USING MULTISPECTRAL DATA TO TARGET POTENTIALLY GOLD-BEARING CONGLOMERATES IN THE MARBLE BAR BASIN, WESTERN AUSTRALIA

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The Marble Bar basin in Western Australia is approximately 65 km long and 55 km wide consisting of 175,000 hectares of land. Its vast size and remote location make mineral exploration cumbersome and expensive. A question was raised on how the basin could be explored in an economically efficient way that can maximize costs on the ground. After much thought, using remote sensing techniques with multispectral data was chosen for planning out potential areas that could host gold bearing conglomerates. This method ended up being a good way for doing office exploration before committing to the cost of expensive ground work.

GOLD DEPOSITS

For a gold exploration project to be successful it must result in a deposit that can be economically profitable. The four key factors for an economically profitable gold deposit are grade, tons, geometry, and depth.

- Grade – The gold grades much be high enough and rich enough to warrant mining.
- Tons – The deposit must have large enough quantities to warrant mining.
- Geometry – The deposit must be large enough to warrant mining.
- Depth – With excessive depth, the ore deposit will have excessive waste and cost to move rock.

The four criteria are dependent on each other. For example, the gold deposits in a Carlin style system (Carlin, Nevada) are highly disseminated with low grade but because of their geometry they have very large tons. They are also very shallow which results in very little waste rock and cost for moving with little or no grade. In other cases, such as the high grade lode deposits in veins, the high grade makes up for the lack of ton and geometry. If the veins are at surface then the waste will be little, but if the veins are deep, then the grade has to be high enough to pay for the cost of moving waste rock.

As much of the “low hanging fruit” that meet the four criteria have been explored and mined, companies are being forced to explore in regions that are remote with little infrastructure. With remote exploration comes the cost of travel, labor, supplies, drilling, and time. So any method that can be used to reduce the costs associated with remote exploration is a benefit to the company and the mining industry.

PALEOPLACER

The Marble Bar Basin, located in Western Australia, is one of several basins that have been identified as similar to the Witswatersrand (South Africa) style quartz pebble conglomerate systems known as a paleoplacer. It contains a series of sediment and volcanic packages that are comparable in age and lithology to that of South Africa. It is within two of the numerous sediment packages at Marble Bar that hopefully another Witswatersrand can be found.

In a paleoplacer, the gold was deposited in streams and alluvial sediments during a time when the gold in water would have been between 4 – 40 ppb in an oxygen deprived environment. Today the average amount of gold in water is about 4 ppt. After multiple iterations of sediment deposition, the deposits were fossilized into rock via compression and burial. These fossilized rocks are referred to as “reefs”. As for the criteria of a Witwatersrand style system, the gold is usually found in a zone a few meters vertically. However, the geometry of these systems can spread over a 100km horizontally. As a result of the geometry of these systems, Witwatersrand has produced over 1.5 billion ounces during modern times and is now being mined at depths of 4km. The overall unrecorded production could be as high as 3 billion ounces since the latter 1800’s resulting in the number one gold producing deposit. (Hennigh, 2013) Should a deposit be found in the Marble Bar Basin, it would have a good chance of being economically profitable.

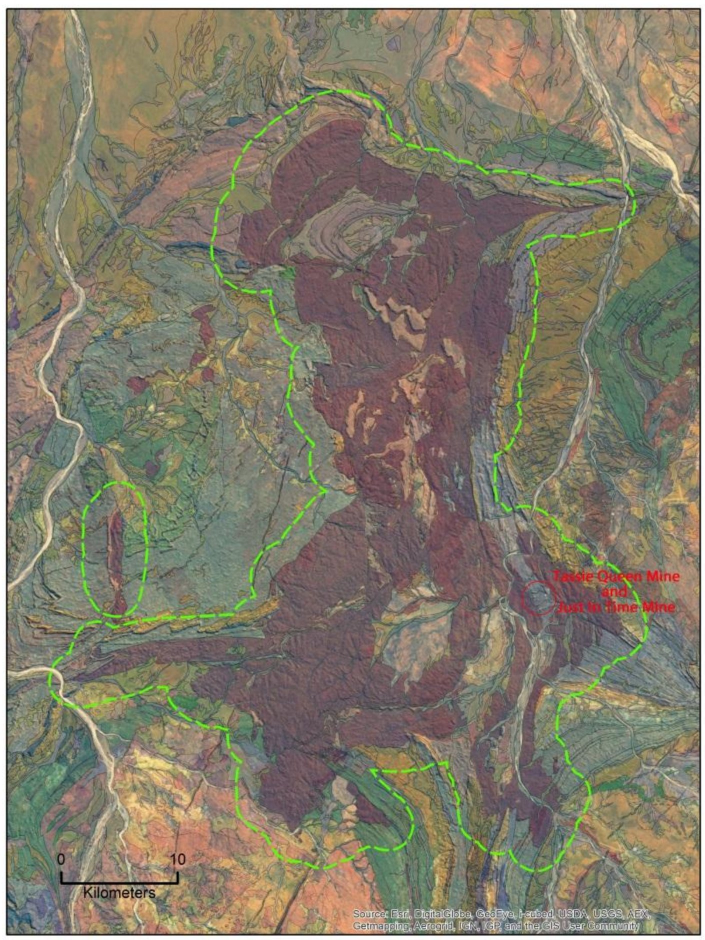


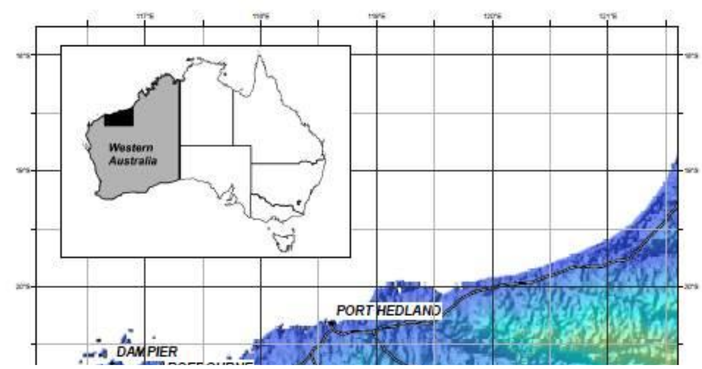
Figure 1 - The green outline indicates the Marble Bar basin boundary. Volcanic units are dark while many of the sediment packages are in lighter colors. The Tassie Queen and Just in Time mine locations are on the eastern flank of the basin

MARBLE BAR BASIC GEOLOGY

The Marble Bar basin has two major volcanic units; the Mount Roe Basalt and the Kylena Basalt. It is below these two volcanic units that the sediment packages that contain potential gold-bearing conglomerates lie. Although there are additional sediment packages that lie above these volcanic units, it appears that they are void of any gold-bearing conglomerates.

The lower unit, Bellary conglomerates (BScb) within the Bellary Formation, can be anywhere from 10-100m thick and lies immediately below the Mount Roe basalt. It is within this unit that the Tassie Queen and Just in Time Mines were worked in the early 1900's. These mines produced approximately 20k ounces gold. (Hennigh, 2013) Although not much, these outcrops still show the potential for economic value as the mines were very small and have upside today.

The second unit that contains the potential to host gold bearing conglomerates is within the Hardy Formation. The Hardy sandstone package can be anywhere from 50-100m thick and lies immediately below the Kylena basalt and above the Mount Roe basalt. Within the sandstone package are the Hardy conglomerates (HScb) that are the same unit that hosts gold within the Nullagine basin located approximately 60km south-southeast of the Marble Bar Basin. In 2012, Novo Resources defined an initial resource of 421,000 ounces of gold at Nullagine within the Hardy sandstone unit. The Hardy sandstone at Marble Bar has yet to reveal a potential economic gold bearing conglomerate.



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REGIONAL ACCESS AND TERRAIN

Access within the Marble Bar region is limited to one major road and a handful of secondary roads. The major road, Marble Bar road, travels between Nullagine and Port Hedland. It is a two lane paved road that allows for major travel along the eastern and northern flanks of the basin.

Numerous secondary roads are limited within the basin. Mostly these exist in the southern portion of the basin. Essentially, no roads exist in the northern portion of the basin. The roads that do exist can range from gravel to two track field roads. The conditions may vary depending on the

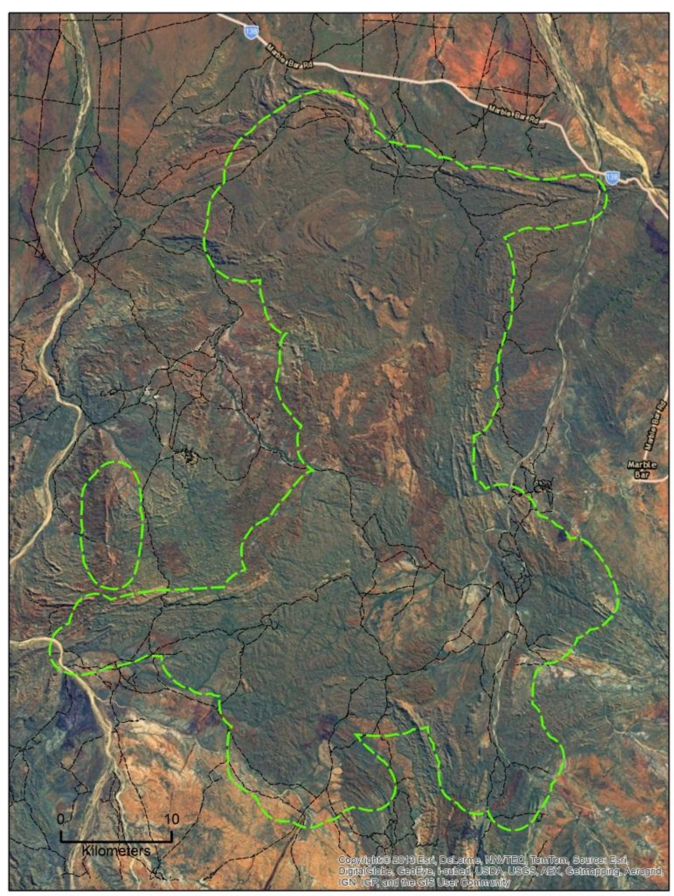

Figure 3 - Road network within the Marble Bar basin

time of the season and when they were last traveled.

Even with these secondary roads, most access within the inner portion of the basin is only available via helicopter, all-terrain vehicle, or foot. Because of the volcanic cover, the terrain is rough with extensive boulders making overland travel hard. Hills and cliffs also complicate ease of travel. Ravines and streams, during the slightest rain, fill quickly making crossings difficult.

In general, the remoteness of the basin's interior requires thorough thought and planning prior to any work or exploration.

REMOTE SENSING AND MINERAL EXPLORATION

Although direct ground observation cannot be replaced, remote sensing can form a valuable supplement to provide information and a perspective that is not otherwise available. By having knowledge of the basic geology of an area and the type of deposit that could be formed within a region, remote sensing can help delineate ore material or their pathfinders. (Rajesh, 2004) This very thought process is why remote sensing was chosen to target potential conglomerates within the Marble Bar Basin.

There are different types of multispectral data used for analysis of mineral identification. Ideally multispectral or hyperspectral data flown with good resolution would be preferable. However the cost of such data is not feasible for a grass roots project. Another option was to use Landsat data. Landsat data has been very successful in mapping alteration. (van der MEER, 2011) However, since conglomerate systems are usually not altered in the traditional scenario of heat and fluid movement, it would be very complicated to use in this exploration scenario.

There are numerous articles and papers that thoroughly documented success of ASTER (Advanced SpaceBourne Thermal Emission and Reflection Radiometer) data used for mineral identification. It differs from Landsat in multiple ways when it comes to mapping. ASTER has a finer resolution in Visible Near Infrared bands (VNIR); it has five bands across the same wave length of short waver infrared (SWIR) bands and has 5 bands across the thermal infrared (TIR) bands as compared to one in Landsat data (Agar, n.d.). However the primary reason to use ASTER is its cost. ASTER is inexpensive data considering the number of bands that are available and the ground that it covers, over 60^2 km per tile at approximately $100 per tile. So it was logical to decide upon ASTER for analyzing the potential gold bearing conglomerate host areas. Where the complication arose was how to use the ASTER data to the maximum capability of the project.

ASTER data has 15 bands. There are four bands of Visible Near Infrared (VNIR) with a 15m resolution, six bands of Shortwave Infrared (SWIR) with a 30m resolution, and five bands of thermal infrared (TIR) with a 90m resolution. The four bands of VNIR are useful for a variety of imagery uses to include vegetation, stereoscopic mapping, and water detection. It is the SWIR and the TIR that have the most

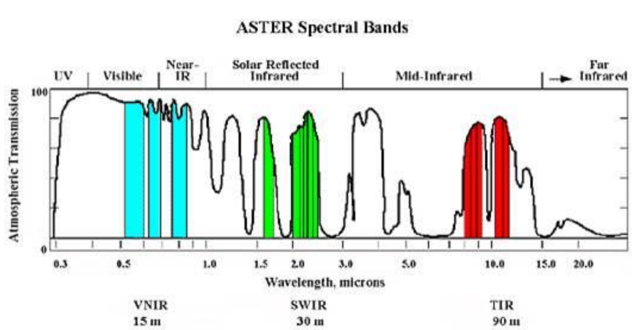

Figure 4 – Spectral ranges of ASTER bands

use in mineral exploration. Either of the types or a combination of the two has been found useful in identifying clays, mafics, and silica material. This is usually done using ratios or a combination of the ratios of bands based on the reflectance spectral profile of the object. (Kalinowski, A., & Oliver, S., 2004)

Despite the aforementioned reasons that ASTER is useful in exploration, it does have its drawbacks. Because of the poor resolution in SWIR and TIR, it is not useful for supervising classification and choosing regions of interest (ROI) for mineral selection. In other words, if you have an area that you know contains a good sample point for observing a rock type but the area is not consistently greater than 30m to 90m in size, it cannot be used as an ROI. ASTER can also have other problems such as line striping, overlapping of spectrums causing misidentification, or poor imagery in areas with cloud cover or fire damage.

PROCESSING ASTER

Two tiles of ASTER data were acquired that covered the entire Marble Bar Basin. The data for the both tiles was from 27 November 2000. It was anticipated that there would be some slight differences in the datasets but not enough to impede a grassroots exploration project.

The data acquired for this project was ASTER Level 1B which had been georefenced and atmospherically corrected to optimize thermal emissivity in the TIR bands. However it was delivered in .dat files that needed to be processed for viewing. This series of four files contained the different bands. The first file contained the three VNIR bands. The second HDF file contained the backward VNIR band. The third file contained the six SWIR bands. Lastly the fourth file contained the five TIR bands.

To use ASTER as a combined data set the data has to be processed. Utilizing ENVI for all aster data processing, all of the .dat files from the North area except for the file containing the backward VNIR band 3b were opened to show each individual band. These individual bands were then layer stacked into one file set of 14 bands using a 15m resolution nearest neighbor (Figure 5). The choice of 15m resolution was chosen because the VNIR bands are also 15m. Although the VNIR bands are not be used in mineral exploration for Marble Bar, they may be needed for other scenarios. The resolution change allowed for bands from different spectrums within the data set to have the same size pixels for pixel math in processing ratios. The same process was then utilized for the southern tile covering the basin.

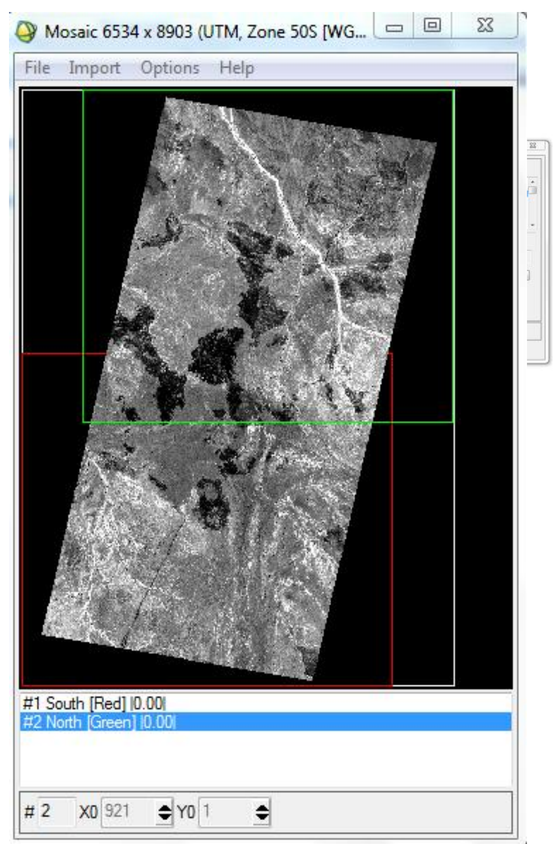

Figure 5 - Two data sets mosaicked into one data set of 14 bands covering the entire basin.

The two data sets were next mosaicked into one data set. The mosaic was completed using the “Georeferenced Mosaic” method in ENVI. The two data sets were imported with option to edit properties. Data values with a value of 0 were set to transparent. This alleviated overlap gaps between the datasets with the value of zero. The mosaic was exported creating one complete data set of 14 bands for the entire basin. (Figure 6)

RATIO WORK AND MINERAL DECISIONS

When doing ratio work, the object is to find the spectral reflectance pattern that works for a particular mineral, rock type, or mineral subject. Using quartz or silica as an example, there is a reflectance high of quartz in TIR Band 12 at approximately 9 µm (micrometer) and a reflectance low in TIR Band 14 at 11.25 µm (micrometer). If you take the reflectance low, Band 14 and divide it by Band 12, you will create a ratio that will highlight quartz (Kalinowski, A., & Oliver, S. , 2004). (Figure 7)

Having knowledge of different ratios from numerous resources, most importantly Kalinowski and Oliver's work of different mineral ratios, the challenge was deciding on the better ratios, suitable for the target conglomerates, of the Marble Bar Basin. There were numerous experiments of trial and error with the different ratios that allowed the user to observe the data, to feel out ENVI and to learn how to process ratios. Once use of the software and creation of ratios became easier, the real task at hand was deciding which ones to use.

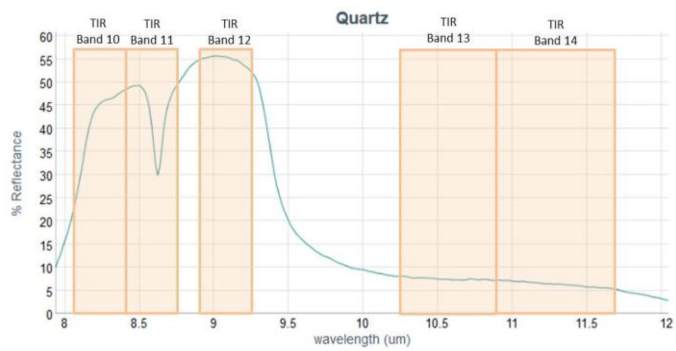

Figure 7 - Quartz spectral range

To identify the conglomerates that have the potential to host gold, different ratios were created that would identify minerals that could either host conglomerates or not host such conglomerates. This resulted in ratios that could be processed using band math, which in turn created a final product that showed areas of potential conglomerates. This band math was similar to raster math if used in ArcGIS.

The first characteristic in the conglomerates is the presence of quartz pebbles and boulders.   A ratio of Band14/Band12 was created to show these characteristics (Kalinowski, A., & Oliver, S., 2004). This ratio was suited well for highlighting quartz rich rocks to include sandstones, quartz pebble conglomerates, veins, and quartz sandy areas. It was noted that by using this ratio many of the major streams and creeks were highlighted in the results. (See Appendix Image 1)

Another characteristic of the conglomerates is the presence of silica. Silica is found in the matrix of sandstones and quartz pebble conglomerates. Using a ratio of B13/B10, areas with high amounts of silica can be detected (Kalinowski, A., & Oliver, S., 2004). In many cases, since silica and quartz have similar reflectance, you see areas that were also detected by the quartz ratio. This includes major creeks that have a high sand content. (See Appendix Image 2)

The last characteristic of the conglomerates is the clays that also make up the matrix. The matrix consists of sericite, muscovite, illite and smectite, a ratio of (b5+b7)/b6 is used to identify these minerals (Kalinowski, A., & Oliver, S., 2004). The presence of areas with high clay is very different from the quartz and silica ratios but also covers areas that are present in those ratios. One thing to note is that kaolinite is also present in this ratio. Areas that tend to pool water may have a high content of kaolinite present. (See Appendix Image 3)

Unlike previous ratios, the ratio used for the clays was from the SWIR bands. One complication that appears in SWIR is the presence of fire (Figure 8). This is one reason why it is important to know the data set that is picked for the region.

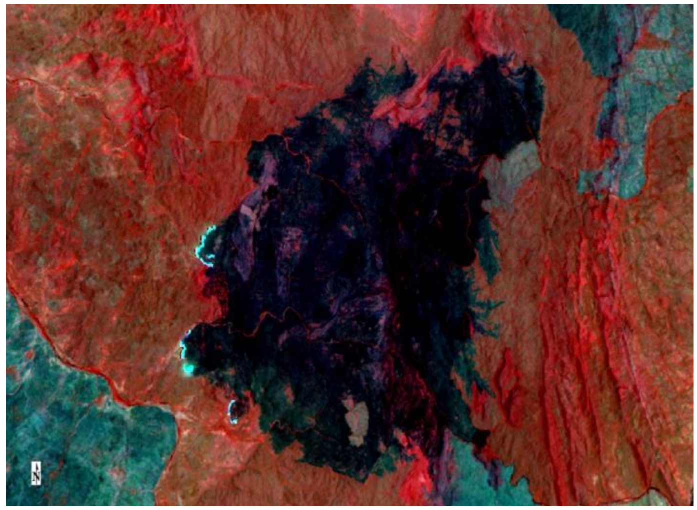

Figure 8 - Burn area seen in the SWIR bands

The next set of ratios involved areas within the basin that do not have characteristics of the conglomerates. The first of these ratios is one that highlights the mafic rocks such as basalt, dolerite and gabbro. These are all extrusive or intrusive igneous rocks that typically cover the conglomerates. The ratio that highlights mafic rocks is b12/b13 (Kalinowski, A., & Oliver, S., 2004). As seen in Appendix Image 3, much of the basin is covered with mafic material.

Another characteristic not found in the conglomerates is the presence of epidote, chlorite, and amphibole minerals. The minerals are associated mostly with the igneous rocks in the Marble Bar Basin. A ratio using SWIR bands (b6+b9)/ (b7+b8) is used to highlight these minerals (Kalinowski, A., & Oliver, S., 2004). Using this ratio there is an area of extreme highlights within the southern portion of the basin. This is mostly likely from granites that are present in that area (See Appendix Image 5).

The last characteristic not found in the conglomerates is the presence of carbonates. Carbonates are usually present in ultramafic rocks, such as igneous rocks, as a form of alteration. The ratio of b13/b14 can be used to highlight these minerals (Kalinowski, A., & Oliver, S., 2004). Carbonates such as talcs, calcite, or calcrete can be seen across the basin and are void in areas where sandstone and conglomerates are potentially present. One thing to note is that calcite or calcrete can be remobilized from weathering igneous rocks and can be found in heavy concentrations within the nearby soil sediments (See Appendix Image 6).

Once all of the ratios were completed, it was time to use a band math of the different ratios that would highlight areas for potential conglomerates that could be gold bearing. The final band math was (r1 +r2+r3)-(r4+r5+r6). In this formula r1 = quartz rich rock, r2 = silica, r3 = sericite, muscovite, illite, and smectite, r4 = mafic rocks, r5 = epidote, chlorite, and amphibole, and r6 = carbonates. The results of the band math highlighted numerous linear features to be explored within the basin. The most important item, considering the size of the basin, is that the ratio combination results are guiding where not to go. (See Appendix Image 7) Thus creating a scenario where costs and valuable resources are not wasted exploring ground that does not have the potential for gold bearing conglomerates.

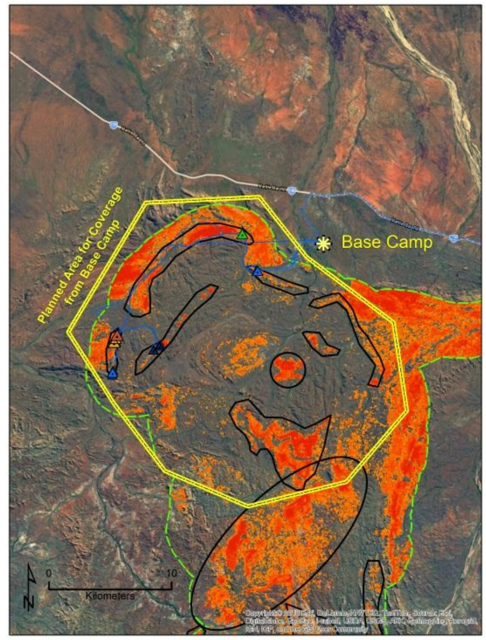

Figure 9 - Area to be covered by base camp. Blue lines show tracks from the first three days.

FIELD EXPLORATION

After much analysis of the terrain and budget constraints, a hit and run approach was planned for the exploration of the Marble Bar Basin. This would allow for quick viewing of the targets within a two month period. The initial plan was to explore the northern and southern areas as part of base camp ground exploration and the central core area via air exploration. For the ground exploration, field bikes would be used to traverse the country side, allowing for close viewing of outcrops, and to carry gear for "fly camps." A "fly camp" is camping with only the bare essentials for an overnight away from the base camp. The air approach would be the final part of the program to quickly hit areas that could not be reached via ground exploration.

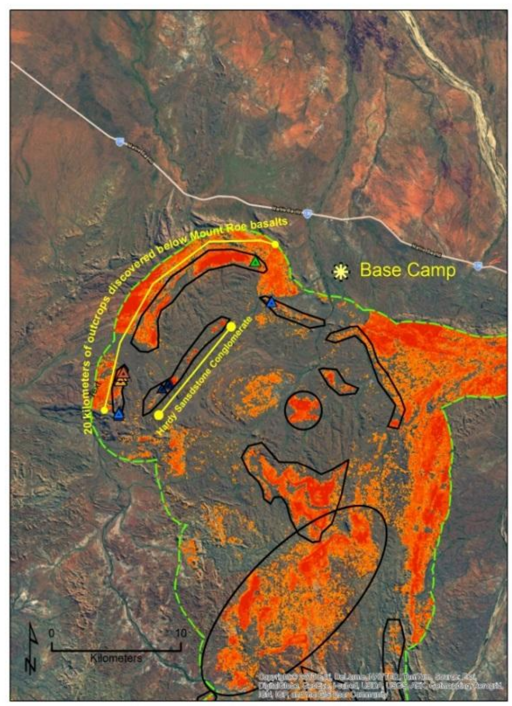

Figure 10 – Sporadic conglomerate outcrops discovered over a distance greater than 20 kilometers was a significant find.

A base camp was established just north of the basin in mid-May. This allowed for easy access to the northern areas within the basin. After three days, including one night with a fly camp, a trail was established to travel across much of the northwestern portion of the basin (Figure 9). During the first three days, 28 samples were collected. The results ranged from traces of detectable gold to a grade of 15.95 gpt (grams per tonne).

The most impressive information gained from the first three days of this ground approach was the revelation that there was a conglomerate band below the Mount Roe Basalt that could be traced from different outcrops for over 20 kilometers.   Although not all of the samples graded economically adequate, the existence of a consistent linear feature allows for more exploration and drilling that could reveal an economic deposit. Also, a conglomerate within the Hardy Sandstones was discovered nestled between the Mount Roe Basalt and the Kylena Basalt units. This conglomerate had traces of detectable gold, although further exploration is not economical at this time (Figure 10).

Because of the remote terrain and trouble with vehicles, the helicopter portion of the project was expedited after five days. During the four and a half days of aerial exploration, the majority of the basin was explored with emphasis on the areas targeted by ASTER work. The result was the identification of more and more conglomerate samples that coincided with the results of the ASTER ratio process. Also facilitated was an understanding of how the basin dips. In the north, a steep dip along the perimeter of the basin toward the center was noticed.   Within the central and southern portions, the basin has a shallow dip towards the center. By the end of the helicopter program, a total of 90 plus samples had been taken across the basin in a hit and run approach. These results ranged from low anomalous gold detected to high grades in excess of 10 gpt.

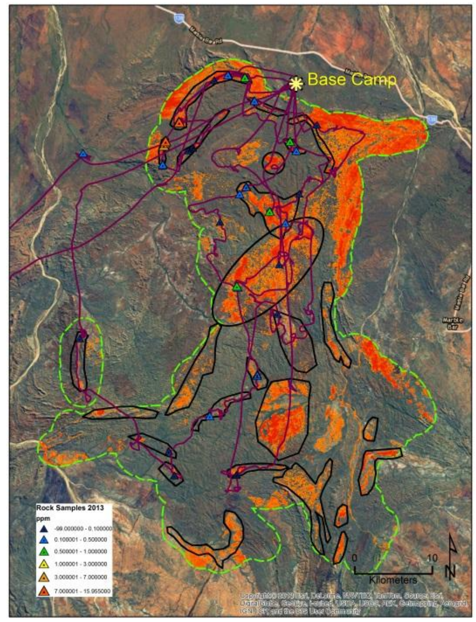

Figure 11 - Aerial exploration program over 4.5 days resulted in over 90 samples taken and confirmation of the ASTER targets.

The conglomerates that were discovered from the exploration were from both the Bellary Formation below the Mount Roe Basalts and within the Hardy Sandstones below the Kylena Basalt. Only in the northern flanks were the Bellary conglomerates discovered. As noted earlier, these were consistent and could be traced over long distances.   As you move south in the basin most, if not all, of the target areas within the center of the basin were Hardy Sandstones. The Hardy Sandstone conglomerates had lower grade results from sampling (Figure 12). However the results in many of the areas were intriguing enough that follow up work will be scheduled.

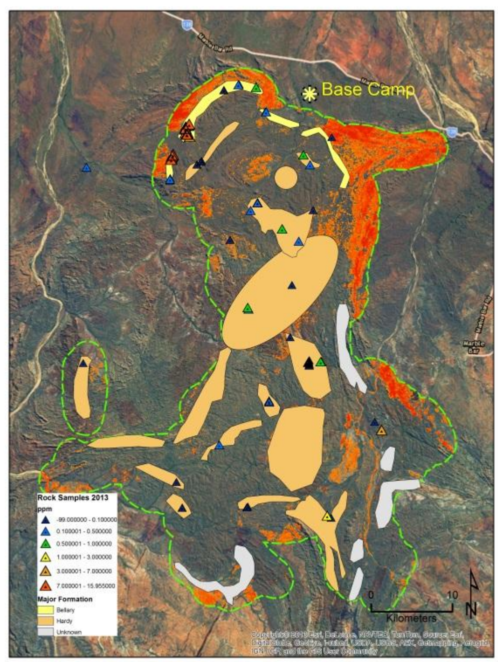

Figure 12- Results of exploration showing the units targets were associated with.

Successful for gaining a better understanding and for making the hit and run much quicker, the excessive helicopter time put a dent in the budget of the exploration program. This resulted in reduced time and budget for follow up. While there were areas with low grade gold detected that needed additional exploration, the emphasis for the follow up work had to be geared toward verifying whether zones with higher grades > 1ppm Au would warrant drilling exploration.

In early July, a systematic approach of exploration was carried out within two zones of higher grade results. These areas were named Contact Creek North and Contact Creek South. The follow up sampling program within the two zones accounted for an additional 150 samples within the area. With results ranging from anomalous to an excess of 7 gpt to 15 gpt in multiple samples, a viable drill target was established (See Appendix Image 8).

Once the two high grade areas had been followed up with additional sampling, an extra couple of days of exploration in the southeast were accomplished via ground. When all was said and done, over 344 samples had been taken across the basin. Of those samples, 118 had low level anomalous gold of 0.1 – 1 gpt and 69 had mid to high level gold > 1 gpt (See Appendix Image 9). Numerous areas with low level gold will require further exploration in the 2014 season along with areas that were skipped in the 2013 season.

FINAL SUMMARY

The use of remote sensing to highlight potential targets for exploration was clearly a success. It allowed for the identification of areas that possessed potential conglomerates. A very high number of these were verified by the ground work. Because targets were identified ahead of time for exploration using ASTER, much of the exploration budget was kept in check and valuable time and resources could be directed with a laser like purpose. Due to the ASTER analysis, the process was both efficient and effective; time was spent simply on covering areas that met criteria.

Papers, References, and Public Data Used for Research:

The ASTER L1B data was purchased through the online Data Pool at the Earth Remote Sensing Data Analysis Center (ERSDAC), (https://ims.aster.ersdac.jspacesystems.or.jp/ims/html/MaiMenu/MainMenu.html).

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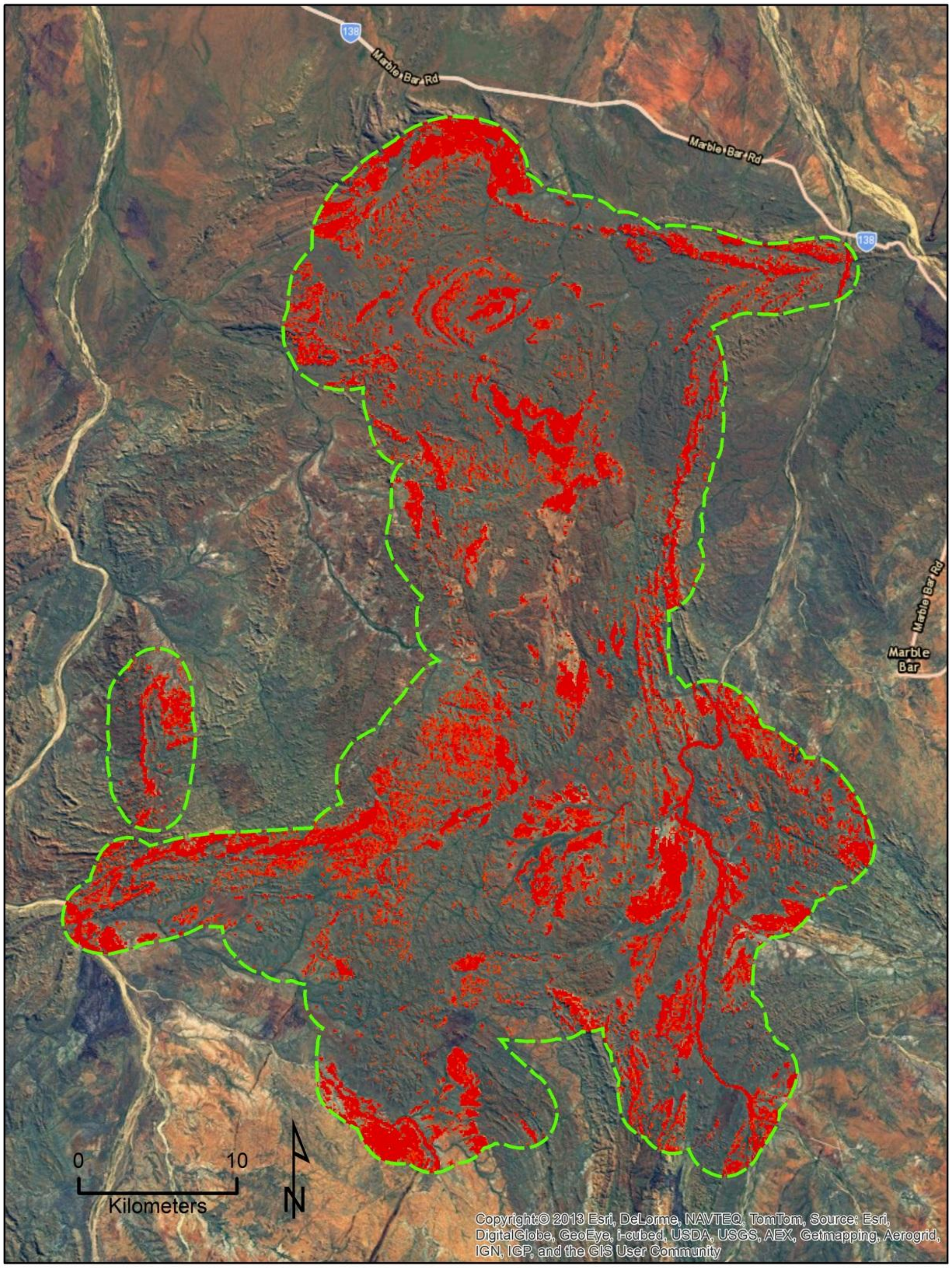
Hennigh, Dr. Quinton. (2013, April 30). Personal Interview Regarding Paleoplacer Deposits and the Witswatersrand Deposit. (K. Box, Interviewer)

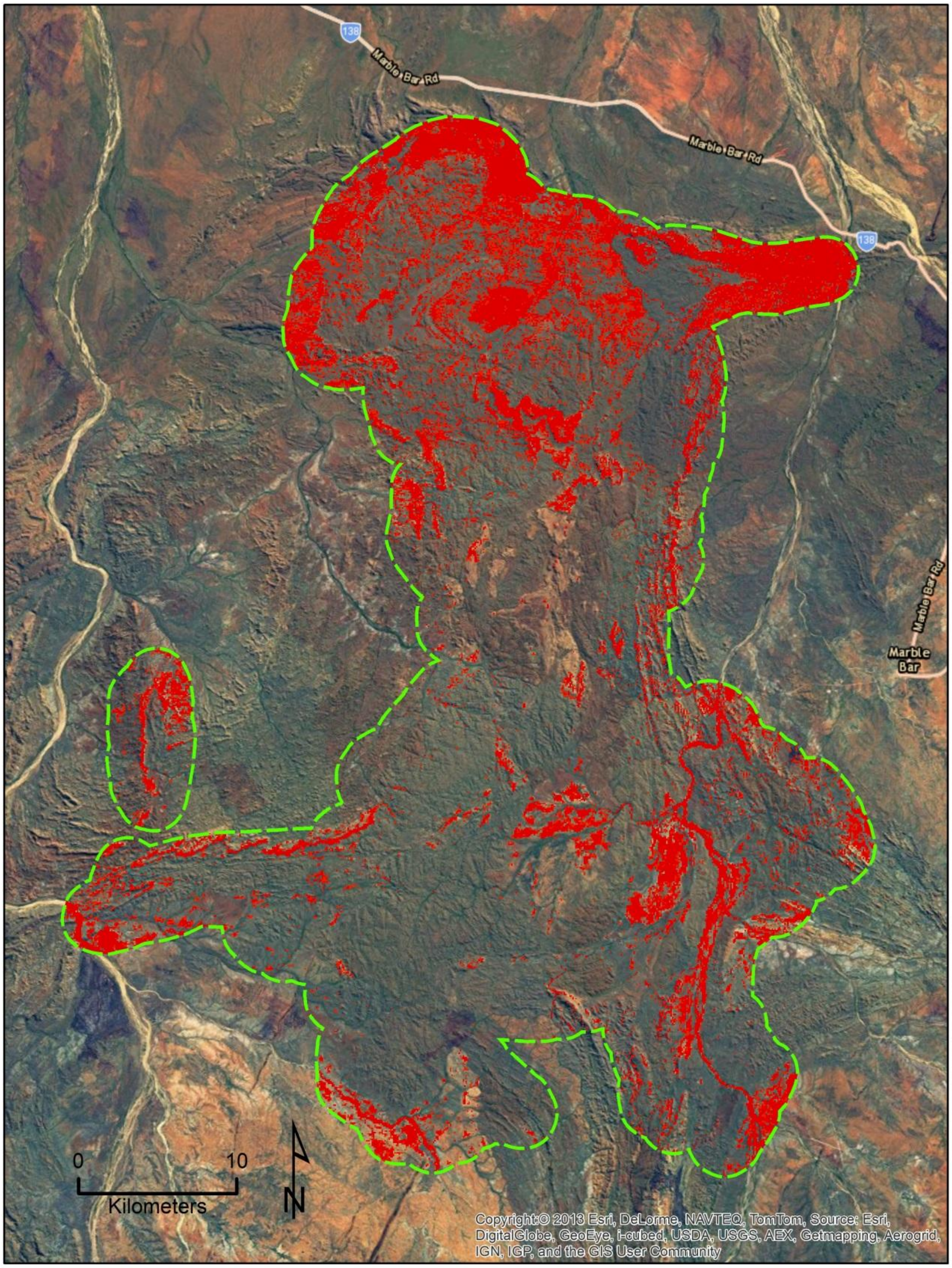
Proposal Citation

Hennigh, Dr. Quinton. (2013, April 30). Personal Interview Regarding Paleoplacer Deposits and the Witswatersrand Deposit. (K. Box, Interviewer)

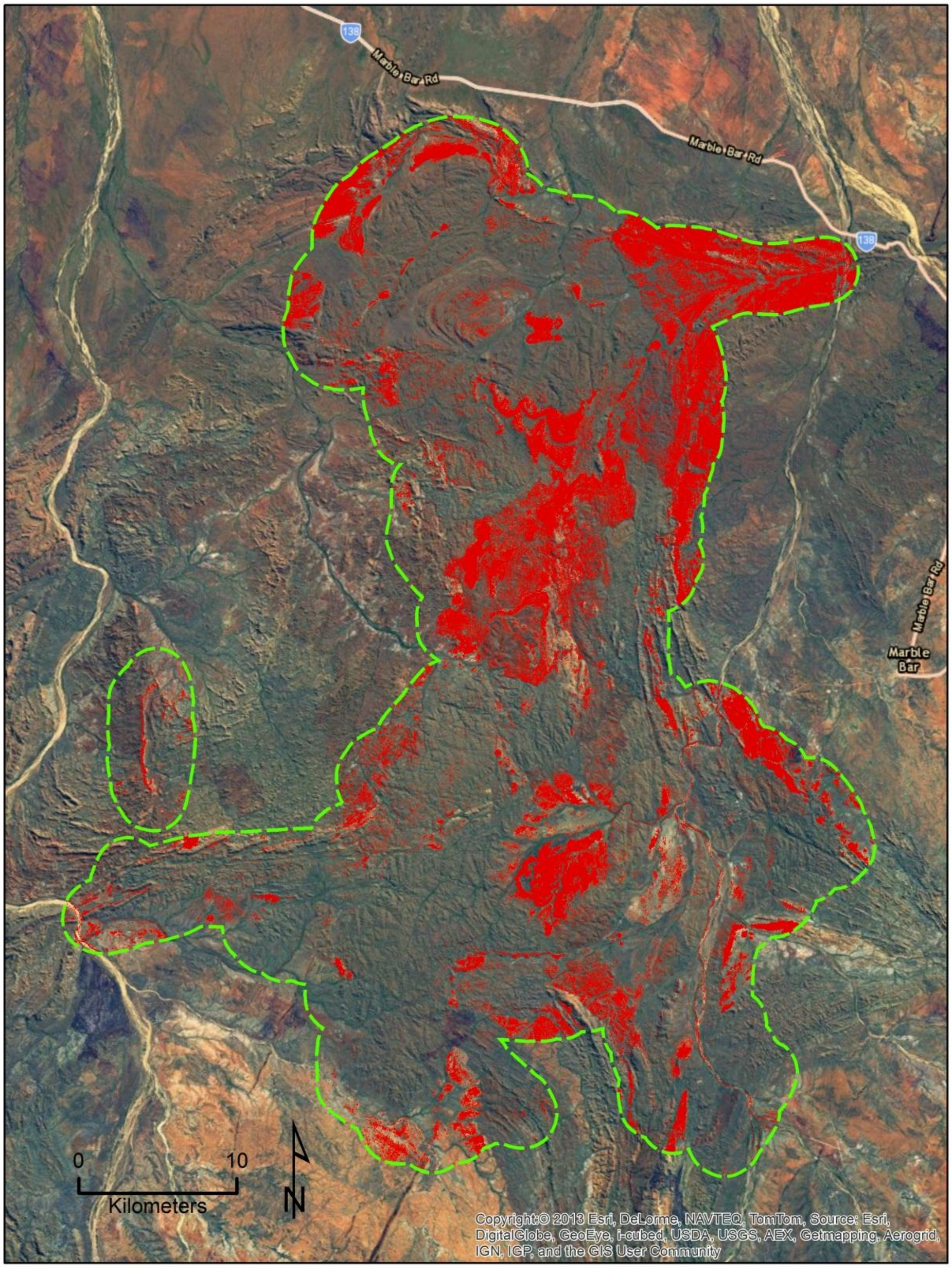
APPENDIX



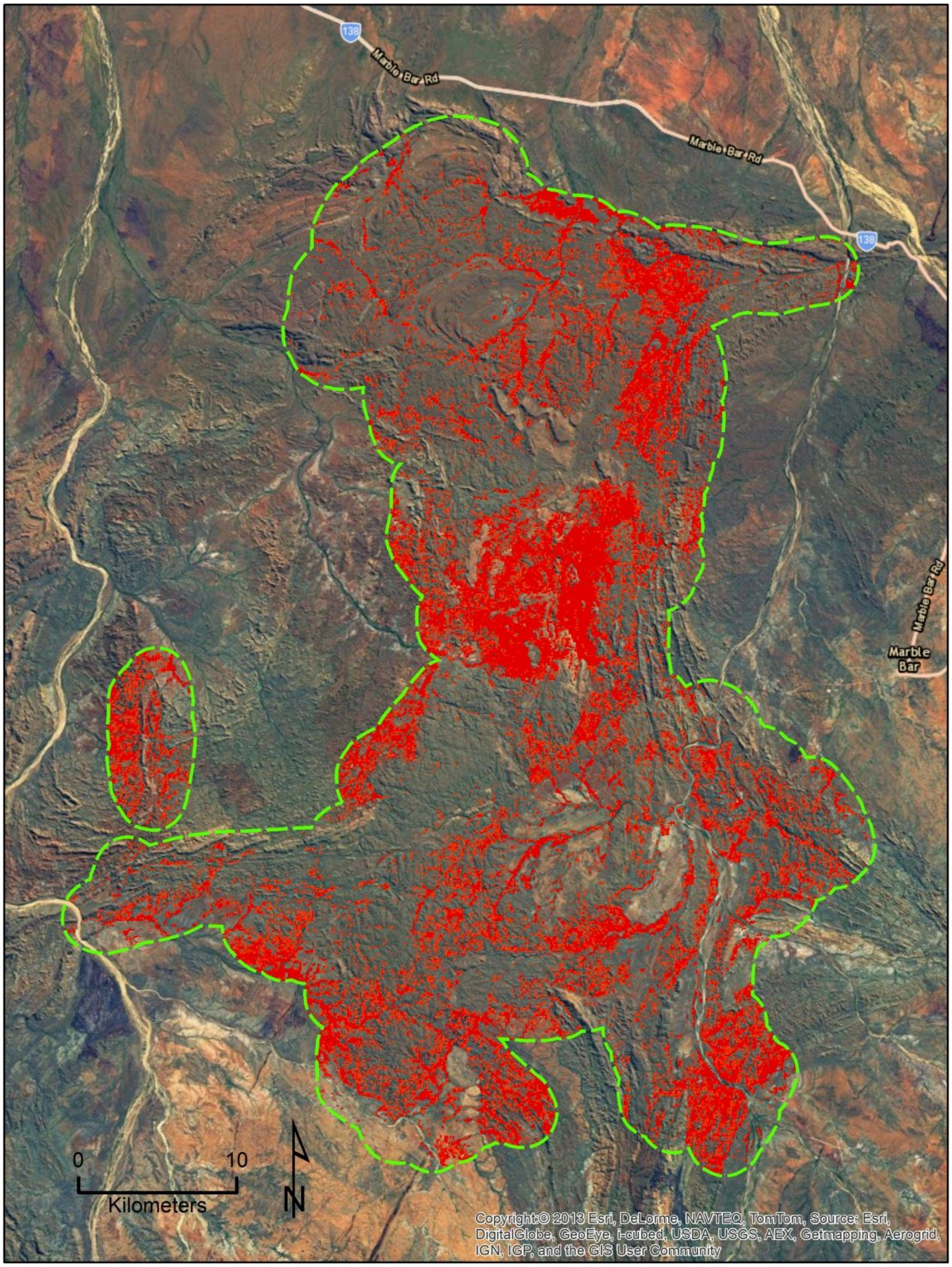
Appendix Image 1 – Highlight of quartz ratio of b14/b12 highlighting quartz and quartz bearing minerals



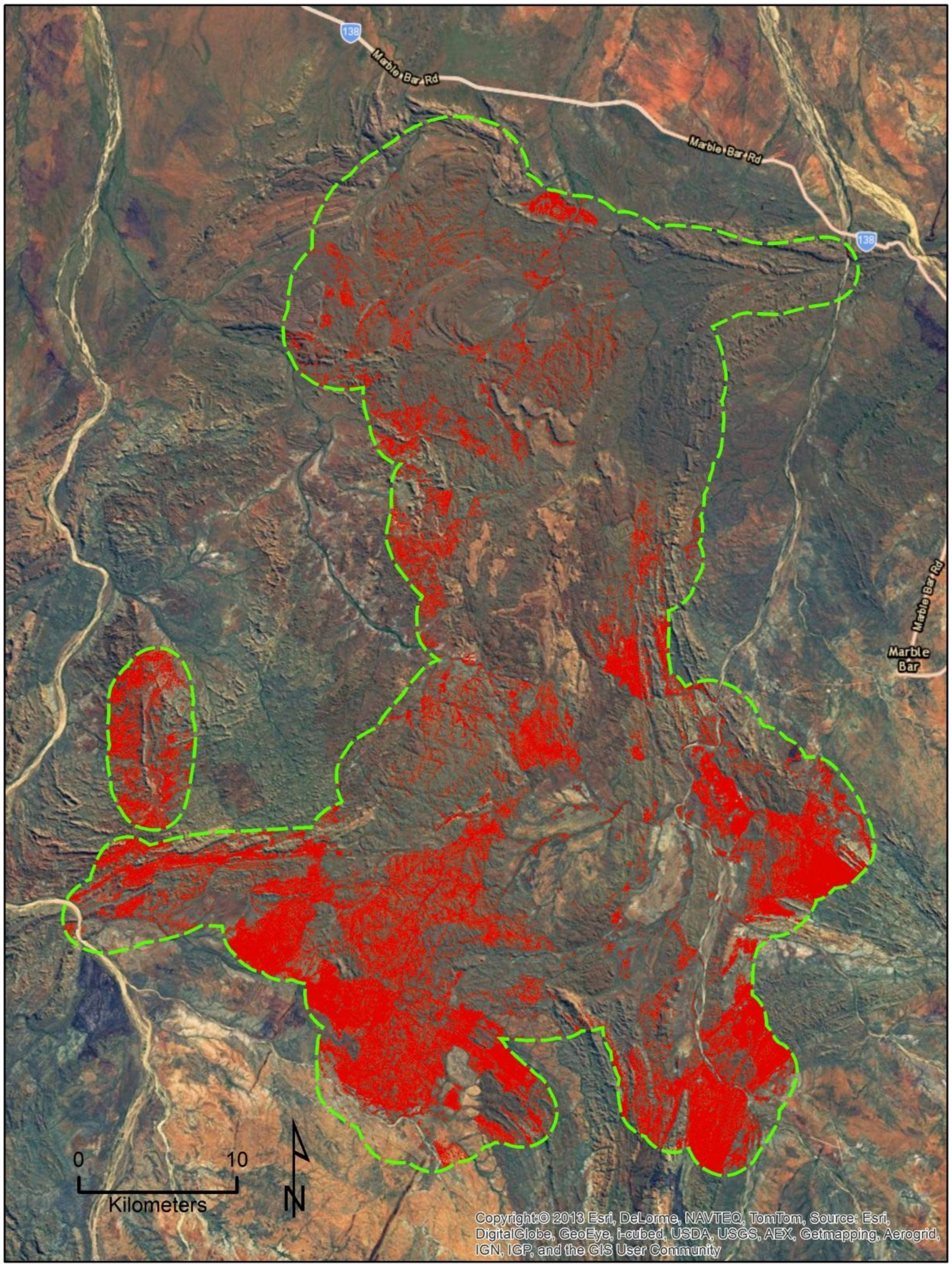
Appendix Image 2 - Areas with high silica content highlighted



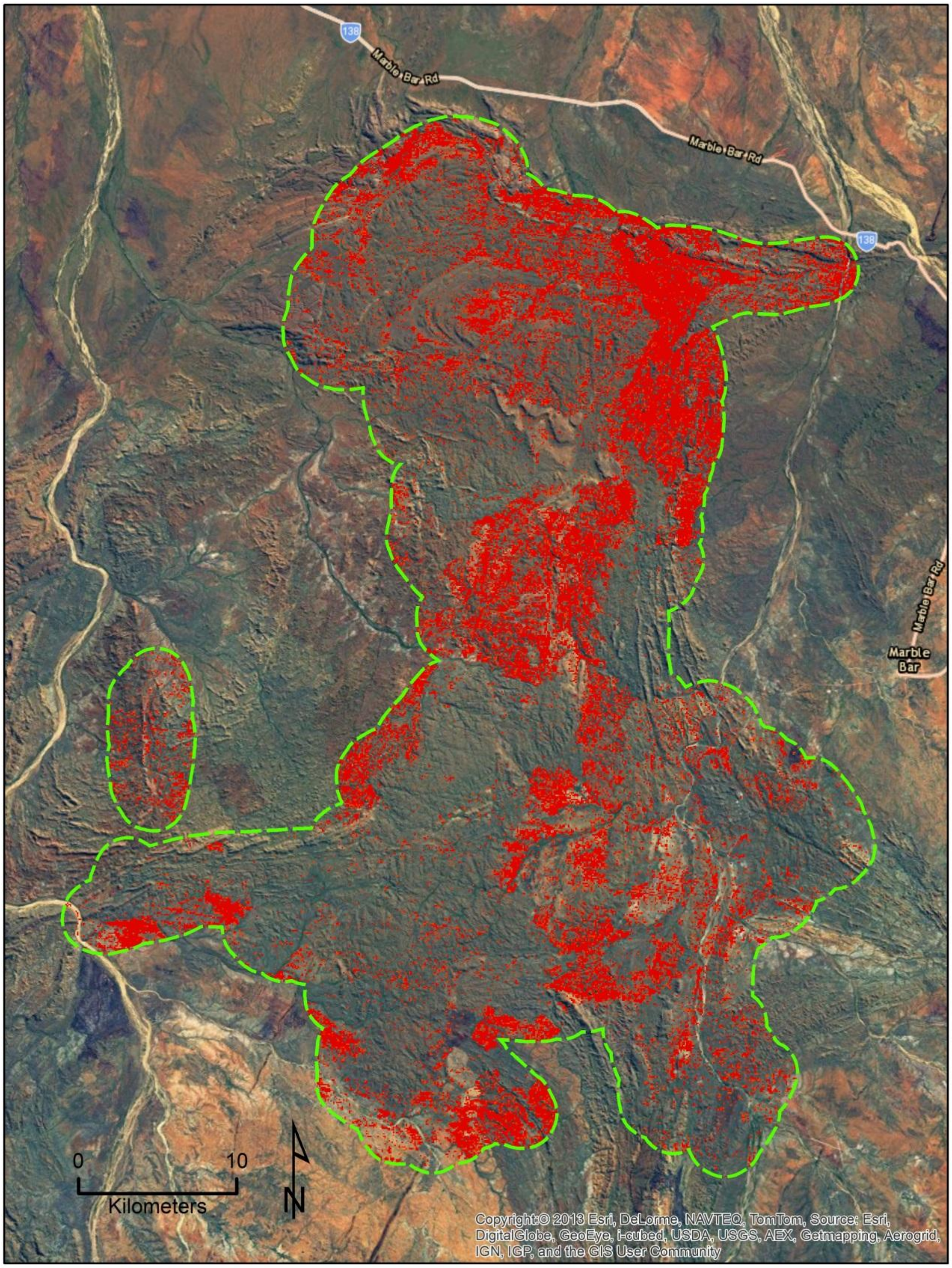
Appendix Image 3 - Ration of (b5+b7)/b6 showing clays that are present within the matrix of sandstones and conglomerates.



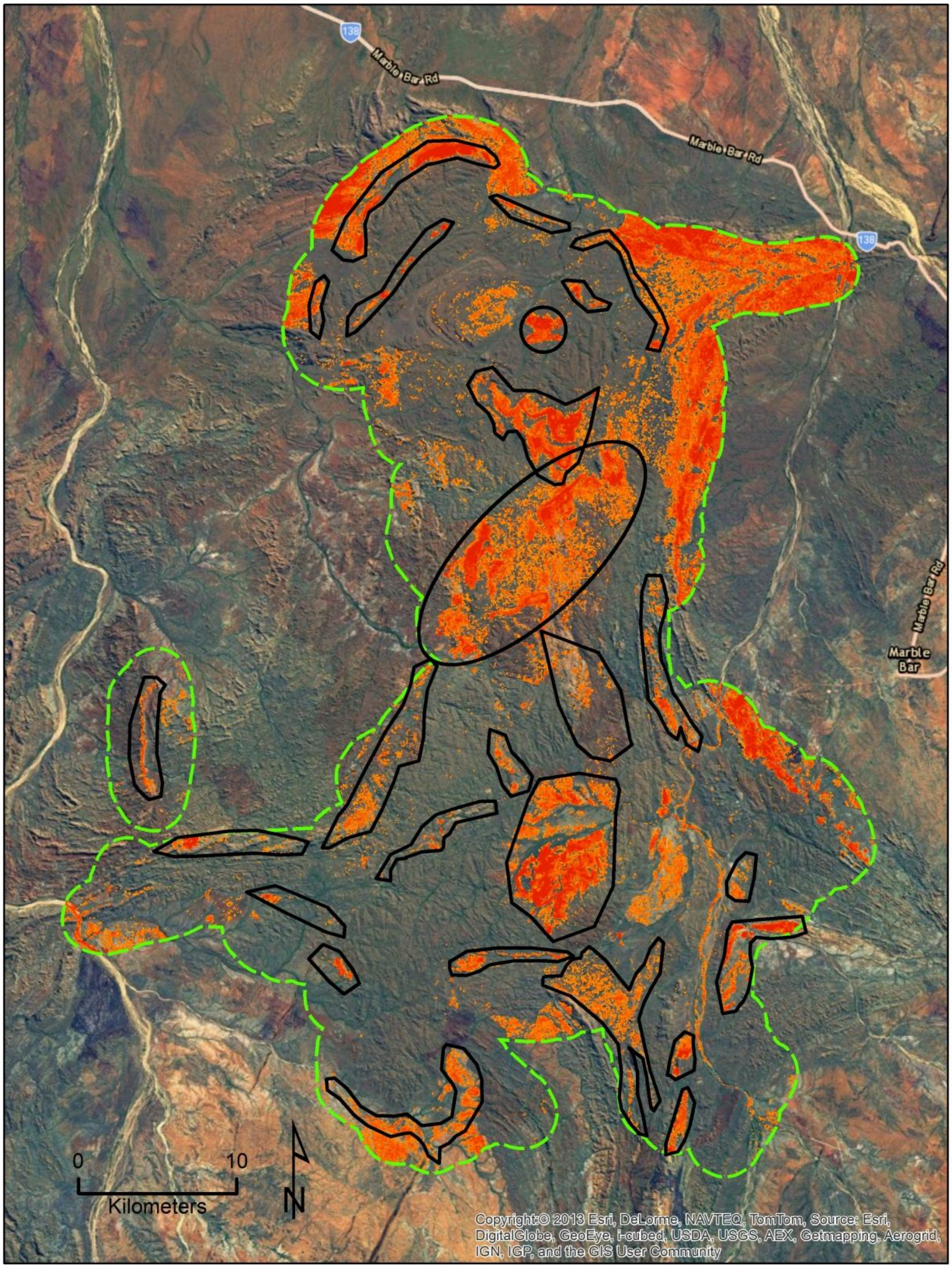
Appendix Image 4 - Mafic ratio of b12/b13 showing rocks such as basalt, dolerite, and gabbro.



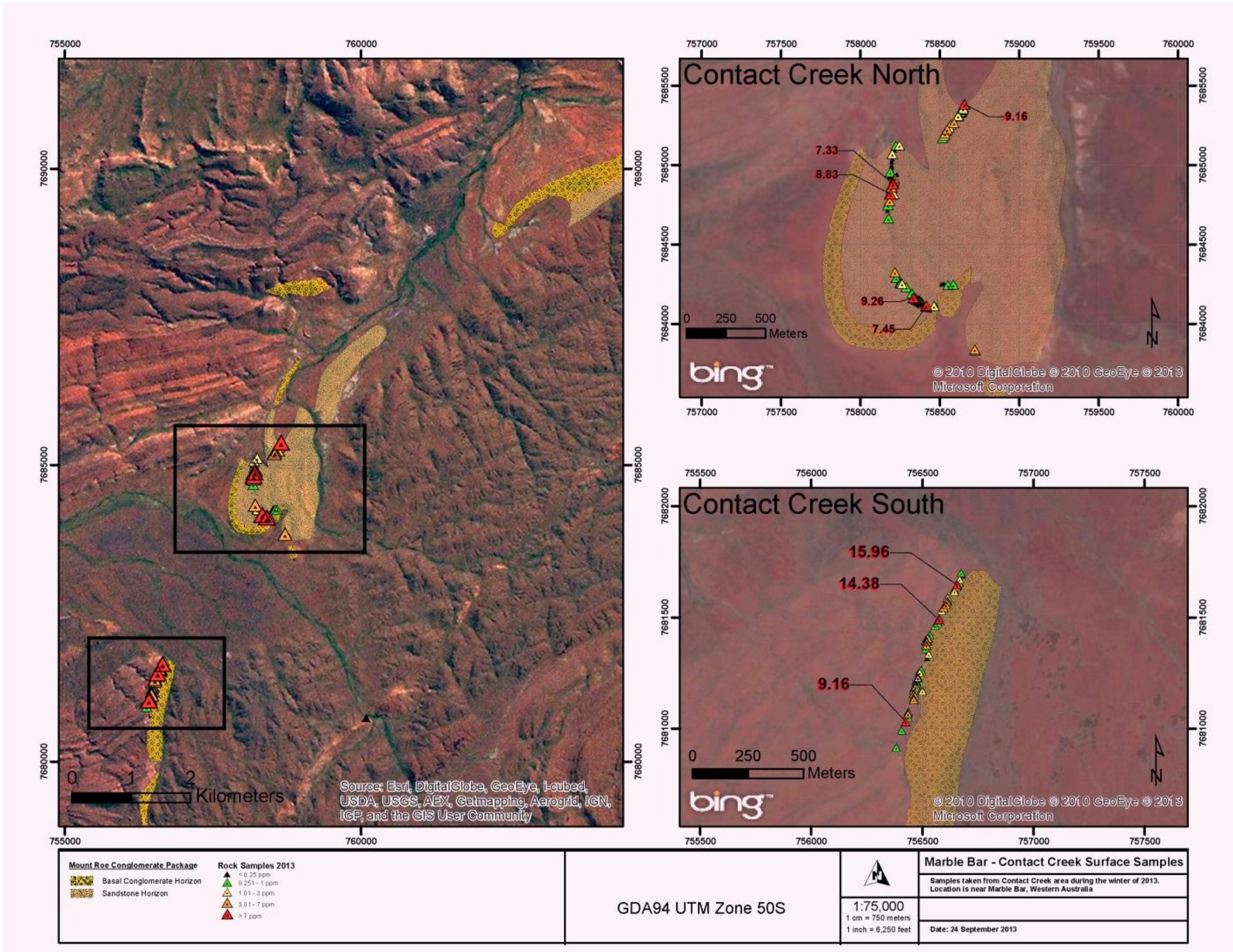
Appendix Image 5 - Ratio of (b6+b9)/(b7+b8) showing minerals such as epidote, chlorite, and amphibole. These minerals are associated with igneous rocks in the Marble Bar basin.



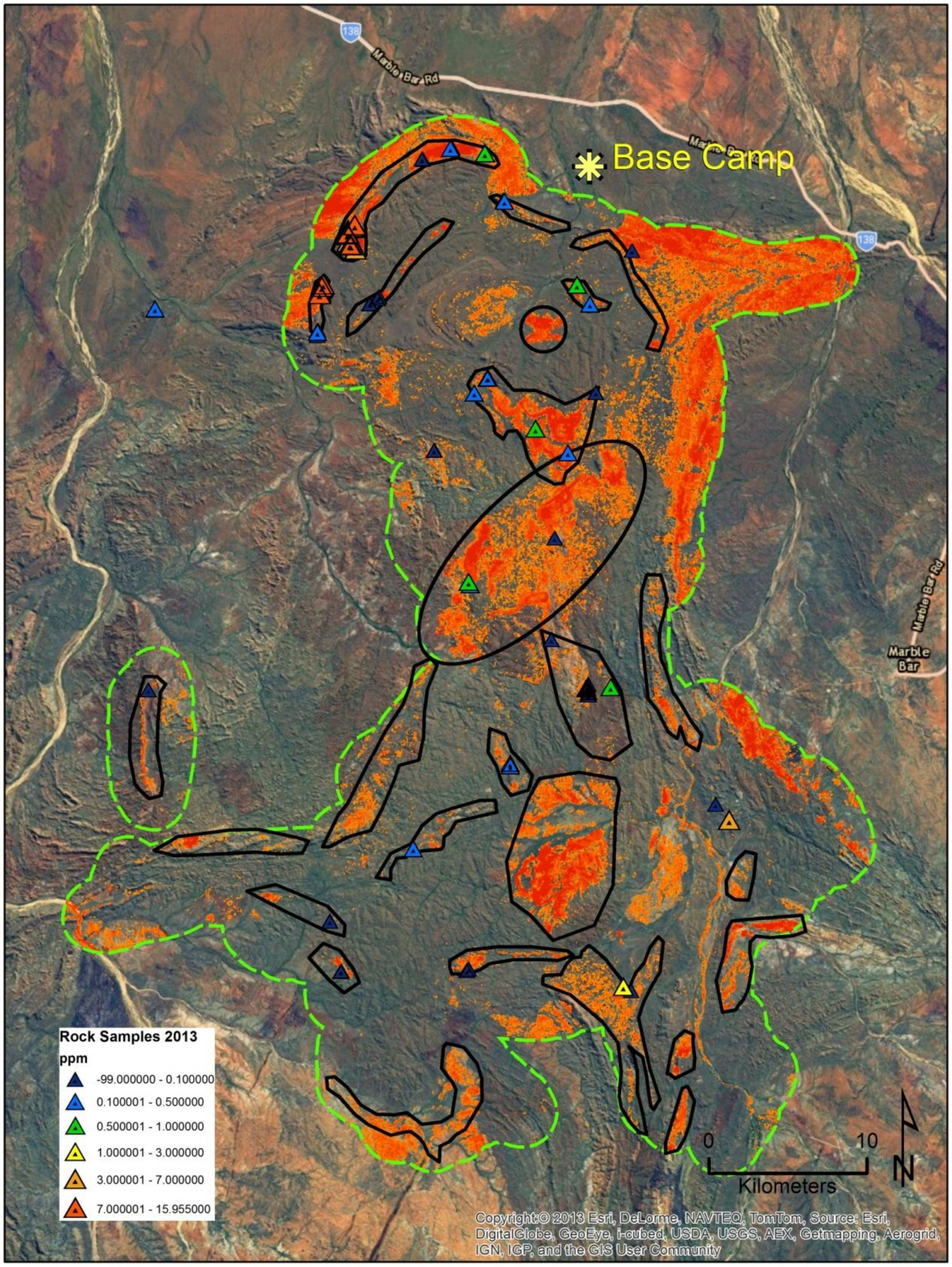
Appendix Image 6 - Using a ratio of b13/b14 areas with high carbonates are highlighted across the basin.



Appendix Image 7 - Using a band math of the different ratios, areas seen that could potentially contain gold bearing conglomerates are identified for further exploration.



Appendix Image 8 - Exploration program based upon ASTER data resulted in two zones with viable drill targets.



Appendix Image 9 - Final surface sample results from ASTER based exploration program.