A STUDY OF THE USEFULNESS OF SKYLAB EREP DATA FOR EARTH RESOURCES. STUDIES IN AUSTRALIA

SR557

Principal Investigator: B.P. Lambert
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Department of Minerals and Energy
Canberra ACT 2600
AUSTRALIA

FINAL REPORT

July 1975

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Co-Investigators

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Land Classification:	R. Story CSIRO Division of Land Use Research

Note: This report is compiled from contributions prepared by the co-investigators named above. The source of particular contributions is identified where necessary by the headings: Forestry, Geology (BMR), Geology (CSIRO) or Land Classification.

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1. INDEX OF THE MAJOR CATEGORIES OF INFORMATION INCLUDED

General: A comparison of results from Skylab and Landsat-1 (formerly ERTS-1).

Forestry: Forest resource assessment, vegetation boundaries, forested versus non-forested areas.

Geology: Interpretation of large scale structures, linear features, analysis of linear features, rock type discrimination, structures, faults, lineaments, photointerpretation, resolution, drainage networks, topography, geomorphology, reproducibility, data quality, correlation, civil engineering, tunnels, irrigation, hydroelectric power.

Land classification: Types of country depicted by S 190A and S 190B, botanical mapping with the aid of S 190A and S 190B.

2. TECHNICAL APPROACH AND TASK DESCRIPTION

The purpose of the investigation was to determine the usefulness of Skylab photography for mapping natural resources. Structural, lithological and vegetation cover maps have been prepared using previously made maps and field work in selected areas as control. Comparisons have been made with the results obtained from Landsat-1 data.

During the planning phase of the mission, the site descriptions and priorities, and the photographic requirements were conveyed to NASA/JSC. Details are given in Sections 3 and 4 of this report.

Field checks have been performed in the Snowy Mountains area to provide control for the interpretation of the Skylab photographs.

Conventional photo-interpretation methods have been employed in preparing from the Skylab photographs maps of structural features, Cainozoic geology, and land systems including vegetation cover.

3. GENERAL HISTORY OF THE INVESTIGATION

In December 1970 the US National Aeronautics and Space Administration (NASA), issued an open invitation for specific proposals for participation in the analysis and interpretation of earth resources data acquired by the Earth Resources Experimental Package (EREP) of the Skylab manned spacecraft program. This resulted in the interdepartmental Australian Committee for ERTS (ACERTS) forwarding, on 8 April 1971, a proposal to NASA entitled "A study of the usefulness of Skylab EREP data for earth resources studies in Australia".

The original proposal was formulated on the understanding that data might be available from a single EREP pass over Australia. ACERTS believed that target site selection should give priority to test areas already nominated for Landsat-1 evaluation. A primary area was therefore selected at Alice Springs (NT). Available data indicated that a descending orbit across Alice Springs would also cover Landsat-1 test sites at Gason (SA) and south of Canberra (ACT-NSW) while an ascending orbit would cover Kalgoorlie and part of Papua New Guinea. Data from the S190 photographic cameras (see Appendix) and S192 multispectral scanner were requested.

On 6 October 1972 notification was received from NASA that the proposal (under NASA control numbers INT-AUS-03, Experiment Proposal Number (EPN) 557 and SR557) had been accepted, with Dr N.H. Fisher, then Director of the Bureau of Mineral Resources, as Principal Investigator.

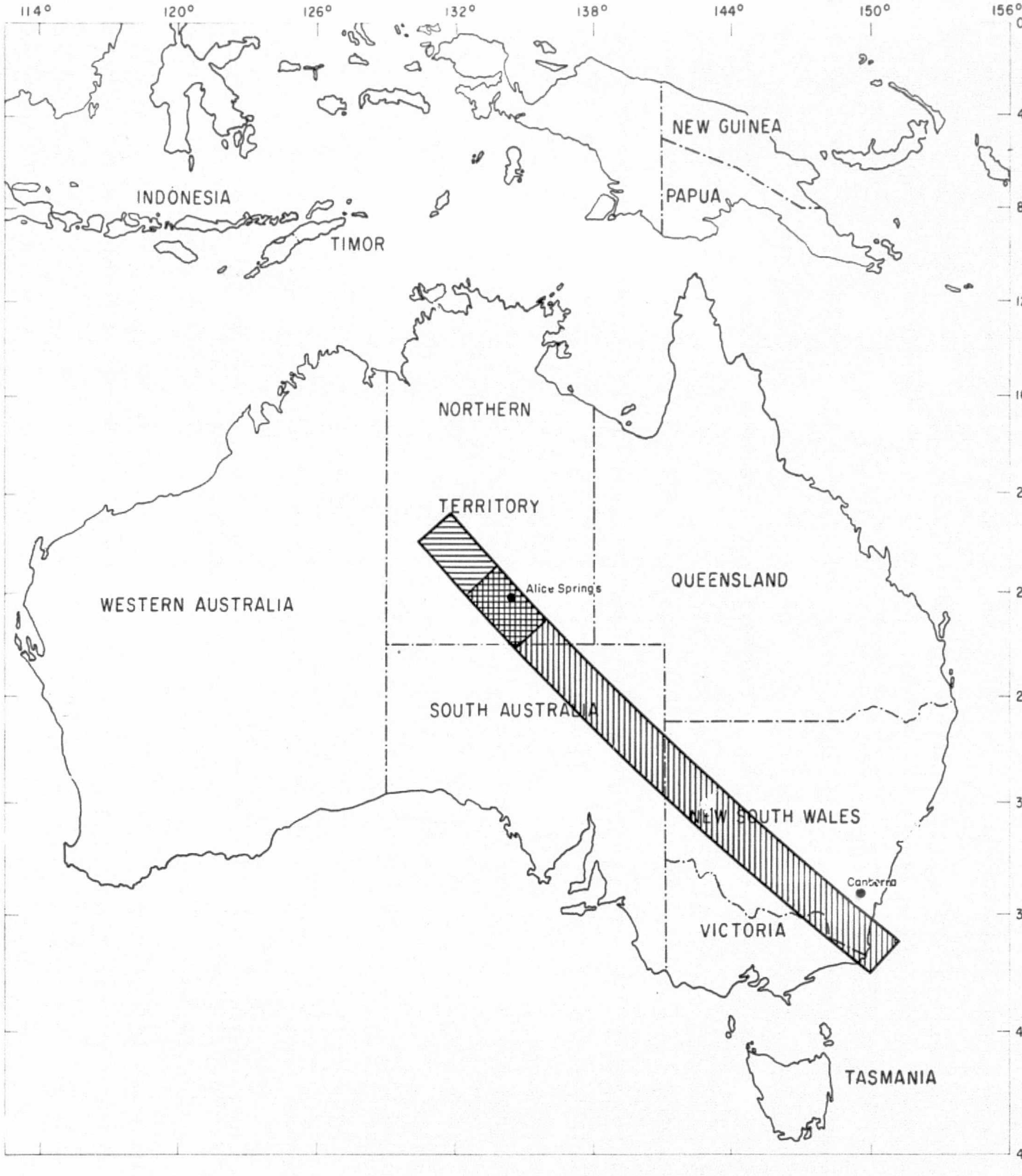
Participation in the research was ratified by the signing on 11 May 1973 of the Provisions for participation in the Skylab Earth Resources Experiment Program.

Following the Principal Investigator's Conference at MSC Houston, Texas (10-13 October 1972), at which comprehensive information on instrumentation and flight programming was released, the Australian proposal was amended. Subsequent changes (with NASA approval) resulted in the Australian proposal being finalized for S190A (Multispectral camera system) and S190B (Earth Terrain camera) data over four test sites Priority 1, Mt Isa (Site 204959) lat. 20°00'S-21°30'S; long. 139°00'E-140°15'E. Equal priority 2, Kalgoorlie (Site 204953) lat. 30°00'S-33°00'S; long. 121°00'E-122°30'E, Canberra (Site 204954) lat. 35°00'S-36°00'S; long. 148°30'E-150°00'E, Alice Springs (Site 204952) lat. 23°00'S-23°45'S; long. 133°30'E-135°00'E.

The Skylab spacecraft (SL1) was launched on 14 May 1973 into a 50 degree inclined circular orbit at an altitude of approximately 430 km, which resulted in a 5 day repeating ground track. During the three manned missions SL2 (25 May-21 June 1973), SL3 (28 July-25 September 1974, and SL4 (16 November-8 February 1974), the astronauts operated the EREP cameras over Australia on two occasions.

During SL3, Track 13 was photographed with both camera systems on EREP Pass 8 (12 August 1973). Figure 1 shows the extent of coverage by the S190A system; within this, the S190B camera covered a narrower central strip. Terrain photography was obtained in the Alice Springs and Snowy Mountains areas while the remainder of the track was extensively cloud covered. Track 13 was photographed again on 15 December 1973 during SL4-EREP Pass 15. Photography was acquired over Alice Springs but additional photography near Canberra was cancelled owing to 100% cloud cover observed by the crew. Details of photography are listed in Section 4, and the locations of the photographs studied are shown in Figs. 2 and 3.

The Commonwealth Scientific and Industrial Research Organization (CSIRO), Divisions of Mineral Physics, and Land Use Research, the Bureau of Mineral Resources (BMR) of the Department of Minerals and Energy, and the Forestry and Timber Bureau (F&TB) now the CSIRO Division of Forest

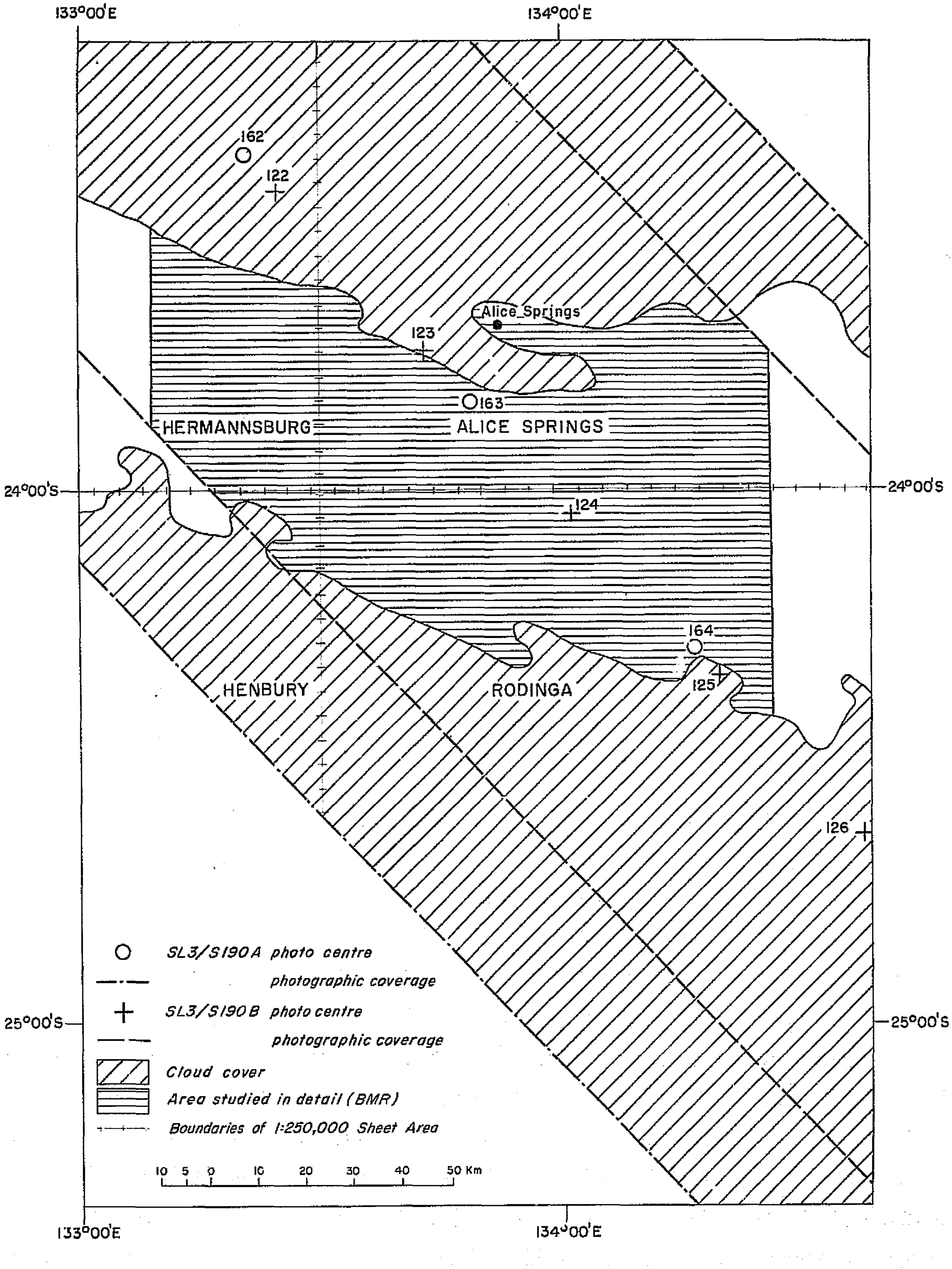


SKYLAB S190A PHOTOGRAPHIC COVERAGE OF AUSTRALIA

SL-3 Track 13 EREP Pass 8 12 August 1973

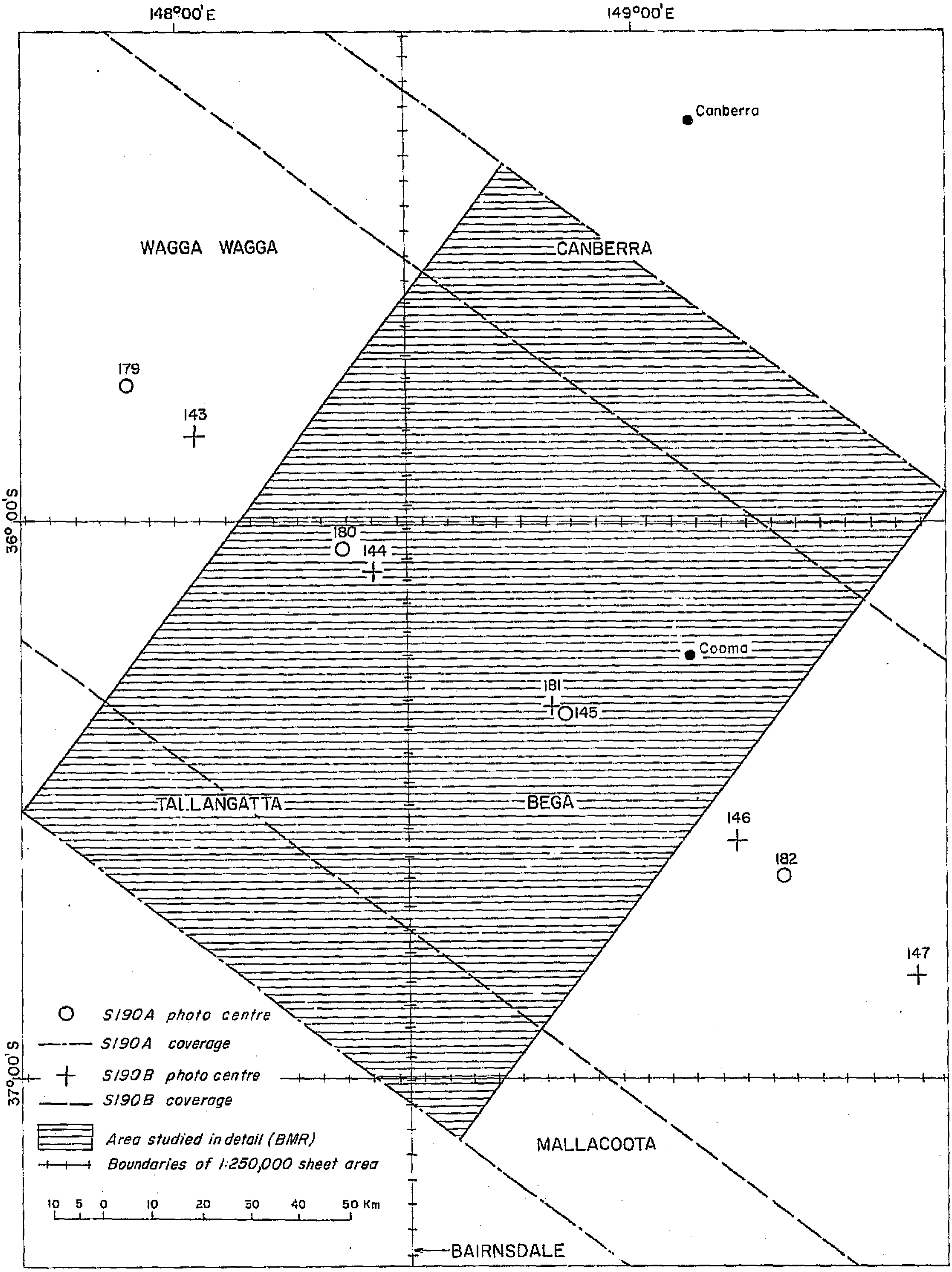
SL-4 Track 13 EREP Pass 15 15 December 1973

Fig. 1



Location of Alice Springs study area

Fig. 2



Location of Snowy Mountains study area

Fig.3

Research - participated in evaluating the photography obtained. The Division of National Mapping (DNM) of the Department of Minerals and Energy, although not an official investigator, made an assessment of its usefulness for land use mapping and topographic map revision (Section 6.5).

On 27 September 1974 Dr N.H. Fisher retired, and Mr B.P. Lambert, Director, Division of National Mapping, was appointed Principal Investigator for SR557.

A draft final report was submitted to NASA Principal Investigator Management Office in August 1975. Approval of the draft and a request for colour illustrations was received from NASA in October. The revised final report was sent to NASA in December 1975.

4. SUMMARY OF THE SKYLAB DATA RECEIVED

The following list shows the dates at which various Skylab photographic products - despatched from NASA Johnson Space Centre, Texas - arrived at BMR, Canberra. In each case the complete Australian photographic coverage per camera per mission was received.

Mission	Camera	Product	Date received
SL3	S190A	contact pos.	18 December 1973
"	S190B	contact pos.	1 January 1974
"	S190A	4x pos.	3 May 1974
"	S190A	4x neg.	3 May 1974
SL4	S190A	contact pos.	2 July 1974
"	S190B	contact pos.	29 July 1974
SL4	S190A	4x pos.	11 October 1974
"	S190A	4x neg. (Pan. only)	11 October 1974
SL3	S190B	2x pos.	28 November 1974
SL4	S190B	2x pos.	16 January 1975

Details of the Australian photographic coverage from SL3 and SL4 are shown in Tables 1 and 2.

TABLE 1 - AUSTRALIAN EREP PHOTOGRAPHIC COVERAGE

Frame number	Percent cloud cover	Centre of frame Latitude S DEG.	Latitude S MIN.	Longitude E DEG.	Longitude E MIN.
a) SL3/S190A					
162*B	65	23	22	133	23
163*BC	60	23	52	133	41
164*B	55	24	19	134	09
165	70	24	47	134	36
166	95	25	42	135	32
167	80	26	36	136	28
168	80	27	30	137	25
169	95	28	24	138	24

170	90	29	16	139	23
171	70	30	09	140	24
172	85	31	01	141	26
173	95	31	52	142	29
174	95	32	43	143	33
175	95	33	32	144	38
176	80	34	22	145	45
177*	80	35	10	146	53
178*	5	35	29	147	21
179*	5	35	48	147	49
180*bcf	5	36	07	148	17
181*bf	10	36	26	148	45
182*	15	36	45	149	14
183	25	37	03	149	43

b) SL3/S190B

117*	10	21	57	131	53
118*	40	22	17	132	11
119*	60	22	36	132	28
120*	70	22	54	132	46
121*	75	23	12	133	04
122*LB	60	23	31	133	22
123*LBC	45	23	50	133	40
124*LB	45	24	08	133	59
125*LB	40	24	27	134	17
126	80	24	45	134	35
127	100	25	26	135	16
128	100	26	05	135	56
129	65	26	44	136	37
130	75	27	22	137	19
131	95	28	01	138	00
132	100	28	40	138	43
133	90	29	18	139	26
134	85	29	55	140	09
135	25	30	33	140	53
136	75	31	10	141	38
137	85	31	47	142	23
138	85	32	23	143	09

139	95	35	59	143	56
140	95	33	35	144	43
141	85	34	11	145	31
142	65	34	45	146	20
143*lb	5	35	54	147	58
144*lbfc	5	36	09	148	21
145*lbf	5	36	25	148	45
146*lbf	10	36	40	149	08
147*l	25	36	55	149	32
148*l	35	37	11	149	56
149	60	37	26	150	20

c) <u>SL4/S190A</u>

91*	50	21	59	132	13
92*L	50	22	28	132	24
93*L	20	22	52	132	46
94*L	30	23	20	133	13
95*L	40	23	46	133	37
96*L	30	24	16	134	09
97 L	20	24	47	134	37

d) <u>SL4/S190B</u>

277*	35	21	55	132	14
278*	30	22	10	132	05
279*L	15	22	27	132	21
280*L	15	22	45	132	38
281*L	20	23	01	132	54
282*L	30	23	19	133	10
283*L	40	23	27	133	12
284*L	55	23	53	133	44
285*	55	24	13	134	05
286	35	24	28	134	19

Approximately 60% overlap with following frame – *
Frames studied in Alice Springs Area: Land Classification – L
Frames studied in Alice Springs Area: Geology (BMR) – B
Frames studied in Alice Springs Area: Geology (CSIRO) – C
Frames studied in Snowy Mountains Area: Land Classification – l
Frames studied in Snowy Mountains Area: Geology (BMR) – b

Frames studied in Snowy Mountains Area: Geology (CSIRO) - c

Frames studied in Snowy Mountains Area: Forestry - f

TABLE 2 - TIME OF PHOTOGRAPHY AT CENTRES OF TEST AREAS

		Alice Springs area		Snowy Mountains area	
	DATE	GMT	AEST	GMT	AEST
SL3	12 August	0241	1211	0246	1246
SL4	15 December	0006	0936	-	-

5. PROBLEMS ENCOUNTERED DURING EVALUATION

Reproduction delays

Because five separate Government agencies evaluated the Skylab photographs it was necessary to regard the films sent to the Principal Investigator as file masters for reproduction and distribution of copies to the co-investigators. For this purpose all film was lodged with the official Australian Government aerial photography contractor, Air Photographs Pty Ltd. The contractor experienced considerable difficulty in obtaining (from Kodak USA) suitable film to make high quality reproductions of the third generation Skylab masters. As a result of this, the initial Skylab films received in Australia on 18 December 1973 were not reproduced and distributed to co-investigators for evaluation until June 1974 by which time the co-investigators were committed to other projects.

Absence of co-investigators

Evaluation of Skylab photography was further delayed by absence of three co-investigators on an official Australian Government visit to the USA and Canada during October-November 1974.

Photographic problems

S190A Film 25 and 26 (EK2424 - B/W IR) proved to be dark-toned and excessively grainy resulting in total loss of fine detail visible in other films. Sensor Performance Report (MSC-05528) Vol. 1 (S190A) September 6, 1974 page 3-7h notes under SL-3 environmental effects on photography "... the 2424 film showed the greatest degradation of the four film types. This consisted of a speed loss of approximately one f stop, a noticeable decrease in the maximum density and an increase in fog of about .22 density units".

Both the S190A colour IR film (No 27) and colour film (No 28) received from NASA appear to be excessively grainy. The NASA report (ibid) notes that both films suffered an effective speed loss of approximately one half f stop. The colour infrared film suffered a decrease in maximum density; the colour film had no significant reduction in maximum density. The first S190B imagery received, while providing the best physical resolution by far, was very poor in colour fidelity. The 1:1 000 000 contact size colour transparencies were excessively blue to purple, and the forested areas were completely lacking in detail and contrast. The later material from S190B (1:500 000 colour transparencies) was considerably better, however reproduction problems prevented any useable imagery being available before the forestry study was finalized. Inherently the S190B imagery was far superior to all other EREP photographic imagery and should have been the best medium on which to work.

In the CSIRO Division of Mineral Physics Laboratory it was found that photographic processing equipment was incapable of preserving the resolution of the S190B photography. Delays in production of copies to desired standards resulted until the cause was eventually traced to vibration due to air turbulence in the cooling system of the enlarger.

Annotation problems

A problem of annotation was encountered during geological evaluations. The 24 cm x 24 cm format (2x enlarged) S190B photographs can be comfortably studied under a mirror stereoscope. The actual photograph scale (1:474 000) however is too small to allow accurate manual annotation of the detail that can be observed using the 3x or 8x stereoscope binocular magnification. Therefore the accuracy of any map thus produced will be limited by the annotation scale irrespective of the interpretation scale.

While the problem did not really affect the Skylab evaluation it is recognised that any future detailed photogeological mapping from the photographs would have to take this problem into consideration. Use of enlarged photographs (eg 10x) or stereo plotting equipment - neither of which are entirely suitable for efficient photogeological interpretation - may have to be considered.

Use of colour additive viewer

The absence of corner marks on the S190A photographs makes it difficult to bring them into register. The 70 mm copies received are affected by small differences in dimension so that satisfactory register could be obtained only over areas not exceeding about 1/10 of a frame at a time.

6. DISCIPLINE REPORTS

6.1 FORESTRY

History of the investigation

The forestry investigation aimed to evaluate the usefulness of Skylab photography in forest resource assessment. Australia does not have a standardized national forest inventory system although the development of a system is currently under active consideration. Satellite imagery or photography appears to offer considerable potential in the early stages of planning an inventory and in providing a base for subsequent detailed sampling. The investigation therefore concentrated on the likely contribution of Skylab or similar types of photography to an inventory system.

Previous forest inventories have been mainly timber inventories but with the growing demands being made on forests to provide non-timber values such as recreation, water production, wildlife habitat, etc. these aspects were included in the approach. In other words more emphasis has been placed on the recognition of ecological or pure vegetation boundaries rather than on timber production type boundaries.

Additional aspects such as forest fire area determination were also considered but were treated as incidental values rather than primary ones.

The investigation took the form of office interpretation and general examination mainly on one frame in the Snowy Mountains and South Coast of N.S.W. A brief field visit was made in August 1974. Following more intensive examination and selection of detailed test sites a further field visit was made in March 1975 to verify forest stratification and other observations.

Techniques and procedures

Conventional interpretation methods were employed exclusively including the use of simple lens stereoscopes and magnifying viewers. All investigations were conducted on transparencies which were considered to provide the best possible resolution and colour fidelity (where appropriate).

Summary of ground truth activities

There was no aerial survey or collection of ground data by field visits at the time of the EREP pass in August 1973.

Information which has provided the basis for the investigation consisted of: available topographic maps in the National Mapping series; a Forest Resources map at a scale of 1:1 000 000 recently completed on the basis of available information and interpretation of conventional aerial photography; aerial photographs mainly at a scale of 1:80 000 taken up to 5 years prior to the EREP pass; and local knowledge.

As mentioned under "History", two specific field visits were made to selected areas containing a range of forest vegetation types or exhibiting unusual patterns.

Landsat-1 imagery obtained in December 1972 and January 1973 provided some of the most useful comparisons.

Results and findings

A serious but unavoidable factor which materially affected the investigation was the fact that the area of Australia covered by the EREP pass included only limited areas of commercial forest and some of these were obscured by cloud. In the cloud free areas however the forest types are few, with species or species associations occurring over extensive areas. As these lend themselves particularly well to delineation at satellite imagery scales, they do not provide a comprehensive testing ground.

The simplest possible delineation is that which provides a differentiation between forested and non-forested land. All classes of EREP photography, with the exception of the two near infrared black and white films, were satisfactory for this simple delineation. The clearest photography was that provided by the S190B camera and in spite of the lack of contrast within the forested areas the most detailed interpretation of forest/non-forest boundaries was possible on this film. The colour IR film in S190A was particularly good in this separation especially where the areas were isolated and small. The colour film from S190A was lower in resolution than the colour film from S190B when photography at the same scale was compared. This was attributed at least in part to the different degree of enlargements involved in bringing both images to the same scale.

The B & W infrared photography from S190A is of little value in vegetation classification since most vegetation types are high reflectors of IR radiation. Detailed forest/non-forest boundaries were not readily determined on this photography.

It would be of considerable value to be able to broadly stratify the native forest into species associations from satellite or very-small-scale aircraft photography as a basis for further detailed sampling. The ability to carry out even a simple classification over large areas imaged at the same time with consistent illumination is a most desirable aim in any forest assessment.

Colour photography from S190A, particularly from the colour IR film showed variation in colour and density which was directly correlated with the occurrence of different forest types. The boundaries were not as clear as those exhibited by a colour composite from bands 4, 5 and 7 of a Landsat-1 mid-summer image. The interpretation was further complicated by the cover of snow on the high mountain areas as the Skylab photography was obtained in late winter.

The group is confident that, with summer photography and the resolution capacity of the camera used in the S190B experiment, coupled with the use of colour IR film, reliable mapping could be carried out for a number of types in the native forest area.

Because the native forests are generally dominated by species of Eucalyptus and up to 20 species may occur in the one area, species or species association mapping from small scale aerial photographs is not possible. Relatively extensive pure stands of single species however occur sometimes in the south of the continent and delineation of these types can be achieved. In the test area the structure of the forest types is relatively simple and this has contributed substantially to the successful delineation of types on the Skylab photography.

In other areas, such as on the north coast of New South Wales where the forest types are more complex and their occurrence is in a more detailed mosaic the same conclusions are almost sure not to apply. On Landsat-1 imagery of coastal areas, a breakdown into associations or types is generally not possible with visual interpretation techniques.

The best differentiation of types occurred where this was related to abrupt changes in topography and aspect. It was simpler to differentiate between non-forest, low density forest and medium density forest, than between medium and high density forest. The colour IR film was the best medium for the separation of the high density forest from the other forest types as the former was characterised by a bright red colour as compared to a red brown or muddy colour.

Generally speaking most of the high productivity forests were high density forests, however there was one notable exception. What is probably the most productive eucalypt forest in the area has been managed and controlled for more than 40 years but it did not show the characteristic red colour of the dense forests. In this case it was concluded that the reason for the anomaly was that the dominant species, Eucalyptus delegatensis, is characterised by relatively thin crowns with the leaves hanging vertically. The typical understorey in the forest is a low xeromorphic shrub and grass combination which in winter would naturally be quite low in IR reflectance, and it would contribute little to the overall density of the colour IR film.

Plantations of conifers are readily recognised on the colour and colour IR films once they achieve an age where the density of the canopy is sufficient to register. The density and colour of older plantations is generally darker for colour film or brighter red for colour IR film and is readily distinguishable from even the high density native forest. The ordered layout of the area is also indicative of plantation activity.

The location and extent of plantation areas is not likely to become a routine aspect of interpretation of satellite pictures simply because plantation management dictates intensive information from the stand.

Two major wildfires occurred in the area covered by the EREP pass during the previous summer season. There was little indication on the Skylab photography that such fires had occurred apart from a slight blue-green tone on the colour IR film in an area which was known to have been back-burned in an effort to control the major fire. Much of the eucalypt forest has a remarkable ability to recover from fire by producing new shoots and it appears that a period of 6 months after the fire is all that is necessary to provide the forest with a reflective canopy equivalent to that existing before the fire. The new crowns are largely made up of epicormic growth and are vigorous, and if the season is favourable can produce the same reflectance patterns as existed previously. This is particularly interesting as the signs of past fires such as dead crowns and old stag headed trees are readily visible for many years on conventional photography.

The Landsat-1 imagery available of the test area spanned the period of the fires and their progress and final burned areas were very clearly indicated. Unfortunately winter 1973 Landsat-1 imagery of the area is not available.

In view of the fact that there are no definite plans to launch further manned satellites in order to obtain photography similar to that obtained by the Skylab missions, it is unlikely that hard copy photography at scales as small as 1:3 000 000 to 1:1 000 000 will be readily available in the future.

One point which emerges very clearly from the Skylab experiment and other research is that there is considerable value in obtaining photography at scales from 1:250 000 to 1:150 000 from aircraft. At the present state of the art, aircraft are available to fly at altitudes of 20 000 metres and with super-wide angle lenses can be expected to achieve such scales. The advantages of broad area coverage would be realised with the detail and resolution of metric quality cameras.

A combination of Landsat-1 imagery and colour or colour IR photography at 1:250 000 scale would be a most satisfactory combination.

Conclusions

1. All EREP photography except that on the two black and white infrared films was satisfactory for forest/non-forest delineation.

2. The particular S190B photography was clearest but lacked detail in forested areas - further subdivision into forest classes was not possible.

3. S190A colour IR film permitted separation of native forested areas into 3 crown density classes and delineation of major forest species associations.

4. Black and white IR films were of little value in vegetation classification in native forests.

5. Separation of forest types (density or species associations) was more easily carried out on summer Landsat-1 MSS colour composite images than on winter Skylab photography.

6. Summer photography with colour IR film in the S190B camera was judged to have the greatest potential for forest classification.

7. Species associations in areas outside the test area are not expected to yield such acceptable results where the forest types occur in mosaic patterns and extensive pure stands are not generally present.

8. Plantations of exotic conifers are readily recognized on the colour and colour IR films once they achieve sufficient canopy density to register - this is directly related to the species, age of plantation and degree of thinning.

9. Photographs at very small scales (either from satellites or high flying aircraft) are of considerable value in forest inventory as an early stage in sampling designs (i.e. as a basic stratification medium).

6.2 GEOLOGY (BMR)

Techniques and procedures

To keep the geological evaluation of SKYLAB as objective as possible examination and interpretation of the EREP photography was initially carried out without reference to available ground data. However, each interpreter already had some familiarity with the general geology of the area he was studying.

Interpretation was carried out on positive transparencies (the location of their centre points is indicated on Figures 2 and 3) illuminated by fixed intensity (fluorescent tube) light tables. Mirror stereoscopes with built-in 1 x and 1.8 x magnification and accessory 3 x and 8 x magnification binoculars were used.

Conventional principles of photogeological interpretation were applied in the examination of the photography. During interpretation attempts were made to differentiate, delineate and correlate rock units and identify rock structures such as trends (foliation in metamorphics, bedding in sediments), folds, faults, joints and dykes.

Interpretation details were annotated in ink with Rapidograph pens (0.2 mm tubular nibs) onto "clear-clear" acetate film overlays.

After completion of the interpretation the results were compared by superimposing the acetate overlays on published geological maps. Any scale adjustment necessary was carried out by optical projection. All geological maps used in the comparison were originally prepared with the aid of panchromatic air photographs. Major differences between the SKYLAB interpretation and map data were further checked against other available ground data and vertical air photography at 1:83 000 scale or larger. Many interesting features, such as the distribution of outcrops in sand plains and in forest- or scrub-covered areas, the location of travertine outcrops, the morphology of sand ridges, and the nature of circular linear features, were checked on air photographs.

In the Alice Springs area the interpretation was commenced on S190B photographs, then completed on S190A photographs, and finally compared with information from Landsat-1.

In the Snowy Mountains area, the S190A photographs were examined first, in this order: film number 28 (true colour), 29 (panchromatic), 30 (panchromatic), 25(B/W IR), 26(B/W IR), and 27(colour IR). Films 25, 26, 29, and 30 were also studied in an I^2S colour additive viewer, but no additional information could be found. Then the S190B photographs and Landsat-1 images were studied. Finally the three interpretations were compared.

A statistical analysis was carried out on straight and slightly curved linear features annotated on the S190A and B photographs. Details are given in the section Linear features analysis - 6.2.2.

Summary of ground truth activities

No field work specifically to check Skylab interpretations was undertaken. Comparisons were made with the referenced geological maps, which are based on field traverses aided by aerial photographs mainly at scales of 1:50 000 and 1:80 000.

Results and findings

6.2.1 Alice Springs area (Site 204952)

SL3/S190 photography of approximately 8500 km^2 in the vicinity of Alice Springs was studied in detail. The area selected (Fig. 2) was part of an irregularly shaped cloud gap having approximate corner co-ordinates:

lat.	23°30'S	long.	133°10'E
	23°50'		134°25'
	24°25'		134°25'
	23°55'		133°10'

The following Skylab photographs were examined:

SL3/S190A - Film: RL's 25, 26, 27, 28, 29, 30

Frames: 162, 163, 164

SL3/S190B - Film: RL 84

Frames: 122, 123, 124, 125

The SL4 photography was not evaluated because of extensive cloud cover over the area at the time of the overpass. However it was noted that the terrain detail in cloud gaps was visibly clearer on SL4/S190B photography than on SL3/S190B photography.

Climate

The whole of the area is arid. Alice Springs, in the central north of the area, has an average annual rainfall of 252 mm (Perry et al., 1962). Most of the rain falls between October and March, but, because of its sporadic nature there is no definite growing season.

Vegetation

The vegetation includes grass, shrubs and low trees. Eucalypts are rare and acacias are the most common trees and shrubs. Spiny plants and succulents, common in overseas arid areas, are not important here. More comprehensive data on vegetation are reported in Perry et al. (1962).

Topography

Shadow effects on Fig.5a allow some appreciation of the topography of the area studied (time of photography 0242 hrs. GMT, 1212 hrs Australian CST August 12, sun elevation angle approximately 55°).

REFERENCE–FIGURE 5b

Era	Period	Unit	Symbol	Description
CAINOZOIC	QUATERNARY		Q	Alluvium, sand, conglomerate, evaporites, travertine, gravel
			Qt	Travertine
	TERTIARY		T	Limestone, conglomerate, laterite, sandstone, siltstone
PALAEOZOIC	DEVONIAN TO CARBONIFEROUS ?	Pertnjara Group	Pzp	Sandstone, siltstone, conglomerate, some limestone. Fish remains
	SILURIAN ? TO DEVONIAN	Mereenie Sandstone	Pzm	Sandstone, minor conglomerate
	CAMBRIAN TO ORDOVICIAN	Larapinta Group	Є-Ol	Siltstone, sandstone, limestone, phosphorite. Marine fossils
	CAMBRIAN	Pertaoorrta Group	Єp	Sandstone, siltstone, shale, limestone, dolomite, some conglomerate. Marine fossils
PRECAMBRIAN	PROTEROZOIC	Winnall Beds	Puw	Sandstone, siltstone, some conglomerate
		Inindia Beds	Pun	Siltstone, shale, sandstone, chert, chert breccia, some dolomite and tillitic conglomerate
		Pertatataka Formation	Pup	Siltstone, shale, limestone, calcarenite, dolomite, some sandstone and tillitic conglomerate
		Areyonga Formation	Pua	Siltstone and tillitic claystone, sandstone, dolomite
		Bitter Springs Formation	Pub	Dolomite, limestone, siltstone, sandstone, mafic volcanics gypsum
		Heavitree Quartzite	Puh	Quartzite, sandstone, conglomeratic sandstone, siltstone
		Arunta Complex	pЄa	Schist, gneiss, amphibolite, marble, quartzite
		Arunta Complex	pЄq	Quartzite and schist
			pЄg	Granite

- Geological boundary
- Anticline, showing plunge
- Syncline, showing plunge
- Overturned anticline
- Overturned syncline
- Fault

Where location of boundaries, folds and faults is approximate, line is broken; where inferred, queried; where concealed, boundaries and folds are dotted, faults are shown by short dashes

- Strike and dip of strata
- Prevailing strike and dip of strata
- Vertical strata
- Horizontal strata
- Overturned strata
- Dip < 15° (airphoto interpretation)
- Dip 15°–45° (airphoto interpretation)
- Trend lines (airphoto interpretation)
- Joint pattern (airphoto interpretation)
- Strike and dip of foliation
- Prevailing strike and dip of foliation
- Strike and dip of foliation with trend of lineation
- Dyke or vein, q – quartz, do – dolerite, p – pegmatite

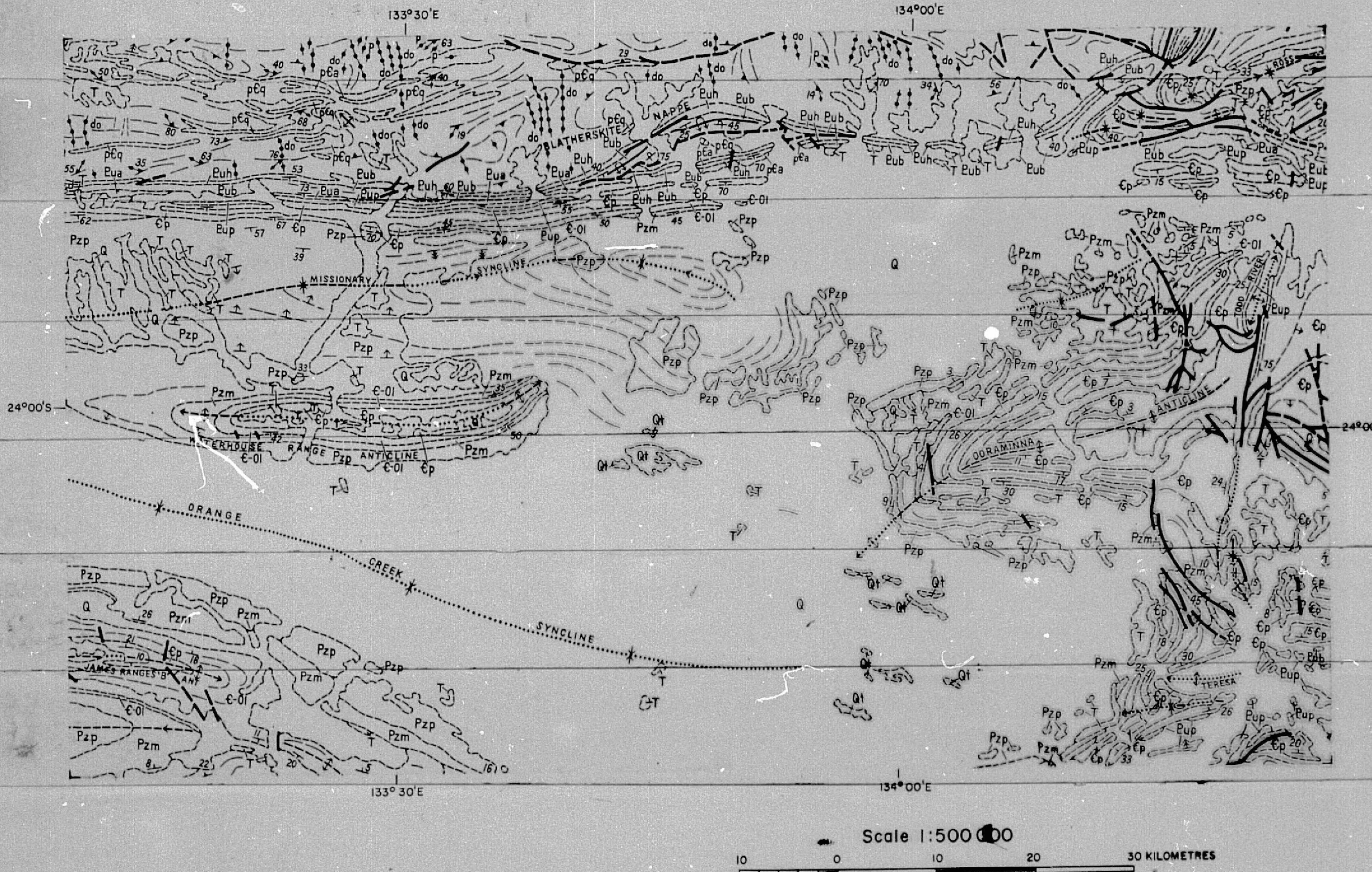
REFERENCE–FIGURE 5c

Era	Period	Symbol	Description
CAINOZOIC	QUATERNARY	a	Stream alluvium
		b	Colluvium, alluvium, active depositional fans
		c	Aeolian sand
		d	Undifferentiated sand, soil
		e	Travertine
	TERTIARY	f	Sediment (sandstone, siltstone)
		g	Gravel conglomerate, fan detritus
PRE-CAINOZOIC		h	Undifferentiated
		(stippled)	Cloud

Fig. 4

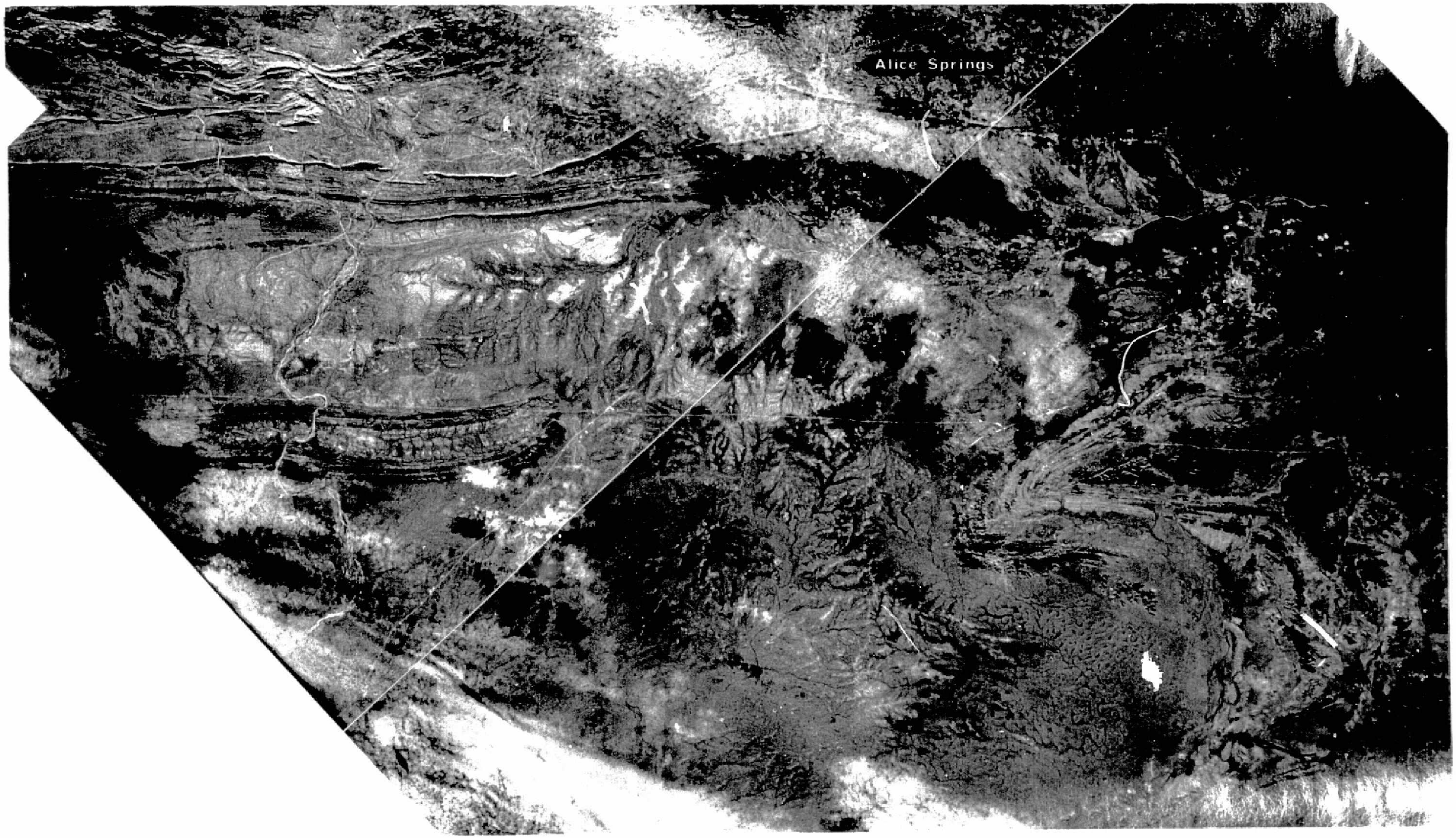
Cainozoic geology interpreted from SL 3/S190 B photography

5 c



Published geology (After Wells et al. 1970)

Fig. 5b



ALICE SPRINGS AREA — SL3/S190B Part mosaic of RL84 frames 123, 124

Fig. 5a

The central part of the area is occupied by sand and alluvial plains at elevations between 540-590 m a.s.l. Aeolian dune development increases to the southeast.

To the east and west of the plains, folded Palaeozoic sediments display well developed strike valley, cuesta and hogback morphology with peaks up to 200 m above plain level.

The northern part of the area consists of an east-west trending zone of ranges and hills within which arid erosion processes have developed excellent rock exposures. Folded quartzites form crests up to 700 m above plain level, whereas most of the crystalline and metamorphic rocks of the ranges have subdued relief.

Major drainage throughout the area consists dominantly of consequent streams which are part of a regional internal drainage network. Subsequent streams are well developed in areas of sedimentary rocks.

General geology

The investigation area covers part of the Amadeus Basin, originally an east-west trending intracratonic depression approximately 800 km long and 200 km wide, within the relatively stable Australian Precambrian Shield. The crystalline basement comprises orogenically deformed igneous and metamorphic rocks known as the Arunta Complex. The basement rocks are unconformably overlain by the Amadeus Basin sequence of Adelaidean (Late Proterozoic) and Palaeozoic (Cambrian, Ordovician) sediments, which have been deformed by epeirogenic and orogenic movements. The distribution of the main rock types is shown om Figure 5b. The 1:250 000 scale mapping (Cook, 1968, 1969, Quinlan & Forman, 1968, Wells, 1969) was concerned primarily with the sedimentary basin, and lithological subdivision of the Arunta Complex was not attempted. Similarly only limited subdivision of Cainozoic surficial units was attempted.

Results

Structure

Foliation. In the metamorphic terrain of the Arunta Complex in the northwest of the area studied (Fig. 5b), the strike of metamorphic foliation can be mapped to the accuracy shown on published 1:250 000 scale maps. Foliation dip direction can be determined in only a limited number of places generally where its influence on topography can be detected by stereoscopic viewing.

Bedding. Within the outcropping Proterozoic and Palaeozoic sedimentary sequences bedding traces and strike direction can be readily identified. This is primarily due to the effects of erosion on rocks of different resistance. Since different rocks of the area often display different natural colours the colour photography is more useful for detecting bedding than panchromatic copies. Dip direction can be readily determined and dip values of well developed cuestas and hogbacks can normally be estimated to within $\pm$ 10° of published field measurements.

Folding. Since the strike and dip directions can be readily determined it follows that the positions of fold axial traces can be interpreted.

With the exception of the axis of Orange Creek Syncline - which could not be positioned because of cloud cover over the southern limb - all fold axes on Fig. 5b could be independently identified and accurately positioned from Skylab photography.

Faulting. Detection of faults was not as successful as expected. Some transgressive faults in well exposed terrain could be definitely identified. Faults such as those 10 km north of Teresa anticline (Fig. 5b) in the southeast of the area, could be inferred, but do not display sufficient photo evidence to allow positive delineation. None of the strike or near-strike faults (e.g. near Blatherskite Nappe) could be detected.

No new faults of major significance were identified, although some new faults were located in the Arunta Complex rock in the northeast of the area.

Lineaments. Numerous photo lineaments can be detected by employing the techniques of both vertical stereoscopic viewing and low angle monoscopic viewing.

Since only a limited area was available for study and problems arose from the presence of scattered cloud and cloud shadows, no intensive study of lineaments was undertaken.

Most lineaments were detected throughout the plain areas of Quaternary alluvium, sand etc. (unit Q on Fig. 5b). The lineaments do not correspond with any structures on published maps and they are believed to be expressions of mega-joints. Where lineaments can be traced through well exposed Proterozoic and Palaeozoic sediments there are no detectable dislocations of the bedding, which suggests that most lineaments are unlikely to be expressions of faults. Similar observations were noted during studies on Landsat-1 lineaments of the Alice Springs area (Maffi et al., 1974).

SL3/S190A Film RL29 (panchromatic) proved best for detecting lineaments. Approximately twice as many lineaments were detected on the Skylab S190A photography as on Landsat imagery of the same area at the same scale. This can be largely attributed to the greater resolution of Skylab photography. Less than 5% of the Skylab lineaments coincide in whole or part with Landsat lineaments. In some places fence lines could be identified on Skylab because of marked vegetational and/or tonal differences on either side of the fence. Where tonal differences are less marked fence lines may be mapped as lineaments.

Joints. Rock exposures throughout the region studied do not contain any extensively developed joint systems. The jointing that is present can be mapped on S190B photography in equivalent detail to that shown on published 1:250 000 maps of the area.

Dykes. Numerous dolerite and pegmatite dykes intrude the Arunta Complex. At least 50% of the dolerite dykes shown on Fig. 5b could be independently identified and annotated in whole or part because of their width (up to 25 m), high colour contrast and transgressive nature. Dolerite dykes in areas of dense topographic shadows or with trend directions similar to the surrounding geology cannot be reliably detected. Light-toned porphyry dykes do not have sufficient width or tonal contrast to be identified.

Rock Type Discrimination

Precambrian metamorphics. On S190B photography regions of Precambrian Arunta Complex metamorphics could be reliably differentiated from Proterozoic and Palaeozoic sediments (Fig. 5b).

Owing to hardness differences and tonal contrast, the distribution of the quartzite and schist unit (Fig. 5b) within the Arunta Complex could be annotated, but no further reliable subdivision of the metamorphics was possible. Some areas of different metamorphic rock types could be recognized, but the boundaries between such areas could seldom be continuously annotated.

Proterozoic and Palaeozoic sediments. The Proterozoic and Palaeozoic sediments cannot be differentiated from one another by photogeological criteria alone. Throughout the sedimentary terrain it is generally possible to photo-interpret bedding and dip information and different rock criteria, thus allowing reliable subdivision of, and correlation between, individual exposures. As with conventional aerial photography photointerpretation subdivision into exactly the same units as shown on published maps would not be possible without additional field data. However, once unit boundaries had been established at key locations, extensive preliminary subdivision of the sedimentary sequence throughout the area could be done on S190B photography with little additional ground data.

Cainozoic surficial materials. The geologic and geomorphic information about surficial materials that could be recognized on S190B photography was greater than expected. For this reason emphasis was placed on evaluating the reliability of photointerpretation of seven subdivisions of Cainozoic surficial materials.

The independently photointerpreted map (Fig. 5c) at 1:500 000 scale was initially compared against 1:250 000 scale published maps. For convenience part of the published 1:500 000 scale map (Fig. 5b) of Wells et al. 1970 is used in this report. Although the 1:500 000 scale map naturally shows less information than the 1:250 000 scale maps from which it was generalized, some information (e.g. Qt) represents the total distribution from all publications.

The map of the Skylab interpretation (Fig. 5c) must be regarded as generalized also and does not represent the maximum amount of information that can be interpreted (see Section 5.4, Problems Encountered). Figs. 5b and 5c show boundary differences which are due to generalization during compilation of both data sources. One example is the boundary between Pzp and Q (Fig. 5b) and h and c (Fig. 5c) to the southwest of Ooraminna Anticline.

For completeness some published information about lithology and ages was added to the reference to Fig. 5c shown in Fig. 4.

The attempt to differentiate pre-Cainozoic rocks (unit h on Fig. 5c) from younger rocks was reasonably successful. Differentiation was more accurate where topographic differences were greatest, e.g. between sand plains and strike ridges. An area of disagreement between published and interpreted geology occurs along the northwestern edge of the Waterhouse Range Anticline (Figs. 5b, c). Examination of 1:25 000 scale colour aerial photographs taken in 1973 shows that although the area marked Pzm on Fig. 5b does contain rock outcrop it is dominantly sand covered and thus the Skylab interpretation is more accurate.

Two early Cainozoic units were interpreted. Their age, relative to other units, was judged on the basis that both units are unconformable on older rocks and both occur as remnants of more extensive deposits.

In the northwest of the area unit g (Fig. 5c) is interpreted from position and morphology to be remnants of fan deposits. Comparison with unit T (Fig. 5b) shows that approximately 70% of the unit was correctly identified on Skylab and that some boundary positions could be improved by the use of the space photographs.

In the central and eastern portions of the area a flat-lying unconformable unit (f) was delineated. In general there is poor agreement with outcrops of unit T of the published geology. Reference to published 1:250 000 scale maps (Wells, 1969, Cook, 1969) shows that at the larger scale the outcrops of T are subdivided into two separate types of Tertiary rocks; silcrete, and freshwater sediments (consisting of chalcedonic limestone, sandstone, siltstone and claystone). When compared against these subdivisions essentially all unit f interpreted from Skylab photography corresponds to the freshwater sediments.

With the exception of the sediments 5 km northwest of Teresa Anticline, all other areas of T (Fig. 5b) that were not detected on Skylab photography correspond to Tertiary silcrete. Non-detection of the sediments near Teresa Anticline was due to the presence of trends parallel to the pre-Cainozoic rock and the absence of light toned scree and alluvium which is characteristic of the other areas designated as f.

North of Ooraminna Anticline the interpretation of Pzm (Fig. 5b) as unit f (Fig. 5c) is due to cappings of Tertiary silcrete over the Pzm.

The independent interpretation of two different (Tertiary) units of fan material and sediments was reasonably successful. In this particular case the ability to detect and differentiate the units on Skylab photography has benefits of possible economic significance since both units are potential sources of secondary uranium mineralization.

One other Cainozoic rock (travertine) is also a possible source of secondary uranium mineralization. Areas of light grey colour (unit e) were interpreted as travertine from Skylab photography and these correlate well with the known areas of travertine (compiled onto Fig. 5b from Cook, 1969). On conventional (1:50 000 and 1:80 000 scale) panchromatic air photographs travertine often cannot be differentiated from light toned units. Despite the difference in scale the rather distinctive hue of travertine on S190B colour photographs allows more reliable identification.

Although the generalized published geology at 1:500 000 scale does not show subdivision of the Quaternary, the 1:250 000 scale map of the area shows at least three subdivisions; alluvium, including river gravel; aeolian sand; conglomerate and scree.

The independent interpretation of Skylab photography indicates that the distribution of aeolian sand and stream alluvium can be mapped in considerable detail. Interpreted aeolian sand includes all areas of recognizable dune development. To the south of Ooraminna Anticline an extensive area of reticulate dunes can be identified on Fig. 5a by the dark speckled pattern of vegetated swales. Individual dune crests can be identified by the light-colour of the mobile sand. The reticulate dunes are up to 12 m high and consist of braided sand ridges or connected smaller dunes (Perry et al. 1962).

Stream alluvium (unit a on Fig. 5c) was differentiated on the basis of texture and position relative to drainage channels. Areas of surficial material which could not be readily classified as either unit c or a were placed into unit d (undifferentiated sand and soil). Published geology (Wells, 1969) indicates that the interpreted unit d consists predominantly of alluvium although there is sufficient evidence on Skylab photographs to differentiate this alluvium from active stream alluvium.

Where colluvial fans are immediately adjacent to high topographic features the boundary between surficial material and Pre-Cainozoic outcrop is difficult to interpret. Unit b includes areas of alluvium and colluvium associated with presently active depositional fans. Such areas could not be consistently differentiated from units a or c.

Table 3

Mappability of geological features on SL3/S190A photography compared with SL3/S190B photography

(G - Good, F - Fair, P - Poor, ND - Not Detectable)

SL3/S190A Films (Spectral Range - micrometres)	25 .7-.8	26 .8-.9	27 .5-.88	28 .4-.7	29 .5-.6	30 .6-.7
a - stream alluvium	P	P	F	F	P	F
b - colluvium, alluvium, active depositional fans	ND	P	P	F	G	P
c - aeolian sand	ND	ND	F	P	F	ND
d - undifferentiated sand, soil	F	P	G	F	P	P
e - travertine	ND	ND	G	G	ND	F
f - Tertiary sediments	ND	ND	P	P	ND	P
g - Tertiary gravel, conglomerates, fan detritus	P	P	F	F	F	F
h - Pre-Cainozoic boundary	P-F	P	G	P	F-G	F
Archaean rock subdivision	P	F	P	P	F	P
dykes	P	P	P	F	F	F
faults	P	F	F	F	F	F
bedding	F	P	G	G	G	G
dips	P	P	F	F	G	G
fold axes	F	P	F	G	G	F

Comparison of SL3/S190A and SL3/S190B photography

Features categorized on 1:500 000 scale S190B photography were examined stereoscopically on 1:1 000 000 S190A photography with 3X and 8X magnification.

As set out in Table 3 the ability to map geological features on S190A photography was graded as good (G), fair (F), poor (P), or not detectable (ND) compared to the S190B photography which was regarded as optimum.

Poor results from films 25, 26 (B/W IR) can be attributed in part to excessive density and grain. Both the colour and false colour infrared films (27 and 28 respectively) contain significant grain effects which are visible on 3X enlargement. Because of the different film defects mentioned above no meaningful comparison can be made. An overall comparison of the films (irrespective of defects) based on interpretation of the fourteen geological features examined would rate them in decreasing order of utility as:

Film 27 (2443 - Colour IR	Filter	EE -	Spectral	Range	.5-.88	micrometres)	
Film 28 (SO356 - Colour	"	FF -	"	"	.4-.7	"	)
Film 29 (SO022 - B/W Pan	"	AA -	"	"	.5-.6	"	)
Film 30 (SO022 - B/W Pan	"	BB -	"	"	.6-.7	"	)
Film 25 (2424 - B/W IR	"	CC -	"	"	.7-.8	"	)
Film 26 (2424 - B/W IR	"	DD -	"	"	.8-.9	"	)

In general the colour and false colour infrared photographs allowed more reliable geological interpretation than any of the black and white films.

Comparison of SL3/S190 photography with Landsat-1 imagery

All four bands of fifth generation positive film transparencies of Landsat-1 scene 1210-00315 were examined individually, and in an I^2S colour additive viewer at 1:1 000 000 scale, in an attempt to detect the geological features listed in Table 3. Some features could be recognized, however the mappability of features on Landsat-1 imagery compared to S190B photography would be classified as either very poor or not detectable. Thus for general geological interpretation the fifth generation Landsat-1 imagery is regarded as inferior to all types of Skylab S190 photography.

Conclusions

In the Alice Springs area the evaluation of Skylab S190B colour photography indicates that:

- differentiation and correlation of broad rock subdivisions, rock trends, joints, and fold axial traces can be interpreted with an accuracy equivalent to that shown on 1:500 000 scale published map of the area.
- ground data from a limited number of selected key traverses would allow reliable and rapid 1:500 000 scale photogeological mapping of the sedimentary sequence.
- only the major transgressive faults and dykes can be recognized.
- photointerpretation of Quaternary surficial materials is sufficiently reliable to allow extensive updating of 1:250 000 scale geological maps.
- travertine occurrences can be more readily mapped than on larger scale panchromatic air photographs.
- in similar arid terrain the S190B colour photographs could assist in the programming and execution of reconnaissance geological mapping projects.
- such photographs are more useful than S190A photographs or Landsat-1 imagery for reconnaissance geological mapping.

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6.2.2 Snowy Mountains area (Site 204954)

Topography and physiography

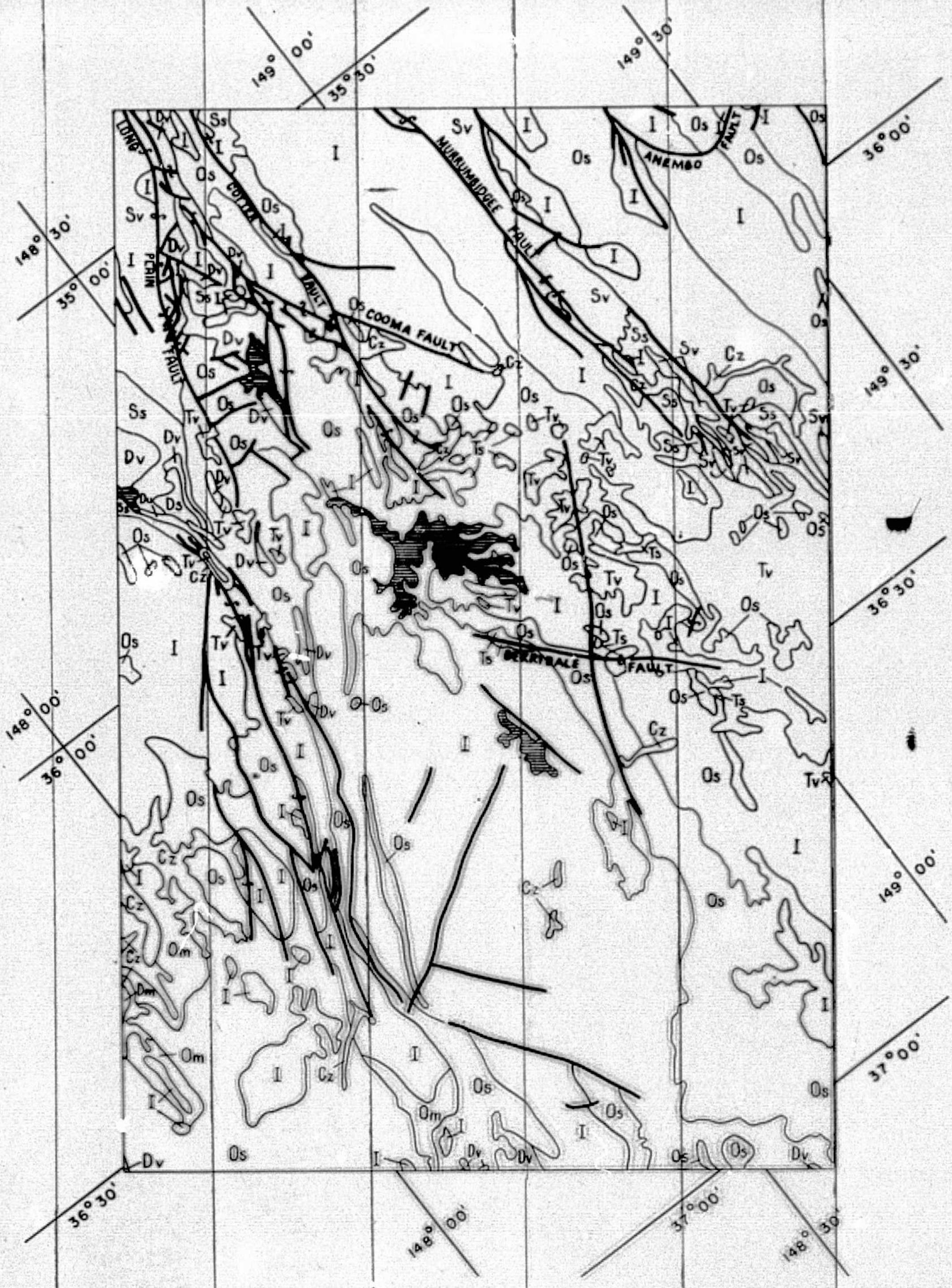
The Snowy Mountains (Fig. 7) are the most prominent feature in the area. They form a plateau which, in several places, rises above 1800 m a.s.l. and which tops 2230 m at Mt Kosciusko, the highest mountain in Australia. The eastern and western slopes of the plateau are deeply dissected. The Murray River system drains the western slope; the point where it flows out of the area is 265 m a.s.l. The eastern slope is flanked by tablelands of 1300 to 730 m elevation. North of the tablelands, the rugged Brindabella-Bimberi Range rises to 1900 m at Bimberi Peak, and the Tinderry Mountains reach 1600 m. The southern margin of the tablelands is deeply incised by the drainage system of the Snowy River, whose lower point in the area is about 200 m a.s.l.

The climate ranges from temperate highlands type at Cooma to alpine mountain type on the Snowy Mountains. The average rainfall is 480 mm at Cooma, and 1238 mm near Mount Kosciusko (Bureau of Meteorology, 1956).

General geology

The oldest rocks exposed in the area are Ordovician and Silurian sandstone-shale sequences (Os and Ss in Fig.6b), and some rocks belonging to the Ordovician metamorphic belt of Victoria (Om). The deformation of these rocks is due to several compressive episodes which started at the end of the Ordovician (Benambran Orogeny) and continued intermittently until the Carboniferous.

Thick sequences of middle to late Silurian acid volcanics (Sv), with minor interbedded sediments, are distributed in north-south trending belts. These belts are bounded by granite batholiths of late Silurian to early Devonian age (I). The intrusive rocks are present in the horsts of horst-and-graben structures, whose predominantly meridional orientation was probably controlled by east-west compressive forces during the Silurian and Devonian periods, culminating with the mid-Devonian Tabberabberan Orogeny.



REFERENCE

Cz	*Cainozoic*
Ts	*Tertiary Sedimentary rocks*
Tv	*Tertiary Volcanic rocks*
Ds	*Devonian Sedimentary rocks*
Dv	*Devonian Volcanic rocks*
Du	*Devonian Ultramafic rocks*
Ss	*Silurian Sedimentary rocks*
Sv	*Silurian Volcanic rocks*
Os	*Ordovician Sedimentary rocks*
Om	*Ordovician Metamorphic rocks*
I	*Intrusive rocks*
	Boundaries
	Faults
	Lakes

Scale 1:1000 000

Fig 6b Snowy Mountains Area Lithological map (faults from Pogson, 1972)

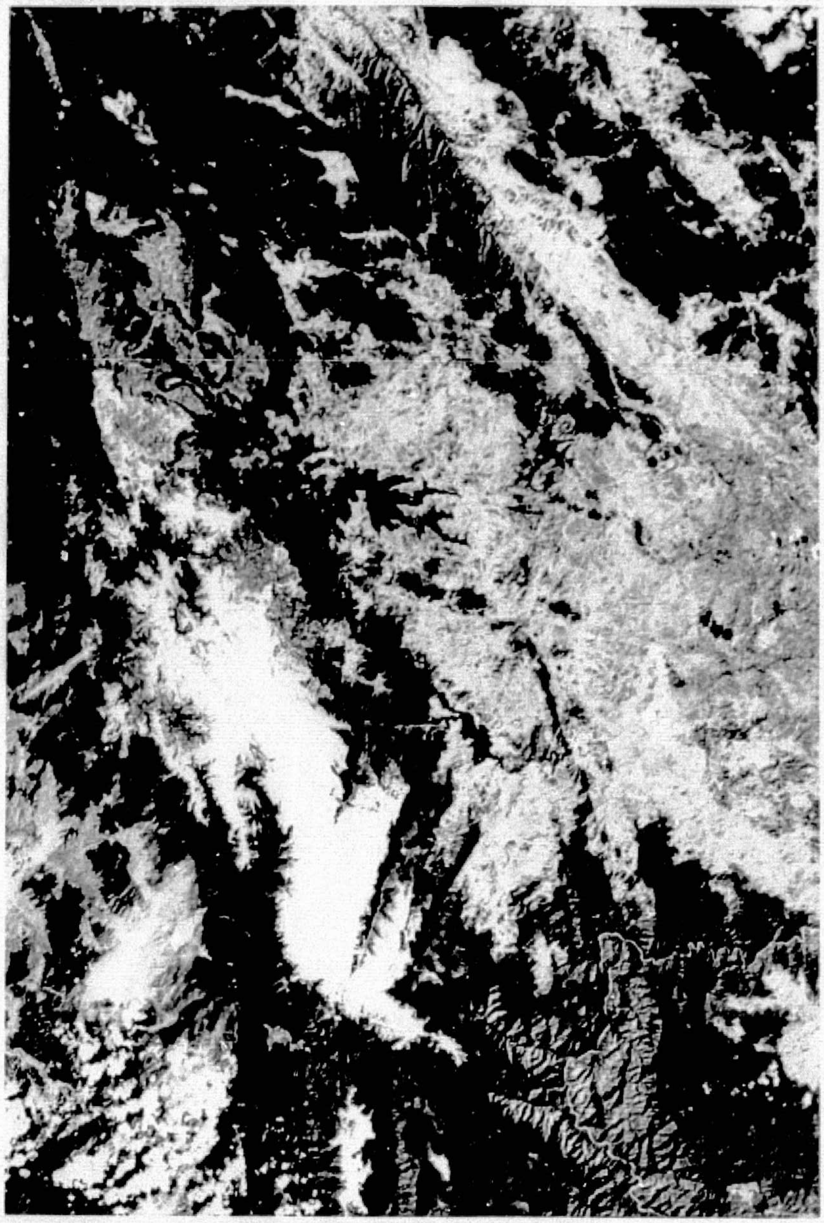


Fig 6a Part of SL3/S190A, RL27 Frame 180 (IR)

East of the Great Dividing Range in the eastern corner of the area (Fig. 7), the structural style consists of fold belts separated by north-south trending faults.

Devonian volcanics (Dv in Fig. 6b), possibly extruded along the major longitudinal faults, crop out in the grabens. Ultramafic rocks (Du) crop out in a northerly trending belt which extends for about 50 km outside the area. In the eastern corner of the area, Devonian molasse-like sandstones (Ds) crop out in a narrow meridional syncline, formed during the Kanimblan Orogeny of Early Carboniferous age.

Tertiary volcanic rocks (Tv) and Tertiary sedimentary clastic rocks (Ts) are scattered in the central part of the area. South of Cooma, the Tertiary volcanics cover several hundred square kilometres.

Many of the Siluro-Devonian faults were rejuvenated by the Late Tertiary Kosciusko uplift.

Cainozoic deposits (Cz) cover the floors of some of the present valleys.

The known dominant structural trends in the area (E. Scheibner, pers. comm.) are:

a) North-south and north-west - south-east: old trends, associated respectively with thrust faults and with left lateral transcurrent faults active during the Banambran and Tabberabberan Orogenies.

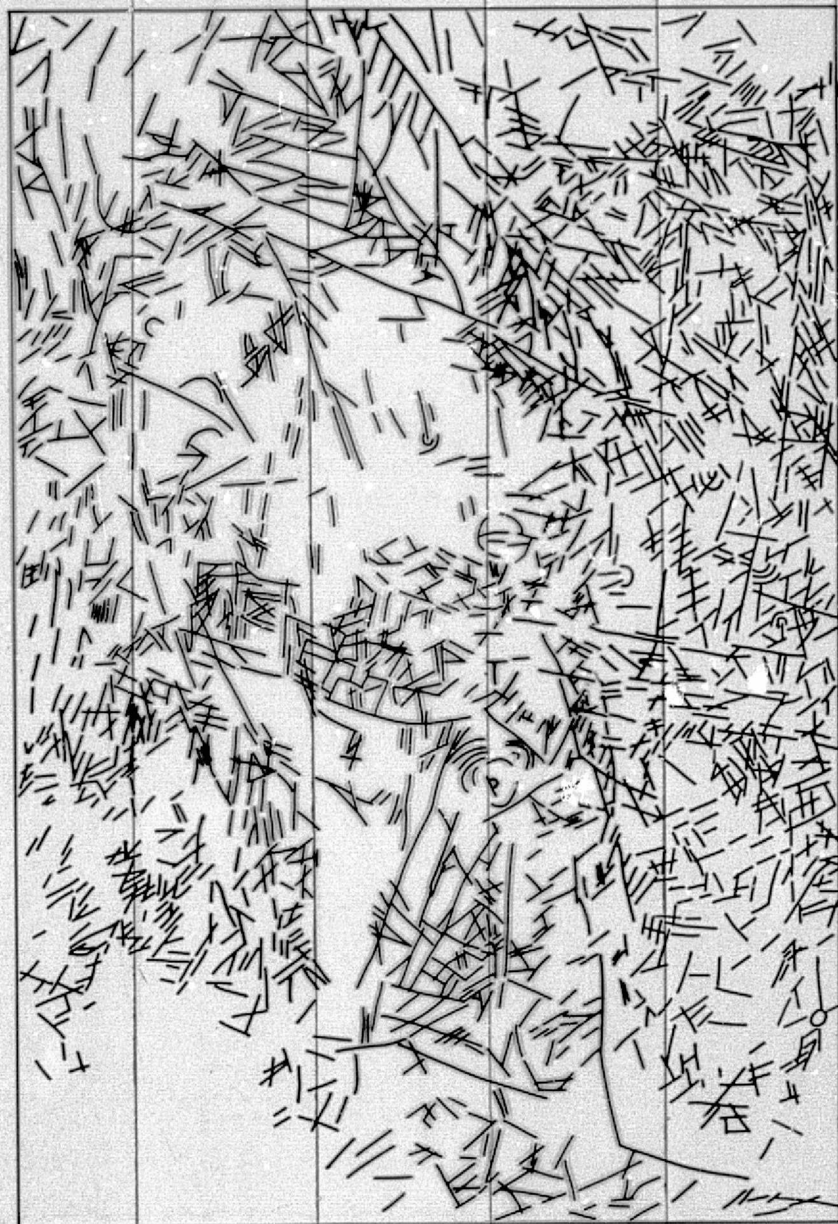
b) East-west to northeast - southwest: young trends, associated with Mesozoic intrusions and Cainozoic volcanism.

Results

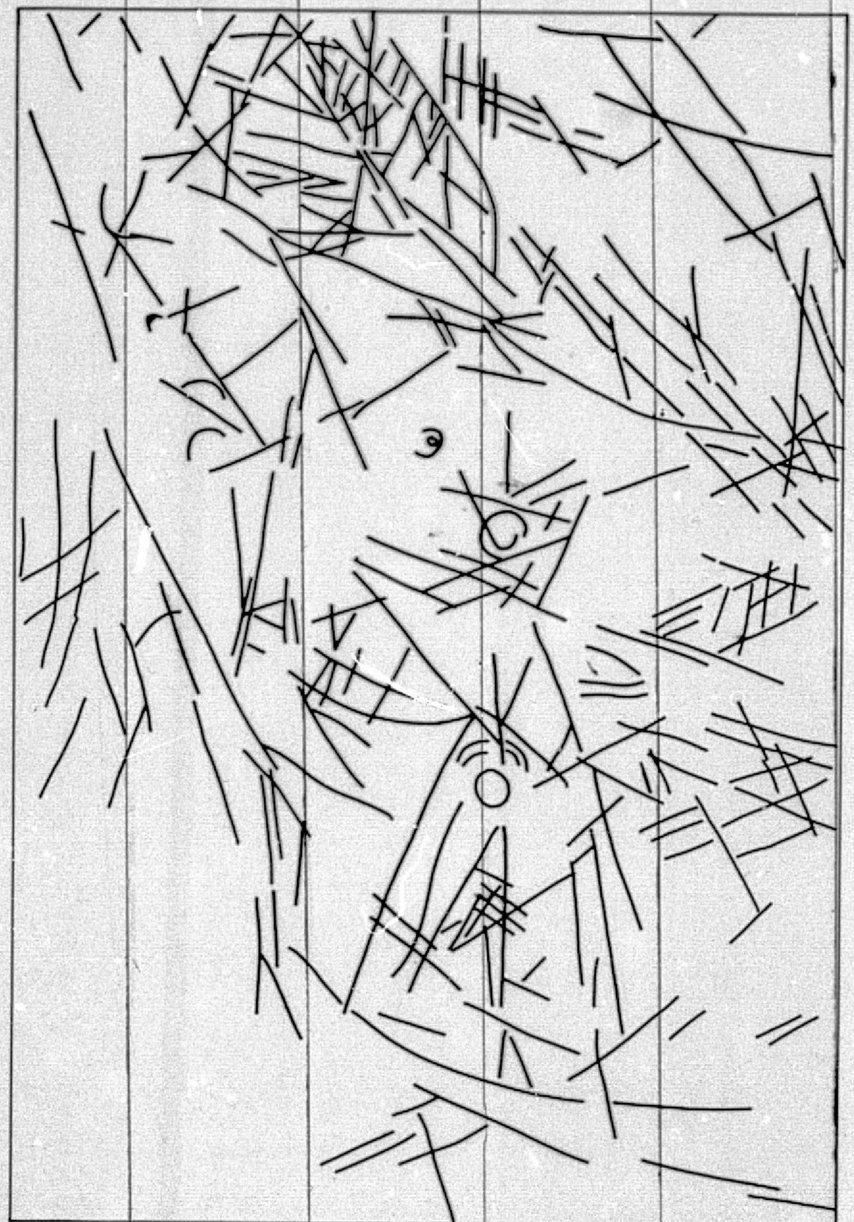
Rock type discrimination from S190A photographs

Film number 28 (0.4 - 0.7 µm, Colour)

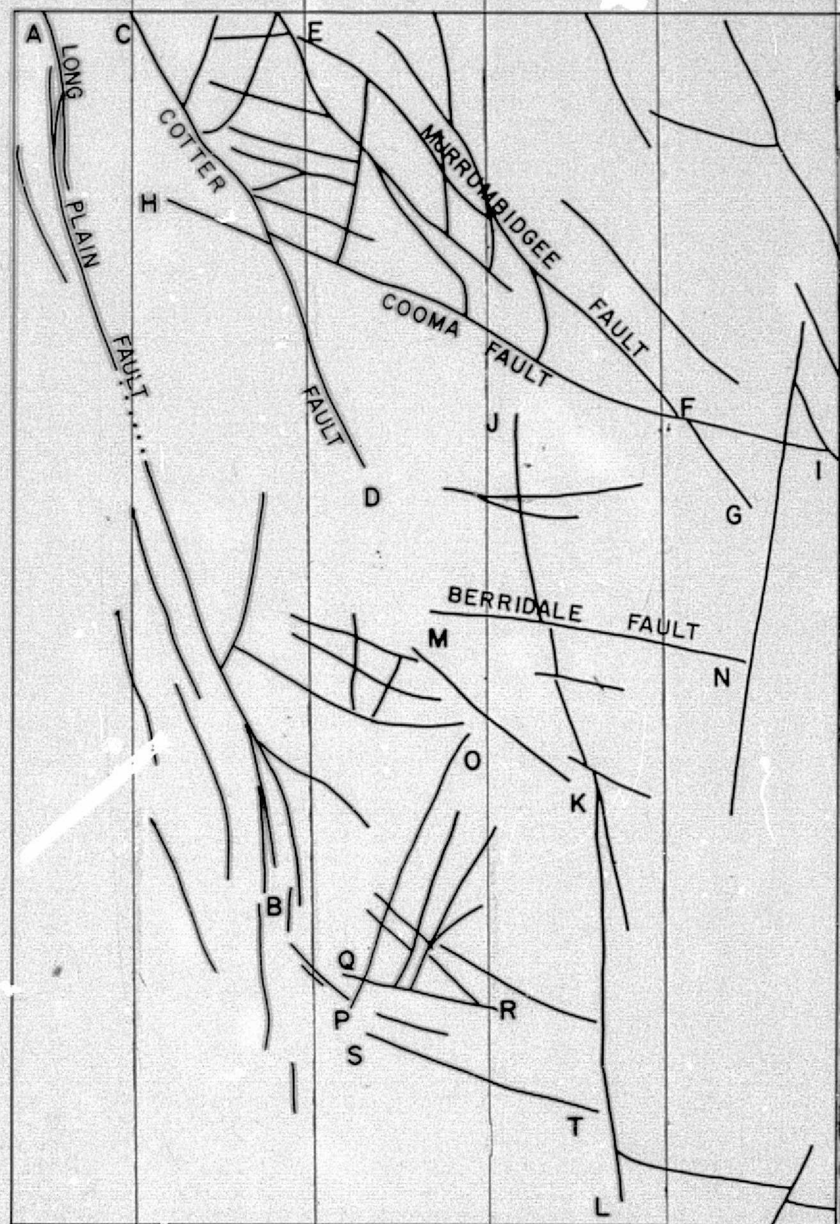
In general, colour, morphology and vegetation do not appear to be directly related with rock type: in places, different rock types are



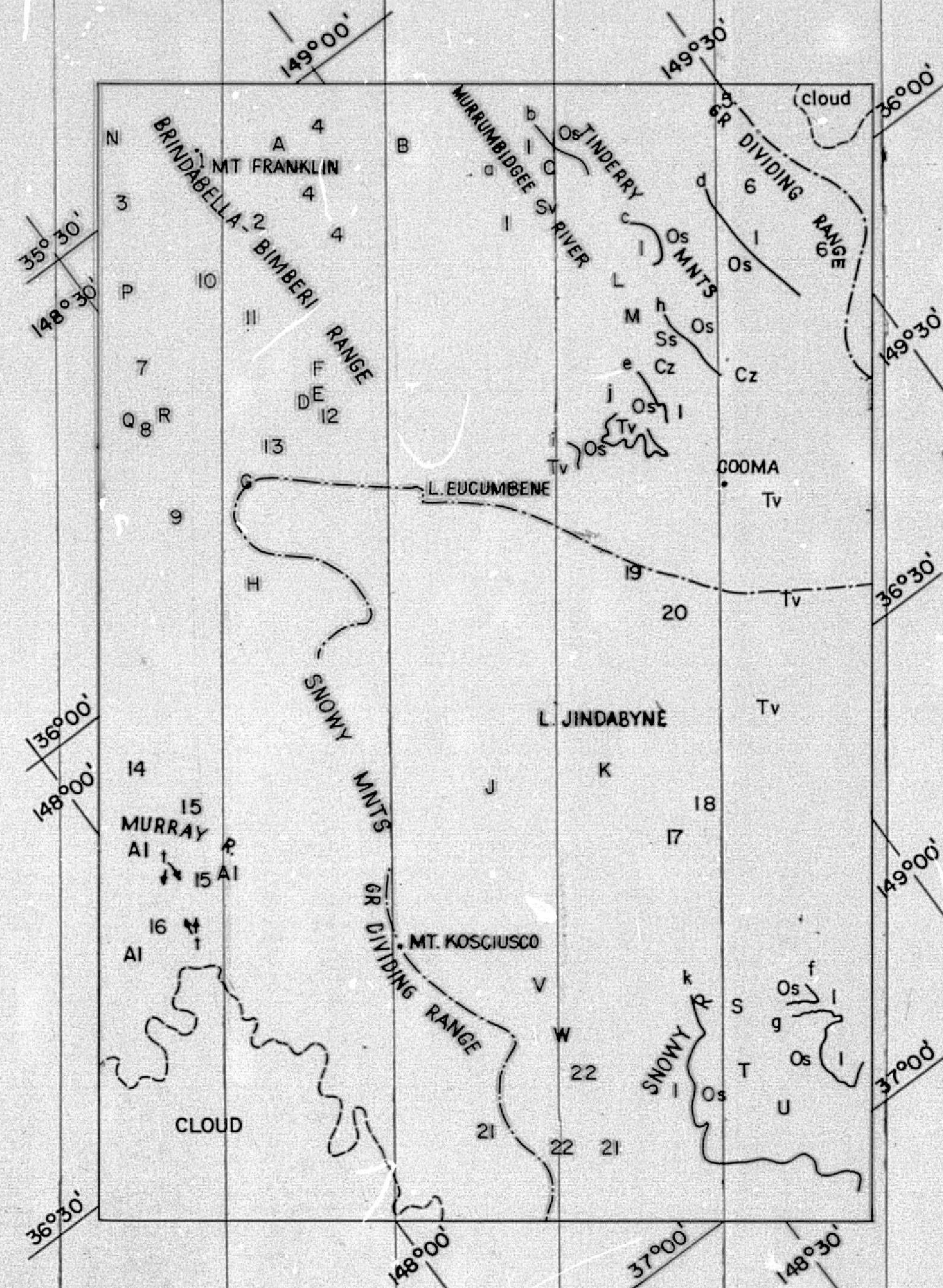
d Liner features annotated with 3X magnification



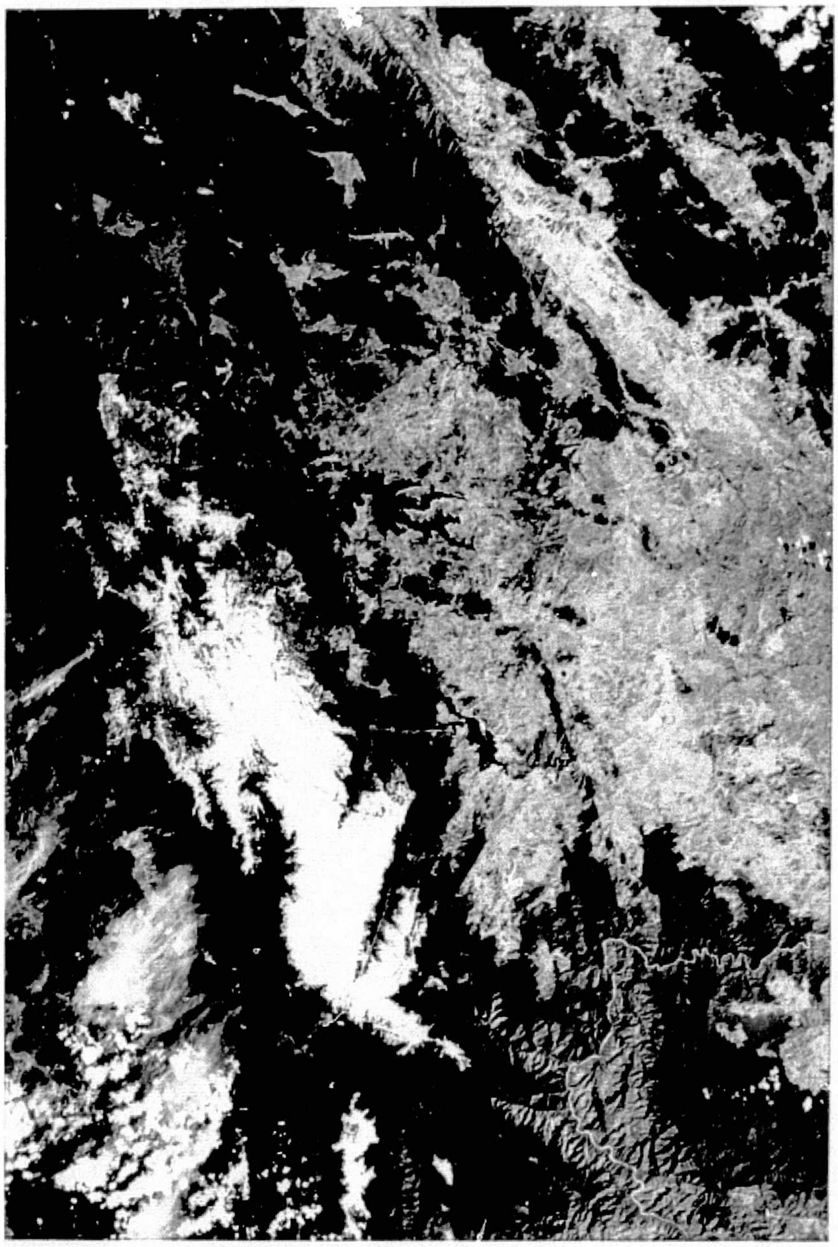
c Linear features annotated without magnification



b Faults interpreted from Skylab S190



a Topographic features and relevant points discussed in text



10 0 20 40 km

Fig 7 SNOWY MOUNTAINS AREA
SL3/S190A Part of frame 181, RL 28

represented with similar characters. For example, in figure 7a: 1 (Os) and 2 (I); 3 (Sv) and 4 (I); 5 (Os) and 6 (I); 7 (Sv), 8 (Ss) and 9 (Ds); 10 (Ss), 11 (Dv), 12 (Os) and 13 (I); 14(I), 15 (Os) and 16 (Om); 17 (Os) and 18 (I); 19(Tv) and 20 (I); 21 (Os) and 22(I). Or, the same rock types may be represented with different characters in different places. For example, in figure 7a: I at A, B and C; Os at D, E and F; Os at G and H; I at J and K; Sv at L and M; Sv at N and P; Ss at Q and R; Os at S, T and U; I at V and W.

In some places, changes in vegetation, relief and texture do coincide with known geological boundaries. Examples of this are, in figure 7a: a, between I and Sv; b, c, d, e, f and g, between I and Os; h, between Ss and Os; i and j, between Tv and Os; k between I and Os. But, in the interpreter's opinion, there is no way of telling, from the images alone, where this coincidence exists or, when the coincidence is known to exist, where it begins and ends. The interpretation of air photographs at 1:50 000 and 1:85 000 scale did not give much better results.

The Tertiary volcanics (Tv, figure 7a) generally exhibit a darker colour than the surrounding rock types, but the variation is so small and gradual that a precise boundary cannot be traced with conventional photointerpretation methods.

Cainozoic outcrops (Cz, figure 7a) smaller than 2 km across in fairly flat areas are difficult to distinguish in the image. Large alluvium deposits (Al, figure 7a) can be easily mapped. Some river terraces (t, figure 7a) are visible on the Murray River valley.

Film number 25 (0.7 - 0.8 μm, B/W IR)

In general, same comments as for film 28.

Medium to high contrast grey tone variations are probably related with vegetation differences.

Alluvium is very easy to map because of the high reflectivity of its vegetation cover, mainly grass; the reflectivity of the cultivated areas in the Murray River valley is second only to that of snow.

Film number 26 (0.8 - 0.9 µm, B/W IR)

Similar to film 25, but contrast is poor.

Film number 27 (0.5 - 0.88 µm Colour IR)

Alluvium and Tertiary volcanics have unique signatures and can be easily mapped; alluvium is imaged in reddish orange and Tv in a particular hue of green. Other comments are similar to those of film 28.

Film number 29 (0.5 to 0.6 µm, Panchromatic)

High contrast between forest (dark tone) and non-forest (light tone). The Murray River alluvium appears dark and is difficult to distinguish from surrounding timbered areas. Other comments are similar to those of film 28.

Film number 30, (0.6 to 0.7 µm, Panchromatic)

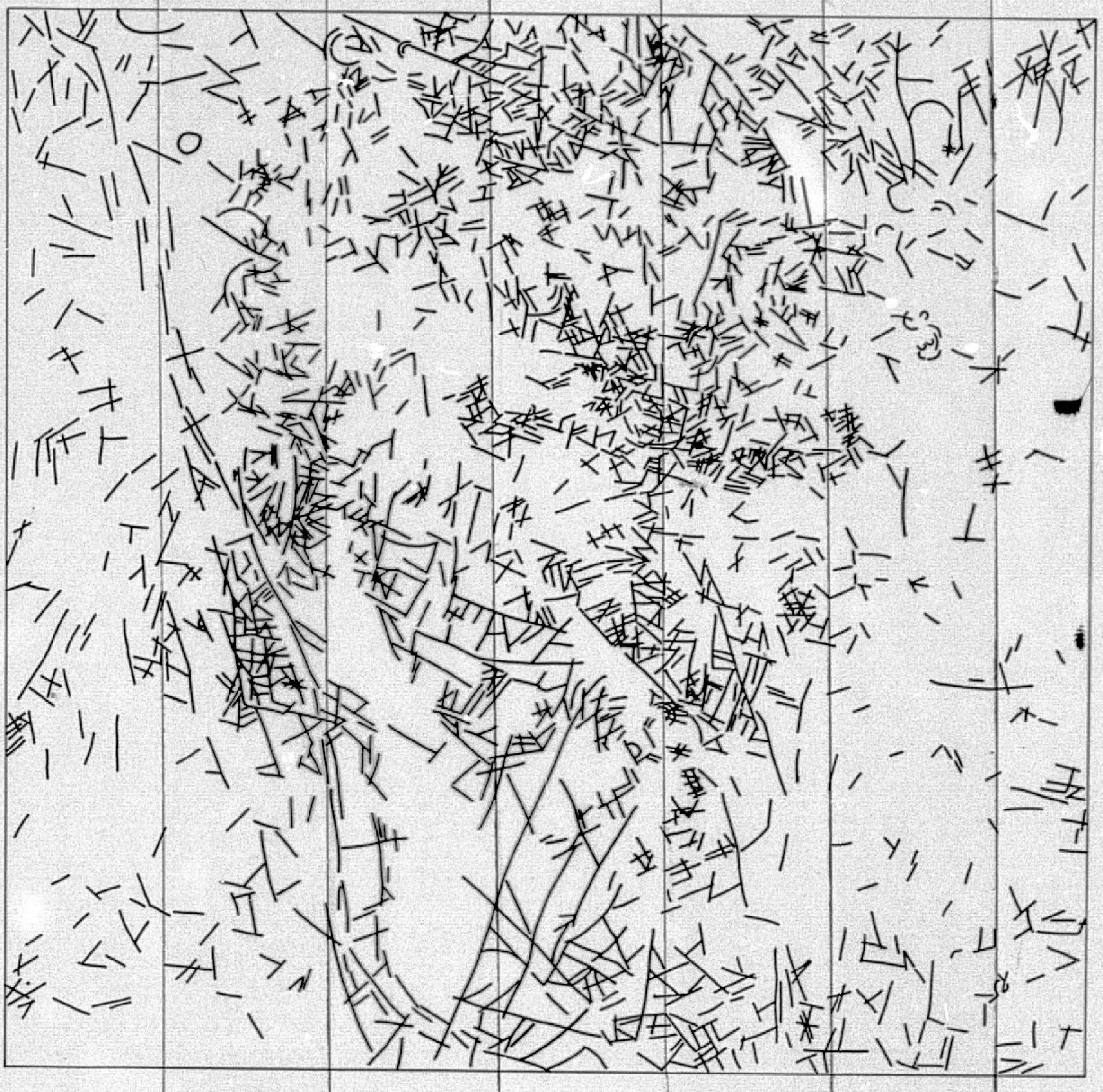
Similar to film 29, but the Murray River alluvium can be easily distinguished.

Rock type discrimination from S190B photographs

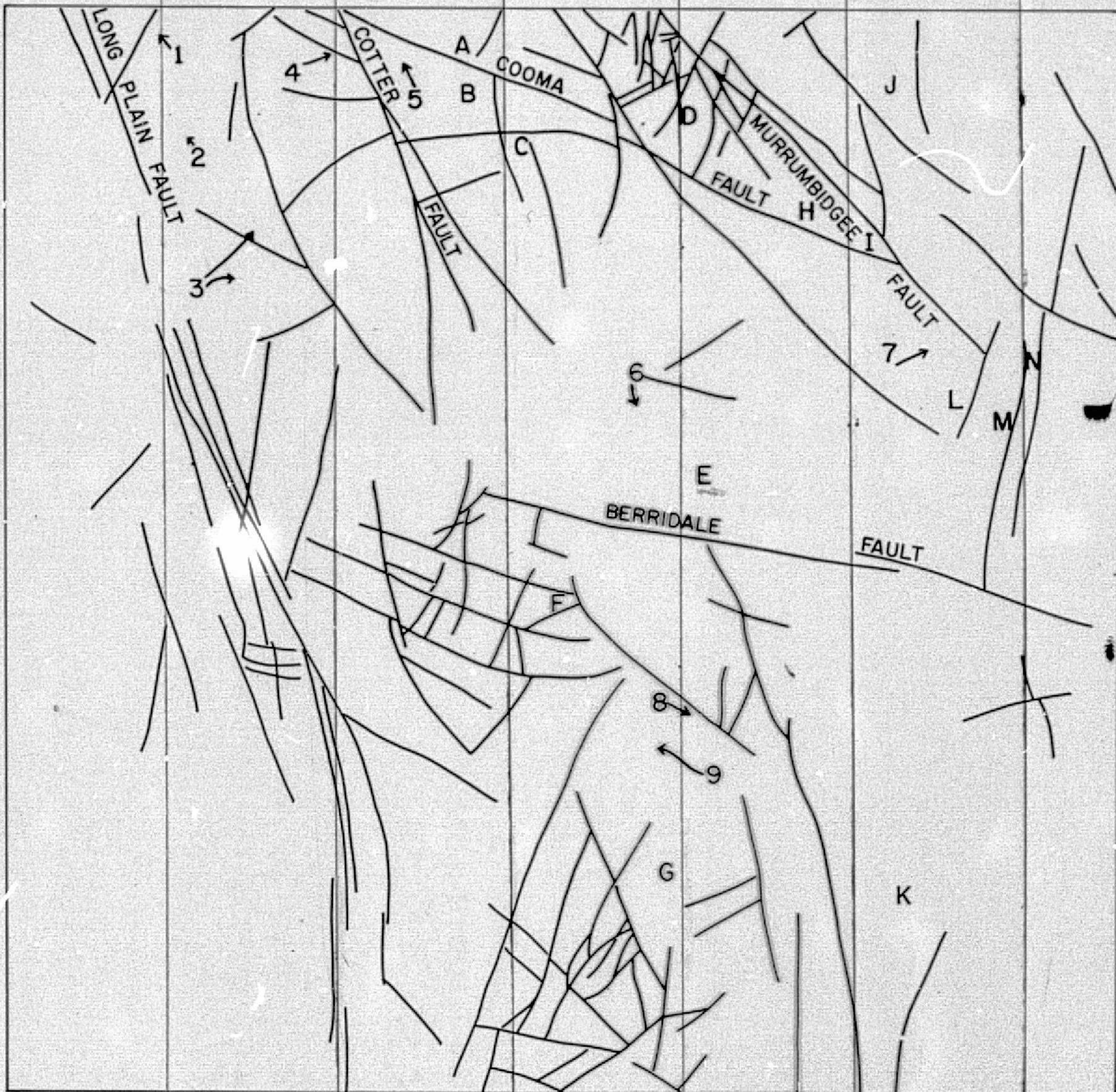
In most places, the results are similar to those obtained from S190A, film 28, photographs. However, because of the high resolution of the S190B photographs, landform elements could be studied in greater detail than on S190A photographs; this led to the detection, in some places, of patterns which are related to rock types.

Examples are shown in Fig. 8a where A, B, C, D, E, F and G are granite; H, I, J and K are Os; L, M and N are Tv. However, these patterns are uniform only over small areas; they can be used locally for rock type identification, but they cannot be used to extrapolate such information to other areas, nor to map rock type boundaries.

In forested areas, bare and isolated rock outcrops as small



b   Linear features annotated with 3X magnification



a Faults interpreted from Skylab S190B
(and relevant points discussed in text)

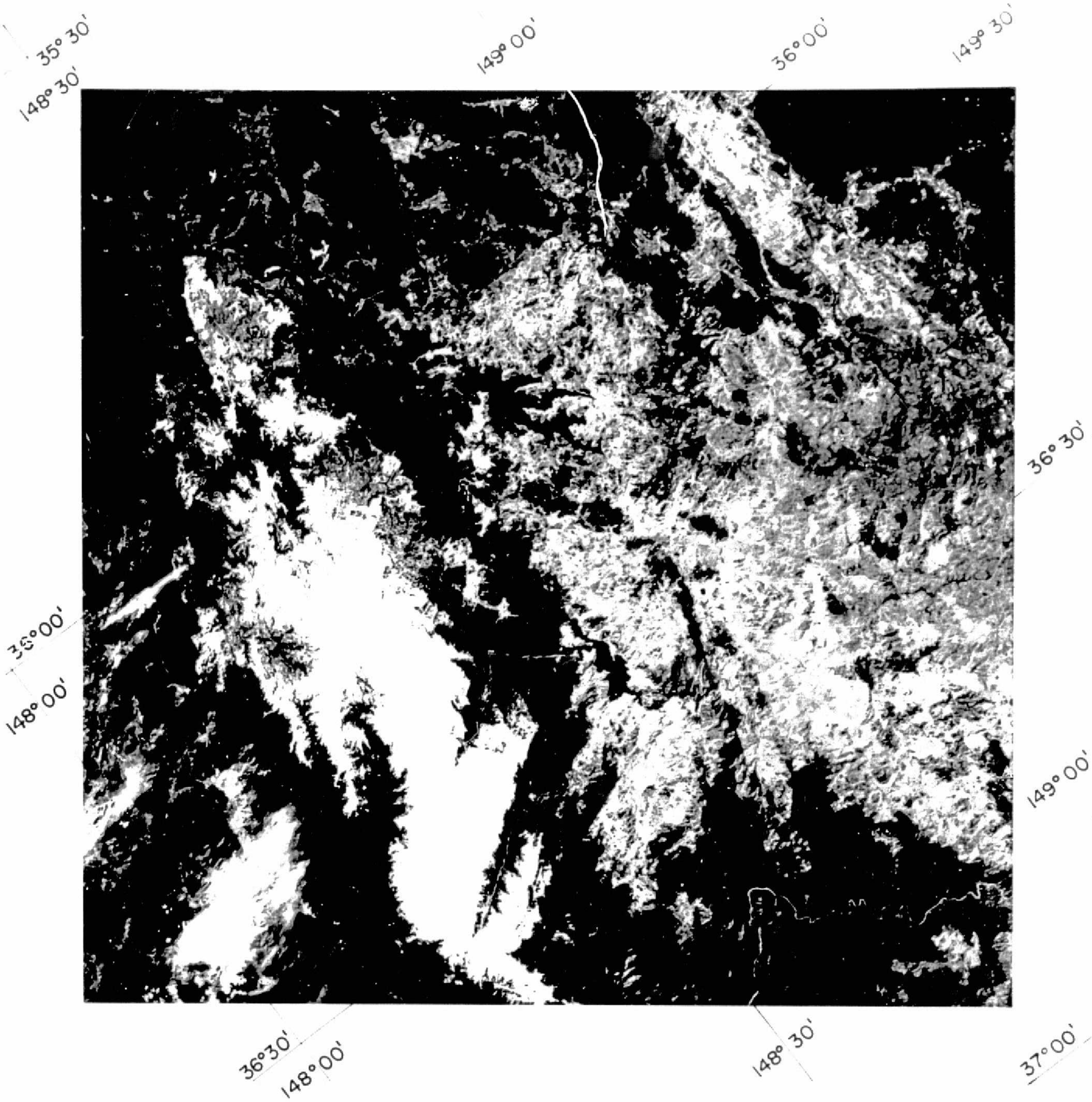


Fig 8 Snowy Mountains Area – Part mosaic of SL3/S190B, RL84 frames 144 and 145

as about 30 m across could be detected on S190B photographs, because their light tone contrasts sharply against the dark tone of the trees. On S190A photographs, the smallest rock outcrop detected in the same area was about 100 m across. In grassland areas the detectability of isolated rock outcrops depends on relief and texture differences; the smallest outcrops detected on S190B were 500 m across, and on S190A 1 km across.

Faults

Continuous and discontinuous linear features expressed by strong, deeply incised traces in the land surface, or accompanied by dislocation of geological or geographical features were interpreted as faults (Fig. 8a).

A comparison between the number of faults shown on the 1:250 000 geological map and the number of faults detected by interpretation of satellite pictures for the area covered by Fig. 8 is made in Tables 4, 5 and 6.

TABLE 4 – NUMBER OF FAULTS FROM VARIOUS SOURCES

FAULTS	With length ≥ 10 km	With length < 10 km	Total
From map	26	39	65
From LANDSAT-1	48	26	74
From S190A	48	4	52
From S190B	72	71	143

TABLE 5 – FAULTS INTERPRETED ON S190A PHOTOGRAPHS

Known faults in area	Detected on S190A	Undetected	New faults interpreted on S190A
65	22	43	30

TABLE 6 - FAULTS INTERPRETED ON S190B PHOTOGRAPHS

Known faults in area	Detected on S190B	Undetected	New faults interpreted on S190B
65	29	36	114

A comparison between the number of faults interpreted on LANDSAT-1 images and on S190B photographs is made in Table 7.

TABLE 7 - FAULTS FROM S190B VERSUS FAULTS FROM LANDSAT-1

Faults from LANDSAT-1	Detected on S190B	Undetected	New faults interpreted on S190B
74	50	24	93

The most interesting points shown by the tables above are:

(i) Many more faults were interpreted from S190B than from any other type of image.

(ii) When the faults shorter than 10 km are excluded from computation, the number of faults interpreted from each type of satellite picture is greater than that of faults shown in the geological map.

(iii) Approximately the same number of known faults were detected on S190A and on S190B photographs. Many more new faults were interpreted on S190B than on S190A: this is probably due to the high resolution of S190B, which makes it easier to recognize the faults among all linear features: in fact about 50% of S190B faults are shorter than 10 km (Table 4).

(iv) Almost 70% of the LANDSAT-1 faults were also interpreted on S190B photographs. But the total number of S190B faults is twice that of LANDSAT-1 faults.

A comparison between figures 6b and 7b shows that:

(i) Fault AB partly coincides with the Long Plain Fault, but it extends for about 70 km to the southwest.

(ii) The northern half of fault CD coincides almost exactly with the Cotter Fault, but the southern half diverges from it.

(iii) Fault EFG coincides with the Murrumbidgee Fault from E to F. Part FG suggests that the Murrumbidgee Fault may extend southward, under the Tertiary volcanics.

(iv) Fault HI partly coincides with the Cooma Fault but it extends beyond it for almost 60 km in a southeast direction.

(v) Part JK of fault JKL coincides with a mapped fault; part KL is new.

(vi) Faults MN (Berridale Fault), OP, QR and ST are examples of interpreted faults which coincide almost exactly with mapped faults.

(vii) Almost all the known faults which were not detected on S190A and S190B photographs are shorter than 10 km.

Linear features analysis

Natural alignments of landform, vegetation and/or colour, continuously expressed for at least 3 mm (i.e. 3 km at 1:1 000 000 scale), were annotated as linear features. The annotation was carried out under the stereoscope, without and with 3x magnification for the S190A photographs (Figs 7c and 7d) and with 3x magnification for the S190B photographs (Fig. 8b).

The linear features were classified into eight azimuth classes of 22°30' amplitude, thus:

Class 1	000°00'	±	11°15'
Class 2	022°30'	±	11°15'
Class 3	045°00'	±	11°15'
Class 4	067°30'	±	11°15'
Class 5	090°00'	±	11°15'

Class 6	112°30'	±	11°15'
Class 7	135°00'	±	11°15'
Class 8	157°30'	±	11°15'

Using the lithological map (Fig.6b) as a guide, generalized boundaries were traced to separate broad lithological units. The linear features of each lithological unit in each azimuth class were then counted. Finally polargraphs were drawn, showing (for each lithological unit and for the total area) the percentage of linear features in each azimuth class (Figs 9, 10, and 11). To emphasize trends, the same percentages were plotted on opposite sides of the polargraphs. No polargraph was made for units containing less than 10 linear features.

The lithological units are:

A Silurian volcanic rocks

B Intrusive rocks

C Silurian volcanic, minor intrusive rocks

D Ordovician sedimentary rocks

E Intrusive rocks

F Ordovician sedimentary, minor intrusive rocks

G Several outcrops too small to be separately considered

H Intrusive rocks

I Tertiary volcanic rocks

J Ordovician sedimentary, minor intrusive rocks

K Intrusive, minor Ordovician sedimentary rocks

L Intrusive rocks

M Ordovician sedimentary rocks

N Intrusive rocks

O Intrusive, minor Ordovician sedimentary rocks

The following units are similar in composition, age, and general history (E. Scheibner, pers. comm.): A and C; B, L and N; D and M. F is a mixture of D and E. G is a mixture mainly of D and M. I is

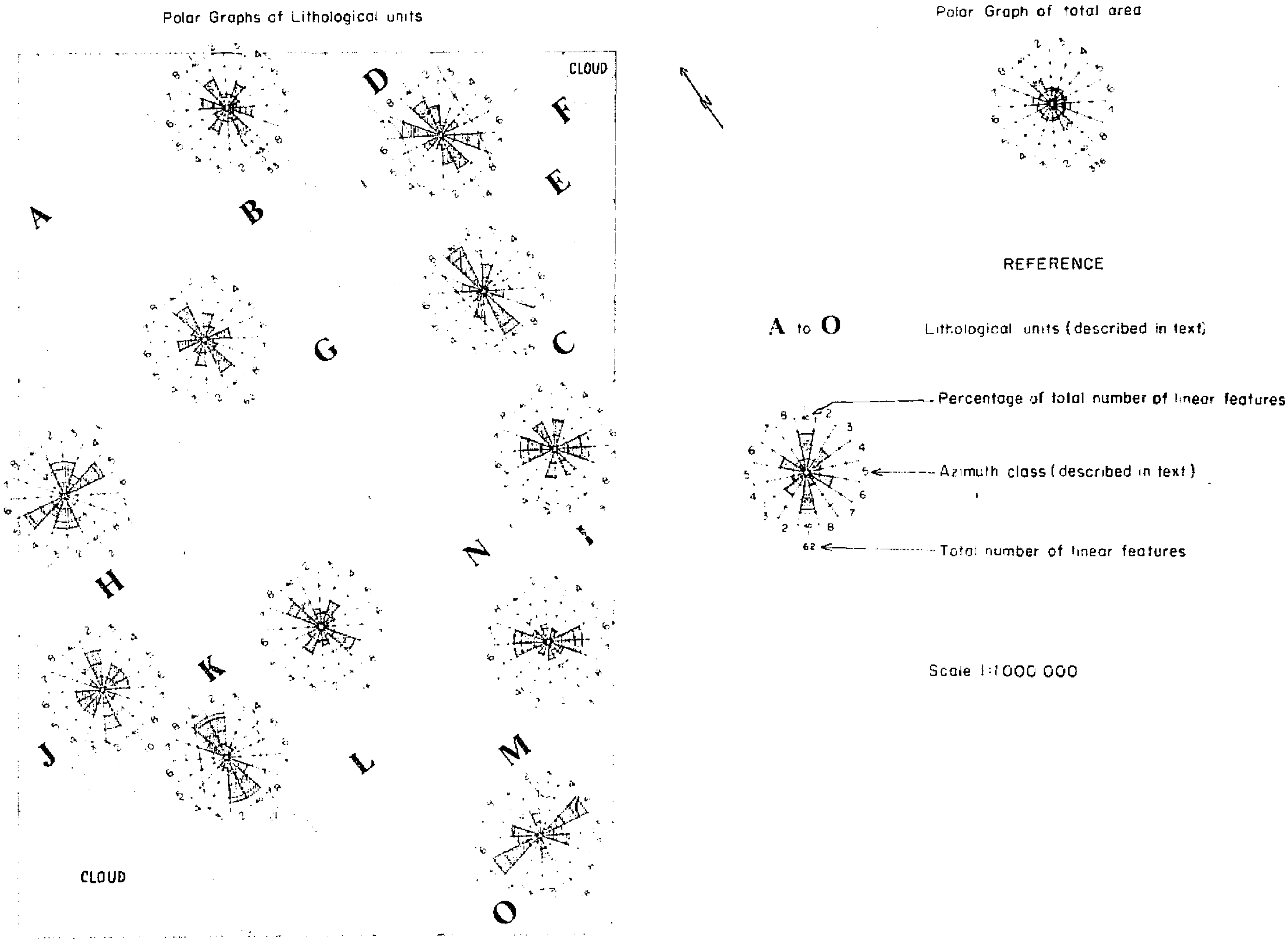


Fig.9 – Azimuth distribution of Linear features from S190A annotated without magnification.

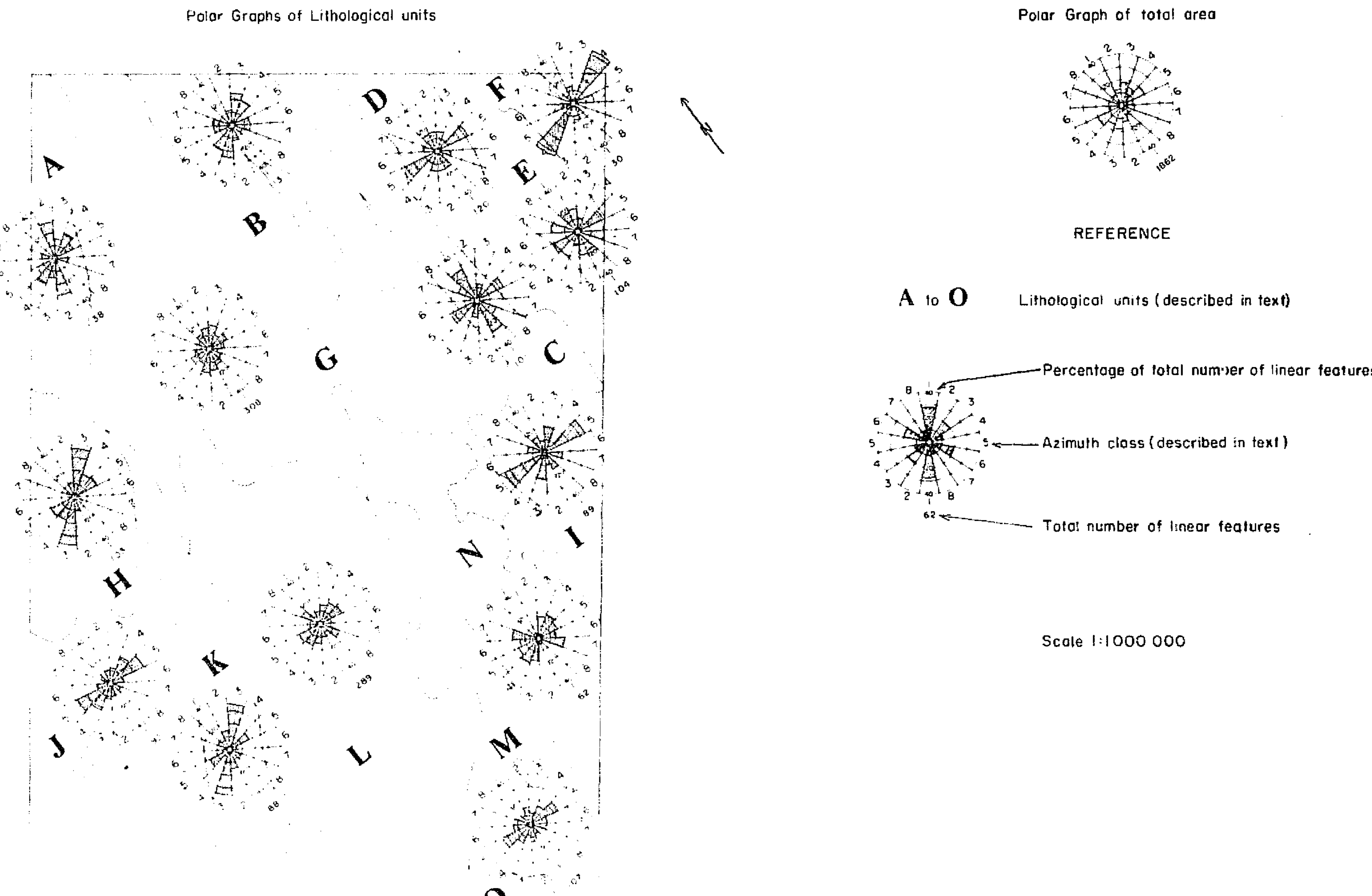


Fig. 10 – Azimuth distribution of Linear features from S190A annotated with 3x magnification

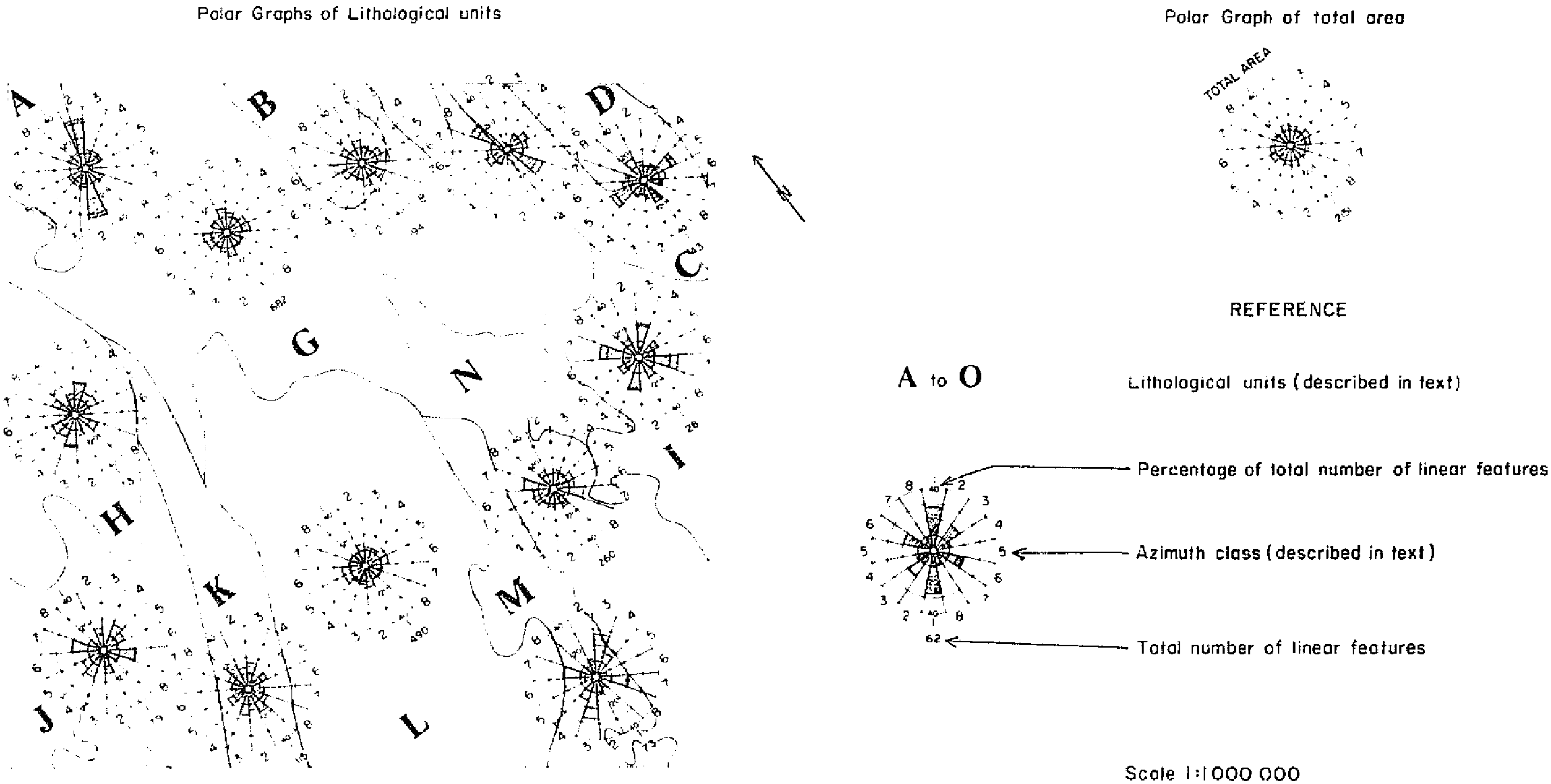


Fig.11 – Azimuth distribution of Linear features from S190B annotated with 3x magnification.

Cainozoic; E is Mesozoic; all other units are Palaeozoic.

Circular features were not included in the statistical analysis described above. Their nature was investigated by use of air photographs and existing geological maps.

(i) Straight and slightly curved linear features

In the azimuth distribution of linear features from S190A, annotated without magnification (Fig. 9), the Palaeozoic trends (north and northwest) are well represented in the polargraph of the total area and in many polargraphs of lithological units. The Mesozoic and Cainozoic trends (east-west to northeast-southwest) are present in some of the polargraphs of lithological units but are not well represented in the polargraph of the total area. No similarity is visible between polargraphs of units having similar rock type, age, and history. Polargraph I (Tertiary volcanics) shows the dominant trends of C (classes 1, 3, and 7) and of G (classes 1, 3, and 6); this may indicate that many linear features of I are inherited from underlying rocks.

In the azimuth distribution of linear features from S190A, annotated with 3x magnification (Fig. 10), the polargraph of the total area clearly indicates a dominance of the east and northeast Mesozoic and Cainozoic trends. With the exception of A and C, polargraphs of similar rock units show similar trends (H and K; B, L and N; D and M). As in Fig. 9, I seems to have inherited features from C and G.

In the azimuth distribution of linear features from S190B, annotated with 3x magnification (Fig. 11), the polargraph of the total area is inexpressive and no clear relationship could be found between polargraphs of the lithological units. The reason may be either a flooding of data due to spurious elements introduced with high resolution; or the fact that the analysis was carried out on the number of linear features: it is possible that significant results may be obtained by analysing their lengths.

(ii) Circular features

The numbers below refer to figure 8a.

Circular feature 1 is a large ring dyke.

Circular feature 2 is formed by a granite body at the center, surrounded by a circular ridge formed by hornfels.

The two circular features at 3 have the same composition as 2; originally they were probably part of a unique circle which was then disrupted by a sinistral wrench fault.

The northwestern quarter of circular feature 4 is visible on air photographs and coincides with the curving boundary between late Ordovician metamorphic rocks and late Silurian intrusive rocks in the Tantangara 1:100 000 geological map. The remainder of the feature is unexplained.

Circular feature 5 is a water course displaced by a landslide, clearly visible on air photographs.

Feature 6 appears formed by circular lineaments on S190A photographs, but on S190B the same lineaments appear to be composed by short straight segments. On air photographs the area appears crossed by a complex pattern of weathered joints, but two concentric rings formed by topographic features can be seen. Recent unpublished geological mapping has shown that a small granite body, probably a late intrusion in the main batholith, is located at the centre of the feature.

The complex circular feature 7 is perfectly visible on air photographs, with the same pattern as on S190B photographs. The three northern-most rings are remains of Tertiary volcanic centres; the southern rings are the result of small multiple intrusions that, after recent geological mapping, have been dated Jurassic.

Features 8 and 9 are clearly visible on air photographs. Both are formed by curving granite ridges, probably of the same origin as feature 6.

Comparison between Skylab photography and Landsat-1 imagery

The results obtained from the lithological interpretation of 5th generation Landsat-1 images at 1:1 000 000 scale are very similar to those obtained from Skylab B & W and true colour photographs.

The characteristic hue of the Tertiary volcanics on Skylab colour IR photographs is not visible on Landsat-1 images, even when observed through a colour additive viewer.

The patterns related to rock type, visible on S190B photographs, are not visible on Landsat-1 images.

The number of faults interpreted from Landsat-1 is about 1.4 times that of faults from S190A, but only about 0.5 times that of faults from S190B. If only faults longer than or equal to 10 km are considered, the number of faults is the same for S190A and Landsat-1.

Conclusions

1. In general, on S190A photographs at 1:1 000 000 scale, examined under a stereoscope with up to 3x magnification, the lithological interpretation by conventional photogeological methods does not appear feasible because the relationship between geology and morphology is complex and varies from place to place. Exceptions to this rule are: the Tertiary volcanic rocks, which are imaged in a particular hue of green on S190A colour IR photographs; and alluvium which is particularly easy to recognize both on B & W and colour IR photographs.

2. On S190B photographs at 1:500 000 scale examined under a stereoscope with up to 3x magnification, patterns related to rock types are visible in some places, but they are uniform only over small areas: they can be used locally for rock type identification, but not to map lithological boundaries.

(Note: in the Snowy Mountains area, the interpretation of conventional air photographs at 1:50 000 and 1:85 000 scales does not produce much better results than those obtained from S190A and S190B photographs.

3. The smallest rock outcrops detected in forest-covered areas were: 100 m across on S190A photographs and 30 m across on S190B photographs. In grassland the minimum sizes were 1 km and 500 m respectively.

4. Of the previously known faults, 34 percent were detected on S190A photographs; 45 percent on S190B photographs. Almost all the undetected faults are shorter than 10 km. 30 new faults were interpreted on S190A and 114 on S190B; none of them has yet been field checked.

5. A statistical analysis has shown that the dominant trends of the linear features annotated on S190A photographs at 1:1 000 000 scale, with stereoscope and 3x magnification are parallel to the Mesozoic and Cainozoic structural trends (east and northeast). The dominant trends of linear features annotated without magnification are parallel to the Palaeozoic structural trends (north and northwest). The azimuth distribution of the latter linear features is also related to lithology, age and geological history; this may provide clues to the differentiation of broad lithological units in the area.

6. The statistical analysis of linear features from S190B photographs at 1:500 000 scale with stereoscope and 3x magnification has not produced significant results. The reason should be investigated.

7. Circular features are visible on all Skylab products. Most are related to intrusive or volcanic features. One is the result of a landslide.

8. The B & W and true colour photographs from S190A have about the same information content as 5th generation Landsat-1 images. The colour IR photographs from S190A and the true colour photographs from S190B have slightly more information content (respectively: the characteristic colour of Tertiary volcanics, and patterns related to some rock types) than Landsat-1 images. More detailed structural information can be obtained from each Skylab product observed under a stereoscope than from Landsat-1 images.

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6.3 GEOLOGY (CSIRO)

Abstract

For the purposes of this study, landscape is classified into two gross types, namely "forested" and "exposed". Different components of the bedrock structure are detectable on the photography in each landscape type, requiring different interpretation methods in each case and different methods of evaluating the quality and practical utility of photography.

In "forested" terrains, discrete structures e.g. faults and master joints, are preferentially selected by drainage processes. The annotation quality, as estimated by measuring the reproducibility between different interpretations, is a function of the length of the structure. A very approximate estimate of the minimum length of discrete structure which may be reliably extracted from pictures is 50 km for Landsat-1 imagery and 5 km for Skylab S190B photography. Detailed studies of hydroelectric and irrigation tunnels in the Snowy Mountains show that S190B photography has applications in civil engineering.

In "exposed" terrains the pictures record information from penetrative structures, which have high spatial frequencies e.g. metamorphic cleavage, as well as discrete structures. Studies of the reproducibility between different interpretations of the same scene show that a much larger proportion of reliable information can be obtained from S190B than S190A photography in one test area at Alice Springs.

Introduction

Skylab photography has been compared with other types of photography and imagery in relation to two different geological problems. These are (1) the detection of discrete structures in humid terrains and (2) the detection of penetrative and discrete structures in arid regions.

The comparisons were made in the course of ongoing projects which have only recently reached the stage where the precise evaluation of picture quality for geological purposes is possible. The measurements given in this report are preliminary results of such evaluation procedures.

Geological information is extracted from pictures by a human photointerpreter. His visual perception faculties are a signal detection system which is both unreliable and noisy. There are two possible solutions to this problem. First, the output could be accepted at face value and evaluated against ground investigations in the field. Second, the interpretation process could be assisted in some way so as to increase the reliability of the output.

The second method recognizes the problem of data quality as a fundamental problem in information theory. The geological information reaching the interpreter is modified by random processes of geomorphological, biological and atmospheric origin and deterministic processes within the imaging system. The interpreter is, in part, acting as a filter for non-geological information and, in part, generating some noise of his own.

It is considered that in the absence of explicit definitions of the nature of geological information, the appropriate immediate approach is phenomenological. We treat the geological information extraction system as a "noisy black box" and are establishing criteria to determine whether the output is geologically acceptable or not. Any change in the data acquisition system, such as using a camera of higher resolution, or at lower altitude, or over a different terrain, is evaluated in terms of the improvement or otherwise of the reproducibility of the output when an information extraction cycle is repeated.

The first requirement of this approach is a measure of the quality and quantity of the output in terms which mirror the value to the end user.

The reproducibility of a photointerpretation is assessed by having the photointerpreter repeat the interpretation process several times, or by having several different observers make an interpretation. This repeats the most highly variable segment of the information acquisition process. Other segments are repeated by using imagery of different spectral bands or multidate imagery. The reproducibility between different results is measured and is an indicator of annotation quality. Problems with this technique are first, there are many possible choices of a reproducibility measure which give widely differing figures. Second, a measure selected injudiciously may not have geological meaning. Third, the measure may be either too insensitive to geological differences, or too sensitive to non-geological changes, to be transferable between observers in different laboratories. All three difficulties require that any proposed measure be calibrated against practical experience in as wide a range of circumstances as possible.

Given a measure of the quality of an annotation, it is then possible to calibrate the information against information from other systems. The most direct method available for this is, in areas of good outcrop, to compare results from picture interpretation with results from detailed ground surveying. This method is not applicable in areas of poor outcrop except for special situations. One such special situation is where long tunnels have been driven for urban water supply, hydro-electric or irrigation purposes. The authors are now paying special attention to these as they supply unique information. Preliminary results for 77.81 km of one tunnel system are described in this report.

History of the investigation

In 1972 considerable effort was expended by the authors in compiling geological maps of selected areas as a basis for comparison with Landsat-1 imagery. Studies of the Landsat imagery showed immediately that only the very large structures could be detected reliably, and the enormous volume of information on small structures contained in the imagery could not be obtained at any acceptable level of reproducibility. Some experienced field geologists would not accept the results claimed from satellite imagery, and even experienced photointerpreters were issuing different results for the same scene. In some cases the imagery was claimed to yield information on new geological processes for which no supporting evidence was provided and was even, occasionally, in direct contradiction with evidence from other sources.

We published some preliminary results on these lines (Burns & Shepherd, 1975) but included the qualification that the image annotations had only an assumed reliability. Reaction to our own work and results published overseas made it clear that it was urgently necessary for investigators to apply some internal standard of information quality if satellite geology is to win acceptance against established systems.

Accordingly work commenced in 1973 on measures of annotation quality. Discussions with visiting scientists including Drs C. Robinove, D. Simonett and N. Short showed that except by a group at the Jet Propulsion Laboratories this was not seen as a problem in other laboratories, and no concurrent work of similar type was known. This has meant the investigations have been isolated and methods built up from scratch.

By late 1973 it had become apparent that on any measure, the information obtained by photointerpretation of Landsat imagery may be of extremely poor quality. In this report we cite measurements of reproducibility of less than 30%. Even if more optimistic measures are used than this particular one, the figure is not shifted upwards to a level high enough to make the information comparable in quality with that obtained from alternative sources.

Skylab studies were incorporated into this program when photography became available late in 1973. The particular value of Skylab photography is in the wide range of resolution available with all other system parameters held constant. It had also been discovered that there are significant changes in the geological content of pictures between aircraft and satellite platforms which are dependent on resolution, and Skylab photography would provide data points within the gap.

The main program in development of reproducibility measures encountered mathematical and statistical difficulties in mid-1973 which were not solved till March, 1974. There has therefore been insufficient time to compile a significant number of practical measurements on Skylab photography. Some preliminary results are described.

Techniques and procedures

The measures of reproducibility of geological data as interpreted from imagery are of two types, geometric and nongeometric, details of which will be discussed in a publication in preparation. Measurements of the geometric parameters are made using a Bendix Datagrid electronic chart digitizer interfaced to a PDP11 minicomputer. With a specially written operating system, this constitutes a cartographic data processing system. Similar systems are being introduced into photogrammetric survey and cadastral survey offices to handle the special problems of cartographic data, the most notable being that they cannot be digitized without interaction with a human operator capable of logical decisions. The best known system of this type is at the Institute of Cartography in the Imperial College of Science and Technology, London. At CSIRO the data are acquired and edited interactively within the installation, an essential procedure because of the difficulty of re-registration of documents and because the logical capabilities of the operator are required, in circumstances where the original measurements can be recovered, for any data correction. The edited, formatted data are written on to paper or magnetic tape, depending on length, and transmitted to a CYBER 7600 for processing.

Nongeometric measures of reproducibility do not require logical capability in the data input system and are amenable to calculation in video scanning systems or digital image processing systems. However the statistical significance of the results depends upon calibration which has been a major delay in finalizing the measures.

For the comparison of topographic lineaments with subsurface data, four digital files are constructed. The data are obtained from standard engineering drawings. The first file is made from the tunnel elevations and consists of a traverse along the tunnel from end to end, returning along the topographic surface. The second is made from tunnel plans and is a similar traverse. The two are combined to reproduce the measurements an engineering surveyor would make if he made the same traverse in the field, and are reduced and corrected in the same way. This forms the geometric control and enables latitudes, departures, bearings, and elevations to be determined as required for any place within the region. The third file is the information contained in the engineering geologists' tunnel log and is an alphanumeric serial record of geological field observations along the tunnel. The fourth file is a record of image-derived information for a strip of country above the tunnel route.

The most difficult problem in projecting geological structures for any distance underground is that they interfere and offset each other, and it may not be possible to determine the directions and amounts of these offsets from field observations. The numeric data file enables various possibilities to be tested easily. The tunnel data are projected in three dimensions and the surface appearance predicted. This may then, given a suitable definition of "match", be matched against the observations from pictures. This sytem is not yet fully operational but, for the purposes of this report, some of the most relevant figures have been extracted.

It may be noted that this work has required development of novel data handling systems which are directly applicable in geological surveying, mining, and engineering situations outside the immediate question of remote sensing. The engineering geologists in the Snowy Mountains Project abandoned some prediction problems because of their complexity and the difficulty of obtaining a result in finite time by manual methods. Some of these, however, appear amenable to machine processing.

Summary of ground truth activities

The ground truth available to this study has been the detailed mapping in the Snowy Mountains by a large number of engineering geologists during the investigation and construction of the Snowy Mountains Scheme. This includes detailed mapping both on the surface and underground. To date it has been found sufficient to work with 1:15 840 (4 inches to 1 mile) "summary plans" which record all rock type changes, dykes, faults, joint roses, ground condition reports, tunnelling rates, ground temperature measurements, and water flows from the face. This is generally regarded as the largest body of systematically-recorded detailed geological field data in Australia, and is comparable to the records of a major mine.

The method of data analysis means that there are no rough field notes as such, only digital files, which are too voluminous for reproduction here.

In the Alice Springs area, detailed mapping on 1:25 000 scale air photographs for publication of 1:100 000 scale maps by field geologists from the Bureau of Mineral Resources and staff and students of Monash University and the Australian National University is in progress. Arrangements have been made for targets of interest to be verified.

Results

Classification of geological structures

Geological structures visible on satellite pictures are of three types. First, structures having a complex pattern, such as a dyke swarm radial to a volcanic neck, circular caldera, breccia pipe, fold basin, and so on. These resemble military targets in that they are localized and contain a variety of recognition cues, and by analogy with Leachtenauer (1973), are detectable with a reproducibility between observers which ranges from 80 to 85%.

The second type are discrete features, such as faults, "master" joints and narrow dykes, characterized in the subsurface by continuity and two-dimensionality. They are "non-penetrative" which means they have little or no mineralogical effect outside a very narrow region. The traces of these structures on the ground surface are continuous, linear, discrete features.

The third type of structure is "penetrative" in that it forms pervasive systems throughout the rocks. It is frequently two-dimensional, such as foliations and bedding, and as a result gives rise to linear surface effects. However the structures do not appear as discrete

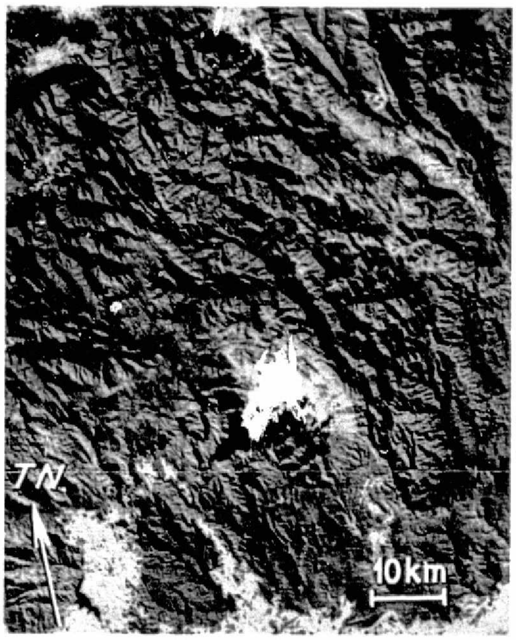


Fig. 12 Landsat imagery of forested region at Warburton, eastern Victoria.

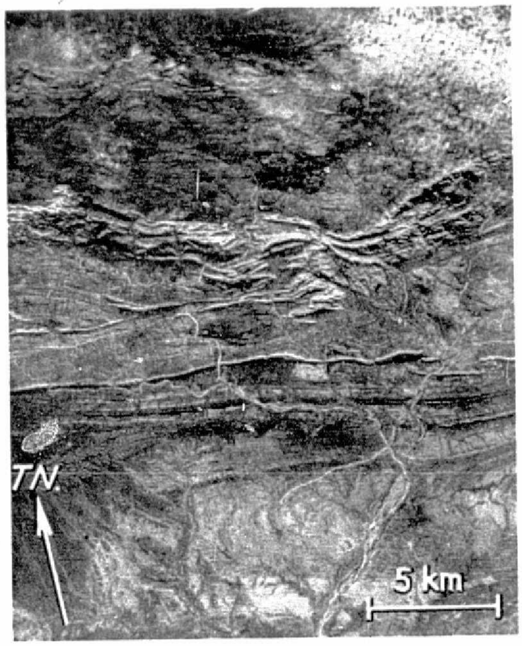


Fig. 13. Skylab photograph of Alice Springs region, Northern Territory.

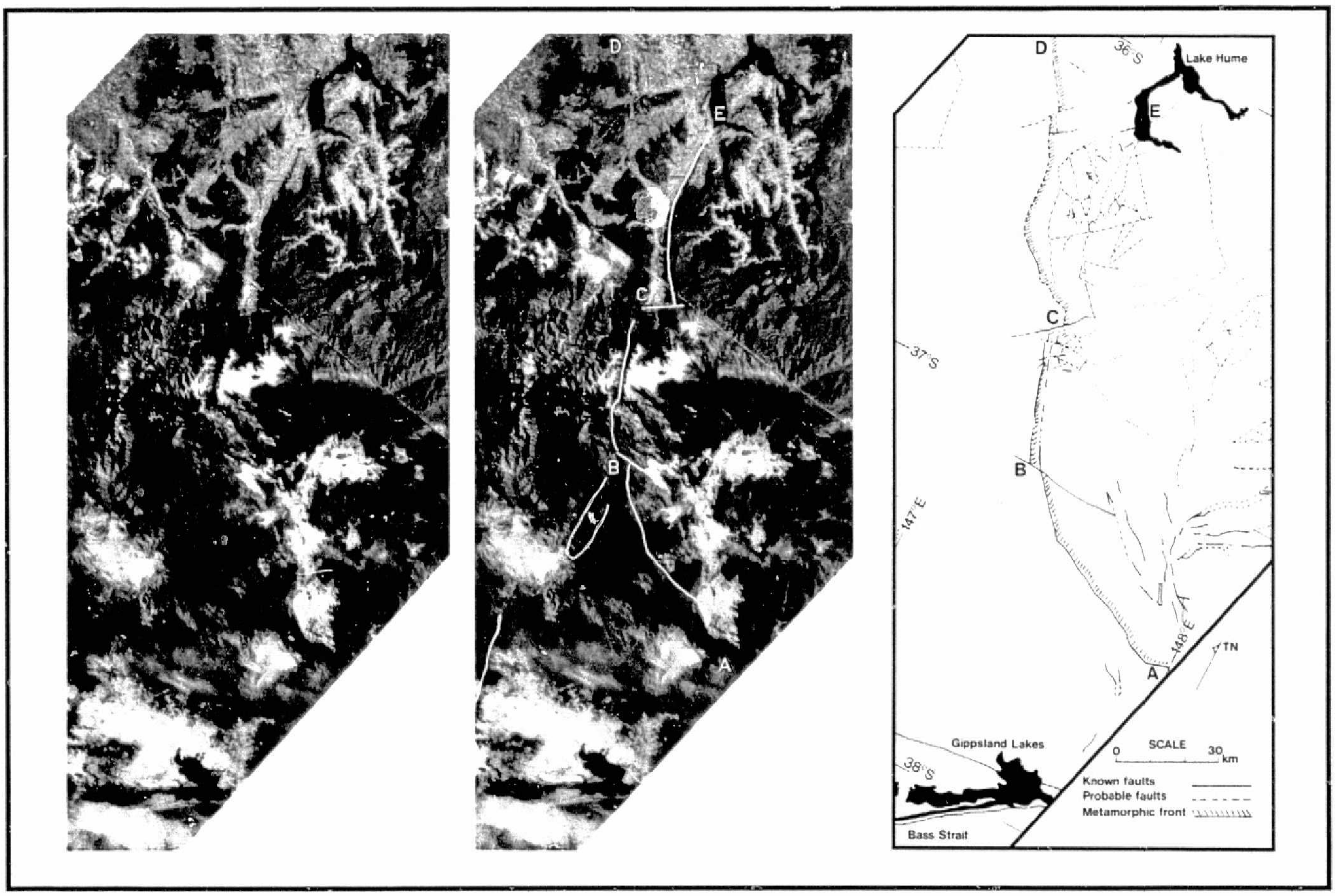


Fig. 14 Landsat-1 imagery of Kiewa region, eastern Victoria.

individuals but in close-packed sheets which give the terrain a distinctive "striped" or banded appearance.

Appearance of structures on photography and imagery

Structures of all three types, "complex", "discrete" and "penetrative", occur simultaneously in all rock types. However on aircraft photography and satellite imagery, the proportion of each structural type varies markedly. For example, imagery of the Precambrian metamorphic Palaeozoic and Proterozoic foldbelts of arid terrains may show all three types simultaneously, whereas in the Proterozoic platform covers and Mesozoic intracratonic basins of Australia there is a much higher proportion of discrete relative to penetrative structures. The differences on pictures amount to differing textures, or "apparent structural styles". In some cases the differences may indicate geological differences. However, in many other cases the differences do not have a bedrock cause and are due to differences in the surface landscape.

A subdivision of Australian landscapes has been made from satellite imagery for one test area by Cole et al.(1975). In the present work we used much simpler subdivision, separating geological studies into two branches according to a crude subdivision of the landscape into two types, "forested" and "exposed". Forested terrains are confined to areas of more than 25 inches rainfall in south western and in eastern Australia. In such regions, (Fig. 12), the forest canopy is sufficiently dense to mask all view of the ground, and the information contained in the image texture comes from the topographic relief of the top of the forest canopy and from the nature of the vegetation.

Exposed terrains are marine platforms, breaks of slope on mountain shoulders, glaciated mountain plateaux, and upland regions in the desert which have thin residual soils and are free of windblown, transported cover (Fig. 13).

The marked differences in the photographic texture between the forested and exposed terrains, even where the bedrock geology is similar, must be taken into account during photointerpretation of each type of terrain.

Forested terrain

Regardless of the proportion of different structural types in the bedrock, almost the only structural features visible in forested areas are discrete lineaments. In the majority of cases, these are expressed in the drainage pattern and are detected by their drainage effects. The reason for this is that first, stream channel formation results in discrete image features, and a whole field of parallel, penetrative structures in bedrock may be expressed on pictures as a single linear stream channel. Second, the forest canopy tends to "level" small channels and has the effect of a low-pass spatial filter. Third, the many discrete structures are mechanically weak and tend to have an influence on drainage out of proportion to their numbers.

In the absence of structural controls, stream channels form dendritic patterns. Photointerpretation of drainage anomalies is the identification of structures as departures from the regional drainage pattern. Formal techniques have been devised (Krumbein, 1970) but are applicable only to rapidly expanding networks in homogeneous material so that they may apply to Australian intracratonic basins such as the Great Artesian or Sydney Basins but are unlikely to be useful in mineralized foldbelts where the rocks are consolidated and inhomogenous. The extraction of structural information in forested terrains is therefore dependent upon the ability of photointerpreters to recognize topological anomalies in complex stream networks.

From a topographic relief model of Australia, Hills (1959, 1963) recognized major linear features with lengths several orders of magnitude greater than the diameter of drainage basins. The topographic resolution of his model was between 10 and 100 km and his method yielded reliable results only for structures such as the Darling Lineament which is over 500 km in length.

From Landsat-1 imagery, which has a resolution of the order of 100 m, structures have been detected in Eastern Australia with lengths of the order of 100 km with what seems to be acceptable reliability (Burns & Shepherd, 1975). A recent new discovery of this size is illustrated in Figure 14. However, when attempts are made to interpret shorter structures, the reliability of the interpretations falls off rapidly. To measure this effect, we have devised a nongeometric measure of the correlation between two interpretations of the same scene by different observers or by the same observer on different occasions. This measure is termed the <u>reproducibility</u> and when obtained by analogue methods is denoted R_4. It resembles a product-moment correlation coefficient in that it ranges from +1 (for complete agreement) to zero (no agreement) to -1 (disagreement). Table 8 shows results derived from Landsat-1 imagery for a region including that illustrated in Fig. 12. The imagery was prepared by a process which considerably degraded the tonal range but the extremely poor results of Table 8 are ascribed mainly to the attempt to resolve small structures.

TABLE 8

Comparison between 6 interpretations of one scene

Observer	A		B		
Interpretation	A5	A6	B10	B11	B12
A4	17.74	13.23	8.48	13.56	13.44
A5		20.15	10.11	13.20	13.84
A6			7.92	12.07	12.68
B10				13.69	13.02
B11					13.02
	Reproducibility (100 R_4)				

The experiments show that there is a very high proportion, ranging from 80% to 92%, of uncorrelated information in interpretations of small discrete features in forested areas. The uncorrelated information may include "noise" or "spurious linears" which a human interpreter tends to generate from a pattern of topologically-random noise (Julesz, 1962; Crain, 1972). In this case the low reproducibility is ascribed to the attempt to detect drainage anomalies in circumstances where the stream network cannot be resolved at the requisite geomorphological order.

This dependence of reproducibility on length is a general experience and has been observed frequently (D. Simonett, personal communication). If the explanation provided above is correct, it means that an objective estimate of the quality of information that may be extracted for interpretation of structure may be obtained by measuring the size of the smallest resolved drainage basin, that is, the smallest region within which two stream orders may be separated. Preliminary assessment of Skylab S190B photography on this basis indicates that reproducible interpretations should be obtainable for discrete structures down to lengths of 5 km in many areas and the lowest practical limit may be about 2 km in especially favourable circumstances.

The relative performance of imagery and photography from different sources is summarized in Table 9. This is preliminary only but the estimate for Skylab S190B photography is supported by detailed studies along the routes of the Snowy Mountains tunnels.

TABLE 9

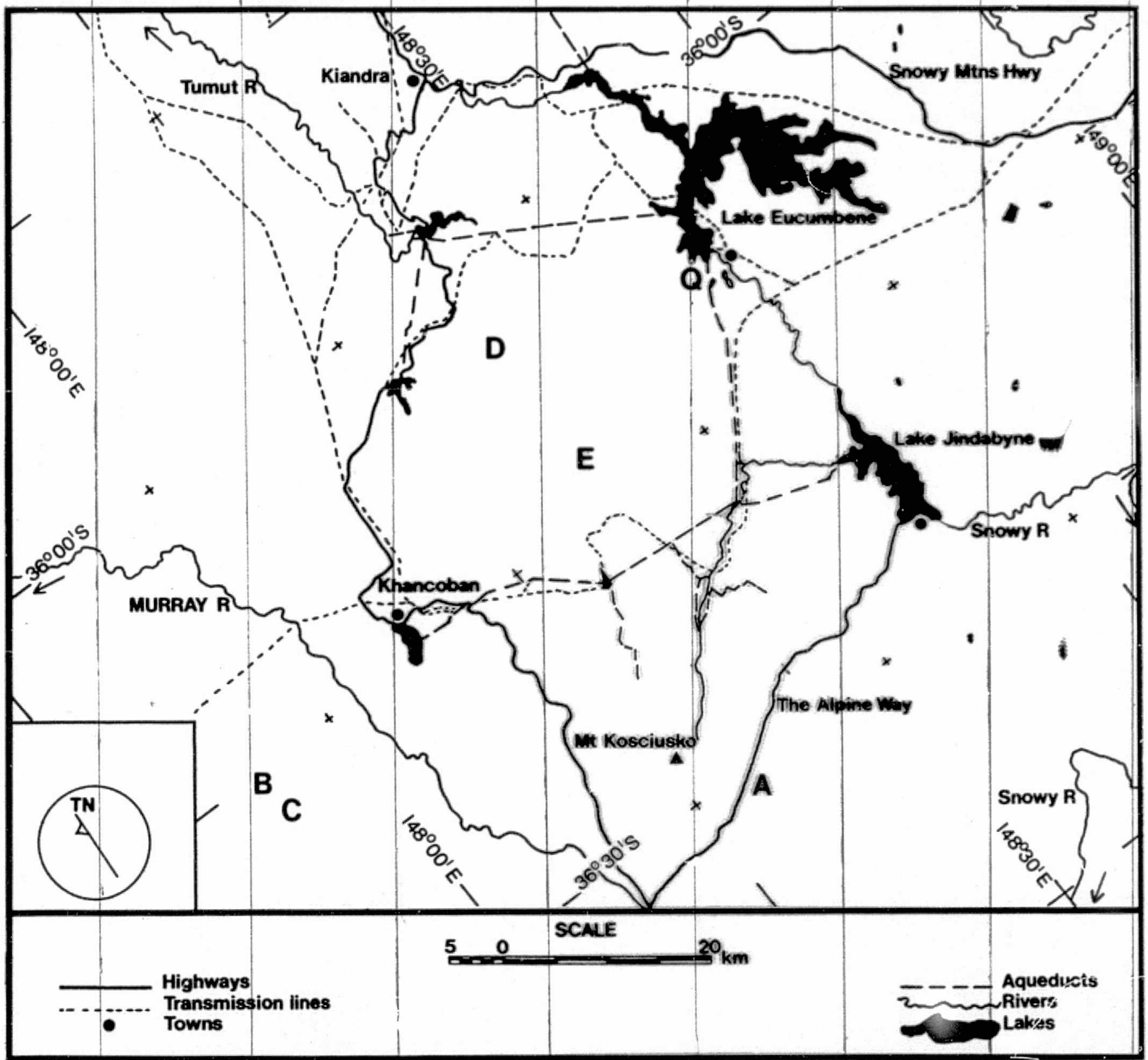
Discrete geological structures expressed as drainage anomalies

Representation of topography	Range of estimated minimum lengths for reproducible perception
Relief model	200 to 500 km
Landsat-1 scanner imagery	50 to 100 km
Skylab S190B photography	2? to 5 km

Skylab photography in Civil Engineering

The Snowy Mountains area is classified as "forested" in that it is humid, with an extensive cover of forest and grassland (Fig. 15). Detailed maps are available for the long tunnels built by the Snowy Mountains Authority for irrigation and hydroelectric purposes, and comparison of the tunnelling records with the surface geomorphology enables the value of remote sensing of discrete structures to be determined directly.

The mean altitude of the tunnels is 1080 m (3541 ft). The topography above the tunnels ranges in altitude from 1118 m (3666 ft) to 1638 m (5375 ft). The tunnels are, on the average, about 245 m (810 ft) below the ground surface. The tunnel routes are shown as aqueducts on the overlay of Fig. 15.



This is an area of multiple land use –

Recreation: the light – toned area in the centre is alpine moorland with August snow cover. Ski tow paths are visible near (A)

Farming: light toned areas in eastern and western corners are where forest has been removed for pastoral and agricultural use. Settlers roads are visible at (B).

Forestry: pine plantations are dark tones at (C).

Irrigation: water in storage reservoirs shows as black. Construction quarries are visible at (Q).

Power: the straight clearings in the forest are transmission lines. Snow – enhanced geological lineaments are visible between (D) and (E)

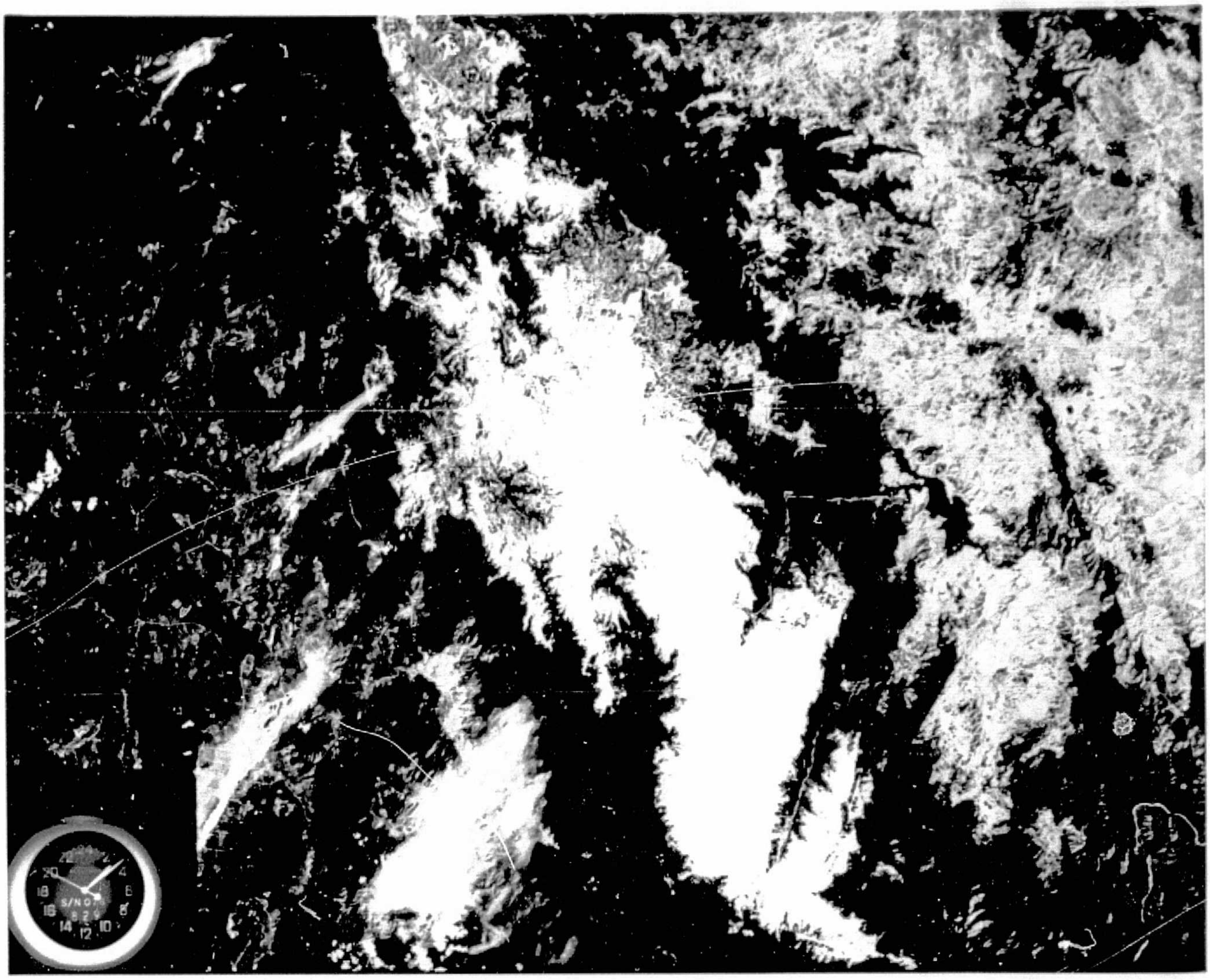


Fig 15 Snowy Mountains test area — S.L. 3/S190 B photograph RL84 No.144 with overlay

The structures in the tunnels are of several types. The most interesting type is "non-penetrative, mineralogically anonymous", that is, it comprises localized faults, shear and crush zones with effects confined to narrow bands less than 12 m (40 ft) in width, and not associated with any mineralogical changes which would make the structures easily detected at the surface. Of the structures in the tunnel with mineralogical expression, such as mylonite zones or dyke margins, over 95% are readily identified at the surface. However the correlation for discrete, anonymous structures is much lower, as shown in Table 10.

TABLE 10

Discrete, mineralogically "anonymous" structures in the Snowy Mountains tunnels

Name of tunnel	Length (km)	Number of discrete structures		
		Underground	Surface	Matching
Eucumbene-Snowy (part 1)	12.47	32	18	17
Eucumbene-Snowy (part 2)	11.75	55	0	0
Jindabyne-Island Bend	10.78	27	6	3
Snowy-Geehi	14.65	82	27	7
Murrumbidgee-Eucumbene	16.57	88	10	10
Murray Pressure	11.59	11	8	1
Total	77.81	295	69	38

The figures from these tunnels are probably widely representative. Discrete, anonymous structures occur at the rate of 3.79/km, and for these, a surface drainage expression can be found for 12.9%. Thus there is 1 chance in 7.75 that a tunnel structure will have a drainage effect at the surface. On the other hand, 55.1% of the surface features have been found in the tunnels, suggesting that there is 1 chance in 1.82 that a surface drainage feature will be encountered in tunnelling 600 ft below.

There are several reasons why these figures should be treated with caution. First, the tunnel occurrences are sometimes grouped into "fault zones" which would appear as one feature at the surface. Second, some tunnel occurrences may be minor structures which terminate on others and never reach the surface. On the other hand, third, it appears that many of the structures were first found in tunnelling, the surface location predicted, and a hunt made for a drainage anomaly near that location. The third factor tends to compensate the other two and we would judge that the figures are reasonable estimates.

The "upward match" (tunnel to surface) is the figure of 12.9% above, while the "downward match" (surface to tunnel) is the figure of 55.1%. The existence of the difference enables the structures to be divided into 2 classes, "major" or "extensive" and "minor" or "localized". The figures may be interpreted by classifying 12.9% of tunnel occurrences and 55.1% of drainage features as due to extensive structures. The remainder are minor structures (in the tunnels) and a mixture of minor structures and spurious features (on the surface).

All the drainage features recognized in engineering investiations from ground surveys and aerial photography are visible in Skylab S190B photography enlarged to about 1:60 000 scale, that is, it is possible to resolve and identify stream networks at a range of orders which overlaps the range of aerial photography, so that the detailed (aerial) and synoptic (satellite) views can be directly related to each other. In the Snowy Mountains we can not only detect some new structures not observed previously for lack of a synoptic overview, and extend some of the known structures along their strike, but expect to be able to relate many surface features to specific zones, a few feet wide, in the tunnels. The latter possibility would give the photography valid operational status.

Exposed terrain

Exposed terrains yield photographic textures due to a mixture of discrete, penetrative and complex structures. A test area has been selected in the Alice Springs region which has low local relief so that hill-shadow effects are minimal, and the image texture results mainly from variations in reflectance of different mineral assemblages or residual soils derived therefrom. Penetrative structures include metamorphic foliations in the Archaean Arunta Complex and bedding in Proterozoic and Palaeozoic rocks.

A comparison was made between the low (S190A) and high (S190B) resolution Skylab photography to see whether the high resolution photography yielded more reproducible interpretations. Results are shown in table 11. The same region was interpreted three times on both types of photography, enlarged to the same scale, (1:250 000) along a traverse line 51.9 kilometres long which was marked out at right angles to the strike of metamorphic foliation in the Precambrian Arunta Complex and bedding in overlying Proterozoic and Palaeozoic rocks. The traverse was located to avoid, as far as possible, hill-shadow and drainage effects. A densitometer profile was run along the same line, the lineaments seen by the photointerpreter were classified, by comparison with the densitometer trace, as "bright bands", "dark bands", or "density gradients". Reproducibilities were then computed for the three traverses, taken in pairs, using the coefficient H_2 which is appropriate to this method. The mean reproducibility, computed by the method of McCammon (1969), is shown in table 11.

TABLE 11

Reproducibility ($100R_2$) of textural features in Skylab photography

Photography	Textural Type			Total
	Bright band	Dark band	Gradient	
S190A	51.273	60.533	45.333	50.786
S190B	68.903	72.395	42.982	66.523

Table 11 shows the reproducibility of the extremes increases with resolution while that for the gradients decreases. The improvement for the extremes is about 26% which is ascribed entirely to the increase in resolution. It is not yet possible to relate these figures for R_2 to those for R_4 in table 8.

Conclusions

The potential value of Skylab photography depends upon three factors, the geometric accuracy as a basis for topographic and photo maps and the tonal and resolution qualities required for scientific interpretation. These investigations have yielded some information on the last named quality.

In forested country, S190B photography provides for the resolution of drainage networks in basins down to about 5 km in diameter which should permit the reliable detection of discrete structures down to about this length. This would give the photography an operational role in 1:100 000 Survey mapping and in major civil engineering works.

A test of the engineering applications yields an estimate that of discrete structures identified from their effects on the surface drainage, approximately 1 in 2 will be encountered in tunnelling 800 ft below the surface.

In exposed terrains, the results from S190B interpretation show an increase in reproducibility of about 26% for "bright" and " dark" bands in comparison with S190A interpretations.

The Landsat-1 imagery, in the form of film products, is disadvantaged because of the difficulties of briding convincingly from satellite imagery to field operating scales. This gap is bridged by S190B photography, to the extent that we believe it is realistic to identify on S190B photographs, surface features representative of structures less than 12 m wide, 245 m underground. The combination of three factors: (i) means of measuring and achieving acceptable standards of data quality, (ii) evidence that approximately 50% of surface features will be detected underground, and (iii) sufficient resolution to identify the location of these features in terms which can be picked up from aircraft photography or imagery and thence translated into a ground location sufficiently precisely located to be a realistic drilling target, all of which are within sight of achievement with S190B photography, indicates a potential operational role in 1:100 000 Survey mapping and in engineering and mining investigations.

For structural geological purposes, there is an important resolution gap between S190A and S190B photography. There may be other ways of bridging this gap than by mounting an S190B system. A doubling of Landsat scanner resolution, accompanied by direct digital reconstruction of imagery from tapes, may be sufficient.

It is concluded that structural geological information from satellite remote sensing systems can be obtained at acceptable levels of reproducibility provided the limitations of the system for different landscapes are known and appropriate quality control procedures are applied.

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6.4 LAND CLASSIFICATION

History of the investigation

a) Alice Springs Area

This investigation was compared with the work of Perry et al. (1962) who wrote a general report on an area of 373 000 sq km in central Australia (the Alice Springs area), including a map and descriptions of the types of country or land systems they encountered. The basis for the map was the stereoscopic examination of black and white aerial photographs at a scale of 1:50 000, which took 11 months, and supporting field studies, which took 5½ months. Part of this area was covered by SL 3 and SL 4 photography from the S190A and S190B cameras. We have correlated the patterns on the Skylab photographs with the land systems mapped by Perry et al., with a view to assessing the value of the Skylab photography for this type of survey.

b) New South Wales

The Skylab photographs were examined for their portrayal of distinct types of country, land use, soil, and vegetation. These were mapped on the photographs and identified by field checks.

Techniques and procedures

a) Alice Springs Area

Mapping on the aerial photographs is done by a team comprising a geomorphologist, a pedologist, and a plant ecologist. They map according to patterns, and at a detail compatible with the scale of the final map. When the team members have completed the mapping they sample their patterns in the field, noting in each the dominant lithology and geomorphology, soils, and vegetation. Among other things, they prepare from their notes a summary description of each pattern. They then revise their mapping according to the field checks. The land systems are established from the air photo patterns and described from the generalised field notes, as given in Table 12.

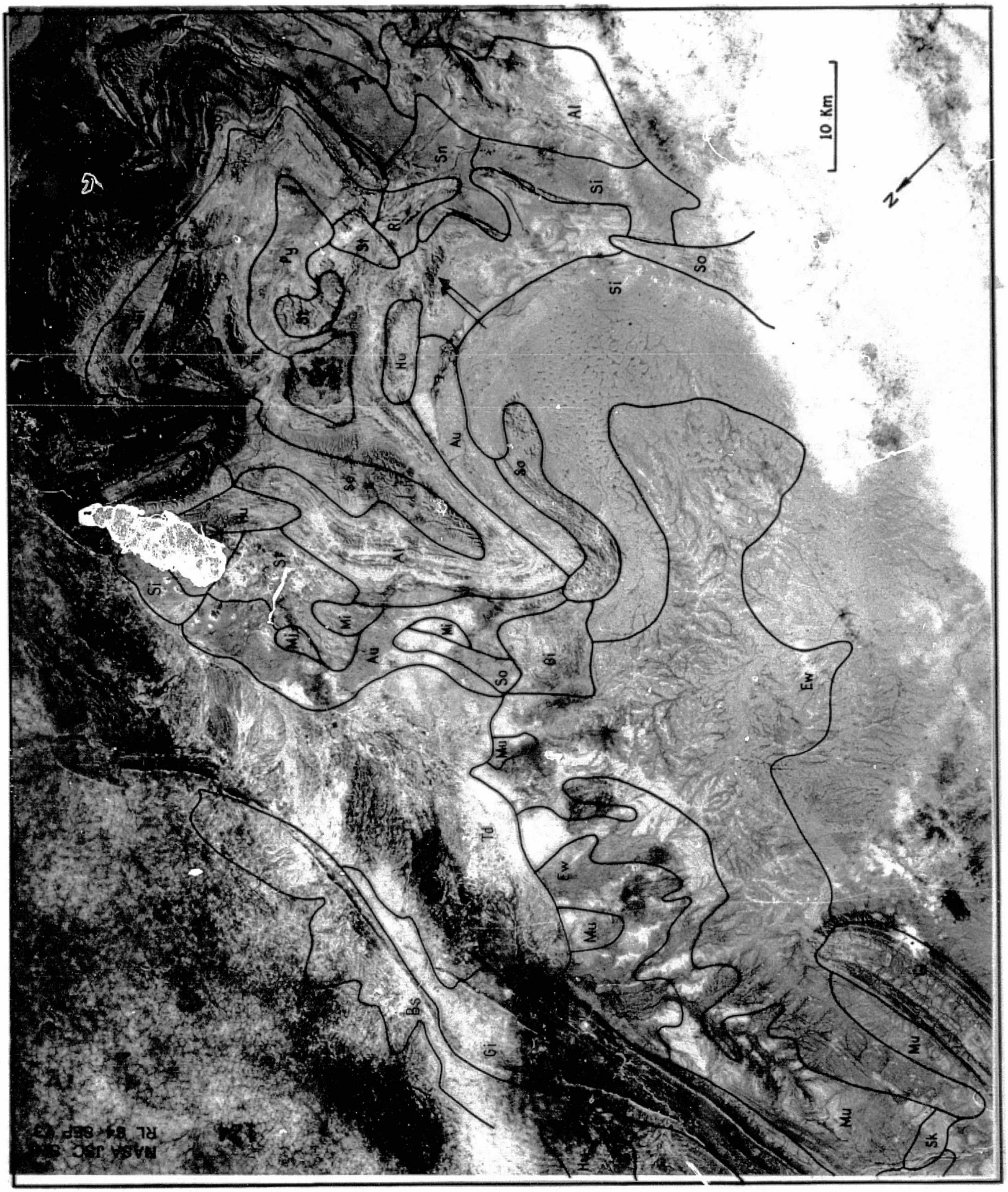


Fig 16 Alice Springs area— relations of land systems to patterns on part of SL 3/S190B RL84 No 124

The Skylab photographs cover approximately 10 000 sq km of cloud-free country. The patterns on them were examined in relation to the land systems mapped by Perry et al. from aerial photographs, this being done through the medium of twice enlarged S190B colour prints (Fig. 16) and a transparent overlay of the land system boundaries at the same scale. The results were then compared with four times enlargements from the six films of the S190A camera.

b) New South Wales

The Skylab photographs from both cameras, as listed in Table 1, were examined stereoscopically. Preliminary observations were made on the black and white photographs. Findings were then transferred to the colour prints, and amendments and additions made. Contact diapositives were used for a final check before the field work.

Summary of ground truth activities

a) Alice Springs Area

Traverses were planned by Perry et al. to sample each air photo pattern during the preliminary mapping. The first field season occupied the period August to October 1956. The aerial photographs were taken into the field and traverse routes, odometer readings, and descriptive notes were marked directly onto them. In order to do this accurately the position of the team was known to within one-sixth of a kilometre (approximately 3 mm on the aerial photographs). Additional traverses were planned during the second period of mapping and a second spell of field work from June to September 1957 was similar to the first.

b) New South Wales

Traverses were planned to sample each unknown Skylab photo pattern during March 1975. The geological map of the area was also consulted.

Results

6.4.1 Alice Springs Area

Summary descriptions of the relevant land systems are given in Table 12. Fig. 16 shows that in most cases each land system boundary contains its own characteristic pattern.

TABLE 12

SYNOPTIC DESCRIPTIONS OF LAND SYSTEMS REPRESENTED IN THE SKYLAB PHOTOGRAPHS

Al	Limestone ridges and foothills, relief up to 500 ft (150 m); little soil; spinifex or sparse grass. Strike vales with alluvial plains; shallow stony soils and calcareous earths; gidgee and/or short grass.
Au	Active alluvial fans with extensive sandy plains within the central ranges; red clayey sands, some alluvial clayey sands; mainly spinifex, some sparse low trees over short grass.
Ew	Undulating dune-covered terrain with stony conglomerate hills, relief up to 30 ft (9 m); red dune sands; spinifex mainly under mulga.
Gi	Quartzite and sandstone ridges up to 1000 ft (300 m) high; little soil; spinifex. Vales with alluvial plains and gravel terraces; stony soils (texture contrast, red earth), red clayey sands, and coarse soils; sparse shrubs and low trees, mulga, or witchetty bush over short grass.
Hu	Limestone ranges with rounded foothills and spurs, relief up to 750 ft. (230 m); little soil; spinifex or sparse grass.
Kr	Bold sandstone plateaux with rock summits and steep, dissected margins, relief up to 500 ft. (150 m); some very stony and sandy soils; sparse shrubs and low trees over spinifex or sparse grass.
Mi	Sandstone ridges and plateaux up to 300 ft. (90 m) high and sandy lowlands; shallow soils and red clayey sands; spinifex.
Mu	Low hilly or undulating limestone country, relief up to 75 ft. (23 m); calcareous earths; open or witchetty bush over short grass.
Py	Piedmont fans of calcareous alluvium and calcreted gravels; shallow red clayey sands over stone, some sandy calcareous earths, and sandy red earths; mainly open or gidgee over short grass.
Ri	Intermont plains of calcareous alluvium; calcareous earths and red earths over marl; open or gidgee over short grass.

Si Parallel, reticulate, and irregular sand dunes with stable flanks, minor areas of mobile sands; red dune sands and red clayey sands; spinifex.

Sk Piedmont gravel terraces, dissected valleys, relief up to 80 ft. (24 m); stony fine red earths, some sandy texture-contrast soils; mainly sparse shrubs and low trees or mulga over spinifex.

Sn Flat or gently undulating plain; red clayey sands and sands; spinifex.

So Bold quartzite and sandstone ridges with rock cliffs and steep slopes, relief up to 2 500 ft. (760 m); very little soil; spinifex.

St Limestone plateaux with dissected escarpments, benches of weathered rocks, relief up to 300 ft. (90 m); little shallow soil; spinifex.

Td Coalescent flood-plains of the Todd River and tributaries, derived mainly from igneous and metamorphic rocks, sandy alluvial soils, some red clayey sands and silty, fine, and layered alluvial soils; sparse low trees over short grass.

The following are noteworthy points:

1. The Skylab photograph (Fig. 16) brings out the difference between Ew and Si more clearly than the descriptions do. It also shows that some of the dune pattern of Si intrudes into Ew, and this is not brought out in the survey air photographs. Sn, also a sand plain, is distinguishable from the other two by its even pattern.

2. Mu can be distinguished from Ew partly by pattern, but stereoscopic examination is needed for accurate delineation of the boundary. There is then little difficulty in separating the two.

3. As vegetation and land forms are similar on all the alluvial land systems, soil colour would appear to be the only photographic criterion for distinguishing them. The photograph shows three that are alike (Au, Py, and Ri) with a rather uniform red pattern, and one (Td) with a more mottled brownish pattern. Reference to the more detailed descriptions (not reproduced) establishes that this is in accord with their soil colours.

4. Mountainous and hilly land systems are not clearly distinguishable among themselves and are not consistent in their patterns, i.e. field checks are needed to work out some rational system of grouping the various patterns into land systems. This is standard practice which applies equally well when aerial photographs are used. Details are as follows:

a) Gi and So have the same lithology (quartzite and sandstone) but Gi is separated because it includes a number of wide valleys among the ridges.

b) Al, Hu, and St are mainly of limestone and dolomite, and distinguishable from the quartzite and sandstone by their greenish colour. Among themselves they are distinguishable through their land forms (see Table 12). The greenish colour can be seen in parts of Gi as well, and reference to the detailed descriptions (not reproduced) shows that it does include beds of limestone.

c) Kr resembles parts of So in the single photograph but stereoscopic examination shows that the beds of So dip while those of Kr do not.

d) Occurrences of Mi are too small for consideration.

e) A singular group of hills (arrowed in the photograph Fig. 16) is of sandstone surrounded by limestone and dolomite. These hills do not show up in any of the S190A films, nor in the Landsat imagery except band 4.

5. Traces of burning were easily identifiable on other frames (not reproduced).

An examination of the equivalent black and white prints from the same negatives at a scale of 1:700 000 confirms the importance of colour in this type of survey. It is not possible to distinguish the limestone or the sandstone hills of paragraph e. on the black and white prints, nor to see the difference between the alluvium with red soils and that with brown soils, and differences between other land systems too are less distinct.

On the S190A photographs, those in false colour show some areas of vegetation in red, distinct from the dominant cover which does not register in this way. They are probably flushes of ephemerals along the watercourses and outwash plains. For our purposes the other S190A films have nothing of advantage over the S190B except in the greater area they cover, and even this is offset by their poorer resolution. In all, we would make very little use of the S190A if a complete cover were available from the S190B.

For part of the Skylab photograph (Fig. 16) that accompanies this report, Landsat imagery dated 1 November 1972 is available at a scale of 1:1 000 000 in false colour diapositive (bands 4, 5, and 7) and in black and white prints of each band separately. For visual interpretation the Skylab photographs are in most respects far superior. The Landsat single band imagery has the disadvantages of less contrast, poorer resolution, no stereoscopic cover, and perceptible scan lines. It has an advantage in the false colour image, which has better contrast that that of the S190A, including a clear magenta which sharply delineates the green vegetation. Some of the Skylab S190A false colour film is heavily suffused with blue and virtually monochrome in consequence. This is probably due to poor processing.

The land systems were erected not only on air photo pattern but also on field work, on the pooled knowledge of a team of 10 workers, and on the literature. The lack of exact correspondence between the land system boundaries and the Skylab photo patterns in Fig. 16 is what normally occurs, and does not necessarily reflect a discrepancy. The correspondence that does exist suggests that Skylab 190B colour photography on its own is most useful for reconnaissance mapping of natural resources in the arid regions of Australia at a scale of about 1:1 000 000. Its full exploitation calls for support from aerial photography and the Landsat imagery.

More detailed information is available from a paddock near Alice Springs which has been studied by the Division of Land Resources Management, CSIRO, in connection with grazing trials. The paddock measures 14 x 11 kilometres and is grazed throughout the year by cattle, the numbers fluctuating from 500 to 1000. It is observable on SL 4 photography except for the south-east corner which is covered by cloud. Table 13 gives the vegetation as mapped from the S190B diapositives and as previously mapped from the ground. Points to be noted are that three of the Skylab mapping units are combinations of the original mapping units, i.e. the original mapping is in finer detail than is permitted by the Skylab photography. Combinations B and F are acceptable, combination E is faulty in its inclusions of calcareous shrubland and questionable in its inclusion of mulga and annual grasses, which has a category of its own (C). The Alice Springs workers have also identified on all the Skylab material active vegetation growth on the flood plains, and irrigated lucerne. They feel that the quality of the photographs and the large area shown in each are assets which could be of great value in land planning programmes, including large-scale stock movements and the identification of "scalded" degraded areas.

TABLE 13

VEGETATION AND LANDFORMS AS MAPPED FROM S190B DIAPOSITIVES AND AS PREVIOUSLY MAPPED FROM THE GROUND

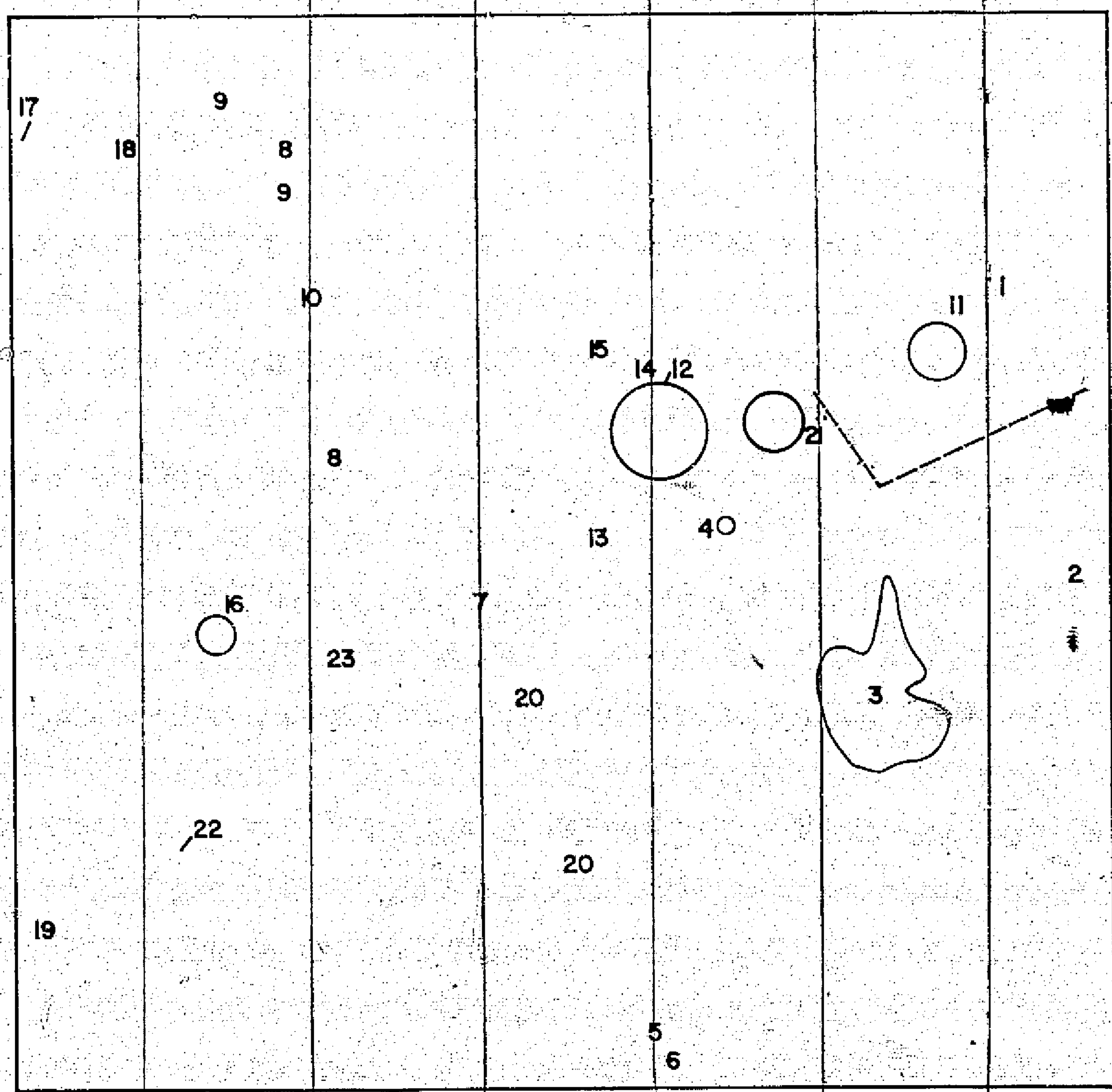
	Skylab Observation	Ground Truth
A.	Hills	Hills
B.	Stream beds and associated plains	Stream channels Floodplains Riparian depressions
C.	Mulga depression channels	Mulga/annual grasses *
D.	Groved mulga	Mulga/perennial grasses
E.	Open woodland	Calcareous shrubland Savanna woodland Mulga-annual grasses
F.	Treeless plains	Foothill fans Gilgai plains * Floodplains
G.	Unidentified, presumably area too small	Spinifex hummock grassland *

* Mulga = Acacia aneura
Spinifex = Triodia and Plectrachne spp.
Gilgai = microrelief caused by the uneven swelling of soils high in montmorillonite content.

Conclusions

The colour, stereoscopic coverage, and good resolution of the Skylab photographs make a useful combination for the mapping of land forms, soil, and vegetation at a scale of about 1:1 000 000. The photographs could probably be used in place of conventional aerial photography for this purpose, other things being equal.

For visual interpretation we rate the S190B photographs first, notwithstanding the smaller area they cover. S190A photographs come second, and Landsat images third.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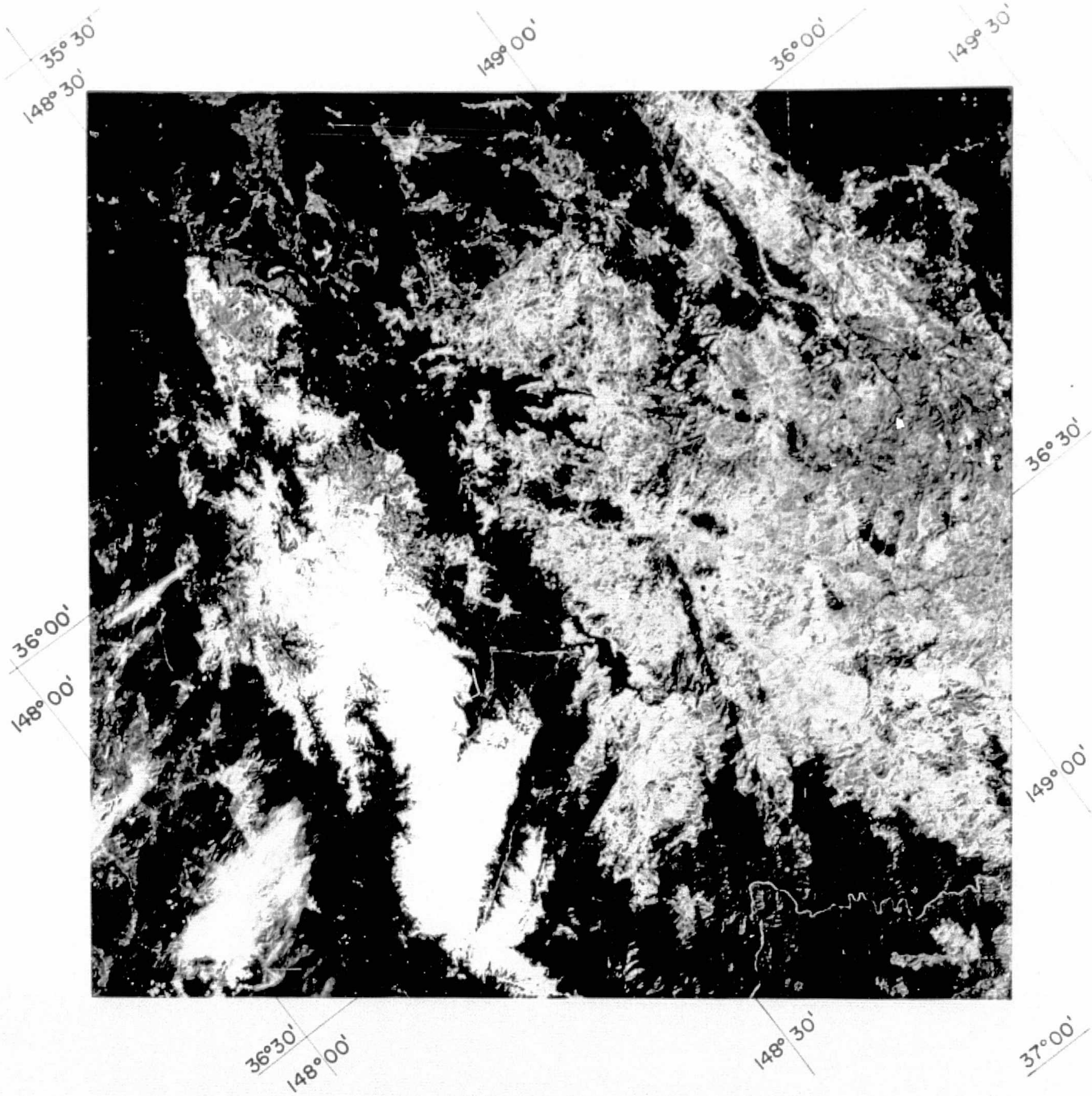

Fig 17 Snowy Mountains Area – Part mosaic of SL3/S190B, RL84 frames 144 and 145

6.4.2 New South Wales - Snowy Mountains area

The notes that follow are with respect to the S190B colour diapositives. Of the photographic products examined they were unquestionably the best, not because of the colour but because of good resolution. They showed a number of features that did not show up in the paper prints.

Soils

Three large areas of different colour (400 sq km and more, areas 1, 2 and 3 of Fig. 17) could be distinguished in the cleared country. The first two were respectively reddish and brown, and from stereoscopic viewing appeared to be on rolling ground. The third was paler and appeared to be on undulating ground. Field checks showed little difference in the vegetation, which was tussock grassland of Stipa and Poa in varying proportions. This indicated that the soil was the determinant, a statement which has support from Fig. 18, which shows soil samples from the three areas, as well as from much smaller areas of bright red from location 4 in the Skylab photographs. The good correlation throughout suggests that the photographs would be of great assistance in regional soils mapping.

It is significant that the photographs were taken in August, which is when the pastures are most meagre after having been grazed through their winter dormancy. The field observations were done in early March when the pastures provided a top cover of about 90%. Contemporary Skylab photographs would have been most unlikely to show the soil differences.

Similar blocky patches of eucalypts at points 12 and 13 (Fig. 17) show differences in detail, those at 12 being surrounded by a paler margin which is lacking at 13. This paler margin is known from previous work to be related to some extent to soil type, and reference to the geological map shows that 12 is on granite while 13 is on Ordovician sediments. Field examination confirmed what could logically be expected, namely that the soils too were different. Lineaments and circular features (circled

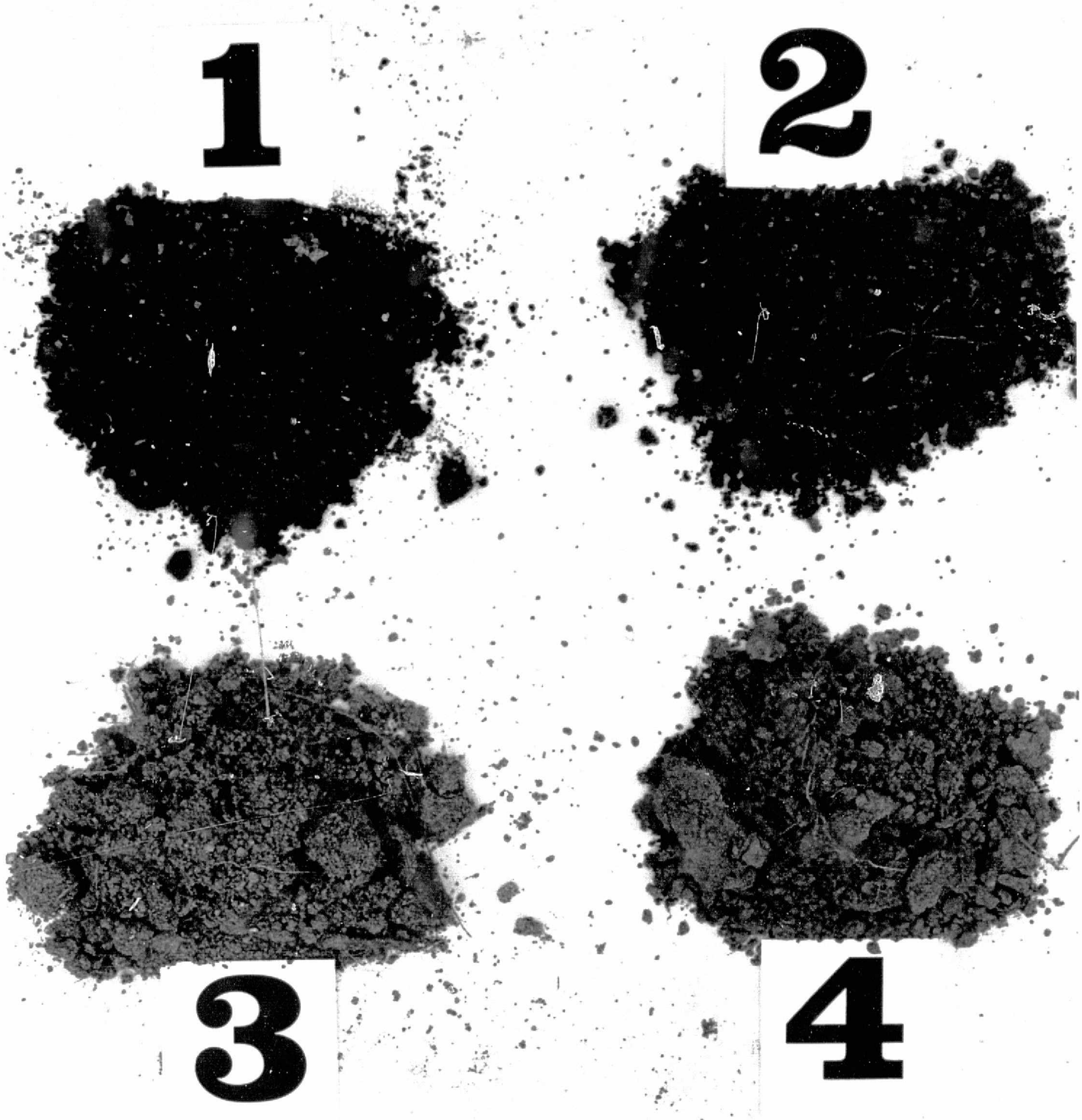

Fig. 18 Soil samples from Snowy Mountains area

at 11, 14, 16 and 21) are the direct concern of geology, nevertheless they have an important bearing on the type of country and the soils and can readily be seen and used by those connected with land resources surveys.

Snowfields

Mostly they are quite obvious, but exceptions do occur. On colour prints we have found some snow-free pastures to be indistinguishable from the snow-fields (points 7 and 23). The difference can be brought out by varying the processing, and is clear in the various S190A films. Areas of heavy and light cover can be distinguished at a glance.

Land Use

Intensive farming can be seen at point 19. This is a dairy area with the non-wooded parts under improved pastures. Semi-intensive farming is distinguishable towards the coast (not illustrated). By far the greater part of the cleared country is grazing land, with a little agriculture in the lowlands (areas 1, 2, and 3).

Vegetation

From the photographs the grazing lands may be divided easily into two - the lowland pastures and the highland pastures. Both these categories can be subdivided on photo pattern, but a field examination shows that the lowland subdivisions reflect only a soil difference, with the pastures essentially the same. Of the highland pastures, 8 and 18 have a darker tone than 7. A field check established that the soil was brown throughout but that the vegetation appeared different. All three areas have a low unbroken sward of Poa, in 7 relatively pure but in 8 and 18 mixed with abundant non-grass herbs and patches of shrubs, which would remain green during the winter instead of dying back as the grasses do. This would provide an explanation for the darker tone of 8 and 18, but a comprehensive botanical analysis is needed to confirm or refute the theory. Areas 8 and 18 are respectively on flat to undulating and on undulating to rolling country, but this is too subtle a difference to be picked up on the photographs even under stereoscopic viewing.

The photographs provide not only a very useful synoptic view of the pastures but also an unexpected amount of detail from the S190B diapositives. At our scale of survey much of this information could be used directly, that is, without recourse to the aerial photography. Field work would remain essential, at about the same intensity.

Forests and woodlands also have an important bearing on the natural resources surveys because of their value in cash, as protection to water catchments, and as indicators of soil and climate, but as they are the direct concern of the Forest Research Institute they are dealt with in Section 6.1 of this report. We have distinguished pine forests and light, intermediate, and dark green eucalypt forests, which can be further subdivided and classified through field work (points 17, 6 and 3, 20, 5 and 10 respectively).

Water supplies

Streams vary according to their size and background from conspicuous to obscure. Except by stereoscopic viewing reservoirs are not easy to distinguish in forested country in any medium (point 22) but elsewhere they are distinct and sharp, to the extent that a small drop in the water level can easily be seen (point 15).

Oceanography

The S190B photographs show two zones of colour near the coast and a narrow paler band along part of their common boundary. These features may represent different depths, but they do not conform to the Royal

Australian Navy coastal chart. They are unlikely to be caused by any form of industrial pollution since there are no towns of the necessary size and character along that part of the coast, and the probability is that they represent algae or plankton, reflecting differences in the quality of the water.

S190A photography

The equivalent S190A photographs of all six films (Appendix) were examined in diapositive form.

The two infrared films (25 and 26) are closely similar, and of value mainly in their very clear differentiation of introduced pastures (Point 19 of Fig. 17) from the surrounding eucalypt forests. The native pastures (18) at that time of the year are dormant and poorly differentiated from the eucalypts.

False colour infrared (Film 27) shows the green non-eucalypt vegetation with even more clarity, not only at point 19 but also in some other areas which can be distinguished in no other medium, at least by eye.

Film 29 (.5 -.6 micrometres) is the only one to provide sufficient contrast between pines and eucalypts for easy recognition.

Film 30 (.6-.7 micrometres) distinguishes with satisfactory clarity between the eucalypt forests, dormant pastures, and growing pastures. None of the other films provide as much contrast between the three.

Comparison with Landsat-1 imagery

Landsat-1 imagery dated 12th December 1972 and 18th January 1973 is available in all bands for this area of New South Wales. The individual bands were compared by eye with respect to the features enumerated in Fig. 17, and the following points noted:

a) The areas of different soils (1, 2, 3, and 4) were not

distinguishable.
This is probably due in some measure at least to the denser summer pasture when the Landsat-imagery was obtained.

b) Wet sclerophyll forest (5) was clearly distinguishable on bands 6 and 7, not on 4 and 5. We have observed in other areas as well, a very clear distinction for some different eucalypt types on the infrared and visible bands respectively. Details are still being investigated.

c) Other eucalypt types (6, 20, 10, and 9) could not be separated on the Landsat imagery.

d) The difference between the lowland and highland pastures (7 and 8) was clear on the infrared bands, barely perceptible on the visible - the opposite to what one could expect from the differentiation shown on the Skylab colour photography. Perhaps some seasonal difference is responsible for the anomaly.

e) Geological features 11, 12, 13, 14, 15, and 21 were not perceptible on the Landsat imagery. This is attributable to the poorer Landsat resolution.

f) Pine plantations (17) were much more clearly shown on band 5 than on the Skylab colour photograph. They were barely perceptible on band 4 and imperceptible on 6 and 7.

g) Relief differences at 8 and 18 could not be seen, as in the Skylab photograph.

h) In all Landsat bands, the difference between eucalypt forest and natural pasture (18) was not as distinct as on the Skylab photography. On the other hand the difference between eucalypt forest and improved pastures (19) was far clearer on the Landsat imagery.

i) Particularly on bands 6 and 7, water stood out very clearly, no matter what the surroundings. It was less clearly differentiated on band

5, and in places not perceptible on band 4. The Skylab photography came closest to band 4 in this respect.

j) Watercourses and roads were clearest on the Skylab photography, much less so on the Landsat visible bands, and not distinguishable on the Landsat infrared bands.

k) The heavy snow cover shown in the Skylab photograph had disappeared by the time the Landsat-1 imagery was obtained, but many narrow snowdrifts are visible in the December imagery, fewer in the January imagery as one would expect. They take the form of a system of thread-like features, diminishing in order of clarity from band 4 to band 7, where they are all but invisible.

Conclusions

The forest cover and probably the summer grass cover over much of this area of New South Wales mask the soil colour, and the Skylab photographs consequently provide less information than they do in arid central Australia. Proportionately more field work is therefore needed in eastern New South Wales. Nevertheless the photographs provide much useful synoptic information and some detailed information of direct value to the mapping of natural resources. Features considered in this report include land forms, soils, vegetation, water supplies, and climate. Mineral resources are considered under Sections 6.2 and 6.3.

In the New South Wales area nearly every band of the S190A had a unique capacity for clearly distinguishing some particular feature which was obscure or invisible on other bands. The camera is a valuable complement to the S190B. Central Australia on the other hand provided little scope for the finer spectral discrimination of the S190A.

Apart from its well-known advantages in commanding a wider field of view, the Landsat imagery offers nothing for visual interpretation that the Skylab photography cannot offer.

Reference

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6.5 INFORMAL REPORT ON USEFULNESS FOR LAND USE MAPPING AND TOPOGRAPHIC MAP REVISION (DNM)

Introduction

Initial examination of the special 1:500 000 scale enlargements of SKYLAB S190B photography supplied by NASA indicated that further investigation was warranted to study its usefulness for Land Use Mapping and Topographic Map Revision.

Land Use mapping

Examination of five frames of southeast Australia included comparisons with Landsat-1 false colour composite imagery of similar areas, 16 times enlargement to about 1:30 000 scale and stereoscopic viewing, to which the photography is most suited because of a 60 per cent overlap of individual frames.

The frames examined enabled much more detail to be extracted than is possible from Landsat-1 false colour composite images, and would be particularly useful if examined in conjunction with similar false colour photographs obtained at the same time. The main advantage over conventional colour photography is the ability to obtain a broad overview as well as fine detail, where required, from the one image.

Lack of availability of extensive coverage of these photographs limits their practical application to land use mapping, otherwise they might largely supersede Landsat imagery. At present, small (1:140 000) scale conventional colour photography would seem to offer the greatest potential as back-up material to the basic Landsat imagery for land use mapping programs in Australia.

Topographic Map revision

Two frames, one in central and the other in southeast Australia, were examined for revision of 1:100 000 scale topographic maps. The standard equipment in use for transfer of additional detail was, however, unable to accommodate the scale differential and the examination was based on a black and white print at 1:100 000 which degraded the image quality considerably.

Much detail useful for revision of maps at this scale was evident and could be accurately located in respect to adjacent existing detail. However, completeness of revision could not be guaranteed and small features, normally symbolised on the map (e.g. bores, dams, farmhouses, fences) could not be identified in many cases.

The examination, due to the inadequate facilities for retaining the resolution of the original photograph, was necessarily inconclusive, but the difficulty of identifying cultural features, the main requirement of map revision, indicated that such photography could not replace completely the need for aerial inspection and medium scale conventional photography in the revision of topographic maps at scales larger than 1:250 000 scale.

If available, they would be useful but here again it was felt that small scale colour photography from conventional aircraft would be of much greater practical use.

7. SUMMARY OF CONCLUSIONS

1. In sub-humid, vegetated areas, S190B photography:

   a) has a potentially operational role in detecting lineaments in 1:100 000 scale geological mapping and in major civil engineering surveys,

   b) is of limited value for regional lithological mapping at 1:500 000 scale,

   c) provided much useful synoptic information and some detailed information of direct value to the mapping of non-mineral natural resources such as vegetation, land, soil, and water.

2. In arid, well exposed areas, S190B photography could be used:

   a) with a limited amount of field traverses, to produce reliable 1:500 000 scale geological maps of sedimentary sequences,

   b) to update superficial geology on 1:250 000 scale maps,

   c) together with the necessary field studies, to prepare landform, soil and vegetation maps at 1:1 000 000 scale.

3. Skylab photography was found to be more useful than Landsat images for small scale mapping of geology and land types, and for the revision of topographic maps at 1:100 000 scale, because of superior spatial resolution and stereoscopic coverage. In forestry small scale mapping, Landsat summer-time images were more useful than the winter-time Skylab photography.

4. For small scale geological mapping S190B proved more useful than S190A.

For 1:100 000 scale land classification mapping, S190A proved to be a valuable complement to S190B.

For forestry, S190A colour IR was more useful than S190A colour for delineating major species associations.

5. The investigation has shown that very small scale, high resolution, stereoscopic colour and colour infrared photography is a useful aid in natural resources mapping.

Only limited coverage of EREP-type photography is available, but the work done suggests that high altitude aircraft photography at suitable scales (1:100 000 and smaller) would be a valuable alternative.

8. RECOMMENDATIONS

1. It is recommended that NASA should bring to the attention of the appropriate section of the United Nations organization (e.g. the Scientific and Technical Sub-Committee of the Committee for the Peaceful Uses of Outer Space) the potential of satellite EREP-type colour and colour infrared stereoscopic photography for assisting in the mapping of poorly known regions of the world.

2. In countries such as Australia, that already have an extensive coverage of maps related to natural resources, experiments with small scale high altitude aircraft photography should be made to determine their suitability for fast, cost-effective map revision.

APPENDIX

SKYLAB PHOTOGRAPHIC PRODUCTS

(Data from Skylab EREP Investigators' Data Book, Oct. 1972 and EREP Sensor Performance Report MSC-05528)

Multispectral Photographic Camera S190A

Focal length (mm)	Negative Size (mm)	Actual image size (mm)	Negative scale	Area covered (km)	Cone angle (degrees) on flats	Cone angle (degrees) in corners
152	70	57	1:2 860 000	163x163	21	29½

Camera Station No.	Film roll No.	S190A Film	Design Bandwidth, µm	Standard Filter
1	25	IR Aerographic B & W, type EK 2424	0.7 to 0.8	CC
2	26	IR Aerographic B & W, type EK 2424	.8 to .9	DD
3	27	Aerochrome IR color, type EK 2443	.5 to .88	[illegible]
4	28	Aerial color (high-resolution), type SO-356	.4 to .7	FF
*5	29	PAN-X aerial B & W, type SO-022	.5 to .6	AA
*6	30	PAN-X aerial B & W, type SO-022	.6 to .7	BB

(* In SL4, filter AA is used for Cam. St. 6 and BB for 5)

Earth Terrain Cambera S190B

Focal length (mm)	Negative Size (mm)	Actual image size (mm)	Negative scale	Area covered (km)	Cone angle (degrees) on flats	Cone angle (degrees) in corners
458	126	115	1:948 000	109x109	14	20

Film type	Filter	Bandwidth (µm)
Aerial colour (high definition) SO-242	5 (neutral density)	.4-.7