4. GEOLOGY

4.1 Summary of Previous Work

Geology

Regional geological mapping was carried out in the Mt. Winter area by the Bureau of Mineral Resources during 1961 (Wells et al., 1965). Earlier cursory investigations prior to 1961 are summarised in the BMR report. The regional mapping established the presence of anticlinal trends in the Mt. Winter area.

Geophysics

A regional gravity survey of the area was made by the Geophysical Branch of BMR in 1962 (Lonsdale & Flavelle, 1963), and in 1965 BMR conducted an airborne magnetic and radiometric survey over the region including the Mt. Winter location (Young & Shelley, 1977). Neither survey delineated the Mt. Winter structure, probably because of the coarseness of the survey grids.

A seismic survey, conducted for Magellan Petroleum (N.T.) Pty. Limited in 1966, indicated the presence of possible structural culmination in the Mt. Winter area. The data quality of this short survey was fair. Subsequently, Pancontinental Petroleum Limited shot part of the Glen Edith Seismic Survey over the area in mid 1981. This survey revealed the presence of an anticlinal feature at top Cleland Sandstone level (base Pacoota Sandstone) and several culminations complicated by Petermann Range Orogeny faulting below the base Cambrian horizon.

Drilling

No wells have been drilled in the immediate vicinity to Mt. Winter-1. The nearest wells are Northwest Mereenie-1, 50kms to the northeast, and Ochre Hill-1, 63 kms to the southeast (Figure 1).

Ochre Hill-1 well was drilled by Exoil (N.T.) Pty. Limited (now Oilmin N.L.) as a stratigraphic and structural test of the surface defined Ochre Hill anticline (McTaggart & Benbow, 1965b).

The well was air, mist and aerated water drilled to a total depth of 1146m and was abandoned in June, 1965, after encountering no significant shows of oil or gas.

A total of 804m of Cambrian sediments was found to overlie steeply dipping Late Proterozoic Bitter Springs Formation. The basal Cambrian is missing, apparently due to onlap, indicating that the anticline is a "bald headed" feature, probably formed during the Petermann Range Orogeny.

Northwest Mereenie-1 was drilled to 1524 metres total depth by Magellan Petroleum (N.T.) Pty. Limited in 1969. The well penetrated 258m of Devonian sandstone overlying 1058m of Ordovician sandstone, siltstone and carbonate and reached total depth in Late Cambrian Pacoota Sandstone.

The well was drilled at the northwestern end of the Mereenie anticline to determine the westerly limits of the oilfield and abandoned as a dry hole after failing to encounter commercial hydrocarbons. Gas was flared at 1156m in the basal Stairway Sandstone while blowing the hole clean prior to drilling ahead. Drill stem tests in the primary reservoir, the Pacoota Sandstone, recovered mud and muddy water. According to Pearson & Benbow (1976, Figure 7), the absence of hydrocarbons in the Pacoota Sandstone was due to a permeability barrier separating the Northwest Mereenie-1 location from the rest of the Mereenie Field. However, the presence of salt water at 1500m, and the results of subsequent seismic surveys, suggest that the well may have been drilled down flank from the anticlinal crest.

4.2 Summary of Regional Geology

The Amadeus Basin is an 800 kilometre long, east west oriented intracratonic depression lying in the southern part of the Northern Territory and extending partly into Western Australia. Commencing with Late Proterozoic clastics, which rest on an older Precambrian basement of metamorphic and igneous rocks, the basin has had a long and diversified history of sedimentation (Figure 3). Following Late Proterozoic sedimentation, rocks of Cambrian, Ordovician, possibly Silurian, Devonian and Permian age were laid down. Depositional and climatic conditions varied greatly in space and time throughout this long history. The Late Proterozoic, Cambrian and Ordovician were largely times of marine sedimentation resulting in the accumulation of great thicknesses of sandstone, shale, limestone and dolomite, with periods of evaporite (salt) deposition in the Late Proterozoic and Cambrian. Two periods of glaciation also occurred in the Late Proterozoic. Silurian?-Devonian sandstones, which were deposited during a period of aridity, are partly fluviatile and aeolian. Mountain building movements along the northern rim of the basin provided material for a thick wedge of fluviatile sediments in the Late Devonian. Minor fluviatile and lacustrine deposition in the Permian and again in the Tertiary concluded the sedimentary history of the Amadeus Basin.

Sedimentation was modified by tectonic movements which occurred intermittently from Late Proterozoic to Late Devonian. Tectonic movements in the Proterozoic established the shape of the basin, and formed the structural framework within which subsequent movement took place (Figure 3).

Two major cycles of sedimentation associated with tectonism are evident. The older cycle began in the Proterozoic with mature orthoquartzite and carbonate rocks and finished with relatively immature fluviatile sandstone in the early Cambrian (Petermann Range Orogeny). The second cycle commenced later in the Cambrian with marine sedimentation predominating and

AMADEUS BASIN

GENERALIZED STATIGRAPHIC TABLE — OP 175 & OP178

AGE	GROUP	FORMATIONS (WEST — CENTRAL — EAST)	OROGENIES
TERTIARY — RECENT		Surficial deposits - Lakes, rivers and dunes	
PERMIAN		Buck Formation ? ?	
LATE DEVONIAN	PERTNJARA	Undifferentiated: Brewer Conglomerate (Undandita Member, Brewer Conglomerate, Ljiltera Member); Hermannsburg S'st (Hermannsburg S'st); Parke Siltstone (Amulda Member, Dare Siltstone, Harajica Sandstone, Deering Siltstone)	ALICE SPRINGS
			PERTNJARA
SILURO-DEVONIAN		MEREENIE SANDSTONE	
			RODINGAN
? LATE ORDOVICIAN	LARAPINTA	Gosse's Bluff S'st.	
MIDDLE ORDOVICIAN	LARAPINTA	Carmichael S'stone — Rodingan	
—?— —?— MIDDLE ORDOVICIAN	LARAPINTA	Stokes Formation — Erosion	
EARLY ORDOVICIAN	LARAPINTA	Stairway Sandstone; Horn Valley Siltstone; Pacoota Sandstone — N'dhala Member	
LATE CAMBRIAN	PERTAOORRTA	Goyder Formation	UNNAMED
MIDDLE CAMBRIAN	PERTAOORRTA	Cleland Sandstone (Petermann S'st, Deception Siltst., Illara Fm.); Tempe Fm. — Jay Ck, Hugh River Shale, Giles Ck — Shannon Fm, Giles Ck Dolomite	
EARLY CAMBRIAN	PERTAOORRTA	Mt Currie Conglomerate; Enita Formation/ Quandong Conglomerate; Chandler Fm., Todd Rv. Dolomite, Arumberra S'st. 3,4 ? ? ?	PETERMANN RANGE
LATE PROTEROZOIC VENDIAN		Arumberra S'st 1,2.; Maurice Formation — ? Julie Fm. — Julie Formation; Sir Frederick Conglom./ Ellis Sandstone ? — Winnall Beds — Pertatataka Fm. (Cyclops Member)	
? VENDIAN - RIPHEAN		Carnegie Formation / Boord Formation — Inindia Beds — Pioneer S'st/Olympic Fm, Aralka Formation, Areyonga Formation	SOUTHS RANGE
			AREYONGA
LATE ? RIPHEAN		Bitter Springs Formations (Loves Creek Member, Gillen Member); Heavitree Quartzite	
			ARUNTA
PRECAMBRIAN		Arunta Complex	

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PANCONTINENTAL PETROLEUM LIMITED

FIGURE 3

ended in the Late Devonian with the Alice Springs Orogeny. Smaller local cycles are associated with the movements that have been named on Figure 3.

Folding and faulting in the southwestern area initiated in the Proterozoic, sometimes associated with salt tectonics, produced east-west striking anticlines, often faulted along the flanks and showing thinning of Late Proterozoic sediments over the crest. These structures were modified, and new ones created, by the Alice Springs Orogeny in Late Devonian time - the final major tectonism in the Amadeus Basin. An important precursor to the Alice Springs Orogeny was the Late Ordovician Rodingan Movement. The low angle unconformity that indicates this movement is best developed in the north and northeast, where the earlier deposited Ordovician sediments were progressively eroded eastwards. The total sediment thickness and the stratigraphy of sediments preserved over any structure depend on the amount of Rodingan erosion to which that has been subjected. Thus more western structures, such as at Palm Valley and Mereenie, are more likely to have a more complete sedimentary section preserved over them than eastern structures, such as the Dingo structure.

Structures may be further complicated by the occurrence of salt diapirs, emanating from the Bitter Springs Formation or Chandler Formation, flowing into the cores of structures, as for example at the Goyder Pass Structure. The salt cored structures are known to have grown intermittently from Late Proterozoic to Devonian time, as shown by local thinning of units.

At least two generations of thrust faulting are present in the Amadeus Basin, with thrusting from both north and southwest. Thrusting events probably took place during the Petermann Range Orogeny (Late Proterozoic - Early Cambrian) in the southwest and during the Alice Springs Orogeny. These thrusting movements further complicate the geology and have lead to thickened section, overthrust anticlines and possibly the development of fracture porosity.

4.3 Stratigraphy

The section penetrated by Mt. Winter-1 is compared with the predicted section in Enclosure 4, and with the sections penetrated by previously drilled wells in the central and western Amadeus Basin in Enclosure 5. Table 1 shows the depth of the various formations penetrated in Mt. Winter-1 relative to KB, and the thickness of those formations.

TABLE 1 : Stratigraphy at Mt. Winter-1

FORMATION	TOP (Metres KB)	THICKNESS (Metres)
Cainozoic	0	62
Stairway Sandstone	62	138
Horn Valley Siltstone	190	62
Pacoota Sandstone	252	71
Lower Pacoota Sandstone	323	45
Goyder Formation	368	95
Petermann Sandstone	463	235
Deception Siltstone	698	238
Illara Sandstone	936	313
Tempe Formation	1,249	163
Eninta Formation	1,412	73
Inindia Beds	1,485	198
Bitter Springs Formation	1,683	967+
Total Depth	2,650	

The formations encountered are discussed below.

CAINOZOIC: Surface to 62m (Thickness 62m)

No samples were collected from the surface to 27m depth. Below 27m to about 43m, the lithology is dominantly loose to friable, poorly calcareous cemented reddish orange sandstone. The sand grains are very fine to very coarse, often frosted or ironstained, quartzose, generally sub round to spherical, moderately well sorted when cemented to very poorly sorted when loose. Chalcedonic rootlet casts and fragmented chalcedonic concretions are present. Limonitic and minor ferricreted grains are sometimes present. The base of this weathered layer probably corresponds to the decrease on the gamma ray log above 43m. Below 43m the amount of chalcedonic material increases and off white, light grey and buff sandstone appears. This sandstone is very fine to occasionally medium grained, with sub angular to sub rounded grains. The amount of siliceous cement is variable, ranging from poor to complete, when the rock type could more correctly be called a silcrete. The sandstone is limonitic in part and occasionally grades to ferricrete. Chalcedonic material continues in the cuttings but may be mostly cavings from above 43m. The base of the Cainozoic is selected on the first appearance of grey siltstone and phosphatic sandstone at about 62m, and an increased penetration rate.

The chalcedonic root casts indicate only a post-Silurian age for the section between 43 and 27m. The silcrete beds between 43m and 62m may correlate with ?Mesozoic sediments mapped in the eastern Mt. Liebig sheet area by Wells et al. (1965), and described as predominantly argillaceous white sandstones and friable siltstones, capped by silicified brecciated material. Wells et al. (1970) have discounted the Mesozoic age for all silcrete in the Amadeus Basin, and suggested its formation was during a prolonged period of Tertiary weathering. Chalcedonic, post-silcrete material in the basin is now generally regarded as Miocene or younger (Wells et al., 1970).

STAIRWAY SANDSTONE: 62 - 190m (Thickness 138m)
Age - Early to Middle Ordovician

Cook (1966) divided the Stairway Sandstone into lower, middle and upper units on the basis of the lithology. The upper unit is eroded at Mt. Winter-1 and only the lower two units are preserved.

Middle Stairway Sandstone: 62 - 137m. The middle Stairway Sandstone is predominantly siltstone, with minor sandstone, shale and carbonate. The top is chosen on the first appearance in cuttings of grey siltstone below white siliceous and chalcedonic sandstone and an increase in the penetration rate. There is no obvious gamma ray change at 62m to use as a convenient formation top, and a bit change near this depth makes use of the penetration rate doubtful.

The siltstone is predominantly light to medium grey, occasionally dark grey, mottled with darker grey in part, often sandy and grading to sandstone, or argillaceous and grading to shale or claystone, moderately well indurated to hard but in part soft (claystone), moderately to very carbonaceous, pyritic in part, especially when sandy, slight to moderately calcareous, with minor mica in the upper part becoming more common with depth, and slightly fossiliferous. The siltstone grades to sandstone, which is light grey to medium grey, white, very fine to fine, occasionally medium grained, sub angular to sub rounded or rounded, moderately well sorted, in part pyritic to very pyritic, in part carbonaceous, rarely micaceous, slightly argillaceous or calcareous, with siliceous cement, in part with common black inclusions (? phosphatic) and rare fossil fragments. Some of the sandstone appears to have been burrowed with grey, pyritic, poorly sorted sandstone/siltstone infill in better sorted white sandstone. Minor limestone occurs in the upper part. It is light grey to grey brown or white, finely crystalline and dense. No shows were recorded while drilling in the middle Stairway Sandstone and potential reservoir rocks are absent.

Geochemical studies by D.L. Marchioni (Appendix H) from 119 - 122m revealed a minor organic content of spores and bottryococcoid algae, indicating poor source potential, although reflectance measurements at the same depth (0.71%) show the section is presently oil mature.

The middle Stairway Sandstone is dated as Early Middle Ordovician by Poejeta & Gilbert-Tomlinson (1977). Microfossils from the unit are abundant and well preserved, but the microflora is not diverse (Appendix G). The microflora is typical of shallow marine, inshore environments.

Lower Stairway Sandstone, 137 - 190m: The lower part of the Stairway Sandstone at Mt. Winter-1 consists predominantly of sandstone, with subordinant siltstone and minor shale. Oil shows were encountered in the unit and Core 1 (Appendicies B & C) was cut in the lower part to assess these shows and investigate the reservoir characteristics of the unit.

The sandstones are white, light to medium grey and occasionally brown stained, quartzose, very fine to coarse grained, dominantly fine and medium, but coarser towards the top, sub angular to sub rounded or well rounded when coarse, moderately well cemented with siliceous cement or slightly to moderately calcareous in part, occasionally moderately pyritic with pyrite clusters, traces of glauconite, in part moderately to very silty and argillaceous, occasionally mottled white and brown with black flecks of ?phosphatic or lithic material, increasing mica content below 180m and becoming banded or laminated with micaceous and carbonaceous laminae (?bioturbated), predominantly very poor to poor visual porosity when consolidated but probably good when coarser grained and friable. Porosity up to 11% was measured in Core 1, but low permeabilities were recorded in the best porosity sands (Appendix C). Low permeability is also suggested by the caliper log over the sand body in which Core 1 was taken. Better permeability is indicated in the overlying sand unit, but no shows were recorded, suggesting flushing.

The siltstones are medium to dark grey, sometimes white to light grey, argillaceous to sandy, in part very micaceous, in part very pyritic, occasionally calcareous, sometimes carbonaceous, moderately well indurated to hard and occasionally brittle, in part grading to silty, mottled grey-white sandstone with black grains (?phosphatic), or to silty shale. The shales are light grey to black, micromicaceous and pyritic, generally well indurated and fissile.

Brown residual oil staining was common down to 152m where the first fluorescence was noted in the cuttings. Free oil was reported from 165m (drillers depth) before running the 13-3/8" casing. Fluorescence and cut persisted below the casing, except through the better permeability sand unit mentioned above (166 - 172m) and below 180m. Core 1 (189.7 - 191.3m drillers depth) had rare oil bleeding from pinpoint pores throughout the core, brown oil staining and patchy fluorescence. Core and log correlation suggest the core was cut corresponding approximately to log depths 183 - 186m. Analyses of the oil shows by AMDEL (Appendix C) indicate that the oil is migrated : the source rock is probably the underlying Horn Valley Siltstone.

HORN VALLEY SILTSTONE: 190 - 252m (Thickness 62m)
Age - Early Ordovician

The top of the Horn Valley Siltstone is marked by an increase on the gamma ray log indicating the presence of finer grained sediments. The sonic velocity also drops considerably at the top of the Horn Valley Siltstone.

The Horn Valley Siltstone can be divided into two units. The upper unit, 190 - 225m is composed of interbedded shale and siltstone with minor sandstone, dolomite and dolomitic limestone.

The shale is medium to dark grey, hard, sub fissile to fissile, brittle, micromicaceous to micaceous and very slightly dolomitic or calcareous in part. The siltstone is medium to dark grey, firm to hard, moderately to well indurated, micromicaceous to micaceous, slightly pyritic and occasionally slightly dolomitic. Sandstones are white to light grey, translucent to opaque, very fine to fine grained, consolidated, hard and well cemented with silica cement. The sandstones are occasionally brown with dark stainings or mottled and silty with up to 50% showing yellow fluorescence with a slow diffuse yellow cut and poor visible porosity. Some of the sandstone may be caved from the overlying lower Stairway Sandstone.

The dolomite is white, grey and brown, mottled, with occasional black bands, calcareous in part, grading to limestone, micritic to medium crystalline or in part sparry, rarely to moderately pyritic and in part fossiliferous, moderately hard to brittle, occasionally chalky or earthy and in part showing poor intercrystalline porosity, with orange gold and yellow fluorescence which has a fast streaming, or slow diffuse, cut and a yellow residual ring.

Rare pyrite nodules, pyritized fossils and phosphatic shelly fossils are present.

The basal unit, 225 - 252m contains more carbonate than the upper unit. The unit consists of brown, grey brown, mottled white and occasionally buff limestone, which is silty, microcrystalline to medium crystalline, hard, brittle, occasionally very carbonaceous, occasionally pyritic and moderately fossiliferous. Porosity is probably intercrystalline when dolomitic, but is tight when limy. The limestone has occasional orange and yellow gold fluorescence, slight slow diffuse cut and a faint yellow fluorescent ring. Below 234m interbeds of medium to dark grey shale and siltstone, similar to those in the upper unit become more common. Between 233 to 234m the logs indicate the presence of a dolomitic limestone or dolomite bed.

The base of the Horn Valley Siltstone is selected below a a dolomitic limestone bed which is readily apparent on the gamma ray curve and the sonic curve from 250.5 - 252m.

The Horn Valley Siltstone at Mt. Winter-1 contains a macrofauna of phosphatic and non phosphatic brachiopods, and a microfauna of conodonts (Nicoll, Appendix G). Chitizozoans and acritarchs are also present (Owen, Appendix G), and Marchioni (Appendix H) reports spores and possible bone (probably conodonts). The age suggested by the contained fossils is Early Ordovician (Arenigian).

The Horn Valley Siltstone is a marine deposit because it contains a marine fauna and microflora. The presence of pyrite in the shales indicates strongly reducing bottom conditions, as do the dark colour and the abundance of organic carbon. The Horn Valley Siltstone represents the late stages of a marine transgression in which the environment of deposition has become progressively deeper marine from the intertidal deposits of the Pacoota Sandatone to the carbonates and deep water clastics of the Horn Valley Siltstone.

Marchioni (Appendix H) has shown that the Horn Valley Siltstone has good source potential and is presently within the zone of oil generation. The Horn Valley is probably the source for the oil encountered in the overlying lower Stairway Sandstone.

PACOOTA SANDSTONE: 252 - 323m (Thickness 71m)
Age - Late Cambrian to Early Ordovician

The upper Pacoota Sandstone consists of sandstone with interbeds of siltstone and shale. The top of the Pacoota Sandstone is selected on an increase in the gamma ray curve and by the first clastic sediments below the basal limestone of the Horn Valley.

The Pacoota Sandstone at Mt. Winter-1 is much thinner than predicted from measured thicknesses in the Cleland Hills area (Wells et al., 1965). The reduced Pacoota section encountered is due to a combination of factors, which are discussed below and in a subsequent section dealing with the Goyder Formation.

The Pacoota Sandstone at Mt. Winter-1 records the transgression which culminated in the overlying Horn Valley Siltstone. The upper part (252 - 281m) represents a series of bar sands and progressively deepening water reflected by the upward increasing glauconitic and fossil content. The lithology is comprised of three coarsening upward cycles, from shale through siltstone to sandstone. The uppermost cycle culminates in the dolomitic limestone at the base of the Horn Valley Siltstone. The sandstone is dominantly light grey, or white when unconsolidated, quartzose, very fine to medium grained but dominantly fine grained, sub angular to rounded, moderately well sorted when cemented but poorly sorted when loose (probably reflecting admixture of grains from the coarsening upward sequence), in part silty, in part with calcareous or siliceous cement, common pyritic cement and aggregates in part, very glauconitic above 263m and moderately fossiliferous with phosphatic shelly fragments (plicate markings), both components decreasing below 263m, generally tight, but with some fair visual porosity.

Minor fluorescence and cut was noted in tight sandstones near the top of the Pacoota Sandstone, although there is no clear log indications of hydrocarbons, and black bituminous material occurs between grains in the sandstone at about 270m. It is possible that most of the shows are caved from the Stairway Sandstone : abundant limestone described from cuttings in the upper part of the Pacoota Sandstone similarly have no log expression, and are probably caved from the Horn Valley Siltstone.

The siltstones are light to medium grey, in part with minor ochreous sandy siltstone below 274m to 280m, slightly argillaceous and in part sandy, firm to moderately well indurated, and non calcareous. The shales are light to medium grey, occasionally dark grey, hard, brittle or fissile, micromicaceous and non calcareous.

A marked colour change occurs between 281m and 283m (corrected depth) with the appearance of ferruginous brown and red brown stained sand grains and pisolitic ironstone. There is no positive evidence for an unconformity, although a slight hiccup is apparent on the dipmeter log between 280 - 282m. The gamma ray log motif is similar to the overlying bar sand signature, although more subdued, and the presence of two carbonate cemented stringers is suggested by the density log. The gamma ray logs below 285m suggest two general fining up cycles overlying an interbedded sandstone and siltstone sequence. Below the ferruginous horizon the section is dominantly sandstone with subordinate siltstone and shale. The sandstones are white to clear when unconsolidated, white to pale pinkish and iron stained when consolidated, occasional yellow grains, minor green and red coloured, fine to very coarse grained, sub angular to well rounded when coarser grained, poorly sorted to moderately well sorted in part, silty in part, non glauconitic, minor calcareous cement, friable but in part well indurated with siliceous or ferruginous clay cement, and with minor very fine to fine grained green or red sandstones with abundant mica, colour mottling. Porosity is probably fair in the friable sandstones but is tight when cemented. No shows were encountered in these sandstones, but the hole was making more than 10 bbls of fresh water per hour while drilling in this section, indicating permeability. The siltstones are medium to dark grey, but becoming more red brown or green with depth. The minor shale is medium to dark grey or green, hard and in part micromicaceous.

The lower part of the section (305 - 324m) may represent intertidal sand flats with the fining upward cycle (305 - 292m) reflecting a transgression. A further transgression is evident in the fining up cycle between 292 - 285m. The calcareous cemented bar sand at 281 - 284m may represent a still stand and a hiatus when carbonate cementation took place subaqueasly and ferruginous oolites, or pellets, were deposited in mildly agitated water, possibly and chamesike or goethite. The proposed depositional hiatus may in part explain the thin Pacoota Sandstone section encountered at Mt. Winter-1.

An alternative hypothesis, to explain the ferruginous layer, is that it marks the top of the Cleland Sandstone. Wells et al. (1965) have noted on the Mount Rennie Sheet area that the contact with the underlying Cleland Sandstone is often marked by a thin bed of pisolitic ironstone, and that this pisolitic zone may represent a break in sedimentation. However, the good log correlation between Mt. Winter-1 and wells of the Mereenie Oil and Gas Field at the top Pacoota and top Goyder levels strongly argues for the correlation adopted above.

LOWER PACOOTA SANDSTONE: 323 - 368m (Thickness 45m)
Age - Late Cambrian

This unit consists predominantly of sandstone with minor shale and siltstone.

The sandstone is clear, white, light tan, occasionally with pink, yellow, and orange staining. It is predominantly very fine to medium grained, occasionally coarse grained, predominantly sub angular to sub rounded with occasional angular fractured quartz grains, poorly sorted and predominantly loose, to in part poorly cemented with silica cement. The very fine to fine grained sandstone is well cemented with silica, slightly calcareous in part, in part slightly glauconitic, micaceous in part, occasionally silty with brown and grey argillaceous matrix. The sandstone has poor to fair visible porosity and no shows. Some permeability is evident from the caliper logs. There was a heavy increase in water influx below about 320m, with the inflow reaching 228 bbl per hour at about 340m, and becoming too high to measure below this depth. The salinity of this water was measured as 1350 ppm NaCl equivalent at 393m.

The siltstones are red brown, green, grey green, argillaceous, micaceous, moderately glauconitic and haematitic. The shales are red brown, orange, micromicaceous, silty in part and rarely pyritic.

This unit is readily correlated in wells across the northern part of the basin (Enclosure 5) as far east as Wallaby-1.

GOYDER FORMATION: 368 - 463m (Thickness 95m)
Age - Late Cambrian

Unlike the Goyder Formation, penetrated by wells in the east of the basin, with its two shoaling upwards sequences of shales and dolomites, at Mt. Winter-1 this formation consists predominantly of sandstone, with minor siltstone and shale.

The sandstone is white, clear, tan, orange and brown. It is predominantly fine to medium grained, sub angular to sub rounded, poor to moderately sorted, in part loose, in part friable to hard, and moderately cemented with silica cement. It is occasionally dolomitic (probably mostly from 368 - 395m from density log), occasionally glauconitic and becomes silty and argillaceous with depth. Visual porosity is generally poor, but is fair in part. There is no permeability shown by the caliper log. The siltstone is red brown, sandy in part, often very micaceous, occasionally slightly calcareous, pyritic in part and well indurated. The shale is red brown, blocky and micaceous.

The Goyder Formation is not mapped in the vicinity of Mt. Winter-1 (Wells et al., 1970), but, because of the absence of recognisable carbonates, may have been included in the Pacoota Sandstone, with which it has some lithological similarity. Wells et al. (1965) remarked on the lithological similarity of the boundary zone between the Goyder Formation and the Pacoota Sandstone in the northeastern part of the Mt. Liebig 1:250,000 sheet area. In this area, the boundary is picked on a change to strongly silicified sandstone of the Lower Pacoota Sandstone. This silification change may be reflected in the increased rate of penetration below about 368m at Mt. Winter-1.

PETERMANN SANDSTONE: 463 - 698m (Thickness 235m)
Age - Late Cambrian

The top of the Petermann Sandstone is marked by a sharp gamma ray break and less well defined breaks on the sonic and neutron/density logs. The Petermann Sandstone has not previously been recognised west of the Gardiner Range (Wells et al., 1965) or Ochre Hill-1.

The Petermann Sandstone is a sequence of predominantly fine grained, micaceous sandstone, with minor siltstones and traces of shale, which lies conformably between the Deception Siltstone below and the Goyder Formation above. From its stratigraphic position, the Petermann Sandstone is thought to be Late Cambrian in age.

The sandstones are white to buff, red-brown to orange-brown, purple, occasionally mottled and very fine to medium grained with occasionally coarse to very coarse loose frosted grains. It is moderately to poorly sorted, sub angular to sub rounded, non calcareous to very slightly calcareous, ferruginous, glauconitic in part, micaceous, moderately firm to hard, with a silty matrix (also suggested by the gamma ray curve), and poor porosity and permeability. The siltstone is red-brown, red-orange, purple-brown, arenaceous, firm to hard, glauconitic in part and grades to very fine grained sandstone. The shale is red to grey-green, blocky to sub fissile, micromicaceous, non calcareous and moderately hard.

Near the base of the Petermann Sandstone, between 691 - 698m, severe washout and lost circulation problems were encountered due to caving sand. The most severe washouts occur opposite the best developed sandstone indicated by the gamma ray log. No returns were received to surface over the interval, but the washout itself and the rapid rate of penetration suggest extremely friable or porous sands were encountered.

DECEPTION SILTSTONE: 698 - 936m (Thickness 238m)
Age - Middle Cambrian

The aptly named Deception Siltstone consists dominantly of sandstone, minor siltstone, and traces of shale.

The sandstone is white, orange, red, brown, fine to medium grained, becoming extremely fine to very fine grained with depth, angular to sub rounded, moderately friable to very hard and poorly to moderately well sorted. It has a silty matrix in part, silica cement, traces of biotite flakes, traces of ferruginous material and is slightly dolomitic in part. Porosity ranges from poor to good, but is generally poor. The siltstones are red to brown, mottled, arenaceous, blocky, hard, dolomitic in part, micromicaceous in part, with traces of glauconite, pyrite and ferruginous material. The shales are dark grey-green to black, blocky to sub fissile and fissile, firm to moderately hard, occasionally dolomitic and bituminous in part.

A minor gas peak of 20 parts per million methane with a trace of ethane was recorded between 911 and 914.5m while air drilling a sandstone in the lower Deception Siltstone. There is no indication of the origin of this gas on the logs, and no porosity or permeability is apparent about the same depth range. Minor bituminous shale was noted from the cuttings over the range 908 - 911m and may be the source of the gas. The remainder of the formation has no source rock potential, consisting essentially of red and brown coloured clastics.

No fossils were found in the Deception Siltstone at Mt. Winter-1, but it is regarded as probably Middle Cambrian in age from its stratigraphical position.

ILLARA FORMATION: 936 - 1249m (Thickness 313m)
Age - Middle Cambrian

This unit consists predominantly of sandstone with minor interbedded siltstone. The top is selected below a dominantly siltstone sequence.

The sandstone is white, orange, red, brown, extremely fine to occasionally medium grained, moderately to poorly sorted, very hard, sub angular to angular and well cemented with silica cement. It has traces of dolomite, glauconite and ferruginous material, it is micaceous in part and has occasional silty matrix. The porosity of the Illara Formation is generally poor in the upper part but becomes better in cuttings below 988m. This downward increase in porosity is reflected in the caliper curve which occasionally indicates mud cake buildup, especially below 1150m. Friable sands accompanied a drillbreak at 1180m, where good porosity was recorded in cuttings, and fair to good porosity was present down to 1231m. The better porosity may reflect a possible coarsening downwards of the sandstones. The interbedded siltstone is dark brown, red orange, very hard, blocky to sub fissile, arenaceous, with traces of glauconite, dolomite and mica. Minor black bituminous material was recorded between 1064 and 1070m.

The Illara Formation lies conformably between the Tempe Formation and the Deception Siltstone, and is considered to be in part a lateral equivalent of the Hugh River Shale by Wells et al. (1970). From its stratigraphic position overlying the Tempe Formation, the Illara Formation is most likely of Middle Cambrian age.

<u>TEMPE FORMATION:</u> <u>1249 - 1412m (Thickness 163m)</u>
<u>Age - Middle Cambrian</u>

The top of the Tempe Formation is selected at a pronounced increase on the gamma ray log below the sandstones of the Illara Sandstone. The lithology of the unit at Mt. Winter-1 bears little resemblance to the lithology described from the type area in the Gardiner Range (Wells et al., 1965, Plate 8). In the Gardiner Range, and also at East Mereenie-4, East Johnny's Creek-1 and Ochre Hill-1, carbonates are present in the sequence. No carbonates were present in the Tempe Formation at Mt. Winter-1.

From the gamma ray curve the Tempe Formation at Mt. Winter-1 is essentially a siltstone-shale sequence, with minor development of sandstone (1306 - 1314m, 1353 - 1354m).

From the gamma ray curve, three units are distinguished:

Unit 3: 1249 - 1314m; The upper part of the unit consists of interbedded red brown, argillaceous to arenaceous, micromicaceous siltstone and grey green, micromicaceous siltstone. The red brown siltstone becomes less abundant with depth and is present in trace amounts only below 1283m. Minor white to pale green, extremely fine grained sandstone, in part glauconitic, dolomitic or cemented by silica, is probably present as sand stringers. Minor pink feldspar occurs within these sands and biotite mica is occasionally present. The siltstone grades shaly below 1283m with light to dark grey, chloritic, fissile to sub fissile, micromicaceous, very hard shale, with occasional conchoidal fracture. The sandstone content increases below 1300m, also shown by the gamma ray curve, and becomes coarser with depth, possibly reflecting an unconformity at 1314m. The sandstones are white to very light grey but becoming more orange with increasing grainsize, generally very fine to fine grained but fine to medium below 1310m, angular to sub rounded, moderately sorted becoming well sorted with depth, with common flakes of mica, lithic fragments and orange feldspar grains. The porosity is poor when cemented by silica but may be better in the lower part when friable. The neutron log suggests 9% porosity may be present in the basal sand, but the caliper log indicates no permeability. No shows were recorded from the section.

Unit 2: 1314 - 1354; The section has a similar gamma ray curve to unit 3 with a basal sandstone. The dipmeter log suggests an unconformity occurs between 1350 and 1360m; above these depths the regional dip is northwest, and below 1360m the regional dip is southwest. Core 2 (Appendix B) was cut in the unit.

The upper part of the unit is composed dominantly of shale, medium to dark grey, fissile, micromicaceous, becoming lighter coloured and silty below 1338m (Core 2) with addition of thin sandstone laminations. The basal sandstones are light grey to brown, very fine to fine, angular to sub angular (? fractured), well sorted, with black grains and orange grains (? feldspar). Clear muscovite mica flakes may be from this sandstone. Poor porosity is evident, probably caused by siliceous cementing. No shows were recorded.

Unit 1: 1354 - 1412m. This unit is poorly represented in cuttings. Gamma ray log analysis and the available cuttings show the unit is dominantly interbedded shale, as in Unit 2, and extremely micaceous sandstone. Below 1400m the shale becomes siltier, very micaceous and becomes reddish brown in colour. There is no clear evidence of an unconformity at 1412m above the Eninta Formation and the units are probably conformable.

Marchioni (Appendix H) has shown that there is no source rock potential in the Tempe Formation at Mt. Winter-1. The formation is post-oil mature on the two reflectance measurements (1.8 - 1.9%) from Core 2 and the incipient fusing of pyrite framboids (Marchioni, Appendix H).

According to Wells et al. (1965), fossils from the Tempe Formation are tentatively dated as late Early Cambrian or early Middle Cambrian. The upper part of the formation in the Parana Hill anticline is dated as early Middle Cambrian (Wells et al., 1970) on the contained shelly fauna. At this locality the lower part is missing, presumably due to onlap over an earlier developed high.

An early Middle Cambrian age is suggested from the microflora recovered from Core 2 (1338.95m) by Owen (Appendix G). Similarly, cuttings from 2377.5 - 2393m, from the upper part of the Tempe Formation in East Mereenie-4, yielded poorly preserved acritarchs with a tentative Middle Cambrian age (Dr. M. Owen, personal communication, 1981).

ENINTA FORMATION: 1412 - 1485m (Thickness 73m)
Age - Early Cambrian

The top of Eninta Formation is marked by the change from overlying white sandstone to grey shales, clearly shown on the gamma ray curve at 1412m. The dipmeter log indicates that the section is part of the post-Proterozoic sequence; the shallow, generally westerly dips in the Tempe Formation continue downward into the Eninta. Below 1485m dips become random. The unit consists of interbedded sandstone and shale.

The sandstones are grey to brown, fine to medium grained, angular to sub rounded, moderately to well sorted, friable, with traces of calcareous or silica cement, minor iron staining and mica, poor porosity and no shows. The shales are grey-brown, to grey-green and becoming reddish below 1420m, blocky to fissile, very micaceous in part and generally firm.

There were no hydrocarbon shows in the unit.

Owen (Appendix G) has suggested a possibly late Early Cambrian age for the unit in Mt. Winter-1. This is the first dating of the Eninta Sandstone on record.

ININDIA BEDS: 1485 - 1683m (Thickness 198m)
Age - Late Proterozoic

The Inindia Beds consists dominantly of sandstone, subordinate shale and siltstone, with minor limestone towards the base.

The top of the formation is marked by a change from shallow westerly dips to random dips below 1485m. The density, sonic and resistivity logs show pronounced changes at the same depth. The base of the unit is marked by a sharp increase in the gamma ray curve at 1684m, indicating the first red shale of the Bitter Springs Formation. This unconformity is also evident as an undulating surface at 1683m on the geodip log.

The sandstone is orange-brown to grey, sometimes strongly iron stained, very fine to coarse grained, occasionally very coarse, sub angular to sub rounded with common pitted and frosted grains about 1500m, poorly sorted to well sorted, glauconitic in part and has traces of silica cement. It has abundant white and minor black mica flakes, traces of chlorite, poor porosity, no shows and occasional grains of 'dead' bituminous material throughout. The glauconite and high mica content of the sandstones gives a higher gamma ray response than expected. The decrease in the gamma ray log values below 1630m may reflect decreasing abundances of mica or glauconite in the sequence. There is a shaly sequence from 1585 - 1658m, which overlies and grades into a dolomitic sandstone, shale and limestone series from 1683 to 1630m. The shale is brownish grey, greenish grey to red brown, micromicaceous, sub fissile to fissile, firm to hard, slightly dolomitic and slightly silty. The siltstone is white to very light grey, slightly calcareous, dolomitic and firm to hard. The limestone is white to very light grey, aphanitic to cryptocrystalline, dolomitic and silty. Minor gypsum is associated with the limy sequence below 1640m.

No shows were recorded through the sections, but black, bituminous material reported from the cuttings may be residual hydrocarbons.

BITTER SPRINGS FORMATION: 1683 - 2650m T.D. (Thickness 967m+)
Age - Late Proterozoic

The top of the Bitter Springs Formation is marked by the first appearance of reddish brown shale and a well defined gamma ray break. Several sub units of the Bitter Springs Formation were encountered at Mt. Winter-1. The uppermost unit consists of 23m of shales and overlies a 20m thick limestone unit. The next unit consists of 33m of silty sandstones and siltstones and overlies the dolomite and evaporite sequences of the Loves Creek and Gillen Members.

The section between 1683 and 1761m is herein separated from the Loves Creek Member below, because it is lithologically distinct, and can be correlated with a very similar section encountered in East Johnny's Creek-1 (Enclosure 5). This section is informally referred to herein as the Johnny's Creek Beds.

JOHNNY'S CREEK BEDS: 1683 - 1761m (Thickness 78m)
Age - Late Proterozoic

The Johnny's Creek Beds have been recognised in East Johnny's Creek-1 and tentatively in Ochre Hill-1 (Enclosure 5), on lithological similarities, and wireline log characteristics. The beds may also be represented in the top 130m of the reference section at Ellery Creek (Wells et al., 1967 Figure 5), and between 1254 to 1343m in Ooraminna-1.

In Mt. Winter-1, three distinct units are apparent in the Johnny's Creek Beds.

The uppermost unit, 1683 - 1707m, consists of shale which is firm, slightly dolomitic, micromicaceous in part, fissile to sub fissile, and slightly silty. The colour is reddish brown, becoming greenish grey with depth. The upper reddish colouration may reflect oxidation at an unconformity.

The unit from 1707 - 1727m consists of dolomitic limestone and dolomite and minor sandstone and shale. The limestone is white to very light grey, aphanatic to cryptocrystalline, dense, silty and dolomitic, grading to dolomite in part. The dolomite is brownish black to greyish black, crypto-crystalline, slightly calcareous, silty, bituminous and dense. The dolomite is present in the top and bottom parts of the unit, ie above 1710 and below 1723m.

The sandstone, which occurs between 1717 and 1722m, is very light grey, fine to medium grained, angular to sub rounded, well sorted with a dolomitic matrix and grades to sandy dolomite. The shales are greenish grey, slightly silty and dolomitic.

The unit from 1727 - 1761m consists of silty sandstones grading to sandy siltstones with traces of shale. The sandstone is very light grey to reddish brown, very fine to fine grained, silty, sub angular to angular, well sorted, severely silicified with quartz overgrowths, firm with poor porosity. Below 1734m there is common black heavy residual oil adhering to grains, common dull yellow pinprick fluorescence, instant yellowish green cloudy cut and a strong petroliferous odour (Sidewall Core at 1747.5 m). However, due to tight formation, no influx of oil to the borehole occurred.

The Johnny's Creek Beds appear to be a consistently petroliferous sequence, with oil shows in Mt. Winter-1, asphaltic sandstone and fluorescence in East Johnnys Creek and fluorescence in Ochre Hill-1. The possible correlative section at Ooraminna-1 contained gas.

LOVES CREEK MEMBER: 1761 - 2111m (Thickness 350m)
Age - Late Proterozoic

The top of the Loves Creek Member is marked by the appearance of light brown dolomites and a marked break on the gamma ray curve and sonic log curves.

The Loves Creek Member consists predominantly of dolomite with minor siltstone and shale beds becoming common below 2008m.

The dolomite is very light brown, pinkish brown, brownish grey, medium olive brown and occasionally mottled. It is aphanitic to cryptocrystalline to microcrystalline, gypsiferous in part, dense and very silty in part grading to dolomitic siltstone. It has common chert in places, traces of bituminous material, traces of quartz infilling fracture porosity and generally very poor porosity, although vuggy porosity is possible. The siltstone is reddish brown, pinkish brown, medium grey, olive brown, blocky to sub fissile and very dolomitic, grading in part to silty dolomite, hard to firm, argillaceous in part and slightly micromicaceous. The shale is brownish grey, sub fissile, very slightly dolomitic and firm to hard. From 1890 - 2011m there are several sections containing massive gypsum (selenite crystals) and other sulphates.

GILLEN MEMBER: 2111 - 2650m T.D. (Thickness 539m+)
Age - Late Proterozoic

The Gillen Member of the Bitter Springs Formation consists of a sequence of interbedded dolomites and shales, with halite, gypsum and minor claystone.

The dolomites are light to dark grey, dark brown, grey-black, white to medium grey, cryptocrystalline to microcrystalline to very finely crystalline becoming micritic with depth. They are silty, have traces of anhydrite in part. The dolomites have occasionally aggregates of selenite containing dead oil or bituminous partings, generally poor porosity and pale yellow mineral fluorescence. Core 3 was cut about 75m below the top of the Gillen Member and had fair to good porosity throughout in vugs and fractures. Yellow green fluorescence with a faint instant yellow cut was observed on some bedding planes and in fractures. The shales are pale grey, dark grey to black, blocky to sub fissile, soft to moderately hard, silty, gypsiferous, very dolomitic, slightly bituminous in part and have possible salt crystal casts in part. The gypsum is very light grey to white, cryptocrystalline to coarsely crystalline (selenite), dense, dolomitic and occasionally slightly pyritic. A large proportion of the gypsum is in the form of selenite, clear, coarsely crystalline, vitreous lustre and occurring as acicular and tabular crystals, as well as aggregates. The claystone is white, kaolinitic, dolomitic, soft and slightly pyritic.

No halite was recovered in the cuttings but the massive salinity increases below 2111m, and the washed-out hole, indicates that a large part of the Gillen lithology is salt.

The shales and claystones can be picked on the gamma ray curve, while the halite and gypsum gives a marked break in the sonic log curve associated with very marked caving or washouts on the caliper logs.

This unit is distinguished from the Loves Creek by the presence of halite and gypsum.

A Late Proterozoic age is suggested by the microflora recovered from Core 3 (2189.80m) by Owen (Appendix G).

4.4 STRUCTURE

Two vintages of seismic data exist over the Mt. Winter prospect. Sixteen kilometres of 1966 single fold data indicate an east-west roll over on trend with the Cleland Hills Anticline to the northwest. A 1981 detail programme of about 80 kilometres confirmed the existence of the broad anticline and provided better detail below the base Cambrian unconformity.

Mt. Winter No. 1 was a Basal Cambrian test at shotpoint 160 on line P81-GE21. Enclosure 6 shows how the synthetic seismogram ties the seismic data. The ties are somewhat unreliable because of the following reasons:-

1. Insufficient check shot control from 369 metres (KB) and 1249 metres (KB);

2. Poor editing of the sonic log within the Deception Siltstone and the Gillen Salt; and

3. Eight degree hole deviation within the Gillen Salt.

The synthetic correlation has been hung on:-

1. the strong troughs, caused by positive acoustic impedance contrasts at 1600 metres (KB) and the Top Loves Creek Dolomite;

2. the peak caused by the negative reflection coefficient above the Tempe Formation; and

3. the seismic signature of the Horn Valley Siltstone, Pacoota Sandstone and Goyder Formation.

There is a fifteen millisecond mistie between the synthetic and the seismic line at Top Goyder Formation. This is attributed to insufficient check shot control for the shallow part of the hole.

A lag of seventy milliseconds was required to tie the synthetic to the seismic line. This is approximately the correction that was added by Velocity Data Pty. Limited, to adjust the check shot times to the seismic datum of 800 metres (a.s.l.). However the total static shift applied at shotpoint 160 by the processors was only -2 milliseconds. This arose because the elevation static was compensated for by weathering statics. To avoid any confusion in future, it has been recommended that all synthetics be tied to ground level and not seismic datum.

The prognosed seismic picks at the Mt. Winter No. 1 location proved to be remarkably accurate. The Base Pacoota Sandstone, Top Tempe Formation, Basal Cambrian Unconformity and Top Bitter Springs Salt were identified correctly. The major surprise, and bonus, was the discovery of Stairway Sandstone, Horn Valley Siltstone and, considerably thinner than expected, Pacoota Sandstone.

Within the Proterozoic, the Johnny's Creek Beds (orange pick) and the Loves Creek Dolomite can be identified with confidence. The Eninta Formation is cautiously identified due to the poor character match of the synthetic with the seismic data. The yellow pick at 1600 metres (KB) correlates with a trough on the synthetic and can be carried with confidence on the seismic data. However, it does not coincide with a recognised formation change on logs.

The Horn Valley Siltstone, Pacoota Sandstone, Goyder Formation, Basal Cambrian Unconformity, Top Loves Creek Dolomite and Top Gillen Salt can be carried with a fair to high degree of confidence.

Mt. Winter No. 1 lies to the south of an anticlinal hinge line which extends from the Cleland Hills in the west, through the Mereenie Field area to the James Ranges structures, then eastward through the Mt. Burrell anticlinorium to the Hale River Metamorphic 'inlier'. North of this line, the Amadeus Basin is considerably downwarped with thick Pertnjara Group infill, gentle folding and generally conformable contacts between formations, except where affected by diapirism. In contrast, the area to the south of this belt is characterised by faulting, major unconformities and appreciable post-depositional folding. Over this belt, the Mereenie, Ochre Hill, Johnny's Creek, Parana Hill and Petermann Creek anticlines show Pertaoorrta Group sediments resting with marked angular unconformity on truncated Late Proterozoic units, indicating considerable uplift and erosion prior to deposition of the Cambrian sequence. Along the hinge line, varying amounts of Eninta Formation and Tempe Formation are missing due to onlap, particularly where the more resistant Bitter Springs Formation had formed highs in the Precambrian erosion surface, producing typical 'bald headed' anticlinal features. The Mt. Winter structure proved to be 'bald headed' with the Eninta Formation overlying the basal Inindia Beds.

Seismic data show that the Mt. Winter Anticline is a fault bounded feature at Basal Cambrian level. At least two episodes of movement can be documented. Thinning of the Johnny's Creek Beds, truncation within the Inindia Beds and at the base of the Eninta Formation show that movement occurred between the deposition of the Loves Creek Member and the Eninta.

Later structuring is assumed to have occurred during the Alice Springs Orogeny but thinning within the Cambrian sequences and in the Horn Valley Siltstone has also been recognised. The cause of this thinning is not known as yet, but may be due in part to Bitter Springs Formation (Gillen Member) salt tectonics.

4.5 RELEVANCE TO THE OCCURRENCE OF HYDROCARBONS

Two significant oil shows were encountered in Mt. Winter No. 1. The first, in the basal Stairway Sandstone, was unexpected because, from field mapping, the Stairway Sandstone was not prognosed at the well site. The second, in the Late Proterozoic Johnny's Creek Beds, has regional significance in the search for hydrocarbons south and west of the main subcrop areas of the Larapinta Group. Several minor shows of cuttings gas and "dead oil" were also encountered and are listed in Table 2. These minor shows will not be considered further.

The shallower of the two shows, in the basal Stairway Sandstone, was penetrated between 150 and 190 metres (KB). According to the daily geological report, the first oil in mud (2%) occurred at 165 metres (KB) and decreased to 1% at 166 metres. This oil sample had bright blue white fluorescence and a moderate to fast streaming yellow cut with a brown residual stain. One percent patchy bright gold fluorescence with moderate to fast streaming yellow cut and a poor brown residual ring were noted at 165 metres, decreasing to 2 - 3 chips at 166 metres. The first fluorescence occurred at about 150 metres (KB), but was very rare (eg. less than 5 chips per sample above 162 metres).

A mud sample from the relevant depth was collected and sent to the Australian Mineral Development Laboratories (AMDEL). AMDEL reported (29.1.82) that all the mud samples received from the Mt. Winter No. 1 well from the interval reputed to contain 2% oil, and below this, did not contain oil. However, there was a trace of drilling mud additive present. The drilling fluid at Mt. Winter No. 1 at the time the oil was reported was a water based mud with gel, soda ash, caustic and bicarb. No diesel or oil had been purposefully added to the mud system.

The 13-3/8" casing was run to 166 metres, according to the drilling report of 10.12.81, however, Schlumberger reported the shoe at 163 metres (logs). The well site geologist reported traces of bright yellow fluorescence on drilling out of the shoe from 166 - 168 metres (drillers depth). Fluorescence and cut persisted below the casing, except through the better permeability sand unit (166 - 172 metres) and below 180 metres. Core 1 (189.7 - 191.3 metres drillers depth) had rare oil bleeding from pinpoint pores throughout the core, brown oil staining and patchy fluorescence (Appendix B). Core and log correlation suggest the core was cut corresponding approximately to log depths 183 - 186 metres. Analyses of the oil shows by AMDEL (Appendix C) indicate that the oil is migrated : the source rock is probably the underlying Horn Valley Siltstone.

Below the 13-3/8" casing Mt. Winter No. 1 was air drilled with no gas shows on either the hot wire detector or flowed to surface. Thus below the 13-3/8" casing the well is considered to have been tested adequately.

In addition, while air drilling below the 13-3/8" casing shoe, the hole began to make water with salinity range of 790 - 8250 ppm NaCl equivalent. By 428.5 metres the influx of water was so great as to preclude the continuation of air/mist drilling, so the drilling medium was changed to aerated water. The presence of these large volumes of meteoric water indicates that the structure is flushed, and the hydrocarbon shows observed in Mt. Winter No. 1 have been interpreted to represent residual oil retained in impermeable lithologies. This interpretation is substantiated by the results of core analyses from Core 1 at Mt. Winter No. 1. These analyses (Appendix C) show that hydrocarbons are only retained in the lowest permeability sandstones and are not present in the better reservoir quality sandstones.

However, the question of possible free hydrocarbons at 165 - 166 metres (drillers depth), which may or may not be behind two sets of casing (based on the loggers measurement to depth of casing shoe) and which was not detected by either the electric or density-neutron logs (run below 163 metres loggers depth) is unresolved.

Possibly the most significant of the two oil shows in Mt. Winter No. 1 occurred in the Late Proterozoic Johnny's Creek Beds. The lithology from 1727 - 1761 metres consists of poor porosity, silty sandstones grading to sandy siltstones with traces of shale. Below 1734 metres there is common black heavy residual oil adhering to grains, common dull yellow pinprick fluorescence, instant yellowish green cloudy cut and a strong petroliferous odour (Sidewall Core at 1747.5 metres). The chromatograph also recorded gas containing up to C_6 hydrocarbons. However, due to tight formation, no influx of oil to the borehole occurred.

TABLE 2. SUMMARY OF HYDROCARBON SHOWS IN MT. WINTER-1

DEPTH	FORMATION	SHOW TYPE & RATING	DESCRIPTION OF SHOW	LOG RESPONSE	GEOCHEMISTRY	REMARKS
152 - 158 m	Stairway	trace oil show	brown residual oil stain, patchy bright gold fluorescence, slow to fast streaming yellow cut, yellow fluorescence residual ring.	nil		Oil in tight sandstones
158 - 165 m	Stairway	poor oil show	as above	"		" " " "
165 - 168 m	Stairway	trace oil show	brown oil stain, trace bright yellow patchy fluorescence, poor yellow slow diffuse cut, faint yellow fluorescence ring.	"		" " " ", air drilled
177 - 180 m	Stairway	trace oil show	very patchy gold fluorescence, occasional brown residual oil stain, very slow diffuse weak yellow cut, very faint residual yellow fluorescence ring.	"		Air drilled
180 - 183 m	Stairway	trace oil show	Occasional brown oil stain, bright yellow patchy fluorescence, slow diffuse cut.			
183 - 186 m	Stairway	poor oil show	Dull yellow to bright yellow fluorescence, fast streaming cut, yellow residual ring.	"		" "
186 - 189 m	Stairway	poor oil show	Occasional brown oil stain, bright yellow gold fluorescence, fast yellow streaming cut and yellow residual ring.	"		" "
189 - 191 m	Stairway	fair oil show	Brown oil stain, patchy greenish blue white fluorescence and yellow/gold fluorescence, fast streaming crush cut, bright yellow residual fluorescence ring, light brown residual oil ring.	"	Migrated oil in tight sandstone in Core 1.	
191 - 192 m	Horn Valley	poor oil show	as above with greenish yellow fluorescence and very slow diffuse cut.	"		" "
192 - 195 m	Horn Valley	poor oil show	yellow-green fluorescence, very slow diffuse cut, poor residual fluorescence ring.	"		" "
195 - 198 m	Horn Valley	trace oil show	gold fluorescence, very poor slow cut.	"	Approx TOC 5.4 wt %	" "
244 - 247 m	Horn Valley	trace oil show	dull yellow fluorescence, very faint crush cut, faint fluorescence ring.	"	Mean max. reflectivity 0.88% on bitumen.	" "
247 m	Horn Valley	Chromatograph	50 ppm C1, 10 ppm C2, 3 ppm C3, trace C4	"		
265 - 274 m	Pacoota	trace oil show	Occasional brown oil stain, yellow/gold fluorescence, fast streaming yellow cut, yellow fluorescence ring and slight residual oil ring, black bituminous material between grains.	"		Possible cavings, air drilled
326 m	Lower Pacoota	Chromatograph	10 ppm C1, 3 ppm C2	"		
913 m	Deception	Chromatograph	20 ppm C1	"		Air drilled
1064 - 1070 m	Illara	Residual oil show	traces of black bituminous material	"		" "
1664 - 1679 m	Inindia Beds	oil show	traces of black grains of dead hydrocarbon	"		" "
1701 - 1707 m	Johnnys Creek Beds	oil show	Common black residual hydrocarbon	"		" "
1704 - 1722 m	" "	Chromatograph	Up to 35 ppm C1	"		" "
1734 - 1737 m	" "	trace oil show	trace spotty yellow-green fluorescence, instant weak streaming yellow cut.	Density/neutron crossover		Tight sand, drilled with air
1737 - 1747 m	" "	Chromatograph	To 2000 ppm C1, 500 ppm C2, 150 ppm C3, 110 ppm C4 and C5	Density/neutron		Chromatograph broken
1740 - 1750 m	" "	Poor - fair oil show	Strong petroliferous odour, common black heavy residual oil adhering to grains, common dull yellow fluorescence, instant yellowish-green cut.	Density/neutron		Tight sand, air drilled

1737 - 1798 m	Johnnys Creek-Loves Creek	Hot wire	Up to 55 units methane	Density/neutron		Tight sand/dolomite, air drilled
1893 - 1911 m	Loves Creek	Residual oil show	Rare traces of dead oil	nil		
1917 - 1939 m	" "	" " "	Traces of residual black hydrocarbons	"		
1942 - 1948 m	" "	" " "	" " " " "	"		
1990 m	" "	Possible oil show	Common pale yellow fluorescence	"		Possibly mineral fluorescence
2015 m	" "	Trip gas	30.4 units	"		
2067 m	" "	Connection gas	10.4 units	"		Air/mist drilled
2106 - 2109 m	" "	Residual oil show	Traces residual black hydrocarbons	"		" " "
2112 - 2115 m	Gillen	" " "	" " " "	Washed-out hole		" " "
2155 - 2158 m	"	" " "	Occasional dead oil, bituminous in part	"		" " "
2179 - 2185 m	"	" " "	" " " " " "	"		" " "
2185 m	"	Possible oil show	Faint yellow fluorescence	"		Possibly mineral fluorescence
2185 - 2650 m	"	Residual oil show	Occasional traces of bituminous material	"		Air/mist drilled
2186.5 - 2195.6 m	"	Weak oil show	Fluorescence and cut in Core 3	"		
2195 m	"	Trip gas	328 units	"		Flare: 6 m 2½ minutes
2207 m	"	Connection gas	18.5 units	"		Air/mist drilled
2301 m	"	Connection gas	4.8 units	"		" " "
2313 m	"	Connection gas	11 units	"		" " "
2408 - 2454 m	"	Chromatograph	to 165 ppm C1, 60 ppm C2, 10 ppm C3, 20 ppm C4	"		Mud drilled Chromatograph working
2505 - 2518 m	"	Chromatograph	to 15 ppm C1	"		" " " "
2542 m	"	Chromatograph	10 ppm C1	Not logged		" " " "

The Johnny's Creek Beds appear to be a consistently petroliferous sequence, with oil shows in Mt. Winter No. 1, asphaltic sandstone and fluorescence in East Johnny's Creek and fluorescence in Ochre Hill No. 1. The hydrocarbon potential of the sequence must be rated as good, with the search for better porosity development a high priority.

4.6 POROSITY, PERMEABILITY AND FORMATION FLUIDS

Porosity was determined while drilling by visual examination of lagged cutting samples. However, the extremely fine grain size of the cuttings obtained during air drilling operations, ie. the majority of the hole, made visual porosity determination difficult. Consequently, porosity and permeability estimates have been determined primarily from logs, supplemented by core and sidewall core data. Formation fluids were sampled regularly from the blooie line while air drilling or misting and analysed for NaCl content.

The basal Stairway Sandstone has predominantly very poor to poor visual porosity when consolidated, but probably has good porosity when coarser grained and friable. Porosity up to 11% was measured in Core 1, but low permeabilities were recorded in the best porosity sands (Appendix C). It is obvious from even a cursory inspection of the core that, while porosity is present in the burrow infils, the frequent shale/siltstone laminae interwoven throughout has severely downgraded the permeability. Low permeability is also suggested by the caliper log throughout the sand body in which Core 1 was taken. Better permeability is indicated in the overlying sand unit, but no shows were recorded, suggesting flushing.

The Upper Pacoota Sandstone is generally tight, but with some fair visual porosity. The hole was making water below 285 metres while air drilling, indicating permeability. Similarly, the Lower Pacoota Sandstone has poor to fair visible porosity. Some permeability is evident from the caliper logs. There was a heavy increase in water influx below about 320 metres, with the inflow reaching 228 bbl per hour at about 340 metres, and becoming too high to measure below this depth. The salinity of this water was measured as 1350 ppm NaCl equivalent at 393 metres.

Visual porosity in the Goyder Formation is generally poor, but is fair in part. There is no permeability shown by the caliper log. The Petermann Sandstone also is generally tight, but near the base, between 691 - 698 metres, severe washout and lost circulation problems were encountered due to caving sand. The most severe washouts occur opposite the best developed sandstone indicated by the gamma ray log. No returns were received to surface over the interval, but the washout itself and the rapid rate of penetration suggest extremely friable or porous sands were encountered.

Poor to good porosity is apparent in the Deception Siltstone, but is generally tight. A minor gas peak of 20 parts per million methane with a trace of ethane was recorded between 911 and 914.5 metres while air drilling a sandstone in the lower Deception Siltstone. There is no indication of the origin of this gas on the logs, and no porosity or permeability is apparent about the same depth range. A water sample taken at about 722 metres had 2500 ppm of NaCl.

The porosity of the Illara Formation is generally poor in the upper part but becomes better in cuttings below 988 metres. This downward increase in porosity is reflected in the caliper curve which occasionally indicates mud cake buildup, especially below 1150 metres. Friable sands accompanied a drillbreak at 1180 metres, where good porosity was recorded in cuttings, and fair to good porosity was present down to 1231 metres. The better porosity may reflect a possible coarsening downwards of the sandstones. Salinity varied between 2500 and 3000 ppm NaCl throughout the sequence.

In the Tempe Formation porosity is poor in the minor sandstone when cemented by silica, but may be better in the lower part where the sandstones are friable. The neutron log suggests 9% porosity may be present in the basal sand, but the caliper log indicates no permeability. Fluids in the upper part of the Tempe Formation had a maximum NaCl content of 3100 ppm. No further water samples were collected below the 9-5/8" casing (1296 metres (KB)) until about 2076 metres.

The Eninta Sandstone and Inindia Beds appear to be tight throughout but may have some minor porosity. Sandstones within the Johnny's Creek Beds are severely silicified with quartz overgrowths reducing porosity, and abundant silty matrix.

The predominantly dolomitic and evaporitic Bitter Springs Formation is generally tight, although there is evidence from the cuttings of possible vuggy porosity and fractures. Core 3, cut in the Gillen Member, had fair to good porosity throughout in vugs and fractures. Salinities measured in the lower part of the Loves Creek Member ranged from 14190 ppm NaCl to 15015 ppm NaCl equivalent. In the evaporitic Gillen Member, salinity ranged from 11798 ppm NaCl equivalent at the top of the unit to 48675 ppm, probably reflecting leaching of halite. Because of the encountered salt sequence, the drill medium was changed to mud at 2344 metres and salt was added from about 2454 metres to contain possible mobile salt and restrict leaching.

4.7 CONTRIBUTION TO GEOLOGICAL CONCEPTS

Although Mt. Winter No. 1 did not discover economic reserves of hydrocarbons, it provided an invaluable data point in a previously undrilled portion of the Amadeus Basin.

Mt. Winter No. 1 showed that good petroleum source facies persists in the Horn Valley Siltstone, considerably further west of the Mereenie Oil and Gas Field and demonstrated the seal potential of the Middle Stairway Sandstone siltstone and shale at shallow depth. The well further demonstrated the hydrocarbon potential of the Late Proterozoic section and downgraded the source rock potential of the Tempe Formation.

The sedimentary succession penetrated by Mt. Winter No. 1 casts doubt on the accuracy of field mapping of the Larapinta-Pertarroota Group sequence in the Cleland Hills and Watson Range area. Neither the Stairway Sandstone nor the Horn Valley Siltstone were expected to occur at the well location: the well was prognosed to intersect the Pacoota Sandstone immediately below surficial deposits. This prediction was based on the basal Pacoota reflector carried from Northwest Mereenie No. 1 and isopach data derived from measured sections in the Cleland Hills (Wells et al., 1965). While the seismic tie proved relatively accurate, the thicknesses and formations identified in the measured sections proved incorrect. The inaccuracy of the outcrop mapping was further demonstrated by the presence of the Goyder Formation in an area in which it was considered to have pinched out.

A newly recognised sequence at the top of the Bitter Springs Formation has been informally named and referred to as the Johnny's Creek Beds. This section, between 1683 and 1751 metres, is separated from the Loves Creek Member below, because it is lithologically distinct, and can be correlated with a very similar section encountered in East Johnny's Creek No. 1 and tentatively in Ochre Hill No. 1 (Enclosure 5). The beds may also be represented in the top 130 metres of the reference section at Ellery Creek (Wells et al., 1967, Figure 5), and between 1254 to 1343 metres in Ooraminna No. 1.

Significant advances in the biostratigraphy of the Cambrian and Late Proterozoic sequence have been made by the discovery of identifiable microfossils (acritarchs) in rocks of this age (Owen, Appendix G).

An early Middle Cambrian age for the Tempe Formation is suggested from the microflora recovered from Core 2 (1338.95 metres) by Owen. A possibly late Early Cambrian age is suggested for the Eninta Sandstone in Mt. Winter No. 1, which is the first dating of the Eninta Sandstone on record. A Late Proterozoic age for the Gillen Member is confirmed by the microflora recovered from Core 3 (2189.80 metres).

The structural style prognosed for the Mt. Winter area proved closely comparable to that encountered except for the absence of the Pertatataka Formation or equivalents(eg. Winnall Beds). The structure proved to be 'bald headed' with the Eninta Formation overlying the basal Inindia Beds. Seismic data show that the Mt. Winter Anticline is a fault bounded feature at Basal Cambrian level. At least two episodes of movement can be documented: Thinning of the Johnny's Creek Beds, truncation within the Inindia Beds and at the base of the Eninta Formation show that movement occurred between the deposition of the Loves Creek Member and the Eninta Formation.

Later structuring is assumed to have occurred during the Alice Springs Orogeny, but thinning within the Cambrian sequences and in the Horn Valley Siltstone has also been recognised. The cause of this thinning is not known as yet, but may be due in part to Bitter Springs Formation (Gillen Member) salt tectonics.

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APPENDICES

NORTHERN TERRITORY
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