REGIONAL INTERPRETATION OF RADAR IMAGERY

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1. INTRODUCTION

Over the past twenty years an extensive literature on SLAR has built up. This includes numerous discussions on widely varied applications ranging from maritime monitoring to landuse mapping for most of which helpful review papers and bibliographies exist. A recent sketch of the history of developments, particularly in relation to geology is given by MacDonald (1979). However, the manner in which interpreters handle large area projects for natural resource investigations seems not proportionately well documented although there are important papers in this respect. The reason may be that although very big areas have been involved the total number of major programmes is rather small and the number of these open to detailed publication of results is smaller still. This paper endeavours to clarify some of the factors that influence regional radar interpretation, making particular reference to three SLAR projects and one SEASAT SAR interpretational programme.

The synoptic views of SLAR imagery lend themselves to regional mapwork as numbers of interpretational studies have shown. Interpretative technique is well established and is essentially the same as applies to black and white LANDSAT and other synoptic monochrome imagery. Generally speaking technique is the same for photographic (optically correlated) SEASAT SAR imagery. However, the arrival of SEASAT has much widened the audience for regional radar imagery and in the discussion that has resulted it has become clear that many new users have little idea of how to deal with large area interpretations. For experienced interpreters SEASAT brings new challenge since, for most, it is the first source of digital radar data. This provides opportunity for computer manipulation of the data and a need for improved understanding of systems so that engineers may be best advised as to the qualities that interpreters require in imagery from future radar satellites.

2. REGIONAL RADAR PROJECTS

2.1 S.L.A.R.

The extent of SLAR commercially flown outside North America is indicated in Table 1 and amounts to a coverage of possibly 12 million sq km, all acquired by three operators: Aero Service Corporation, now the Aero Service Division of the Western Geophysical Company, Motorola Aerial Remote Sensing Incorporated and Westinghouse. Westinghouse ceased commercial operations in 1973.

TABLE 1

Area/Region	Operator	Sq km
Brazil	AS/G	8,500,000
Venezuela	AS/G	900,000
Colombia	AS/G	320,000
	W	6,000
Peru	AS/G	600,000
	M	?
Central America	M	71,000
Nicaragua	W	120,000
Panama	W	17,000
Nigeria	M	950,000
Togo and other	M	64,000
SE Asia	M	40,000
	W	? 300,000
	AS/G	?
	Total, perhaps	12,500,000

AS	Aero Service/Goodyear	X-Band SAR Modified	AN/APQ-102
M	Motorola	X-Band Real Aperture	AN/APS-94
W	Westinghouse	Ka-Band Real Aperture	AN/APQ-97

(Data by courtesy of H. Jensen, Aero Service Division of Western Geophysical Company of America; R. H. Gelnett, Motorola Aerial Remote Sensing Incorporated, also of other sources).

The list of Table 1 is incomplete as the operators are not free to specify details of some surveys. In addition small areas of commercially acquired radar imagery have been obtained in the United Kingdom, France, Australia and probably elsewhere.

North America has about 2 million square kilometres of commercially acquired radar imagery which the three operators that have been noted are able to mention. In addition Intertech of Canada, operating the ex-ERIM equipment of the Canadian Centre of Remote Sensing, have imaged about 300,000 sq km in the United States, Canada and Alaska. This system has not yet worked to any extent outside Northern America. These four operators have performed almost all the commercial work undertaken by SLAR throughout the world although there are other systems in official use.

The projects listed in Table 1 have mostly been funded by Government, sometimes acting for other participants. In Nigeria the programme was jointly sponsored by the Federal Government and F.A.O. Some projects, particularly in South East Asia have been constructed from piecemeal requirements of oil and mineral exploration.

Most of these programmes have been motivated by the necessity for rapid acquisition of consistent data for resources inventory in relation to regional planning or for oil or mineral exploration purposes. The present paper takes the Nicaragua, South East Peru and Nigeria projects as examples of rapid, large area, interpretative programmes.

Nicaragua was the first case in which an entire country was given complete commercial mapping radar cover, subsequently joined by Brazil, Venezuela, Nigeria and Togo. The objective was data acquisition for regional planning and development purposes. The programme, flown in 1972 by the Westinghouse DC.6B/real aperture K_a band system, resulted in a 48-sheet series of mosaics covering 120,000 sq km. Planimetric, geomorphic, geological and natural vegetation/landuse interpretations (Hunting Geology and Geophysics Limited) were produced for 80,000 sq km of the east and centre of the country. The mosaics, 1:100,000 scale map sequences, and reports are held by the Instituto Geografico Nacional in Managua. Only synopses of the results have been published (M-K etc ......). The entire project from commencement of imaging to delivery of maps was accomplished within six months representing an average interpretative production rate of 20,000 sq km/month.

Some 600,000 sq km of central, southern and eastern Peru were imaged in 1974/5 by Aero Service Corporation using a Goodyear X Band, synthetic aperture radar in a Caravelle aircraft. It seems that this system first utilised the acronym SLAR which has since passed into general usage. Some 305,000 sq km of the SLAR cover of Peru was of the SE Oriente, flown for Petroleos del Peru in association with several international oil companies. The objective was geological information in these logistically difficult upper Amazonian forest lands. Interpretation, which was separated from acquisition, was carried out in six months. (Hunting Geology and Geophysics Limited), representing an average interpretational production rate of about 60,000 sq km/month, in this case at a mapping scale of 1:250,000 28 whole and part map sheets were involved. The data are held by Petroleos del Peru.

The whole of Nigeria (950,000 sq km) was radar imaged in 1976/77 by Motorola Aerial Remote Sensing Incorporated with the Motorola X-band real aperture dual-look radar system in a Grumman Gulfstream. The original impetus for the project came from the need for a base-line forest inventory by a joint F.A.O/U.N.D.P/ Nigerian Federal Department of Forestry programme. It was necessary to find out the status of forest reserves and it became recognised that this could most rapidly be established by radar. The programme was later extended to cover the entire country for landuse and vegetation mapping. A twin (north and south look) cover of 1:250,000 scale mosaics was produced by Motorola and these and strip imagery were used for the preparation of a compatible interpretative 68 mapsheet series in landuse and natural vegetation by Hunting Technical Services Limited. In this case rapid ground check reconnaissance was included in the interpretative stages which were accomplished in 18 months representing average production rates of about 50,000 square kilometres per month. The data are held by the Nigerian Federal Department of Forestry. Accounts of the work have been given by Parry and Trevett (1979).

The interpretative production rate of these three projects thus ranges from 15,000 sq km/month at 1:100,000 scale in the case of Nicaragua to 50-60,000 sq km/month at 1:250,000 scale in the case of Peru and Nigeria. They illustrate the rates at which interpretation is expected and achieved for large area SLAR surveys.

2.2 SEASAT SAR

SEASAT overland imagery is available for North America and Europe, the coverage being controlled by the distribution of ground receiving stations and limited by the early failure of the satellite. Nevertheless large areas were imaged and northwards as the tracks converged, the 100 km swaths overlapped. Considerable areas are available for interpretation.

From the interpretation viewpoint the main factors influencing interpretation are (a) the waveband (L), (b) the comparatively steep depression angle, and (c) the availability of digital format.

L-band (23 cm) has not been commercially used outside North America and its utility for multidisciplinary work for comparable areas and environments as listed in Table 1 awaits evaluation. There seems no reason to suppose that it will not be equally effective. The steep depression angle of SEASAT aggravates layover problems and in areas of more than modest relief these become objectionable. The imagery is either optically or digitally correlated. The former is a rapid, elegant system. Digital correlation produces better imagery and digital tapes permit manipulation in digital image processors but the correlation process is highly demanding in computer time and currently only small areas have been handled in this way.

Owing to the comparatively recent availability of SEASAT imagery there are yet only few accounts of overland interpretative studies. Evaluations have shown it to be effective in flatland landuse studies (Huntings 1979/1980: East Anglia, UK) and geology (Huntings ibid, Ford 1979, Sabins, Blom and Elachi 1979, Bodechtal 1979).

Coverage of Iceland by SEASAT is about 80% complete and enabled construction of an effective single sheet mosaic at 1:500,000 scale from optically correlated (survey mode) imagery. It is a region of interesting geology, although somewhat restricted in variety, exposing part of the mid-Atlantic ridge. Worksheet interpretation of the geology (70,000 sq km) was completed in about four weeks. Most of the major mapping units of the Geological Survey of Iceland could be recognised on the imagery and some additional subdivisions were made in ice and alluvial units. The results were submitted to the 1980 Pecora Symposium (McDonough and Martin-Kaye).

3. REGIONAL INTERPRETATION

3.1 Objectives

It may appear as a problem, almost an impossibility, for such areas as noted above to be effectively dealt with in the short time scales often involved. The problem begins to resolve when on consideration of the objectives of regional mapwork are considered and type of information that it is practical to get out of SLAR and SAR, the mapwork scales, and the amount of varied data that it is sensible to put on any map.

In the first place, regional resources mapwork, which most suitably is within the 1:100,000 to 1:500,000 scale range, necessarily aims not at expressing all the information available but at making a sensible synopsis of it, emphasising those points major to the particular purpose.

3.2 Limiting Factors

The expertise of the regional interpreter is only partially the recognition of features on the imagery. Equally important is ability in establishing a classification that satisfactorily accommodates the data into coherent categories which permit a readily understandable map.

There is, in fact, a maximum level of varied information that it is useful to put on a map, controlled by the needs of clarity and the limitations of line weights, conventions etc. available to the interpreter. Consideration of the matter shows that, although the exact type of information may differ, the level is apt to be of the same order over a range of map scales. This is tantamount to saying that the quantity of work involved in a mapping programme is as much related to the size and number of mapsheets involved as to the area that the project covers. This is exemplified by the Nicaragua and Peru projects. Although the latter covered 3.8 times the area dealt with in Nicaragua the number of mapsheets, owing to different scales, was similar and the two interpretative projects were completed in approximately the same time. The Nigerian project generated four times the number of whole mapsheets at the same scale as Peru and the interpretative work accordingly took four times as long.

Map legends reflect the map makers opinion as to the digestible extent to which categorisation, exclusive of symbols, usefully can go. Table II which principally illustrates the usage of radar interpretational parameters suggests that 25-35 units is regarded as about right. In the case of Nigeria 45 were established but this stems from the size of the survey which covered an unusual range of environments. Iceland, a single sheet SEASAT interpretation has fewer than the average but the geology is largely volcanic and not of great variety in the present context.

3.3 Interpretative Parameters

Interpretation itself is based upon texture, shape, tone, and context considered in the light of experience and any relevant ground data that may be available. Definitions of these parameters tend to produce more complication than clarification. Contrary to some impression the concept of signatures unique to specific natural surfaces scarcely applies and, in fact, for SLAR it seems questionable whether these exist to any extent owing to the different expressions at different incident angles in the radar beam and, some times, with different look directions. The more restricted angles of satellite imaging, broadens the possibility of unique signatures but, and in any event, land units that extend over a matter of square kilometres will rarely be uniform even in the most monotonous terrain; they will comprise an assemblage of features characterised by some common element of texture, pattern or implication.

Table II shows the results of an analysis of the relative importance of the four interpretative parameters of tone, texture, shape and context in attribution to interpreted units of five interpretative programmes for landuse/natural vegetation mapping or geology.

TABLE II

Interpretational Parameters

	Scale	Mapping Units	Percent Usage of Interpretational parameters: Brightness of tone	Texture	Shape	Context
LANDUSE						
Nicaragua	1:100,000	28	39	93	46	86
Nigeria	1:250,000	45	22	69	33	53
	Average percentages		29	78	38	66
GEOLOGY						
Nicaragua	1:100,000	25	44	84	76	60
Peru	1:250,000	37	11	86	81	89
Iceland	1:500,000	18	33	56	50	56
	Average percentages		27	81	74	74
GEOLOGY AND LANDUSE COMBINED						
	Average percentages		28	79	56	70

In further analysis of the geological interpretation of Peru it was found that 3% of all attributions depended on one parameter along, 20% upon two, 71% upon three and 6% upon all four parameters.

These analyses were not made at the time of the studies and will be as subjective as the interpretations themselves. The exercise is statistically precarious. Nevertheless the results clearly state that the interpreter ordinarily requires two or three of the parameters, occasionally four and that one is rarely sufficient. Brightness, ie the strength of signal return is relatively unimportant in comparison with texture, shape and context although it is in changes of tone that all features are expressed. Perhaps most interesting is the fact that in both landuse and geology the interpreter depends heavily in his determinations upon features exterior to the unit itself ie, the context. That this must be so is readily seen by taking the example of beaches which are largely recognisable by their position at a shore. Analysis shows that context plays an important role in a high proportion of determinations.

The importance of context explains why automated mapping has advanced slowly. Machine systems can easily register tonal differences and have some success in texture recognition but face a difficult problem in equalling the interpreter's ability to appreciate relationships.

Table II also shows that shape is more utilised by geologists than landuse interpreters. This is inevitably the case as geological interpretation of radar imagery often resolves to the interpretation of morphology. The rocks themselves are usually covered by soils and vegetation. The latter are of direct interest to the landuse specialist and, whilst landuse is commonly related to morphology, correlations emphasize patterns and textures.

4. RESOLUTION

An interpreter will not ordinarily attempt systematically to extract interpretable units of less than about one square centimetre in extent on his worksheet unless these are point features of interest or of some particular consequence. In fact the average will be much larger, perhaps tens of square centimetres although some internal detail may also be put. In consequence the features on the ground will cover at least a square kilometre and ordinarily be several square kilometres or bigger in the case of 1:100,000 scale, and larger by a factor of 6.25 in the case of 1:250,000.

It might be inferred, since interpreted units in regional mapping normally relate to several or many square kilometres on the ground that it would not greatly matter if resolution were 5, 10, 20, 40 metres or even less, since the regional interpreter may seem unconcerned with detail. Detail might even be taken as an encumbrance. For some units this will be the case but in general the inference would be incorrect as the interpreter depends upon textural detail to categorise many units and the more distinctly is this detail shown the more rapidly and confidently can attributions be made. Table II states that texture is significant in about 80% of determinations. Texture may be on various scales from a coarse fracture patterning in geology to the furrowing of agricultural land. Sometimes certain textures may be emphasised by degrading the image but for many instances textural information will be improved with improving resolution.

This is not to say that the detail is required for plotting; it is needed for the more confident and rapid attribution of units. For example, Ford (1979) states that greater SAR resolution enables more geological lineaments to be mapped. This improved expression will allow readier categorisation of those units that tend to be categorised by fracture pattern which itself may not be necessary to depict.

Generally speaking it seems from Table II, and in any event might be supposed, that resolution is more important to landuse interpreters than to geologists in handling regional work. Certainly the 10 metre resolution imagery of Nicaragua was found more amenable to confident rapid landuse interpretation than the 20 metre resolution imagery of Nigeria. These differences were however diminished in consequence to the result by the different mapping scales.

5. BIAS AND SUBJECTIVITY

As has long been recognised, although not everywhere acknowledged radar information is biassed. Alignments in the look direction and to a recognisable but lesser degree in the swath direction are subdued in comparison with similar features orientated in other directions. This stems from the directional illumination and a comparable effect is seen in LANDSAT for the sun azimuth direction. The result is particularly noticeable in radargeologic lineament maps, where few, if any, linears are ordinarily represented parallel to the look direction.

Comparison of the results from different observers working on lineament analysis of the same area shows that they rarely replicate exactly more than the most unambiguous features. Sometimes there is disagreement as to the most important trend and some observers may omit certain linear directions entirely. This results from subconscious bias arising from some reason of perception, subconscious interpretational preference or even the convenience of the drawing arm.

If this is the case for linears it may be supposed that interpreter bias will also apply in various degrees in other types of feature. Personality, in fact, strongly expresses itself in interpretation. Where one will be tentative and meticulous another may be bold and schematic. Neither is necessarily better than the other. In regional mapwork both need to compromise. It is achieving and sustaining an objective consistent interpretative approach that poses one of the more difficult problems.

6. Interpretative Teams

Multi-sheet mapping projects necessitate teams, single interpreters would take too long and limit the authority of the map. As is well known it is difficult for committees to reach decisions and for joint authors long to agree. Interpretational teams may have an advantage in that there is always a consistent third party, the imagery itself, against which opinion must always be tested.

In practice disagreements on technical matters and personality disharmonies mostly can readily be overcome, the former, if unresolved, by indicating the options in the legend and discussing them in the report. The imprint of personalities on individual mapsheets at worksheet stage is impossible to avoid and can make a compilation of sheets look like a checker-board if work is planned unwarily. This effect will subdue with fair drawing to standard line weights and conventions but needs care to obviate entirely.

To maximise consistency all team members need to provide some input and editing to all the interpretative sheets, if only in comment. In this way a concensus style tends to develop. Prior work on the specific discipline, geology or landuse, involves everyone applying themselves to the base map in the extraction of drainage pattern and other principle geographic features. Whilst this relatively uncontentious work is in progress familiarity with interpretable units grows and by the time of completion it is normally possible to establish the main frame of the legend.

The region may then be broken down into sectors that are each dominated by a particular assemblage of units in which individuals or two or three interpreters working as a group become specialists and can attend to the same assemblages wherever else it may occur. In this manner it will uniformly receive the same treatment. Differences of interpretational philosophy between different assemblages is of less moment than upon the same assemblage from one sheet or area to another as can readily occur if work is distributed purely on a sheet basis.

All sheets need to be reviewed by the chief interpreter and adjusted as necessary to bring an overall consistency of representation. Valuable to this purpose is photographic reduction and compilation of the worksheets so that a convenient overview of the entire area can be obtained.

7. Ground Truth

In the three examples, SLAR projects of Nicaragua, Peru and Nigeria, ground validation operations were only specified in the last case where a considerable amount of rapid reconnaissance was undertaken. Interpreters are fond of stressing the importance of field checking and there is no question about its desirability but the absolute need becomes less pressing as the mapwork scale decreases.

In regional mapwork there is ordinarily a level of existing data, perhaps in some detail locally, that can allow correlations with image units and successful extrapolation to ill-mapped parts. As scales increase, the greater is the need for variety in the attributions and the more often will the interpreter encounter situations that demand checking in the field.

The point made here is that provided there is an adequacy of existing control data and provided that the map is remembered to be an interpretation, not claiming necessarily to be a definitive statement, very serviceable regional work can be accomplished without field checking. It represents a different task to the construction of a map from field observation and usually has as a principle objective the rapid indication of where the time and effort required for the latter are best applied.

It is certainly correct, however, that interpretations can benefit substantially in authority from even the most skeletal, if well chosen, of ground verifications.

8. Computerisation

LANDSAT regional interpretations can be carried out satisfactorily to about 1:250,000 scale on standard NASA photographic products but for detailed studies and to gain access to all the original information it is necessary to use CCTs and image processing computers. The same is certainly the case for satellite SAR and will become even more so when multiband images arrive. Digitally correlated imagery is much superior to optically processed material in everything but cost.

Once upon film the information is rendered relatively inflexible and the empirical interpretative techniques that have so far prevailed have been appropriate both to the regional base-line inventory applications to which SLAR has been put and to the photographic registration of the data. The digital formats that are now available from SEASAT SAR and at least one commercial SLAR, and which can be expected for future unmanned satellite SAR's necessitate a re-orientation amongst interpreters. The data will possess greater interpretative potential than can be developed from subjective technique alone and it is necessary for the potential to be realised if some highly important applications in view (eg. crop yield forecasting) are to have hope of satisfaction. LANDSAT/SAR combinations and the analysis of multiband SAR can only make headway with computer processing. For example the digital data can differentiate a vastly greater range of energy levels in the returned radar signals than can be distinguished in grey levels by the human eye. In any event such formidable quantities of information, much of it duplicative or not notably interesting, can arise from orbiting SARs that a substantial level of machine sorting of data seems essential. Interpreters and engineers need to collaborate closely to establish the systems than can satisfy the economic applications without burying everyone in unmanageable or unwanted data.

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