PETRONAS
PETROLEUM NASIONAL BERHAD
MALAYSIA

QUALITY CONTROL SERVICES FOR THE ACQUISITION AND PROCESSING OF SYNTHETIC APERTURE RADAR

FINAL QC VISIT REPORT

February 1993

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16th February, 1993

The Exploration Manager
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Dear Sir,

Sabah and Sarawak SAR Survey: Final QC Visit Report

We are pleased to submit herewith our technical report for the Final QC visit which took place between the 10th and 22nd January, 1993.

Our consultant has carefully examined each of the re-processed mosaics prepared for the survey and our report presents general conclusions related to these observations as well as specific comments on each sheet.

We trust that you find this report satisfactory and confirm that our QC consultant will be pleased to provide further information on any technical aspects that may arise.

We are very pleased to have been associated with this very interesting study. We look forward to the possibility of again working on your behalf in the future and to participation in any final workshop on the SAR survey that you may organise.

Yours faithfully

G C Deane
Director

Enclosed

CONTENTS

PETRONAS QC REPORT JANUARY 1993

1. INTRODUCTION

This report constitutes the final Quality Control report by Hunting Technical Services Limited on the radar surveys of Sabah and Sarawak undertaken for Petronas by Intera Technologies Limited.

The QC took place from the 10th of January to the 22nd. At the request of Intera Technologies, the work was undertaken in their Calgary headquarters. The QC was carried out by Mr Trevett, Mr. Mohammed Adib Hudi of Petronas was also in attendance during this period.

The previous major QC was carried out in Kuala Lumpur in August 1992 and had resulted in the rejection of all the mosaics because they failed to fit either each other or the relevant maps. The current QC was carried out in Calgary in order to avoid shipping data to Malaysia before it had been approved.

The QC involved all the mosaics covering both Sabah and Sarawak and resulted in most of the mosaics being accepted as suitable for their intended use. A total of 11 sheets were identified as requiring further adjustment.

The procedures for revising these rejected sheets were established and it was also agreed that the remedial work would be completed during the visit of Mr Hudi who would carry out the final verification of these sheets.

In this final report, a brief overview of the use of SAR, in particular the construction of mosaics, has been included. It is hoped that these notes will be of value to users within Petronas and may be of assistance when preparing guidance to external users. This is followed by a short section on the current QC and finally a section has been included with some summary comments and conclusions.

2. SAR IMAGERY AND MOSAICS

The following notes on SAR data, in particular the construction and use of mosaics, are not intended to be a comprehensive guide to radar remote sensing; there are numerous well known text books that cover all aspects of the subject in far greater detail than can be achieved here. It is hoped that they will, however, help to explain the background to the QC and the problems encountered and at the same time form a basis for a set of notes for the guidance of users of the data.

2.1 SAR GEOMETRY

SAR, whether airborne or satellite derived, is an oblique viewing system and as such is unlike conventional air photography or optical satellite systems which are usually vertical viewing. The oblique view is essential to the production of a SAR image, only by using such a view is it possible to achieve an impression of relief over the area.

The SAR has to provide both the illuminating source and the recording or viewing device. The illumination in this case being micro-wave energy at a specified wave length, whilst the recorded data is based upon the strength of the return signal of that illuminating energy made by a ground target. In optical systems, the illuminating source is provided externally, in this case the sun, and this is usually already an oblique illumination, as a result the recording device can make a vertical view without losing the effect of relief caused by the shadows.

This oblique SAR view will result in scale differences across the image as well as distortions or displacement of data due to height differences. The processing of the data includes special routines that remove most of the scale differences to give a pseudo-vertical view, but many of the other distortions will remain. These can only be rectified by extensive and complex additional processing, usually referenced to a reliable data set such as a map or the use of positional data such as Global Positioning Satellite (GPS) information.

Even in the vertical view, distortions occur at the edges of the data, especially in areas with severe changes in elevation and in both SAR and photography these distortions will have an effect on the overall accuracy of mosaicing, unless additional special processing is used. The unique geometrical properties of the SAR image mean that the displacement due to relief will be more pronounced than in conventional photography and, as a result, a direct correlation to map detail cannot be achieved without the additional geometric processing.

2.2 MOSAIC CONSTRUCTION

In the construction of mosaics from image data, internationally accepted terms are used to describe the accuracy level of mosaicing; from these the user can identify the level of accuracy and reliability that can be expected.

The terms and the methods of mosaic construction are:-

UNCONTROLLED No map or other reference data has been used in the construction of the mosaic, either because none exists or the use of the data does not warrant such accuracy, (for example preparing a layout index of photography). The images are matched to each other to obtain the best continuation of detail possible. The scale is controlled by the acquisition scale or photographic enlargement in the case of photography, or by calculations based on the acquisition instrument parameters in the case of SAR.

SEMI-CONTROLLED A limited amount of control has been used. This may be selected detail which is assessed to be reliable, taken from maps, identified points surveyed and located by conventional land survey, or from data supplied through the GPS. In the case of this survey GPS positional data have been linked to the recording instrument in the aircraft. The mosaic is controlled only at these known locations and the intermediate detail is mosaiced to the best fit between these points.

In the case of the SAR the GPS is a continuous record and is used to rectify and control the length and position of the notional flight line, the data across the swath is uncontrolled.

CONTROLLED Usually for areas where reliable maps occur; but can be constructed from more rigorous survey information or additional GPS data. In the case of photography the photographs are rectified to remove the basic aircraft positional distortions and to ensure a better overall fit to the map. In modern mapping this is usually a digital process. In the SAR the same techniques can be used, that is to produce a photographic image and rectify this to the map or control data, or by the use of digital rectification.

Although the result will mean a greater correlation between map and image data, distortions due to height displacement will still remain. Controlling mosaics involves considerable additional time and expense and is only justified where the use of the image data as a compilation base is considered essential.

ORTHOPHOTO For certain applications, for example where no reliable maps exist, a mosaic that can serve as an accurate map base is required. In some countries, although accurate maps do exist, the visual quality of the photo-map is regarded as an additional advantage; in other countries the additional detail on the photograph gives an advantage over a map where the potential to illustrate features is limited (this is particularly true in otherwise featureless areas such as deserts).

The procedure requires either accurate maps with height information or detailed survey control, also with height data. The data have to be related to the control in a similar manner to conventional map production and requires either the use of mapping machines or complex computer programmes. The objective is to relate every element of the image to its relative true ground position and to reproduce a new image with each picture element or pixel in this new position. The result is a mosaic which is as accurate as a map and which can be used to display height information such as contours.

In the present survey the mosaics have been designated as semi-controlled. Any use of the mosaics must recognise the limitations of this classification especially when comparing with maps. Significantly the mosaics should not be used for measurements between points or to determine precise location by co-ordinate values.

The control for the mosaics has been taken from the GPS data recorded on the aircraft at the time of acquisition and not by any reference to the maps. These data have been used to control both the location and the scale. Furthermore the method of construction has been to mosaic each 1:100,000 sheet as a separate entity without reference to the adjacent sheet other than through the overall GPS location.

In these circumstances, because of the inherent scale differences, the blocks of mosaics will not fit to the maps, at the same time the mosaic blocks do not fit to each other. The expectations had been that, since a reliable series of 1:50,000 scale maps existed for all the area, the mosaics would relate to those maps with reasonable conformity in order that reference could be made to other data sources already in map form and to assist with field location.

The first 'final' QC had determined that the mosaics in fitting neither each other nor the maps did not fulfil the expectations of Petronas and therefore were not acceptable.

In this 'repeated final' QC the mosaics were re-examined to evaluate whether the revised sheets came closer to the anticipated results, given the level of survey and the inherent problems of the SAR.

In conducting this QC it was necessary to make some allowances for the type of mosaic and the method of construction as well as recognising the expectations of Petronas. To eliminate all the inaccuracies of fit would require a return to the basic processing in order to carry out the more complex computations required for a controlled mosaic, this could not be justified in terms of additional expense or the ultimate use of the product.

The agreement was to try and obtain the best mean fit of each mosaic to the corresponding map sheet using readily identifiable features such as roads, rivers and coastline; the latter being of particular importance. Features such as mountain ridges were not used because of the height distortions. It had been recognised that the maps available were on the whole very reliable, the main differences occurring where river meanders or the coastline had changed, and allowance was made for this when checking.

2.3 SAR INTERPRETATION

In this survey the flight lines were flown in such a manner as to give a substantial overlap between each strip of imagery, this overlap produces two views of the same terrain and enables the images to be viewed stereoscopically thereby increasing their interpretation potential.

The recommendation to users is that detailed interpretation should be carried out using the strip imagery and not on the mosaics. The mosaics provide a valuable synoptic view which is essential for determining regional trends and whilst it may be useful to compile the interpreted data onto the mosaic to observe these trends, it is nonetheless preferable that the final mapped data are compiled directly onto the map base. Only in this way can reliable scaled information be obtained, to enable interpretations to be related to other existing information and used in field operations.

The SAR system used by Intera is a fully integrated system. The airborne instrumentation provides the transmitted energy, records the reflected energy, samples the data to extract the principal target return for each element of the image and modifies the oblique data to be reformatted as a pseudo-vertical image. All the processing is built into the system with the result that the recorded data is the processed and corrected preferred image.

This has the effect that there is no longer the possibility to reprocess the original image data to improve the quality of the data, other than through normal image enhancements such as improvements to grey scale balances. Thus it is not possible to carry out multilook processing or similar procedures comparable to those used on the data obtained from satellites such as ERS 1. It also means that there is no possibility for the QC to validate the various processes used in producing the image; this was referred to in the previous report by the data specialist from the GEC-Marconi Research Centre.

The final deliverables include a set of digital data on CCT's. In using these images it should be remembered that the data cannot be re-worked to improve the information content of the imagery. In some SAR systems particularly satellite based systems, the possibility exists for combining multiple look images to improve overall image interpretability. The CCT's as delivered for Sabah and Sarawak will reproduce the image as seen on the strip prints. They do contain all the recorded data

and this will include some data in the sea areas which has been subsequently processed to give a black image on the photographic output. This being so it is possible to enhance the digital data in such a way as to increase the expression of offshore features and this could be of particular significance in studies to locate potential loading terminals or for coastal fisheries surveys.

The same comments do not apply to the areas of radar shadow. These occur in all the areas of relief but are of particular concern on certain islands where the shadow merges with the sea area in such a way that the coastline appears to be in error. Enhancement may reveal sea features but where the area is affected by shadow, radar shadow being an area of no signal return, no amount of enhancement will reveal any additional information.

The resolution of SAR is not always understood, it is necessary to accept that the term is different to the understanding used for photography. In photography a resolution of 10 metres would indicate that anything of 10 metres dimensions should be resolved on the image and anything under that will not be, in radar the same concept does not apply.

SAR resolution is the distance apart two good radar reflectors need to be in order to resolve as two signal responses on the image. Targets may be larger than the resolution cited but still not be visible on the image because they do not have a reflectance that differs from the background; targets significantly smaller than the resolution may be recorded if they are good reflectors. An example of this can be seen on some of the images where objects such as street lamps or power pylons appear as bright spots on the image even though, as individual targets they are smaller than the stated resolution. Such features are good radar reflectors. Other features, such as roads, may not be apparent because they produce the same reflectance as the surrounding detail.

The flight lines of the survey have been chosen to relate to the general grain of the country, that is the overall trend of the structures are at around 45^{0} to the flight lines. Such a pattern is necessary because of the strong linear bias of radar imagery, and this bias will effect the analysis of linear features such as fracture patterns.

In any imaging system with a strong illumination a bias in the expression of geological lineaments will occur. If the radar beam is angled along the ridges and valleys, shadows will be reduced or eliminated, thereby reducing the expression of relief. As a result some lineaments may not be identifiable. On the other hand, where the beam is across the hills and valleys there will be a strong shadow effect that may result in less significant lineaments being given undue importance. By trying to fly so that the grain lies at an angle to the flight line the bias is balanced, even so the inherent bias should be borne in mind when analysing lineament patterns.

Similar effects occur on satellite imagery such as Landsat and Spot where the regular repeat cycle means that the sun is at the same angle to the terrain for each pass over a particular area, within the limits of normal annual solar migration. Thus a linear bias can be detected on these optical satellite images.

3 FINAL QUALITY CONTROL

The term semi-controlled, used here to describe the SAR mosaics has been defined in Section 2 and some of the potential constraints of such mosaics have been identified.

It is recognised that one option for the QC assignment would be to request that all the mosaics were assembled so that all sheets related to each other without any gaps or overlaps at the edges. However, the accumulation of the inherent scale differences between the radar and the maps would result in increasing the overall problem of the mosaics not being in coincidence with the maps. It was determined that the principal requirement was for the mosaics to relate to their respective maps, in so doing it had to be accepted that there would of necessity be some errors arising along the joins of the mosaic sheets.

At the September QC meeting in the Houston offices of Intera, the problems that were likely to arise from reassembling the mosaics were discussed. It was then clear that in order to avoid a complete digital reworking of the data to produce new mosaics, some compromise had to be accepted. The inherent scale differences and the normal internal distortions meant that a precise fit to the maps would never be possible and that the edge differences referred to above would inevitably occur.

It was agreed that the existing mosaic negatives should be located over the map sheets to obtain the best mean fit possible. The border layout would then be added so that the mosaic sheet corners were in coincidence with those on the map. It was accepted that as a result of this process edge differences would result, and only by varying the sheet sizes could this be avoided.

The QC therefore concentrated on examining each of the revised 1:50,000 mosaic sheets in turn against the relevant map sheet in order to determine whether the fit to the maps had been improved to within acceptable tolerances. The examination had to recognise the problems associated with achieving a best mean fit, including the scale difference, oblique related distortions and the reliable identification of control detail. After examining a number of sheets at random it was possible to assess the potential success of the system and to establish a tolerance limit of 5mm in any one direction and that anything outside this tolerance would need to be re-examined.

Overall there had been a considerable improvement in the relationship of the mosaics to the maps and the majority of the sheets fell within the tolerances set. Where some of the tolerances could be considered as marginal it was evident that it was difficult to identify sufficient reliable detail on both map and mosaic to confirm or improve the fit.

In about four per cent of the sheets the errors were considered to be either outside the tolerance limit or of such a type as to warrant requesting that the mosaics should be re-examined and where possible the situation improved.

The sheets rejected were:-

7/117/10 The relationship of the main island to the smaller offshore islands indicated a basic digital image positional error. It was agreed that the digital data would be re-examined and if possible re-processed to remove the positional error so as to relate to the positions given on the map.

6/116/11 The fit to the map was not acceptable and will be relocated.

6/117/15 Fit to the map not acceptable mainly the mosaic was skewed and will be relocated.

5/115/4 A small portion of the coastline did not fit the map and gave an unnecessary overlap with sheet 5/116/1 and the sheet is to be relocated.

5/116/1 This is the Kota Kinabalu sheet and is the state capital sheet as well as the location of the base GPS station. Some of the misfit was due to coastline changes but after allowing for this, the poor fit and the skew were not acceptable. There is a possibility that there is some discrepancy in the internal mosaicing. The sheet to be examined to improve the overall relationship to the map.

5/118/5 & 6 These were the sheets that had shown a substantial internal error in the mosaics, although the situation had been improved, there was still a clear difference with the map and it was agreed that the digital data would be examined to determine if the mosaicing could be improved.

5/115/9 Labuan island, Petronas had requested that the island appear as a separate sheet in view of its status as Federal Territory and not part of either of the local states, this had not been done.

The mosaic will be assembled as a single unique sheet and entitled LABUAN ISLAND-FEDERAL TERRITORY.

4/118/3 Fit unacceptable, to be re-located

5/118/5 Fit unacceptable, to be re-located.

3/114/7 Fit unacceptable, to be re-located.

2/112/15 Fit unacceptable, to be re- located.

There were some instances where the previous QC had recommended that small sections of mosaic presented as a separate sheet should be better presented as part of the adjacent sheet, and in the map layout diagram these larger sheets had been shown. In most cases this had not been carried out, however as this was a matter of user convenience rather than an error, it was decided not to insist on compliance.

Before completing the QC, each mosaic determined as requiring further revision was re-located on the map in what was considered as an acceptable position. It was agreed that, as soon as the negatives arrived from the Houston office, this revised location would be tested and used to produce a final revised mosaic. As this would be undertaken in the presence of the Petronas representative, who would still be in Calgary, it would be possible for him to examine the revised sheets and to pass them for final production.

The names that were in error on the titles of the mosaic sheets have either been changed or the changes were noted and in hand.

The 1:100,000 series cannot be related to any map series but they have been modified where possible, to agree to the new 1:50,000 series. Some overlap or gaps will still occur between sheets and this should be taken into account when using these sheets, in view of the overall improvement in the 1:50,000 series these discrepancies were not considered to affect the utility of the smaller scale mosaics.

The internal processing of the radar has been described in Section 2 of this report and the QC has had to be on the basis that the parameters of the system, as specified, have been met and that the radar is at the optimum throughout. It was learnt that the system has been tested as part of other projects carried out by Intera and that these measurements, mainly of resolution, have been over

targeted areas and carried out by independent specialists. These indicate that the resolution of the system can be expected to be better than specifications.

The problems relating to the notations on the digital data, were discussed and clarified. It would appear that the data have been presented in such a way that the CCT carries a straightforward image record that can be read by any computer system. The confusion arises where operators are used to receiving digital satellite data where the processing systems differ depending upon the receiving station, and header information is essential.

Intera have agreed to prepare a short technical note explaining the situation. At the same time Mr. Hudi will get the opportunity during his visit to become familiar with the digital data, and will be able to demonstrate to potential users of the digital data.

A significant element of the previous QC had been the insistence on the inclusion of a cautionary note on each mosaic sheet. Such a note has now been included which clearly specifies the level of mosaicing and includes a warning on the use of the graticule for location. This note is welcomed and is considered as a normal inclusion in most forms of mosaic presentation. The user should now be well aware of the limitations of the media and its inclusion in no way detracts from the overall value of the mosaics.

4 SUMMARY AND CONCLUSIONS

This report concludes the quality control of the radar survey of Sabah and Sarawak. When all the minor final adjustments have been carried out to the satisfaction of the Petronas representative, the deliverables will be within specification and will satisfy the expectations of Petronas. They are, therefore, passed for acceptance.

The 1:50,000 mosaics relate to the map sheets within acceptable tolerances; the smaller scale mosaics are comparably acceptable; all the strip imagery is to an acceptable standard; and as far as can be judged from a limited random sampling, all the digital data are acceptable. The two areas have been satisfactorily covered, with some minor gaps on the boundaries, mostly in the vicinity of Brunei, where constraints were imposed by that country on the flying operations.

Despite the problems that arose with the mosaics, and there is some evidence that a misunderstanding occurred at the contract stage and at the initial commencement meeting with the potential expectations from the survey being over emphasised, it must be recognised that the SAR data themselves are of the highest standard.

The strip data provide excellent stereoscopic cover which should be of great value to a wide range of disciplines. The mosaics have been constructed in such a manner that the overall tone is well balanced and the junction between strips is not discernible.

It is considered that Petronas now have a valuable data set well suited to their requirements and to those of potential concessionaires. There is the potential to use the digital data in the future, either through MACRES the national remote sensing centre or at Petronas if they install their own facility. A first examination indicated that by using image enhancement, additional information in the coastal areas could be displayed and this could extend the use and applications of the radar.

In relation to the digital data, it should be remembered that CCT's must be checked at regular intervals as they have a limited shelf life. It is known that Intera now have the capability to record the digital data as CD ROM discs, these are not only easier to store, they are believed to have a much longer storage life. It may be worth considering obtaining the data in this format, although this would incur some additional expense.

In conclusion we should like to acknowledge the considerable assistance provided by Petronas for this QC and in particular the constant help of Mr Adib Hudi. We should also like to record that the QC has at all times been facilitated by Intera and their staff, from the initial acquisition campaign through to the final production.