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DEPARTMENT OF MINES
SOUTH AUSTRALIA

GIDGEALPA GAS FIELD - SOUTH AUSTRALIA

A CASE HISTORY

by

H. Wopfner *)

ABSTRACT

Extensive oil exploration work carried out by Delhi Australian Petroleum Ltd. and Santos Ltd. in the central portion of the Great Australian Artesian Basin since 1957 lead to the discovery of the Gidgealpa Gas Field in north-easternmost South Australia late in 1963.

Exploration work responsible for the discovery of the Gidgealpa Field consisted of geological surface investigations, extensive airborne magnetometer and reflection and refraction seismograph surveys. Eight dry holes had been drilled prior to the discovery of the field.

Prior to the commencement of this exploration programme virtually nothing was known about the subsurface geology of those parts of the Great Australian Artesian Basin below the Mesozoic artesian aquifer. Zealous exploration progressively estabilished the basic data which ultimately lead to success.

Five gas producing wells have been completed with a total flow capacity of 62.5 MMCFD through ½ inch choke.

INTRODUCTION

The Gidgealpa Gas Field, discovered in late 1963 is the only occurrence of hydrocarbons of potential commercial value found so far in the state of South Australia. The field is situated in the far north-east corner of South Australia, within some of the most arid parts of the Australian Continent. Average rainfall is less than 5 inches (182 mm.) and summer shade-temperatures commonly reach as high as 120°F (48.8°C). The country is extremely flat and extensively covered by north-

*) Supervising Geologist, Petroleum Division, S.Aust. Dept. of Mines.

trending, linear, desert dunes, interspersed with flood flats of Coopers Creek (figure 1). Generally, Coopers Creek flows water between April and July but is dry for the remaining parts of the year when intermittent water holes along its course furnish the only surface supply of fresh water.

Geologically, the Gidgealpa Gas Field is situated within the western central portion of the Great Australian Artesian Basin. Active exploration work in this basin, previously condemned by several experts, for lack of surface structure and other reasons, dates back to 1956 - 1957 when SANTOS geologists, recognised and mapped major surface structures in the western and central portion of the Great Australian Artesian Basin. (Wopfner, 1958; Sprigg, 1958; Wopfner, 1960). Credit must also be given to the late Professor A.I. Levorsen, who in his capacity as consultant to SANTOS Ltd. encouraged this company in its early exploration efforts in the Great Australian Artesian Basin.

In 1958 an agreement was reached between SANTOS Ltd. and Delhi Taylor Oil Corporation of Dallas, Texas to jointly explore the large lease areas held by SANTOS Ltd., comprising approximately 176,650 square miles in South Australia, (O.E.L. 20 and 21) and about 67,600 square miles in adjoining parts of Queensland (66P and 67P) (Fig. 2). Delhi Australian Petroleum Ltd., at that stage a fully owned subsidiary of Delhi Taylor Oil Corporation, was appointed operator for the Delhi-Santos Group.

Initial seismic work carried out by a crew of the S.A. Department of Mines, was conducted in 1958 to confirm certain surface structures at depth. In 1959 the Innamincka Dome, a large surface structure discovered by Santos Geologists in 1957 north of Coopers Creek, (Fig. 3) was selected for the first deep test (DSS Innamincka No. 1).

During the early stages of this drilling programme the Delhi - Santos Group was joined by the Frome - Broken Hill Group of Companies. However, Frome - Broken Hill withdrew from the venture after the completion of the second test well (DPS Betoota No. 1).

When Delhi - Santos commenced their drilling programme in 1959, the geological succession below the main artesian aquifer (Hooga Sandstone) was virtually unknown. Realising this one will appreciate the challenging task these companies were faced with. Prior to the discovery of commercial quantities of gas in Gidgealpa No. 2, Delhi-Santos drilled eight dry holes, amounting to a total footage of 77,196 feet. The new information obtained from these wells, however, tremendously improved the understanding of the geological history of this portion of the Great Australian Artesian Basin and was instrumental in the discovery of the Gidgealpa Field.

REGIONAL GEOLOGY

The Great Australian Artesian Basin is essentially a Mesozoic, intracratonic basin which originated by large scale epeirogenic downwarp in early to middle Jurassic time. It is the largest geological unit of the Australian continent and its sediments cover an area of approximately 600,000 square miles.

The eastern and south-eastern margins of the Great Artesian Basin are formed by the Palaeozoic Tasman Geosynclinal Zone which occupies the entire easternmost rim of the Australian continent. The southern, western and north-western boundaries of the Great Artesian Basin are delineated by outcrops of the West Australian Shield (Gawler Platform), various dismembered basement blocks (nesocratons) and of Proterozoic (Adelaidean) to Lower Palaeozoic sedimentary basins, either peripheral to the shield or wedged between the nesocratons (see figure 2).

As these older sedimentary basins extend under the western and central portions of the Great Artesian Basin (including the Gidgealpa area) it will be essential to briefly discuss their history.

The Adelaide Geosyncline and the Officer Basin are situated along the eastern and northern periphery of the West Australian Shield (see figure 2) Sedimentation in these basins commenced in Adelaidean (Upper Proterozoic) time and continued intermittently into the early Palaeozoic. Thick developments of lower and Middle Cambrian sediments are known from the Adelaide Geosyncline, including several thousand feet of Lower Cambrian carbonates and reef-deposits (Dalgarno 1964). Sedimentation may have extended into the Ordovician but hitherto fossil evidence is lacking. Virtually nothing is known about the deeper parts of the Officer Basin. So far no Cambrian sediments have been found but transgressive Ordovician sandstones are exposed along the north-eastern margin of that basin. Field evidence and latest radiometric age determinations suggest final deformation of these basins by orogenic movements in middle Ordovician to early Silurian time. Only the southern portion of the Adelaide Geosyncline was affected by regional metamorphism.

The Amadeus Trough, the Georgina Basin and the sedimentary complex along the Darling River between Broken Hill and Bourke (see map fig. 2) contain unmetamorphosed sediments ranging from Upper Proterozoic to Upper Devonian. These sedimentary basins are separated from the previously discussed basins by various basement blocks as shown in figure 2. Sedimentation commenced in the areas closest to shield and from there spread eastward and north-eastward, particularly in Cambrian time. Orogenic movements in late Ordovician to Silurian time temporarily interrupted deposition in these basins. Sedimentation recommenced in the Devonian but was finally terminated by fold-movements in very late Devonian time.

Information obtained from oil-exploration wells shows, that large portions of the central Great Artesian Basin are underlain by folded sediments, comparable in age and lithology with the Lower Palaeozoic strata exposed in the Amadeus Trough, the Georgina Basin and the Darling area, suggesting that these basins are exposed portions of a large and extensive Lower Palaeozoic sedimentary belt, extending from the Amadeus Trough to western New South Wales where it merged with the Tasman Geosyncline.

Within large portions of the western and central Great Artesian Basin the folded, Lower Palaeozoic rocks are unconformably overlain by strata of Permo-Carboniferous, Permian and Lower Triassic age. The sediments accumulated during these time intervals were deposited in intracratonic basins and according to their present distribution several Permian sub-basins and Permian troughs have been identified (Wopfner, 1964, Freytag, 1965). The Gidgealpa structure is contained within the Strzelecki Permian sub-basin, whose approximate outlines are shown on figure 3.

The sedimentary cycle of the Great Artesian Basin proper, commenced in early to middle Jurassic time with the deposition of lacustrine, dominantly arenaceous sediments. The stratigraphic units recognised in the central portions of the Great Artesian Basin are referred to (in ascending order) as Hutton Sandstone equivalent, Walloon Formation equivalent and Hooga Sandstone. Only equivalents of the Hooga Sandstone occur in outcrop along the southern and western basin margin. The Hutton and Hooga Sandstones carry large volumes of fresh artesian water, the Hooga Sandstone being the most extensively developed artesian aquifer of the Great Artesian Basin.

The Jurassic arenite-sequence is followed by the Lower Cretaceous marine sequence consisting of Transition Beds, Roma Formation and Tambo Formation. These formations are overlain by the Upper Cretaceous Winton Formation which forms a transition from marine sediments at its base to lacustrine deposits at its top. The Winton Formation is the youngest sedimentary sequence reaching significant thickness and distribution, although sporadic fluviatile, lacustrine and terrestrial deposits were laid down intermittently throughout the Upper Cretaceous and the Tertiary.

Regional epeirogenic movements in Mid Tertiary time caused the formation of large, dome like surface structures. Limb dip generally does not exceed 5° but steeper dips, up to 25° are present (Wopfner, 1960). In marginal areas where the Mesozoic sediments have been faulted against old Proterozoic highs, the Mesozoic and Lower Tertiary sediments are steeply to vertically drag-folded along the fault-lines.

The stratigraphic sequence as observed in the deeper portions of the Great Artesian Basin is shown in Table I.

SEISMIC INVESTIGATIONS

First experimental seismograph surveys in the central Great Artesian Basin were carried out by the Bureau of Mineral Resources in 1957.

Regional seismic surveys undertaken by the South Australian Department of Mines on behalf of Delhi-Santos in 1958-59, established three major reflecting horizons, designated "C", "P", and "Z".

The "C" - Seismic horizon is a strong, persistent event which corresponds to the Transition Beds of the Lower Cretaceous sequence. It has been mapped since over the whole South Australian portion of the Great Artesian Basin and in adjoining parts of Queensland and New South Wales. (see Figure 3).

AGE	ROCK UNIT	LITHOLOGY
QUATERNARY	-	gravel, silt and aeolian sand
PLIOCENE	Etadunna Formation	white marly dolomite and dolomitic clay.
U N C O N F O R M I T Y		
Miocene	Silcrete Duricrust / no deposition	fossil soil profile, consisting of bleached kaolinitic zone capped by dense quartz-silcrete.
Eocene	unnamed	coarse, freshwater sands, grey to yellow, lignitic clays, highly polished conglomerate at base
D I S C O N F O R M I T Y		
? Turonian	Mt. Howie Sandstone	white, torrentially bedded sandstone
D I S C O N F O R M I T Y		
CRETACEOUS	Winton Formation	greenish grey siltstone with interbedded green salt and pepper sands, lenticular limestone and bands of lignitic coal. Marine at base becoming brackish towards top.
	Tambo Formation	bluish grey, soft marine shale with lenses of limestone.
	Toolebuc Member	grey limestone and glauconitic sand
	Roma Formation	dark bluish grey marine shale, soft, with concretionary limestones.
	Transition Beds	fine grained calcareous sands with interbedded siltstone and shale, marine.
	Hooray Sandstone	white, medium to coarse grained, freshwater sandstone
	Walloon Formation equivalent	dark brown, carbonaceous, silty shale with interbeds of fine to medium grained, kaolinitic sandstone
	Hutton Sandstone equivalent	light grey, medium to very coarse grained, kaolinitic sandstone with some shale interbeds.
	No deposition	
D I S C O N F O R M I T Y O R S L I G H T U N C O N F O R M I T Y		
	unnamed	grey to white, fine grained sandstone, some grey shale
	No deposition	
	unnamed	light grey fine grained sandstone and greenish grey dolomitic siltstone
Lower	unnamed	light grey, fine to very coarse grained sandstone; dark grey, carbonaceous shale and coal seams.
	unnamed	conglomerate and sedimentary breccia in black or dark grey silty matrix and carbonaceous shale interbeds.
CARBONIFEROUS		
M A J O R U N C O N F O R M I T Y		
DEVONIAN	"Innamincka Red Beds"	maroon and green, hard silty, micaceous shale with interbeds of white and tan, fine to medium grained, calcareous sandstone.
SILURIAN	No deposition	
ORDOVICIAN	unnamed	dark grey, pyritic, hard indurated shale. (Dullingari) dark grey, fine to medium grained, quartzitic sandstone. (Pandieburra).
Cambrian	unnamed	grey, dense limestone; cream, vuggy dolomite; grey green, tuffaceous shale and agglomerate. Gidgealpa
?Proterozoic	unnamed	red to brown tuff, welded tuff and red trachyte.

TABLE I

Stratigraphy of central portion of Great Artesian Basin (north-easternmost South Australia). Dashed lines between rock-units denote uncertain position of time-boundary.

The "P" - seismic horizon is thought to originate from low-velocity layers, probably coal seams, within the top of the Permian whilst the "Z" - seismic horizon originates at the Pre-Permian unconformity.

Good to fair reflections from below the "Z" horizon have been obtained in some areas but are generally not persistent.

Since commencement of seismic exploration work, total survey time spent within the central Great Artesian Basin amounted to some 70 crew months.

EARLY EXPLORATION DRILLING

1959 - 1963

The first drilling location selected by Delhi - Santos was an on-structure test of Innamincka Dome (figure 3). Delhi-Frome-Santos Innamincka No. 1 was spudded in April, 1959, and drilled to a total depth of 12,637 feet. The thick Mesozoic sequence was found to lie on thin Permian sediments which in turn rested unconformably on steeply dipping red-beds of probable Devonian age. Small shows of gas were encountered in the Jurassic and the Permian. Although no oil or gas of commercial importance was found, interesting and important geological information was obtained from this first deep test.

At the same time, additional seismic work was carried out over the Betoota, Curalie and Morney domes, and a second test site was chosen at Betoota Dome (fig. 3). Delhi - Frome - Santos Betoota No. 1 was drilled to a total depth of 9,824 feet and bottomed in steeply dipping, slightly metamorphosed conglomerate of unknown age. No significant hydro-carbon accumulations were encountered.

The tests at Innamincka and Betoota showed that these surface structures were bald headed. Subsequent exploration work was therefore directed towards the location of buried structures as it was hoped that a more complete Palaeozoic sequence would be preserved over the top of such structures. With this aim in mind extensive seismic exploration work and aeromagnetic surveys were conducted during the remainder of 1960 and through 1961.

From the result of these investigations a site was chosen approximately 40 miles south of Innamincka, where a large sub-surface structure (without surface expression) had been located. Delhi-Santos Dullingari No. 1 well was subsequently drilled to test this structure (see figure 3). Dullingari No. 1 was the first well to encounter a thick Permian sequence including black shale of probably marine origin. At 9,050 ft. i.e. below the unconformity, the well entered dark, slightly dolomitic shale of Lower Ordovician age. Again no significant amounts of hydro-carbons were encountered.

Delhi-Santos Orientos No. 1 was designed to test a structure similar to Dullingari and nearly identical results were obtained.

The importance of Dullingari No. 1 and Orientos No. 1 was in the discovery of thick Permian strata showing marine affinities and of definite marine sediments of Ordovician age.

Delhi - Santos Marryilee No. 1 drilled some 60 miles south of Orientos encountered a Mesozoic section and bottomed in Proterozoic quartzites at 4247 feet. No Palaeozoic sediments were encountered.

The next two wells, Delhi - Santos Pandieburra No. 1 and Delhi - Santos Putamurdie No. 1 were situated to the north-west of Innamincka and to the south of Birdsville, where seismic surveys had indicated several sub-surface structures (see fig. 3).

The reason for selecting these drill sites to the north-west of the previous exploration wells, was made in an attempt to obtain more porous Palaeozoic sediments, as it was thought that these locations would be closer to the assumed shore-line of the Lower Palaeozoic basin.

Neither of the wells encountered any Permian sediments. Both wells bottomed in marine, Ordovician sandstone, confirming the palaeogeographical assumptions as outlined above. The sandstones however were lacking porosity.

As all previous wells, drilled on structure, had failed to produce a satisfactory section, Delhi-Santos decided to drill an off-structure test. The site selected for this test was the eastern flank of Gidgealpa anticline, where seismic exploration had indicated a thick Permian section resting on moderately dipping Lower Palaeozoic sediments. The well designated Delhi-Santos Gidgealpa No. 1 was drilled to a total depth of 13,118 feet. Below a normal Mesozoic sequence the well encountered 1,420 feet of Permian and Permo-Carboniferous sediments resting on Upper and Middle Cambrian limestone, shale, and tuffaceous sediments. Good gas shows were observed in porous sands of the Permian section. A drill stem test of a porous interval (12,757 to 12,783) in the Cambrian dolomite produced gas cut salt water.

A summary of the stratigraphy of these wells is given in table II.

DISCOVERY OF THE FIELD

The proposal to drill Gidgealpa No. 2 was motivated by the very encouraging shows of hydro-carbons and the presence of strata with good reservoir characteristics in the Permian of Gidgealpa No. 1 together with the discovery of 430 ft. of porous dolomite in Middle Cambrian dolomite, flowing gas-cut salt water on test from below 12,757 feet.

As Gidgealpa No. 1 was drilled as an off-structure test there was good reason to believe that a well drilled higher on Gidgealpa structure would encounter hydro-carbons in both these formations. Delhi-Santos Gidgealpa No. 2 was thus proposed as an on-structure test, the primary targets being both the porous Permian sandstones and the porous dolomite sequence of the Middle Cambrian. The geological section as inferred prior to the drilling of Gidgealpa No. 2 is shown in Fig. 5.

Having two objectives in mind the site selected for Gidgealpa No. 2 had to be somewhat of a compromise. Firstly it had to be high enough on structure to be above the hydrocarbon-water contact thought to lie west of Gidgealpa No. 1. Secondly, seismic evidence showed rapid thinning of the Permian towards the top of the structure. As reflection quality from below the Permian was very poor across the apex, and considering the bald-headed nature of structures drilled previously, it was desirable that the location should not be selected at the culmination of the structure.

For these reasons the location for Gidgealpa No. 2 was selected two miles west of Gidgealpa No. 1 and on the north plunge of the anticline. With reference to the "P" seismic horizon No. 2 well was about 1,000 feet structurally higher than No. 1 but some 230 feet below the apex of the anticline. (see figure 4).

The Gidgealpa Anticline, situated in the western portion of the Strzelecki Permian sub-basin (Fig. 2) has no obvious surface-expression. The structure, as outlined by seismograph surveys, has a NNE-trend and measures about 13.5 miles along its axis and between 5.5 and 3.5 miles across. Maximum closure on the "P" - seismic horizon which, as previously mentioned corresponds roughly to the top of the Permian, is in the order of 550 feet. Two distinctive culminations, separated by a shallow saddle are apparent on the "P" - contour map.

figure 4.

<u>Delhi Santos Gidgealpa No. 2</u> was spudded on the 12th December, 1963, and drilling proceeded rapidly (12¼" hole) through the Cretaceous section and the Hooray Sandstone to 5,921 feet at which depth 9⅝" casing was run and cemented. A 8½" hole was drilled below the casing and on the 28th December, the top of the Permian was reached at 6,686 feet. The first porous sands were encountered at 6,755 feet. As the cuttings however, showed only very weak traces of fluorescence no test was called. The core cut from 6,810 to 6,820 feet recovered shale and coal (see Fig. 7). The next core cut on the 31st December from 6,858 to 6,865 feet recovered 7 feet of very coarse grained sandstone with conglomeratic bands. (figure 6). The core showed light brown oil stain, strong golden fluorescence and gave a very strong, pale yellow cut, and a drill stem test was called for. For reasons yet unexplained no "kicks" were observed on the gas detector neither while coring nor while drilling through the gas bearing sands.

The drill stem test was to test the interval 6,852 to 6,865 feet. Immediately after opening the test tool a strong "blow" was observed and five minutes after the tool had been opened gas flowed to the surface at an estimated rate of 2.9 million cubic feet per day through a ⅜" surface choke.

After the discovery test, drilling proceeded and the pre-Permian unconformity was encountered at 6,868 feet at which depth the drill entered tuffaceous dolomite, welded tuffs and trachytes. This sequence persisted to 9,020 feet, the total depth of the well. No Cambrian was encountered and it was thought that the Cambrian carbonate sequence had been downfaulted against an (?) Upper Proterozoic high, consisting largely of volcanic rocks and forming the "core" of Gidgealpa anticline (see figure 5).

After drilling had ceased Gidgealpa No. 2 was completed as a potential gasproducer. 7" casing was set to 6,932 feet and cemented. The casing was perforated opposite the permeable Permian sands viz. 6,857 to 6,871 feet, 6,836 to 6,842 feet, 6,792 to 6,804 feet, and 6,756 to 6,779 feet (see figure 7). The perforated intervals were tested individually each of them producing gas and small amounts of 49° A.P.I. distillate. Small amounts of oil were recovered from the two lower sands. Average reservoir pressure was approximately 3,000 p.s.i. A summary of the testing results together with a stratigraphic column of the producing horizon is shown in Figure 7.

Delhi-Santos Gidgealpa No. 2, the first gas well in South Australia, is capable of flowing 11.6 million cubic feet of gas per day and 42 barrels of distillate per day through ½" choke at 2,015 p.s.i. The calculated absolute open flow potential is 29.5 million cubic feet of gas per day (Harrison and Higginbotham, 1964b).

The producing interval in Gidgealpa No. 2 can be correlated with the upper sandy unit of the Permian sequence in the No. 1 well between 7,690 feet and 7,873 feet. This indicates that about 870 feet of Permian section and about 350 feet of (?) Permo-Carboniferous section are lost due to wedge-out and on-lap between the No. 1 and the No. 2 well. (See Figs. 8 and 10).

DEVELOPMENT OF THE FIELD

<u>Delhi-Santos Gidgealpa No. 3</u> was programmed to follow up the gas discovered in Gidgealpa No. 2. The site selected for Gidgealpa No. 3 is on the eastern flank of the Gidgealpa anti-cline, about two miles south from the previous well (see map Figure 4). With regard to the "P" seismic horizon Gidgealpa

No. 3 was some 350 feet structurally lower than No. 2 but approximately 700 feet structurally higher than No. 1. It was therefore expected to encounter a considerably thicker Permian sequence and the primary targets of the well were the gas producing sandstones encountered in No. 2 and any additional porous strata in the lower parts of the Permian sequence. Furthermore it was anticipated to find the porous Cambrian dolomite encountered in No. 1, but about 2,000 feet structurally higher.

The Permian sequence encountered in Gidgealpa No. 3 resembled that from the No. 1 well but was slightly teloscoped. However, the upper sand sequence which produced gas in No. 2 yielded only gas cut water, and the only gas production was obtained from sands near the bottom of the Permian sequence (7,523 to 7,554 feet, 7,373 to 7,483 feet and several sand stringers).

The various Permian sands have been referred to subsequently as the "Top sands" (the gas producing interval in No. 2), "Wedge sands" and "Bottom sands" (producing gas in No. 3). The position of these sands within the Permian column is demonstrated in figure 8.

Below the Permian (7,559 feet) about 130 feet of (?) Permo-Carboniferous breccia and 93 feet of Cambrian limestone were encountered. At 7,785 feet the well entered tuffs and volcanics which persisted to the total depth of the well at 10,934 feet. Gidgealpa No. 3 was completed as a potential gas producer, flowing 5.59 million cubic feet of gas per day through 3/4" choke at 498 p.s.i. with only minor amounts of condensate.

<u>Delhi-Santos Gidgealpa No. 4</u> was located on the south-west nose of the Gidgealpa structure (figure 4) and was solely designed to test and evaluate the Permian. The well encountered

excellent gas flows in both the "Top" and the "Bottom" sands of the Permian. In addition an oil (22° A.P.I.) and water bearing zone was observed between the two gas bearing intervals.

Below the unconformity, at 7,245 feet the drill entered (?) Precambrian volcanics which persisted to 7,783 feet at which depth drilling ceased.

Delhi-Santos Gidgealpa No. 4 was subsequently dually completed as a gas well capable of flowing 17.76 million cubic feet of gas per day through ¼" choke plus 73 barrels of condensate per day. This was the first dual completion carried out in Australia.

Until now all wells had been drilled on the northern culmination of the Gidgealpa anticline.

Delhi-Santos Gidgealpa No. 5 was the first well to test the southern culmination of the structure. The well was situated on the south-west salient of the southern culmination approximately 7½ miles south-southwest of Gidgealpa No. 2 (see Figure 4).

The "Top sands" of the Permian were found to be water bearing but gas production was obtained from the intermediate "Wedge sands" between 7,090 and 7,274 feet. The bottom sands, although much thicker than in any of the previous wells produced only gas cut water.

The base of the Permian was encountered at 7,618 feet. Below the Permian the drill penetrated 312 feet of ?Permo-Carboniferous, 424 feet of Cambrian carbonates and bottomed at 8,723 feet in ?Proterozoic volcanics.

Gidgealpa No. 5 was completed as a potential gas producer capable of flowing 3.75 million cubic feet of gas per day and 303 barrels of 53° A.P.I. condensate per day.

<u>Delhi-Santos Gidgealpa No. 6</u> was a flank test on the northwest flank of the northern culmination of the Gidgealpa structure and situated about two miles north-northwest of

FORMATION TOPS BELOW ROTARY TABLE

Elevation	D.F.S. Innamincka No. 1	D.F.S. Betoota No. 1	D.F.S. Dullingari No. 1	D.F.S. Orientos No. 1	D.S. Maryilco No. 1	D.S. Pandieburra No. 1	D.S. Putamurdie No. 1	D.S. Gidgealpa No. 1
Ground	401	345	304	458	433	101	120	165
Rotary table	412	359	320	474	449	117	136	181
Quaternary-Tertiary	Nil	Nil	surf.	surf.	surf.	surf.	surf.	surf.
Winton Form. Cenomanian	surf.	surf.	448	392	120	330	280	798
Tambo Form. Albian	1795	1350	2544	2200	1427	2275	2220	3357
Toolebuc Member	2610	2460	3462	2911	2082	3462	3246	4362
Roma Formation Aptian	2685	2541	3547	3014	2200	3484	3305	4477
Transition Beds Aptian-Neocomian	3928	3423	4492	4075	3223	4174	3970	5211
Hooga Sandstone Upper Jurassic	4665	3651	4774	4373	3512	4370	4103	5450
Walloon Formation Middle Jurassic	5132	4105	5792	5050	4153	5050	4725	6372
Hutton Sandstone Middle Jurassic	5447	4478	Nil	Nil	Nil	5352	4866	6780
Upper Triassic	Nil	5605	Nil	Nil	Nil	6770	6003	Nil
Lower Triassic	5915	Nil	6182	5553	Nil	Nil	Nil	7185
Permian	6723	Nil)	6707	5964	Nil	Nil	Nil	7690
Permo-Carbon.	Nil	Nil)			Nil	Nil	Nil	8690
Devonian	7050	5757	Nil	Nil	Nil	Nil	Nil	Nil
Silurian	Nil		Nil	Nil	Nil	Nil	Nil	Nil
Ordovician	Nil		9050	7288	Nil	6970	6130	Nil
Cambrian	Nil		Nil	Nil	Nil	Nil	Nil	9110
Upper Proterozoic	Nil	?	Nil	Nil	4739	Nil	Nil	Nil
Total depth	12637	9824	11588	11527	4847	7253	6406	13114

TABLE XI
Stratigraphic summary (formation tops) of exploration wells drilled by Delhi-Santos in the years 1959 - 1963.

Gidgealpa No. 2 (Fig. 4). The "Top sands" of the Permian produced water as expected. The intermediate "Wedge sands" were tight and produced small amounts of gas the largest flow being 0.12 million cubic feet of gas per day. The "Bottom sands" appeared to be missing (See Fig. 8).

Below the bottom of the Permian at 7,565 feet the well entered into volcanics of ?Precambrian age and drilling ceased at 7,803 ft. The well was subsequently completed as an artesian water well producing water from the Walloon Formation and the Hutton Sandstone.

Delhi-Santos Gidgealpa No. 7 was the second well to be drilled on the southern culmination of the Gidgealpa structure. The well was sited about two miles southeast of Gidgealpa No. 5. Seismic surveys indicated the presence of a north-northeast trending fault to the west of the location as indicated in figure 4.

Gas was encountered in the "Top sands" and in the top of the "Bottom sands" of the Permian sequence, the two gas producing zones being separated by water bearing sandstones. The lower parts of the "Bottom sands" also produced water. (fig. 9).

The Permian was found to rest directly on Cambrian carbonates at 7,609 feet. No Permo-Carboniferous sediments were present. (?) Precambrian volcanics were encountered at 10,495 feet and the well bottomed in volcanics at 10,582 feet.

Gidgealpa No. 7 was dually completed as a potential gas producer from the intervals 6,877 to 6,945 feet (casing side) and 7,239 to 7,288 feet (tubing side). The well is capable of flowing 21.8 million cubic feet of gas per day plus 292 barrels of condensate per day through ½" choke.

Delhi-Santos Gidgealpa No. 7 was the last well drilled on the Gidgealpa structure and drilling activities were concentrated on the Merrimelia structure situated about 15 miles northeast of the Gidgealpa anticline.

GEOLOGICAL SUMMARY

A great deal of new and most valuable geological information was obtained from the Gidgealpa wells leading to a far better understanding of Mesozoic, but particularly of the Pre-Mesozoic history of the Strzelecki sub-basin. The stratigraphy of the Gidgealpa wells is summarised in Table XII.

The Mesozoic sequence proved to be of very uniform lithology over the whole of the Gidgealpa structure and only slight variations in thickness were observed, the Winton Formation being the most variable unit (see Fig. 10).

The results obtained from the Permian succession of the area of the Gidgealpa structure demonstrated considerably greater stratigraphic and structural complexity than expected and variations are evident both with regard to thickness and to lateral lithologic changes. The Permian section is drastically reduced in thickness across the structure, particularly across the northern culmination where only the "upper sands" were deposited. It appears on present information that the thinning of the Permian section is largely controlled by on-lap of the lower and middle parts of the section. There are however, indications of minor stripping prior to the deposition of the "upper sands" which drape fairly uniformly across the apex of the structure. (see figures 8 and 9).

The changes in lithological composition are due to an increased sand content from the northeast to the southwest of the structure, again particularly noticeable in the middle

DELHI SANTOS GIDGEALPA

		No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
LOCATION	South-Lat.	27°56'46"	27°56'44"	27°58'27"	27°58'37"	28°01'21"	27°55'24"	28°02'19"
	East Long.	140°04'36"	140°03'01"	140°03'05"	140°00'34"	139°58'26"	140°02'38"	140°00'09"
ELEVATION	Ground	165	161.5	160	150	150	161	152
	Kelly bushing	181	178	176	163	166	177	168
FORMATION TOPS, FEET BELOW KELLY BUSHING	Quaternary - Tertiary	surface	surface	surface	surface	surface	surface	surface
	Winton Form. Cenomanian	748	634	639	615	670	653	670
	Tambo Form. Albian	3357	2911	3064	2970	3000	3160	3045
	Toolebuc Member	4362	3897	4050	3852	3865	4250	3924
	Roma Form. Aptian	4477	4016	4176	3994	3990	4368	4050
	Transition Beds Apt.-Neocom.	5211	4657	4864	4749	4770	4980	4785
	Hooray Sandst. Upper Jurassic	5450	4881	5103	4981	4970	5172	5010
	Walloon Form. Middle Jurassic	6372	5788	6010	5875	5904	6046	5940
	Hutton Sandst. Lower-M-Jurassic	6780	6158	6428	6256	6300	6482	6280
	Unnamed Lower Triassic	7185	6562	6790	6675	6682	6885	6652
	Unnamed Perm.	7690	6686	7037	6864	6880	7077	6852
	Unnamed Permo-Carbon	8690	NIL	7560	NIL	7618	NIL	NIL
	Unnamed Camb.	9110	NIL	7692	NIL	7930	NIL	7609
	Unnamed Volcanics ?Precamb.	NIL	6868	7785	7245	8354	7565	10426
	TOTAL DEPTH	13114	9920	10934	7783	8723	7805	10582

TABLE XXI

Summary of stratigraphic data of Gidgealpa wells.

and lower parts of the Permian column. The sand shale ratio increases from 0.19 at No. 1 well to about 0.4 at the No. 4 and No. 5 wells. In estimating these values certain allowances have to be made to cancel statistical errors caused by the progressive on-lap.

The stratigraphic and structural complexity of the Permian section is also reflected in the reservoir characteristics of the producing wells. The gas produced from the northern culmination of the structure is different from the gas produced on the southern culmination both in composition and in the amount of distillate per unit gas. The gas produced from the northern culmination is a lean gas averaging about four barrels of condensate per one million cubic feet of gas in the "top sands" and less than two barrels of condensate per million cubic feet of gas in the "bottom sands". Average CO_2 content is about 15%. These figures contrast with 53 barrels of condensate per million cubic feet of gas produced from the No. 5 well and about 35 barrels of condensate per million cubic feet of gas produced from No. 7, both wells being situated on the southern culmination of the structure.

Furthermore the "top sands" in No. 5 well were found to be water bearing whilst the same sands in No. 4 although only 15ft. structurally higher produced an excellent flow of gas.

These features imply the presence of separate pools in the two structural culminations of the Gidgealpa anticline. The separation might have been affected by either structural complications or by virtue of a permeability barrier or a combination of both factors.

An anomaly also exists between No. 5 and No. 7 well. The gas producing "top sands" in No. 7 are structurally lower than the water bearing intervals in the top part of the Permian in No. 5. The anomalous situation is perhaps explained by the northeast trending fault situated between the two wells as mentioned previously.

The clastic sediments of the ?Permo-Carboniferous section appear to be strongly influenced by the configuration of the Gidgealpa anticline, the coarsest fractions occurring in the immediate periphery of the structure and changing down dip to smaller grain sizes. Stripping prior to the deposition of the Permian and evidenced by the unconformable relationship between the Permian and the ?Permo-Carboniferous strata appears to have been responsible for the absence of ?Permo-Carboniferous sediments over parts of the anticline (No. 2, 4, 6 and 7).

A marked angular unconformity separates the Upper Palaeozoic sediments from the Cambrian and the ?Precambrian volcanics. This is clearly demonstrated by the sharp increase in dip readings in the Cambrian on continuous dip meter surveys, but also from core data, particularly from the No. 4 Well, where a core was cut across the unconformity, exhibiting a pencil-sharp unconformity between the Permian sediments and the (?) Proterozoic volcanics. Dips in the Cambrian average 30 to 40 degrees and are generally in accordance with the configuration of the Gidgealpa anticline (See Fig. 4). In No. 3 well where dip-readings are available from both the Cambrian and the (?) Proterozoic volcanics the two units appear to be conformable. Thrust faulting is indicated in the Cambrian sequence of No. 1 well, where, according to the fossil contents identified by Dr. Öpik late Middle Cambrian limestones rest on early Upper Cambrian sediments. The palaeontological evidence is supported by the results from dip meter surveys. Above 10,000 feet dipmeter readings are 30° to 40° in a southeasterly direction whilst dip meter data below 11,300 feet are consistently east-northeast with an average dip of 50°. Erratic dip meter readings were obtained from the interval 10,000 to 11,300 feet and it is thought that the thrust fault occurs in that interval (Harrison and Higginbotham, 1964a).

The rapid thinning of the Cambrian carbonates across the anticline is most probably caused by faulting and subsequent stripping of the up-thrown block.

GEOLOGICAL HISTORY

Summarising the information outlined above one may interpret the following geological history:-

A period of intense volcanic activity in late Proterozoic time and perhaps reaching into the Lower Cambrian was succeeded by the deposition of carbonates in Middle to Late Cambrian time. Intermittent volcanic activity re-occurred towards the later part of this interval intercalating tuffs and agglomerates into the Cambrian carbonate sequence. From information obtained in other wells (Dullingari No. 1, Orientos No. 1, Pandieburra No. 1, etc.) and the continuity of sedimentation from the Cambrian into the Ordovician in related areas of Lower Palaeozoic sedimentation (Amadeus Trough, Georgina Basin, West Darling District) one will be justified in assuming that sedimentation in the Gidgealpa area also continued into Ordovician time. The exact time at which Lower Palaeozoic sedimentation ceased is not known but it is thought that orogenic movements in late Ordovician to Silurian time terminated the Cambro-Ordovician period of deposition.

Crustal foreshortening lead to the formation of generally gentle folds although more severe types of deformation and thrust movements did sometimes occur as indicated by evidence from Gidgealpa No. 1.

Outside the Gidgealpa area as for instance in the Mootwingee region or the Amadeus Trough, the Silurian fold movements were followed by a depositional period in Devonian time when great thicknesses of flysch and molasse type sediments were deposited and subsequently folded by renewed tectonic movements in very late Devonian time. A similar situation appears to have been present in the Strzelecki sub-basin indicated by the presence of (?) Devonian sediments in Innamincka No. 1 well.

Through most of the Carboniferous the Gidgealpa area was exposed to erosion and stripping. Crustal downwarping in late Carboniferous led to the deposition of the Permo-Carboniferous sediments. The Gidgealpa structure must either have been exposed or covered by only extremely shallow water to account for the coarse breccia rimming the anticline. Uplift and erosion in mid Permian time led to partial stripping of the Permo-Carboniferous strata on structural "highs". Sedimentation may have been continuous in the deeper, structurally depressed areas, however this is conjectural.

Downwarping in the late Permian led to the formation of a shallow water body in which the structural highs submerged thus producing transgressive on-lap of the gas producing sediment-interval. Down-folding however did not proceed continuously but was halted frequently and during such periods of stagnation coal seams developed. Periods of active down movements are represented by the porous sand layers. In very late Permian however sedimentation was temporarily interrupted prior to the deposition of the "upper sands". No appreciable break is noticeable between the "upper sands" and the Lower Triassic sediments, and deposition seems to have been continuous across the Permian-Triassic boundary.

This Upper Permian - Lower Triassic basin (Strzelecki sub-basin) extended from the east of Orientos No. 1 to a point about half way between Gidgealpa and Dandieburra and from about 27° south lat. to about 29° south lat. in meridional direction.

Towards the middle Triassic, epeirogenic uplift transformed the whole of the Strzelecki sub-basin into land. The long ensuing period of erosion lasted well into the Jurassic.

The topography of this land surface was however very subdued (?plane of emergence) and only little stripping and lateral transport took place, the main process being deep weathering.

On this surface the equivalents of the Hutton Sandstone were laid down in early to early Middle Jurassic followed by the Walloon Formation and the Hooga Sandstone in late Jurassic time.

Marine transgression in the Neocomian led to the formation of a shallow sea in which the Tambo and Roma Formations were deposited and which blanketed the whole of the Great Artesian Basin. Regression commenced in Late Albian to Early Cenomanian during which time the Winton Formation was laid down.

For the remaining interval of the Cretaceous the area was land and essentially a plain of emergence. A thin sheet of gravels, sands and lignitic clays was spread over the area in the Early Tertiary.

Renewed epirogenic movements in Mid Tertiary time resulted in gentle doming and some faulting of the Late Palaeozoic and Mesozoic sediments. (Wopfner, 1960; Sprigg, 1962).

CONCLUSIONS

Drilling of the Gidgealpa anticline proved the long held belief in the potential of the Permian sediments as hydrocarbon producers. The question of the origin of the gas is still open for discussion. The presence of various reservoir zones with intermittent water and oil-water horizons would appear to be in favour of an indigenous Permian source. The occurrence of gas, although only in non-commercial quantities in Permian sediments on other structures where the Permian strata do not rest on Cambrian sediments would seemingly support this interpretation. Without more conclusive evidence however, the possibility of a Cambrian source for the Gidgealpa gas cannot be rejected entirely.

The Gidgealpa gas field can be classed as a medium size field, probable recoverable reserves being presently estimated at about 450 billion cubic feet of gas. The great distance to the nearest market (500 miles to Adelaide) however poses an economic problem which requires careful study before the field can be profitably exploited.

A number of other anticlinal structures have been outlined by seismograph surveys within the Strzelecki sub-basin. There are good prospects of obtaining commercial production if not on all but at least on some of these anticlines, particularly to the south and southeast of Gidgealpa in which direction more favourable sand - shale ratios may be expected.

Additional drilling will no doubt enhance our knowledge of such factors as stratigraphy, structure and hydrodynamics and thus build the foundation for the evaluation of more sophisticated exploration targets within the Permian as well as within the underlying Lower Palaeozoic sediments.

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H. Wopfner
Supervising Geologist
PETROLEUM EXPLORATION DIVISION

HW:AGH
20/10/63

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Fig. 1 Oblique air-photograph looking south over Gidgealpa region and demonstrating typical physiography of desert sand-dunes encroaching ephemeral flood-plains of Coopers Creek. Gidgealpa field is situated in the far distance on top right corner of picture.

TEXT TO FIGURES

Fig. 2 Generalised geological map of Great Australian Artesian Basin showing major geological units along its margin and major surface structures within the basin. The licence areas held by Delhi-Santos in South Australia (O.E.L. 20 & 21) and in Queensland (66P & 67P) are outlined.

Legend:

(1) Craton (Gawler Platform) and early Precambrian (pre-Adelaidean), substable blocks (mesocratons).

(2) Sedimentary basins of Adelaidean to Devonian age.

(3) Tasman geosynclinal zone consisting largely of metamorphosed sediments of early Palaeozoic age.

(4) Permian to Triassic sedimentary Basins.

(5) Sedimentary basins of Jurassic-Cretaceous age but containing some Triassic sediments.

(6) Tertiary sedimentary basins.

Fig. 3 Structural contour map on "C" - seismic horizon (approximate top of Transition Beds) of central portion of Great Artesian Basin. Also showing position of early exploration wells drilled by Delhi-Santos between 1959 and 1963, and approximate outline of Strzelecki Permian sub-basin (dotted line).

Fig. 4 Structural contour map of Gidgealpa structure on "P" - seismic horizon and position of Gidgealpa wells. Contours are corrected to actual top of Permian according to well-data.

Fig. 5 Schematic cross section through Gidgealpa anticline as interpreted before and after drilling of D.S. Gidgealpa No. 2.

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Fig. 6 Core No. 4 (6838 - 6868 feet) from D.S. Gidgealpa No. 2. Photograph shows face cut perpendicular to core-axis, demonstrating lithology and porous texture of lowest, gas-bearing Permian sandstone ("upper sands").

Fig. 7 Detailed section of Permian gas-producing interval in D.S. Gidgealpa No. 2 showing lithology and log characteristics. This interval corresponds with the "top sands" as shown in figure 8. Results of final drill stem tests through casing-perforations are given to the right of the micro-log curve.

Fig. 8 Stratigraphic cross-section through northern culmination of Gidgealpa structure showing informal stratigraphic subdivisions of Permian sequence and their relation to gas-production.

Fig. 9 Generalized longitudinal section through Gidgealpa Anticline, demonstrating the double-culmination of the structure and the thickening of the "bottom sands" to the south. For location of section refer to figure 4.

Fig. 10 Stratigraphic cross section and well correlation, northern culmination of Gidgealpa Anticline. Note the uniform deposition of Mesozoic strata across the structure.