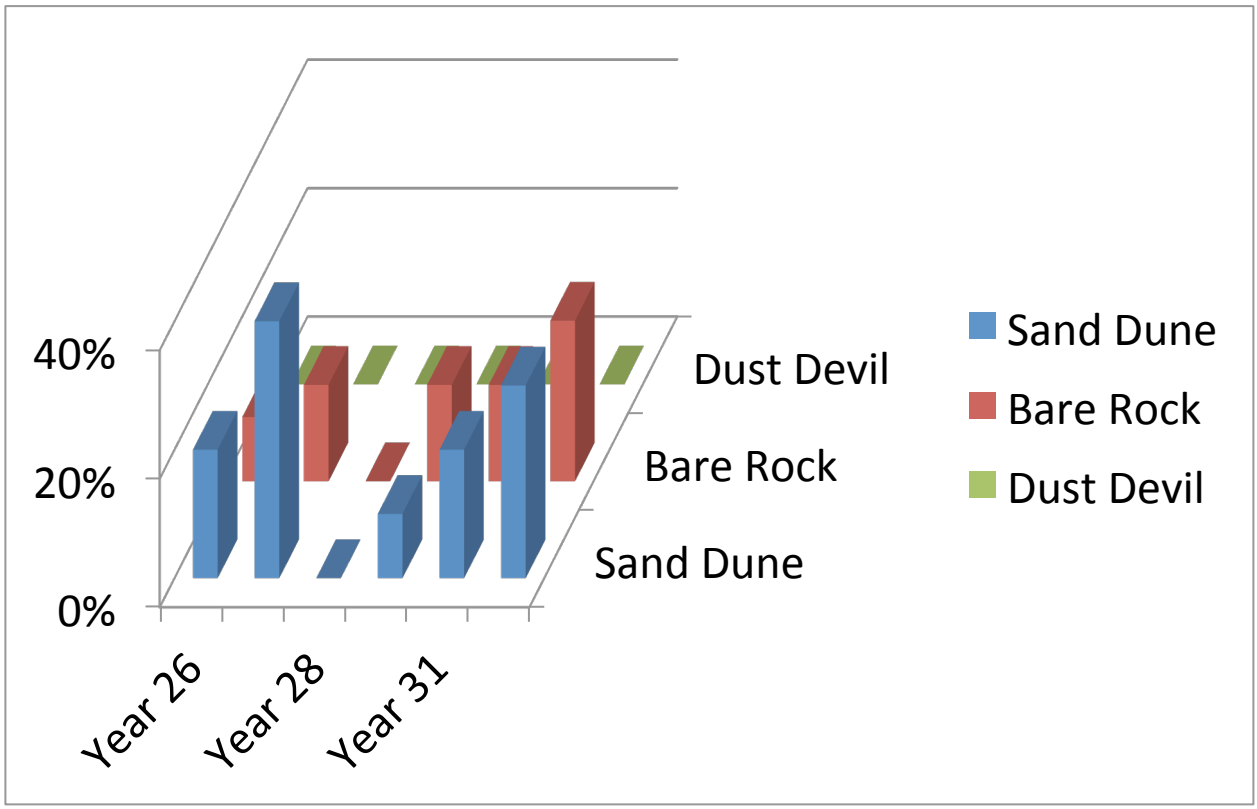
RESULTS AND HOW THEY ARE RELATED TO THE SCIENCE QUESTION

Valles Marineris Region

The science question in regards to the Tharsis Region proved to be a bit more consistent than Hellas. We saw a buildup of sand dunes and exposure of bare rock then nothing at all. We concluded a dust storm took place and in fact, the data supported this claim. We then witnessed another sand dune buildup which one would predict that a dust storm would be happening soon. There does seem to be a pattern from year to year and is consistent with dust storm activity. From this, our results are consistent with the Gusev Crater data. However, it should be noted that we only studied 9 images and is not a large enough sample size to warrant any conclusive findings.

Tharsis Region Data Collection

Observations Based on 9 Themis Images



Analysis of Data

- ***Problems with using qualitative data***
- ***Consistency between the three sites***
- ***Data compared to known dust storms***
- ***Location differences from year to year***
- ***Missing Years***
- ***Current Data***

Problems With Using Qualitative Data

Before starting our project, we did not have a great understanding of how different qualitative and quantitative data were. Now we know! We seldom came up with the

same values when looking at the Themis images, even though we established a rubric. All of us had differing ideas of the percentage that was covered in a image. If possible for the next study, changing to quantitative data would be much better. Measuring the percentage of area covered or exposed, counting individual sand dunes would be more precise and helpful.

Consistency Between the Three Sites

If we could pictures of the same precise location from year to year instead of somewhat close by, our study would give more accurate information. We have found that winds can be very localized and change according to the landforms that are present. Trying to do a study using just Themis images is difficult to do because of this. By using approximate locations, too many variables come into play and possibly skew the results.

Data Compared to Known Dust Storms

We could draw some conclusions in what we saw on the surface and when known dust storms took place. Gusev and Valles Marineris were consistent with visible sand patterns and dust storm activity. The Hellas Basin was far from consistent. We feel that our particular area was very isolated and probably taken out of context when looking at the big picture of a dust storm. We could find no sand patterns in relation to know dust storm activity for this site location.

- ***Location Differences From Year to Year / Missing Years & Current Data***

In some cases, no Themis image was available for our area in certain years. Very seldom could we find the precise location from one year to the next. We feel that these two variances have to be considered when making any type of conclusion. Finally, the availability of recent photos hindered the study as well. The time period is very small for the type of study we proposed. Faced with these limitations, widening our search parameters would be more effective. We would also propose to just concentrate on one particular area and use all of the available resources to get a better picture of the conditions on the surface of Mars.

Conclusion

Science Question – "Is it Possible to Predict Dust Storms Based on Sand Patterns?"

There is a cyclical pattern of winds which caused by uneven heating and cooling of the surface which then results in the movement of dust perpetuating the cycle. We did see some of this pattern that we were looking for and conclude that by just using the qualitative data we used, you can make a prediction of a dust storm. However, the timing and intensity would be not be possible by just using our data.

Conclusion

Hypothesis - When we see increasing black surfaces and the formation of sand dunes, a dust storm will soon be created. This is because the exposure of rock will increase the surface temperature, thus creating wind and leading to dust storms.

From the three different sites we examined, the results were inconclusive. We could see evidence of sand build-up and increasing bare rock which soon after a dust storm event did happen. We used qualitative data which is subjective. Also, we did not have consistent pictures of exact locations from year to year. As a result, hard to see the same accumulation from year to year as different locations could easily be effected by the wind differently. For future projects, combining the qualitative data that we used (sand dunes, bare rocks, dust devil tracks) along with quantitative data of ground temperature and amount of dust in the air, would give us a better reading of what we are actually seeing in the photographs. There did seem to be a pattern that we predicted but not conclusive proof.

Conclusion

A Special Thank You!

We would like to first thank Ms. Jessica Swann from MSIP who was very patient with us in doing our project. This is the first time we have ever done something on this scale and it would never have been possible without her help and patience. THANK YOU!

Next, we would like to thank our school administration for allowing us to step outside the normal class schedule to experience a real-world science project. We have learned a lot and thank you for giving us this opportunity.

Image References

Title Page *– All pictures except for Kingswood Elementary were taken from the www.jpl.nasa.gov website @ http://marsed.mars.asu.edu/msip-home. Kingswood Elementary picture was taken from the Hillsborough County School website @http://www.sdhc.k12.fl.us/schools/School_Info.asp*

Page 1 *- Mars Dust Devil Tracks: Themis Image V00881003, Mars Sand Dunes: Themis Image V08862013, http://universe-beauty.com/gallery/search/(keyword)/mart*

Page 2 *- Earth Dust storm - http://www.bing.com/images/search?q=dust+storm&FORM=HDRSC2#view=detail&id=028595FC4709349CF07CCC28386FA658F42AC961&selectedIndex=69,*

Earth Satellite Photo of Dust Storm-http://www.news.wisc.edu/newsphotos/images/dustStorm12MAR2009.jpg

Mars Satellite Dust Storm - http://wanderingspace.net/category/mars/page/4/

Page 3 *- Mars Sand Image taken from JPL website at: http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA16469*

Florida Sand Image taken from: http://www.bing.com/images/search?q=florida+sand&qpvt=florida+sand&FORM=IGRE#view=detail&id=3EFE4E0FFD9FACBEAF867982859E71F005420F86&selectedIndex=2

Page 4 *- Mars Dust Devil: http://www.nasa.gov/mission_pages/MRO/news/mro20120404.html*

Page 5 *- Mojave Desert Image taken from: http://www.bing.com/images/search?q=mojave+desert+sand+dunes&go=&qs=n&form=QBIR&pq=mojave+desert+sand+dunes&sc=1-23&sp=-1&sk=#view=detail&id=C8820B8A6E7C02B436EF1BE809E0B87DFC259FC2&selectedIndex=3*

Page 6 *- Picture of Mars orbit is from the website: Encyclopedia Brittannica, Inc.*

Page 7 *- Thermal Images were taken from JMARS and the Mars Image Explorer website @http://viewer.mars.asu.edu/planetview/inst/themis#start. Mars Dust Devil: http://www.nasa.gov/mission_pages/MRO/news/mro20120404.html*

Mars Dust Devil Tracks: Themis Image V00881003

Mars Sand Dunes: Themis Image V08862013

Mars Bare Rock: Themis Image V12639003

Page 8 *- Cloud Image taken from website at: http://www.texasmountainbiketrails.com/wind-noise/*

Page 8 continued, *- Earth Dust Storm Images taken from:*
http://www.news.wisc.edu/newsphotos/images/dustStorm12MAR2009.jpg

http://www.bing.com/images/search?q=dust+storm&FORM=HDRSC2#view=detail&id=028595FC4709349CF07CCC28386FA658F42AC961&selectedIndex=69

Mars Dust Storm Images taken from http://wanderingspace.net/category/mars/page/4/

and http://universe-beauty.com/gallery/search/(keyword)/mart

Page 9 *- Mars Sand Image taken from JPL website at:*
http://www.jpl.nasa.gov/spaceimages/details.php?id=PIA16469

Florida Sand Image taken from:
http://www.bing.com/images/search?q=florida+sand&qpvt=florida+sand&FORM=IGRE#view=detail&id=3EFE4E0FFD9FACBEAF867982859E71F005420F86&selectedIndex=2

Mojave Desert Image taken from:
http://www.bing.com/images/search?q=mojave+desert+sand+dunes&go=&qs=n&form=QBIR&pq=mojave+desert+sand+dunes&sc=1-23&sp=-1&sk=#view=detail&id=C8820B8A6E7C02B436EF1BE809E0B87DFC259FC2&selectedIndex=3

Page 10 *- Picture of Mars orbit is from the website: Encyclopedia Brittannica, Inc.*

Themis Camera and Odyssey Satellite image taken from the Themis website at: http://themis.asu.edu/about

Page 11 *- MOLA Map is courtesy of JPL MSIP*

Page 13 *- Gusev Images taken from JMARS and the Themis website at:*
http://viewer.mars.asu.edu/planetview/inst/themis#start

Themis Image Year 25: V00881003, Themis Image Year 27: V18155004,

Themis Image Year 28: V18467004, Themis Image Year 29: V34027003,

Themis Image Year 30: V35637004, Themis Image Year 31 V45047004

Page 15 *- Hellas Basin Images taken from JMARS and the Themis website at:*
http://viewer.mars.asu.edu/planetview/inst/themis#start

Themis Image Year 26: V08862013, Themis Image Year 27: V10397004,

Themis Image Year 28: V18671005, Themis Image Year 29: V27182009,

Themis Image Year 30: V35529007, Themis Image Year 31 V43291002

Page 17 *- Tharsis Region Images taken from JMARS and the Themis website at:*
http://viewer.mars.asu.edu/planetview/inst/themis#start

Page 17 continued, -

Themis Image Year 27: V14856001, Themis Image Year 28: V26487004,

Themis Image Year 30: V35383002, Themis Image Year 31: V44281001,

Themis Image Year 26: V04659002, Current Themis Image: V48688001

References

Information was used from the following reports:

NASA Sites:

- ***http://science.nasa.gov/science-news/science-at-nasa/2001/ast11oct_2/***
- ***http://science.nasa.gov/science-news/science-at-nasa/2003/09jul_marsdust/***
- ***http://www.nasa.gov/mission_pages/mars/news/mars20121121.html***
- ***http://science.nasa.gov/science-news/science-at-nasa/2001/ast16jul_1/***
- ***http://www.nasa.gov/mission_pages/mars/news/mars20121127.html***
- ***http://www.nasa.gov/mission_pages/msl/multimedia/vasavada-4.html***
- ***http://www.nasa.gov/mission_pages/mars/multimedia/pia16450.html***
- ***http://mars.jpl.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1395***
- ***http://science.nasa.gov/science-news/science-at-nasa/2007/20jul_duststorm/***
- ***http://www.nasa.gov/mission_pages/MRO/news/mro20120404.html***
- ***http://science.nasa.gov/science-news/science-at-nasa/2005/14jul_dustdevils/***
- ***http://www.nasa.gov/mission_pages/MRO/multimedia/pia15116.html***
- ***http://apod.nasa.gov/apod/ap050426.html***
- ***http://www.jpl.nasa.gov/news/news.php?release=2012-063***
- ***http://marsrovers.nasa.gov/gallery/press/spirit/20050819a.html***
- ***http://www.nasa.gov/mission_pages/msl/multimedia/pia07139.html***

JPL Sites:

- ***http://mars.jpl.nasa.gov/gallery/duststorms/***
- ***http://mars.jpl.nasa.gov/gallery/duststorms/dust-storm-animation.html***
- ***http://mars.jpl.nasa.gov/msl/multimedia/images/?ImageID=4892***
- ***http://mars.jpl.nasa.gov/gallery/duststorms/PIA02807.html***
- ***http://mars.jpl.nasa.gov/msl/multimedia/images/?ImageID=4196***
- ***http://www.jpl.nasa.gov/releases/2001/duststorm_010709.html***
- ***http://www.jpl.nasa.gov/news/news.php?release=2012-365***

References continued, -

JPL Sites:

- ***http://mars.jpl.nasa.gov/mro/***
- ***http://mars.jpl.nasa.gov/programmissions/science/goal2/***
- ***http://mars.jpl.nasa.gov/gallery/duststorms/Dust_Devil_E03-00938_annot.html***
- ***http://www.jpl.nasa.gov/video/index.php?all_videos&id=1072***
- ***http://marsrovers.jpl.nasa.gov/gallery/press/spirit/20050314a.html***
- ***http://marsrovers.jpl.nasa.gov/gallery/press/spirit/20090326a.html***
- ***http://marsrover.nasa.gov/spotlight/20050325.html***
- ***http://photojournal.jpl.nasa.gov/catalog/pia04157***
- ***http://www.nasa.gov/mission_pages/mer/images/mer20100728.html***
- ***http://descanso.jpl.nasa.gov/Propagation/mars/MarsPub_sec5.pdf***

Universe Today Site: ***http://www.universetoday.com/14892/mars-dust-storms/***

Ann Melnichuk Report: ***http://www2.hawaii.edu/~annam/marsfinalpaper.pdf***

Arizona State University: ***Background Talks (opens via webinar software tool, Elluminate)***

JMARS Instruments presented by Jonathon Hill, Mars Mission Planner
JMARS Map presented by Jonathon Hill, Mars Mission Planner
Mars Geology presented by Dr. Steve Ruff, Mars Planetary Scientist

European Space Agency:

http://www.esa.int/Our_Activities/Space_Science/Mars_Express

http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Mars_VideoTalk_Archive

http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Geography_of_Mars

http://www.esa.int/Our_Activities/Space_Science/Mars_Express_watches_a_dust_storm_engulf_Mars

http://www.esa.int/Our_Activities/Space_Science/Entry_descent_and_surface_science_for_2016_Mars_mission

http://www.esa.int/About_Us/Welcome_to_ESA/ESA_history/Voyages_to_Mars

http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Mars_northern_polar_regions_in_transition

Science Daily Web Site: ***http://www.sciencedaily.com/releases/2012/11/121128070512.htm***

http://www.sciencedaily.com/releases/2012/11/121121180100.htm

References continued, -

Science Daily Web Site:

http://www.sciencedaily.com/releases/2012/09/120906112603.htm

http://www.sciencedaily.com/releases/2012/03/120307111113.htm

http://www.sciencedaily.com/releases/2012/04/120406105725.htm

Facts About Mars: ***http://www.space.com/47-mars-the-red-planet-fourth-planet-from-the-sun.html/***

Other Sources of Information:

http://science.nationalgeographic.com/science/space/solar-system/mars-article/

http://en.wikipedia.org/wiki/Mars

http://www.planet-facts.net/facts_about_mars/facts_about_mars.html

http://www.enn.com/sci-tech/article/45263

http://www.spaceref.com/news/viewpr.html?pid=39298

Themis Images Used

- ***Gusev Crater***

- ***V00881003 V01243002 V01580003 V01605003 V02304003 V02666002 V02691003 V03440002 V03777003 V04189004 V04963003 V05662001 V05712002 V06798003 V07522003 V07547001 V07909002 V09544002 V09569002 V09881003 V10193002 V10480002 V10792003 V10817003 V11079003 V11391002 V11728003 V12614003 V12951002 V14461003 V15085003 V15372003 V16021003 V16932003 V17244004 V17556004 V18155004 V18467004 V19091003 V19378003 V22785004 V23384004 V23671003 V23958003 V24607002 V26117002 V26404004 V26978003 V31295004 V31320002 V33453001 V34027003 V34626003 V34651004 V35637004 V35974003 V36573003 V37434001 V37746002 V38033001 V38607003 V39181004 V39468003 V40042003 V40067003 V40953003 V45047004***

- ***Hellas Basin***

- ***V0123500 V06453003 V08575005 V08700004 V08725001 V08787003 V08837005 V08862013 V08887001 V09636005 V09798005 V09798006 V09873006 V09898005 V10397004 V10422002 V14815006 V14865004 V15077008 V15077009 V15177004 V15339005 V15464003 V15651004 V15751002 V16063001 V16063002 V16088002 V16175002 V16250003 V16387004 V16400003 V16562006 V16587010 V16587011 V16637005 V16687005 V16774004 V16924003 V16974003 V17024003 V17061009 V17398001 V17473005 V17498005 V17573006 V17598006 V17598008 V17623006 V17623008 V17685010 V17710006 V17735010 V17810007 V17835009 V17860005 V17860006 V17885007 V17897005 V17910005 V17922007 V17935005 V17997009 V18022007 V18097008 V18097009 V18222004 V18234006 V18234007 V18284008 V18284009 V18309006 V18534006 V18559007 V23114005 V23139005 V23139006 V23301007 V23376007 V23376008 V23401008 V23401009 V23426004 V23563010 V23663010 V23688004 V23713004 V23975007 V23975008 V24025007 V24050008 V24237006 V24262005 V24287010 V24337006 V24337007 V24362006 V24387007 V25847002 V25847003 V25872003 V25922007 V25984009 V26009009 V26009010 V26059003 V26084008 V26084009 V26159004 V26184008 V26184009 V26196007 V26221006 V26246010 V26246011 V26246012 V26271005 V26271006 V26296005 V26321010 V26346010 V26371003 V26396006 V26446005 V26458005 V26471008 V26471009 V26471010 V26483008 V26483009 V26496012 V26583011 V26583012 V26583013 V26658013 V26658014 V26658015 V26683014 V26683015 V26683016 V26708012 V26733011 V26783009 V26995008 V31599004 V33757003 V33969002 V33969003 V34044003 V34468004 V35504004 V35504005 V35529006 V35529007 V35529008 V40271005 V42380003 V43291002***

- ***Tharsis Region***

- ***V16391001 V10563003 V23155001 V35383002 V26487004 V14856001 V04659002 V44281001 V43607001 V48688001***