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RECORD 1975/165

AERIAL THERMAL INFRARED IMAGING OVER COAL MEASURES, HAIL CREEK, QLD, 1971

by

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CONTENTS

SUMMARY

During August 1971 the BMR conducted an experimental aerial thermal infrared imaging survey over coal measures in the Hail Creek Syncline to evaluate the technique for detecting thermal effects related to buried coal. Pre-dawn, mid-day and post-sunset infrared line scanning was carried out using an 8-14 micrometre wavelength detector.

No significant thermal effects were detected that could be attributed directly to coal. Relatively cool areas detected on night-time imagery of the eastern flank of the syncline are considered to be due to the effects of dense grass cover growing on soil derived from coal. Such areas would not normally be identified without field data or if bedding trends were absent. Less information about rock boundaries or structure could be interpreted from the thermal imagery than from the aerial photography.

In the environment studied the technique is unlikely to provide sufficient data of value to coal exploration to warrant its use.

The rather featureless terrain of the survey area presented problems for both aircraft navigation and image interpretation that are not readily resolved.

1. INTRODUCTION

On 30 and 31 August 1971 an experimental aerial thermal infrared imaging (thermographic) survey was carried out over coal deposits of the Hail Creek Syncline in the Bowen Basin, Queensland (Fig. 1).

The survey was flown by Qasco Air Surveys Ltd using a Daedalus thermal infrared line scanner, and was conducted by the BMR Photogeology and Remote Sensing Group as part of an ongoing program to evaluate the geological applications of various imaging remote sensing techniques.

Although various reports on thermal imaging had been published at the time of the survey, only very limited information was available on the application of thermal imaging techniques to coal geology. The thermal properties of coal compared with those of associated sedimentary rocks suggested that, for relatively fresh exposures, the appearance of coal on thermal imagery should contrast strongly with that of surrounding rocks.

Fresh outcrops of coal are rare at Hail Creek. However, previous field observations had indicated that the clayey soil - which locally is the common expression of the surface trace of a coal seam - seems to be somewhat moister than the adjacent sandy soils and it was expected that this moisture difference would be expressed in a temperature difference detectable on thermal imagery.

The Hail Creek region appeared to be well suited for conducting research into thermal imaging for coal since:

a) it contained coal under various depths of overburden,

b) the natural surface of the area was relatively undisturbed

c) extensive subsurface drill-hole data was available from Hail Creek Associates (H.C.A.).

If areas of coal displayed distinctive tonal difference on the thermal imagery then the technique would offer potential for coal exploration in other areas of the Bowen Basin.

The aims of the project were to evaluate the potential of airborne imaging for:

a) its capability for indirect indication of coal by differentiating soil derived from coal from soil of other derivation;

b) detecting thermal effects from coal under various depths of soil.

The Hail Creek survey was BMR's first field-supported experiment in the application of thermal imagery to geological problems, and hence it was expected to provide valuable information on the operations, problems, limitations, and potential of the technique.

2. NATURAL ENVIRONMENT OF THE HAIL CREEK REGION

As the appearance of terrain features on thermal imagery may vary with changes in the soil moisture and soil type, vegetation, and micro-climatic conditions, some brief notes are included on the environmental setting of the Hail Creek Syncline. Details of vegetation, soils and land-forms are discussed in the land systems report by Story et al. (1967).

2.1. Geology

The Hail Creek Syncline is a relatively shallow southeast-plunging asymmetrical structure of the Nebo Synclinorium (Malone, 1969). The steeper eastern limb dips westerly at angles between 9° and 32° (generally greater than 15°) and the west limb dips easterly at 6° - 15°.

The flanks of the Syncline (Fig. 1) are composed of Upper Permian continental sediments of the Blackwater Group (Malone, 1969). From the base upwards this group consists of the Hail Creek Beds (sandstone, mudstone, carbonaceous shale), Fort Cooper Coal Measures (sandstone, conglomerate, mudstone, carbonaceous shale, coal, tuff) and the uppermost unit, the Elphinstone Coal Measures (carbonaceous mudstone, sandy limestone, coal) (Jensen, 1971). Four main seams of coking coal occur within the Elphinstone Coal Measures. In order of decreasing age the seams are named Fort Cooper, Hynds, Schammer, and Elphinstone. Of the four seams the Hynds and Elphinstone are of economic importance, the latter being the most regionally consistent in thickness and averaging 6 m in the Hail Creek region (Australian Mining, 1974).

At the northern end of the syncline several Cretaceous acid to intermediate intrusives have been mapped (Fig. 1), many of which are partly concordant with fold structures, suggesting that intrusion and folding were contemporaneous (Malone, 1969). Post-intrusive faulting has resulted in some localized disruption of the sediments (Fig. 1).

2.2. Topography

The Hail Creek Syncline occupies a broad valley which opens to the southeast.

Topographic development has been influenced by the underlying geology to the extent that the general position of Hail Creek approximates to that of the synclinal axis (Fig. 1).

Erosion in the immediate region of the syncline is at a mature stage resulting in lowlands topography with local relief of less than 40 m. The overall relief between the valley floor and the outer flanks, where resistant Cretaceous sediments crop out as low strike ridges, is less than 100 m.

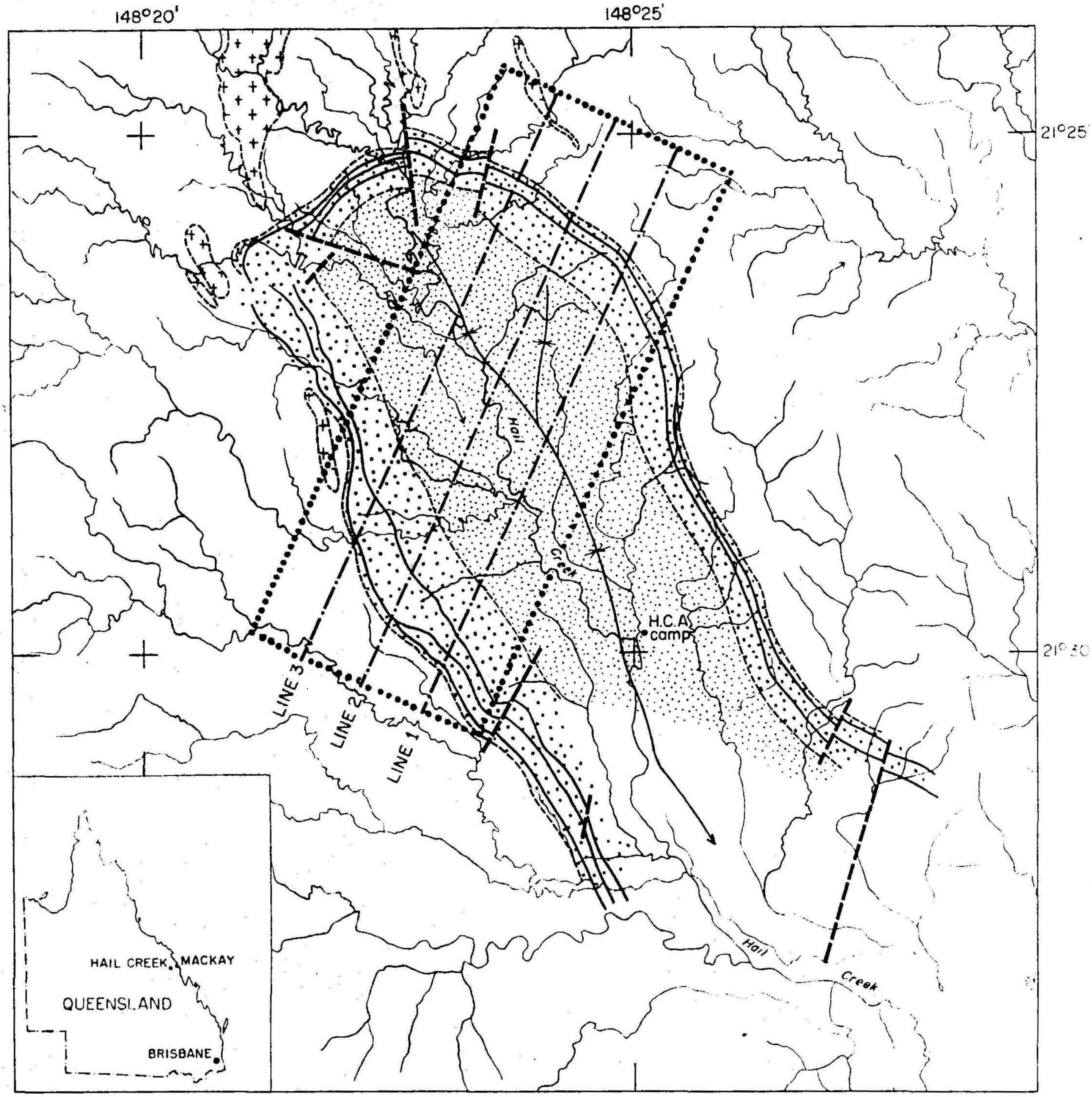
Hail Creek has deposited alluvium over most of its length resulting in a belt of creek flats averaging 700 m wide (part of the Connors land system of Story et al., 1967). The region to the east of the alluvium is the Hillalong land system typified by undulating lowlands and very low strike rises and to the west of the alluvium by lowlands and low rises (the Girrah land system).

Stony incised strike ridge terrain dominates the region in the headwaters of Hail Creek and tributaries around the nose of the syncline (the Cotherstone land system).

2.3. Soil

Soils of the area have been discussed in detail by Gunn in Story et al. (1967). Thick sandy texture-contrast soils which abruptly change to clayey subsoils have developed on the alluvium along Hail Creek and on the terrain around the nose of the syncline.

To the east of Hail Creek shallow texture-contrast soils predominate. These have sandy or loamy surface soils and heavy clayey, acid to alkaline subsoils.



Lower Cretaceous — Acid to intermediate intrusive

Triassic — Rewan Formation

Upper Permian — Elphinstone Coal Measures; Fort Cooper Coal Measures; Hail Creek Beds

Geological boundary

Syncline, showing plunge

Fault, inferred

Proposed thermal imaging flight line

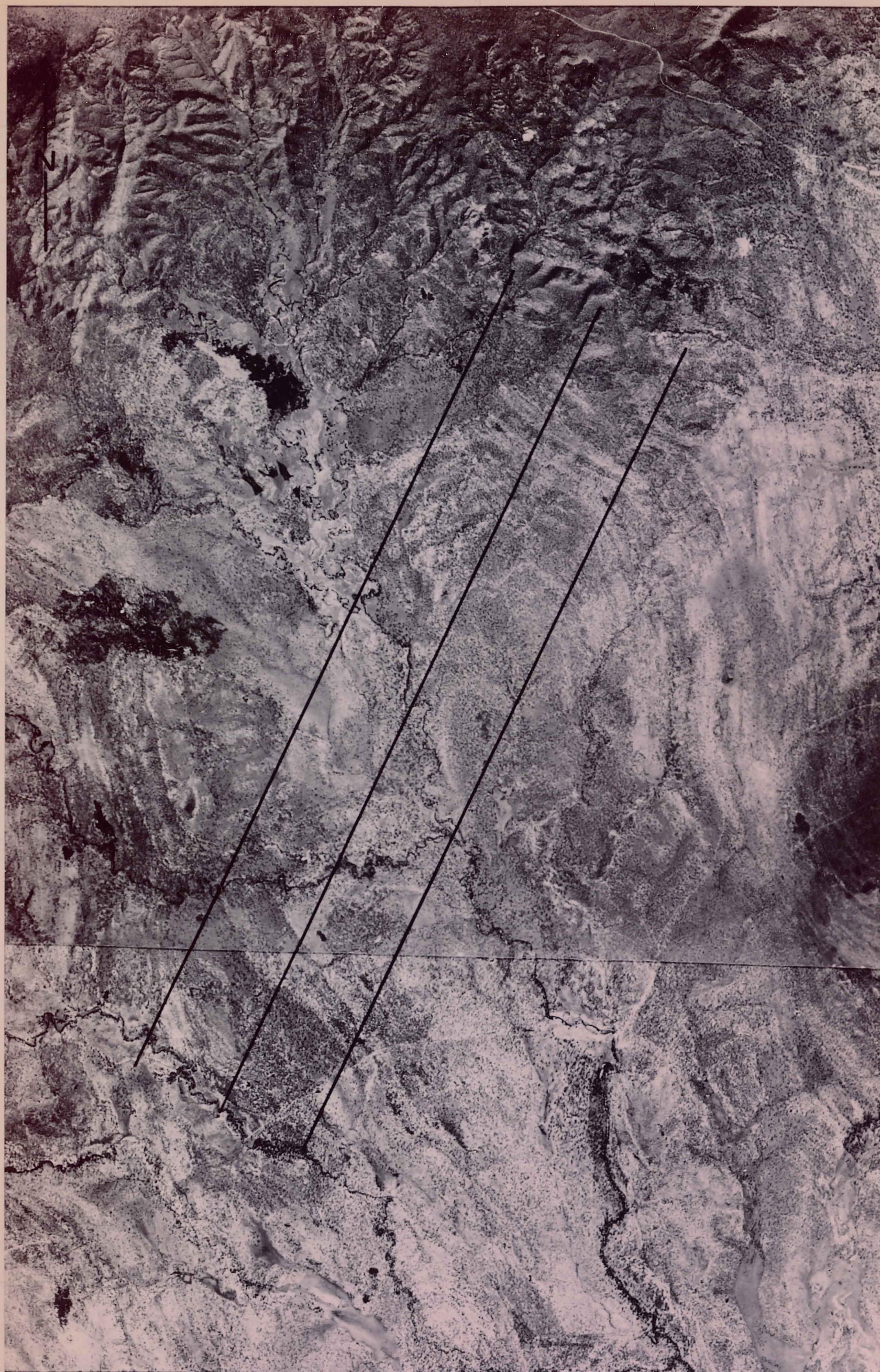
Projected outcrop of coal seam

Outline of survey area

(Note- Geology after Hail Creek Associates - Plate 1, 23.2.1973)

0 1 2 3 4 5 kilometres

Fig. 1 Geology of the Hail Creek Syncline.



Record 1975/165 1 2 3 4 5 km F55/A7/26

Fig. 2 Photomosaic - Hail Creek area - showing proposed thermal imaging flight lines.

Note bedding trends emphasized by vegetation.

Fig. 3. Typical grass cover - western end of flight line 3.

Fig. 4. Exposure of Elphinstone seam on eastern end of flight line 2. (Refer point C, Fig. 5.) Distance a-a′ is approximately 1.5 m.

To the west of Hail Creek cracking clay soils predominate. These are dark brown to very dark grey (black earth) soils of heavy texture and poor internal drainage.

2.4. Vegetation

The natural vegetation throughout the area is primarily savannah woodland with areas of downs (Story et al., 1967), Figure 2 gives some idea of the density and distribution of vegetation. Savannah woodland consists of open spaced trees (box and ironbark varieties predominate) 9-12 m high with an open grassy floor and few shrubs as illustrated in Figure 3. Perennial bunch grasses (blue grass and spear grasses) predominate. Savannah woodland is mostly developed on texture-contrast soils, and grades into downs vegetation on clay soils.

Downs vegetation is typified by more widely scattered ironbark, bloodwood, and box trees, and dense bunch grasses up to 1 m high.

2.5. Climate

In general the climate of the region can be regarded as sub-humid (Fitzpatrick *in* Story et al., 1967) with a well defined summer (November-April) maximum rainfall and an increasing incidence of thunderstorms during late spring and early summer.

At Nebo - approximately 35 km to the southeast of Hail Creek - the closest point at which continuous rainfall records have been kept, the mean annual rainfall is in the range 760-800 mm.

Appendix 1 lists the rainfall recorded at Hail Creek Associates (H.C.A.) camp (Fig. 1) for the month proceeding the infrared imaging survey.

Mean maximum temperature of the area ranges from somewhat above 20°C during the coolest months (June and July) to the mid-thirties in the warmest months (December to January).

Mean minimum temperatures range from about 6°C in July to about 21°C in January. Although day temperatures are high throughout the winter, under prevailing clear skies and stable anticyclonic conditions, radiational cooling at night is intense and frosts can be expected (Story et al., 1967).

3. SURVEY INFORMATION

The aerial survey was carried out by Qasco Air Surveys Ltd using an Aero Commander aircraft fitted with a Daedalus optical-mechanical line scanner owned by the Physics Department of Newcastle University. Survey details are listed in Appendix 2.

3.1. The Daedalus Scanner

The Daedalus scanner used had a 120° angular field of view (f.o.v.) and an instantaneous f.o.v. of 2.5 milliradians (i.e. at a flight altitude of 610 m AMGL the theoretical spatial resolution of the detector was equivalent to a square of 610 x .0025 m = 1.5 m on a side). It was fitted with a mercury-cadmium-telluride detector head capable of recording the emitted infrared radiation in the 8-14 micrometre wavelength range. The thermal resolution of the detector is considered to be 0.3°C. No other compatible airborne thermal instrument (i.e. detectors for other wavelengths or radiometers) was available for the survey.

Output from the scanner was recorded on magnetic tape, which was subsequently re-played through a tape-to-film conversion unit to produce 70 mm panchromatic film strips in which warm terrain is displayed by light tones on positive products. The tape recorded data proved essential since manipulation of playback variables was necessary to produce imagery with acceptable matching of cross-track and along-track scales.

3.2. Infrared imaging flight planning

Three parallel survey lines were chosen for infrared imaging of an area 11 km x 3.7 km. Flight lines (Fig. 1) were positioned so that the scanner imagery would cover areas of intensive drilling (i.e. well documented sub-surface geology) and granitic intrusive outcrop on the western limb, and faulting, coal outcrop in the vicinity of 148° 24.2E, 21° 25.8'S (Fig. 4), and intrusives, on the eastern limb.

Each flight line was to be approximately 11 km long and spaced 1220 m from the adjacent line. Owing to the effects of scale change and distortion towards the edges of scanner imagery, only the central two-thirds of the image strip are usable for reliable interpretation. Flight line spacing was therefore calculated assuming a 90° effective f.o.v. rather than the 120° total f.o.v. A flight altitude of 610 m AMGL (900 m AMSL) was selected to provide a usable ground coverage of approximately 1220 m within a total strip width of 2100 m at a nominal image scale of 1:26 000.

3.3. Vertical air photography

Previous investigations of infrared imagery (Simpson, 1971) indicated that up-to-date information about the land surface conditions (tracks, bare ground, vegetation distribution) at the time of imagery is essential to aid interpretation. To obtain this information simultaneous panchromatic air photographs were taken with an RC10 camera (focal length 151.93 mm) during the daylight imaging flights to produce photographs at a nominal scale of 1:4000. Because of the difference in angular f.o.v. between the camera (74°) and scanner (120°) there are unavoidable gaps between the adjacent photographic strips.

3.4. Timing of survey

In an effort to minimize any masking effects of excessively wet soil the survey was planned to take advantage of the dry early winter conditions (see section 2.5).

Delays in finalizing the flying contract resulted in the survey being put back to late August. On 26 and 27 August thunderstorms rained a total of 35.6 mm at Hail Creek (Appendix 1). To take advantage of good drying conditions on 28, 29 August the survey flying was delayed until forecasts from the Bureau of Meteorology in Brisbane indicated the likelihood of further thunderstorm activity in the area. The survey was carried out under fine and calm, clear weather conditions on 30, 31 August 1971.

The optimum time of day for thermal imaging is when the maximum difference occurs between the emissivity of the target and that of surrounding materials. Determination of optimum time requires extensive monitoring of the target area with a radiometer or similar temperature sensing device. Bonn et al. (1972), found that optimum imaging times for relatively simple targets (bare ground and grassed ground) may vary considerably throughout a period of several months.

For geological purposes night-time imagery is necessary to record thermal emittance properties without solar reflectance and shadow effects (Stingelin, 1969). Wolfe (1971) concluded that on day-time imagery topography is the dominant control of tonal densities.

In the absence of any suitable equipment to carry out pre-flight investigations at Hail Creek the area was flown at three separate time intervals (see Appendix 2) equivalent to pre-dawn (0436-0520 hours), mid-day (1100-1130 hours), and post-sunset (2008-2048) hours.

3.5. Field activities

To assist in interpretation of the line scan imagery some monitoring of terrain temperatures was carried out using BMR designed thermistor probes capable of measuring to $\pm 0.5^{\circ}C$. Field activities during survey overflights involved observations of geology, terrain, and wind conditions and assisting with aircraft navigational aids (section 5.1).

4. RESULTS

4.1. Coal detection

No thermal signals on the imagery can be readily attributed to the effects of either coal outcrop or near surface coal.

The best outcrop of coal in the survey area is a gully exposure indicated at C in Figure 5. Direct detection of the coal by thermal imaging techniques was not really expected as the surface width of the exposure to the vertical view is only about 2 m. This is close to the theoretical limits of spatial resolution of the thermal scanner (1.5 m x 1.5 m) and such an outcrop is unlikely to be detected unless it is at a markedly different temperature from the surrounding material.

Sabins (1973 a) reports that spatial resolution alone is not a valid measure of the quality or useful information content of imagery. His investigations tend to confirm that the ability to detect a geologic anomaly is related more to imagery contrast than to spatial resolution. On post-sunset imagery (Fig. 6C) road r of 5 m width is readily detectable whereas track t of 3 m width - and perpendicular to the road - can only be identified with certainty where it passes through relatively cool open grassed areas.

Thermistor temperature measurements taken on moist coal of outcrop C (Fig. 5) at 1400 hours on 31 August (i.e. 2.5 hours after the midday overflight) showed the coal surface was $4.5^{\circ}C$ cooler than that of the enclosing silty sandstone and $2^{\circ}C$ cooler than air temperature. (The low temperature of the coal relative to the sandstone is considered to be due to the moisture content of the coal.) In this case the temperature difference, although relatively large, between coal and sandstone was insufficient to record from such a small outcrop.

Some of the dark-toned (relatively cool) areas on the pre-dawn and post-sunset imagery can be equated to the predicted surface positions of coal seams. The best example occurs where flight line 2 crosses the eastern flank of the syncline. On the post-sunset imagery (Fig. 6C) discontinuous cool areas between a-a' and b-b' correlate respectively with the surface projections of the Elphinstone and combined Hynds-Fort Cooper coal seams.

Examination of the large-scale air photography (Fig. 5) taken during the survey shows that the cool areas correspond to patches of dense grass cover with comparatively sparse tree density. Warmer areas on the thermal imagery (Fig. 6C) correspond to some of the larger tree crowns and areas of bare ground.

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The width of the grassed zones is 2-3 times the expected surface width of the underlying coal seams. This may be accounted for in terms of soil depth and local slope.

The post-sunset and pre-dawn imagery on which the grassed areas show as cool were recorded during periods of cooling (thermograph record - Appendix 1). As substantial areas of grass cover record as cooler than the general environment the thermal behaviour of the grass can be regarded as that of a uniform body of low thermal inertia because of its extremely low specific gravity and high porosity. Similar thermal effects have been observed by Wolfe (1971) on pre-dawn imagery of piled tumbleweed.

No field observations were made on the specific nature (i.e. overall height, clump density etc.) of the grassed areas that record as cool. Air photography (Fig. 5) shows the particular grass cover is often more widespread than can be interpreted from the thermal imagery. Where tree density is relatively high the warm signals from the crowns predominate since the passive system is non-penetrative beyond the first surface sensed.

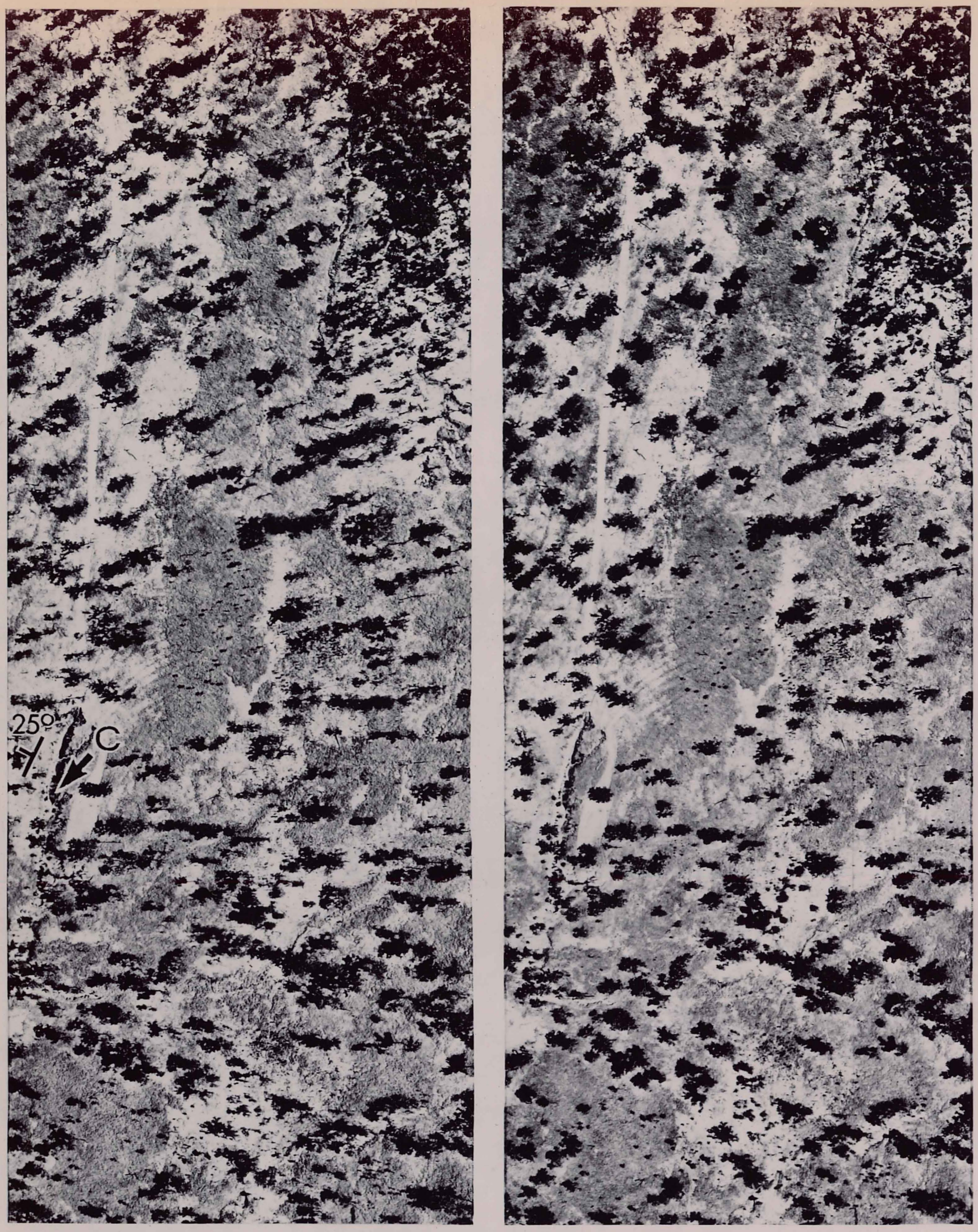
Thus on the eastern limb of the syncline where soil depths are generally shallower than on the western limb it appears that soil developed over coal supports a vegetation community characterized by dense ground cover grasses and relatively sparse trees. This association can be regarded as a geo-botanical anomaly which collectively records as relatively cool on post-sunset and pre-dawn thermal imagery.

Further examination of Fig. 6C shows a relatively cool zone d-d' approximately 200 m to the east of zone b-b'. The zone d-d' can be recognized on pre-dawn (Fig. 6A) and midday (Fig. 6B) imagery as having very similar appearance to the zones a-a' and b-b' that coincide with the projected surface positions of coal seams. Air photographs show that the zone d-d' has a grass/tree density similar to that developed over the coal. No subsurface data is available beneath the zone d-d' and it is not known whether coal is present. Correlation with H.C.A. detailed geological maps show that the zone d-d' is within Fort Cooper Coal Measures.

It should be emphasized that in the area surveyed, the recognition of thermal patterns having a geological association depends on the presence of identifiable geological trends emphasized by vegetation. Such trends are obvious on the thermal imagery only on the eastern limb of the syncline. Elsewhere on the pre-dawn and post-sunset imagery there are dark tones (e.g. f on Fig. 6A) which appear identical to the tones associated with the vegetation developed over the coal seams. Air photographs and field data show that some cool areas are associated with damp soil, some with freshly burnt grass (i.e. carbon ash accumulations on the ground surface); some other dark toned areas on the imagery may be associated with coal, but there is no way of identifying them as having significance for coal search.

4.2. Differentiation of rock types on thermal imagery

On pre-dawn and post-sunset imagery a relatively warm (light-toned) zone (not illustrated) coincides in part with the narrow intrusive body on the northeastern end of flight line 3 (Fig. 1). Detailed examination of the imagery shows that the light-toned zone is made up from the combined effects of relatively warm tree crowns and slightly cooler background. The latter effect is from tors, outcrop, and rubble. Similar heat patterns occur over the outcrop area of the granitic intrusive close to where flight line 3 crosses the western limb of the syncline. Parts of the intrusives covered by soil or grass cannot, by thermal effects, be differentiated from areas of soil or vegetation over other rock types.



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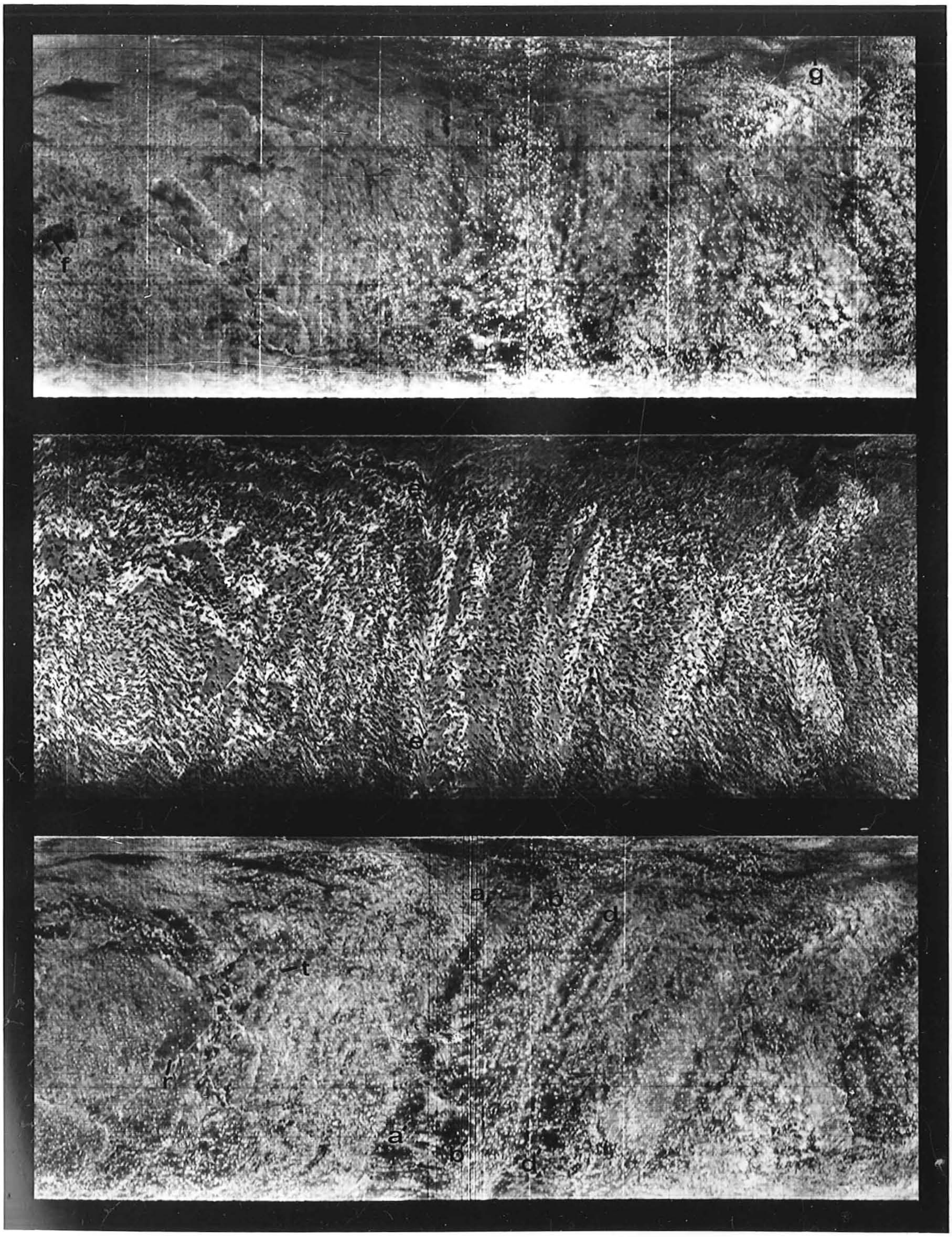
0 100 200 300 m

Fig. 5 Stereopair showing vegetation on eastern end of flight line 2. (C - coal outcrop Elphinstone seam)



PREDAWN

0500 hrs
31 Aug 1971

Fig 6A

MIDDAY

1117 hrs
31 Aug 1971

Fig 6B

POST-SUNSET

2032 hrs
30 Aug 1971

Fig 6C

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0 1 2

Fig.6 Thermal imagery-eastern end of flight line 2

Intrusives could not be identified as such on thermal infrared imagery without supporting field data. Attempts to map the extent of the intrusives would result in delineation only of areas of outcrop and rubble which relate to high topography developed over the more resistant rock type; soil covered areas would not be recognized. Simpson (1971) previously noted the ability of thermal infrared imagery to detect granite outcrop in forested terrain.

In general, in the area surveyed, no rock type produced a sufficiently diagnostic signal on the thermal imagery to allow lithological boundaries to be mapped.

4.3. Structural lineaments

Examination of the imagery for linear features representing faults, - particularly the inferred fault near the northeastern end of flight line 3 (Fig. 1) - was unsuccessful. Within the survey area on distinct tonal alignments were found that could be attributed to faulting. In sedimentary terrain Rowan et al. (1970) found that faults showed as relatively cool zones on pre-dawn infrared imagery and concluded that the effect was due to increased water content and concomitant evaporation.

Narrow dark-toned lineaments can be observed throughout the intrusive body discussed under 4.2: Air photographs show the lineaments correlate with fractures (probably joints). In the survey area lineaments and fractures are more readily mapped on conventional air photographs than on thermal imagery.

4.4. Soil and vegetation effects

Since rock outcrop is sparse throughout the survey area the overall patterns on the thermal imagery reflect the thermal properties of soil and vegetation. As indicated in 4.1 thermal effects of vegetation generally dominate.

Pre-dawn and post-sunset imagery of all flight lines shows a distinctly cooler (dark-toned) region up to 1000 m wide extending along Hail Creek. This zone corresponds well with the alluvium along Hail Creek. As discussed under 2.3 the alluvium is characterized by sandy texture-contrast soils which could be expected to image cooler owing to their topographic position and their water content from rainfall before the survey. However detailed examination of the aerial photographs shows that on the night-time imagery bare soil patches within the alluvial belt imaged warm, and the dark-toned areas correspond to patches of relatively dense ground cover which in the Connors land system of Story et al. (1967) are dominated by varieties of spear and blue grasses.

5. PROBLEMS ENCOUNTERED

Both the acquisition and interpretation of thermal imagery, particularly night-time imagery, present problems not applicable to conventional aerial photography. Although most problems have been documented, or are predictable, satisfactory solutions may not be applicable to all survey situations.

Various airborne survey problems associated with thermal infrared imaging have been discussed by Stingelin (1969), Dickinson (1973) and Sabins (1973a). Problems of image processing and interpretation have been discussed by Sabins (1973b) and Quiel (1975).

5.1. Airborne survey problems

The main problem encountered during the survey was that of accurate aircraft navigation along the survey flight lines both at night and (to a lesser extent) during the day.

Mackay airport was the operational base for all flying during the survey and navigation in the survey area was by means of conventional visual and dead-reckoning techniques.

No problems were encountered by the aircrew in locating the general survey area by day or night. Location at night was assisted by switching on the main H.C.A. camp lights.

5.1.1. Night-time survey

To assist aircraft navigation two ground stations were established on each proposed flight line. The ground stations were approximately 5.5 km apart and the first was positioned 3-4 km from the approach end of each survey line. Station separation was controlled by the availability of vehicle tracks along the H.C.A. survey grid throughout the area.

Ground stations were manned during overflight, and vehicle headlamps were aimed along the survey line towards the aircraft approach direction. Radio communication was maintained between the ground stations so that signal flares could be fired simultaneously when the aircraft was on line approach. Two-way communication between aircraft and ground stations did not operate; only the air to ground transmissions could be received. After successful imaging of a flight line it was necessary for the ground crews to drive to, and man, the ground stations on the adjacent flight line. Under conditions of more difficult access it would be necessary to man each ground station for the duration of each survey flight.

Ground activities presented no problems but the aircrew experienced considerable difficulty in locating lights or signal flares. This activity was hampered by the presence of some burning logs (from a bushfire) on the western side of the survey area.

The signal flares used (Schermuly 'Signal distress day and night No. 1 Mk 1') proved to have too short a duration (approx. 25 seconds) to be useful for air navigation.

The times for imaging of each survey line (Appendix 2) allows a comparison between the time needed to fly the 11-km-long flight lines and that needed to establish correct aircraft position.

5.1.2. Day-time survey

Day-time flight line location and navigation was difficult because of the relatively uniform vegetation cover and lack of distinct landmarks in the survey area.

Ground stations were manned and smoke flares, flashing mirrors and ground markers (white or yellow cloth 4.5 m x 0.75 m) were used to assist aircraft navigation. The orange-coloured signal flare smoke was not visible from the air because it dissipated too rapidly before rising above tree level. Comments from the pilot indicated that the flashing mirrors directed at the aircraft were the most useful aid to navigation.

5.1.3. Discussion

From the experience of the Hail Creek survey and discussion with survey pilots it is apparent that in similar low terrain, accurate night-time visual navigation would require a rotary flashing amber light (of the type used by road maintenance crews) positioned approximately every 3 km along the survey line. At Hail Creek the ground station separation (5.5 km) was too wide to allow the pilot to maintain accurate alignment.

In Australia at present there does not appear to be any simple technique for achieving accurate night-time line flying. Doppler navigation is available in some Australian-based survey aircraft, but it may not be sufficient for accurate line flying under all circumstances. Perry & Crick (1974) found that Doppler was ineffective on flight lines partly over land and partly over calm water. Sabins (1973a) discusses a newly developed VLF radio navigation system that has proven satisfactory for night-time infrared imaging surveys in the USA.

5.2. Interpretation problems

Local image distortion due to aircraft roll (e.g. between e-e' Fig. 6B) was common on all mid-day imagery but was not significant on night imagery. Difficulty in recognizing ground features on some areas of night-time imagery was a more serious problem.

Many ground observation points had to be plotted on the infrared imagery by relating their position to identifiable tree patterns correlated initially from aerial photographs. This was satisfactory on mid-day imagery where tree crowns are identifiable. On night-time imagery of topographic lows (e.g. along Hail Creek) many areas of trees did not image at all, and the location of ground observation points was not possible owing to the absence of identifiable features. In these places the radiant existance (or emittance - the radiant energy emitted per unit area of surface) of the trees and their background is so similar that they cannot be separated on the thermal imagery. This phenomenon is attributed to the effects of air temperature inversion in topographic depressions as it is more pronounced (e.g. g on Fig. 6A) on the pre-dawn than the post-sunset imagery. However, even within hollows affected by air temperature inversion, the crowns could be recognized in places where the background consisted of dense grass patches and thus imaged cooler than the trees (see 4.1).

In such featureless terrain as that of the survey area the difficulty of recognizing ground points on the imagery was anticipated, and an attempt was made to indicate on the thermal imagery the position of manned ground stations by using anhydrous calcium chloride. The chemical was spread on bare ground to cover areas approximately 1.2 m x 1.5 m. Before imaging overflight the calcium chloride was sprinkled with water and the resulting exothermic reaction raised the temperature of the chemical patch up to 10°C above that of the background soil. By this technique it was hoped to create warm patches of sufficient radiant exitance to register on the imagery as hot spots. Detailed examination of the imagery showed that the chemical patches were detected in a few places but without additional information they could not be differentiated from warm tree crowns.

The experiment indicated that at the survey altitude a considerably larger area of chemical would be required to produce a distinct, readily recognizable signal on the thermal imagery. The operational problems involved in transporting, laying, and watering (at the optimum time), the necessary quantities of anhydrous calcium chloride rule it out as a useful technique for marking thermal imagery.

Although only very limited experimentation has been undertaken at this stage, no simple technique is apparent for producing ground position marks on thermal imagery of relatively featureless terrain.

6. CONCLUSIONS

The following conclusions apply to the area surveyed and due consideration should be given to environmental conditions in attempting to extrapolate them to other areas.

No significant thermal effects directly attributable to near-surface coal were detected by airborne thermal imaging.

Where soil is sufficiently thin that bedrock structure is reflected by vegetation, in situ soil developed from coal may support a ground cover vegetation community that on night-time imagery produces a distinctly cool thermal response that could be used as an indirect indication of coal.

None of the rock types produced sufficiently distinctive thermal patterns to allow boundaries to be accurately mapped.

Structural lineaments could be mapped more readily from conventional aerial photographs than from thermal imagery.

The thermal characteristics of ground cover vegetation tended to predominate on all imagery flown, and effects due to soil moisture (despite 35 mm of rain falling 4 days before the survey) seldom image more strongly.

In the environment studies, thermal infrared imaging is unlikely to provide sufficient data of value to coal exploration to warrant the use of the method.

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APPENDIX 1

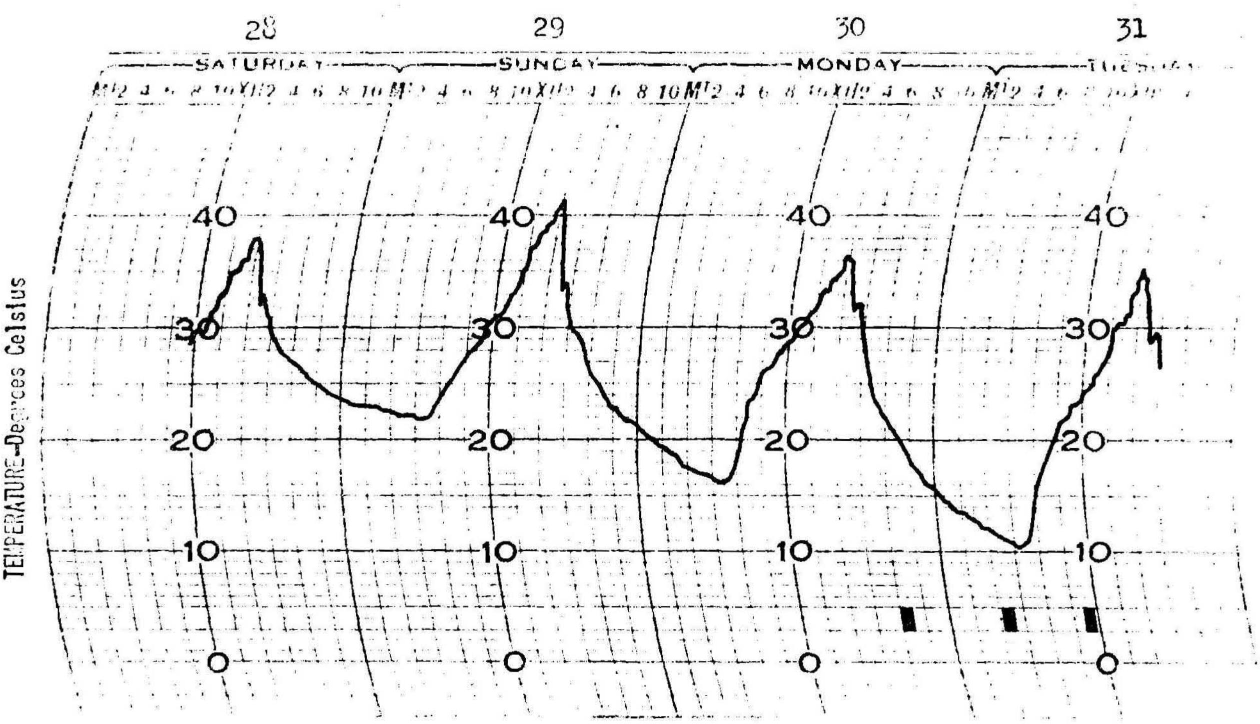
METEOROLOGICAL DATA

Rainfall recorded at Hail Creek for August 1971.

(Measured at H.C.A. camp, 0900 hours daily).

DAY	RAINFALL mm
20	0.8
23	0.5
25	11.4
26	2.0
27	22.9
28	12.7

Thermograph Record - H.C.A. Camp August 28 - 31.



Bars (▌) indicate times of survey imaging - See Appendix 2.

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APPENDIX 2

SURVEY FLIGHT INFORMATION

Date	Flight line	Time Commenced	Time Completed	Alt AMSL (metres)	Air Speed (knots)
30 Aug	1	2008	2011	900	142
"	2	2030	2033	900	142
"	3	2045	2048	900	142
31 Aug	1	0436	0438	884	140
"	2	0457	0500	884	140
"	3	0516	0520	884	140
"	1	1100	1104	900	140
"	2	1115	1118	900	140
"	3	1127	1130	900	140

All imaging lines were flown from SW to NE

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