RECORD 1989/2

SEDIMENTOLOGY AND FACIES DISTRIBUTION WITHIN THE HORN VALLEY SILTSTONE, AMADEUS BASIN: A RECONNAISSANCE STUDY

by

R. ELPHINSTONE

CONTENTS

ABSTRACT

Exposure of the Horn Valley Siltstone is usually poor, but well preserved material can be obtained from some of the fully cored wells intersecting this interval throughout the Amadeus Basin. In this study, the following cored holes were used: Henbury #4, Henbury #6, Mt Liebig #2, Tempe Vale #1 and Tent Hill #1. I have subdivided the formation into ten informal members, HV1 (lowermost) to HV10, which reflect vertical lithofacies variations in a shallow marine shelf environment. These members have been defined primarily from sedimentological and palaeontological information such as the presence or absence of body fossils, mode of preservation, species associations within groups of fossils, presence or absence of bioturbating organisms (trace fossils), lithology and bedding types. It can be inferred that the amount and composition of organic matter preserved in the sediment was determined largely by the concentration of oxygen in the bottom water and the extent to which the sediment was disrupted by burrowing organisms because burrowing and scavenging activities of benthic organisms are controlled by the concentration of oxygen in the bottom water. Organic geochemical data from Tempe Vale #1 and Tent Hill #1 were used to confirm these facies variations.

The transition between HV6 and HV7, which can be recognised easily by the sudden change in shale to carbonate ratio, has been found to coincide with the presence of high organic rich sediments, with recorded TOC values of up to 6.30%.

INTRODUCTION

Interest in the stratigraphy of the Amadeus Basin, and especially the Horn Valley Siltstone, the probable source rock for petroleum, was rekindled by the discovery of the Mereenie Oil Field and Palm Valley Gas Field in the early 1960's. The stratigraphy and structural geology of the Amadeus Basin has been described by Wells and others (1967 and 1970), McNaughton and others (1968), Froelich & Kreig (1969), Forman & Shaw (1973), Pearson & Benbow (1976) and Kennard and others (1986). Recently extensive work has been undertaken with several wells, both wildcat and appraisal, being drilled in the Amadeus Basin (Figs 1 and 2).

This study was undertaken to obtain stratigraphic, sedimentological and facies variations in the Horn Valley Siltstone using previously drilled wells and to provide a framework upon which palaeontological data could be placed.

PREVIOUS INVESTIGATIONS OF THE HORN VALLEY SILTSTONE

The Larapinta Group consists of five formations (Fig. 3) of predominantly siliciclastic sediment deposited in a shallow intracratonic sea. Prichard & Quinlan (1962) redefined the Larapinta Group and its constituent formations, revising terms introduced earlier by Tate (1896), Madigan (1932) and Chewings (1935). Madigan's type section for the Horn Valley Siltstone was in the Ellery Creek valley. Subsequent revisions have been made by Wells and others (1965, 1970).

The Horn Valley Siltstone is very fossiliferous and contains a rich and varied biota. It was one of the first formations in the Amadeus Basin to be palaeontologically investigated, during the Horn Expedition of 1894 (Tate, 1896). According to Gilbert-Tomlinson (*in* Wells and others, 1970), the formation contains trilobites, brachiopods, pelecypods, nautiloids, ostracodes, graptolites,

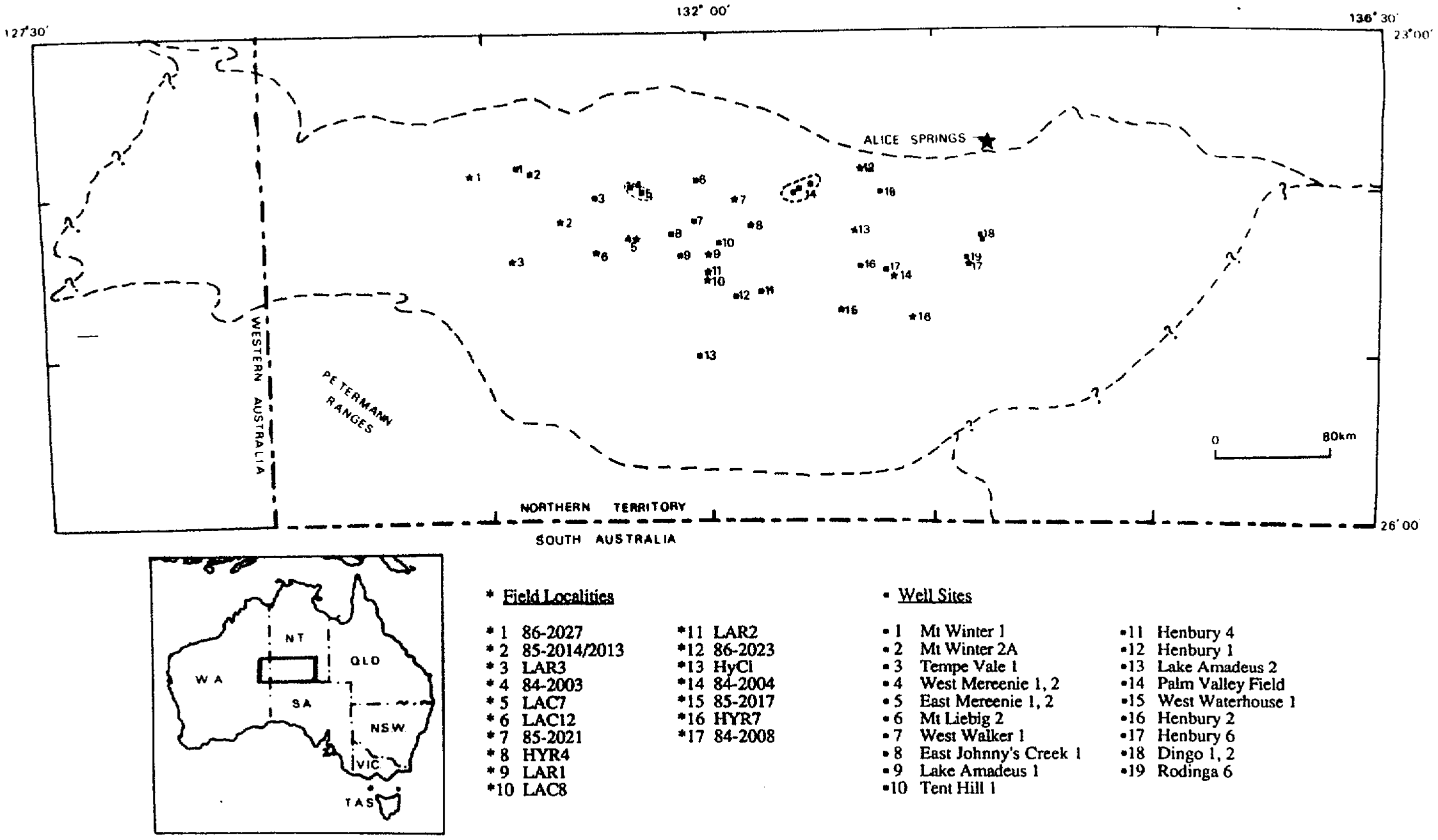


Figure 1. Distribution of wells and field localities intersecting the Horn Valley Siltstone.

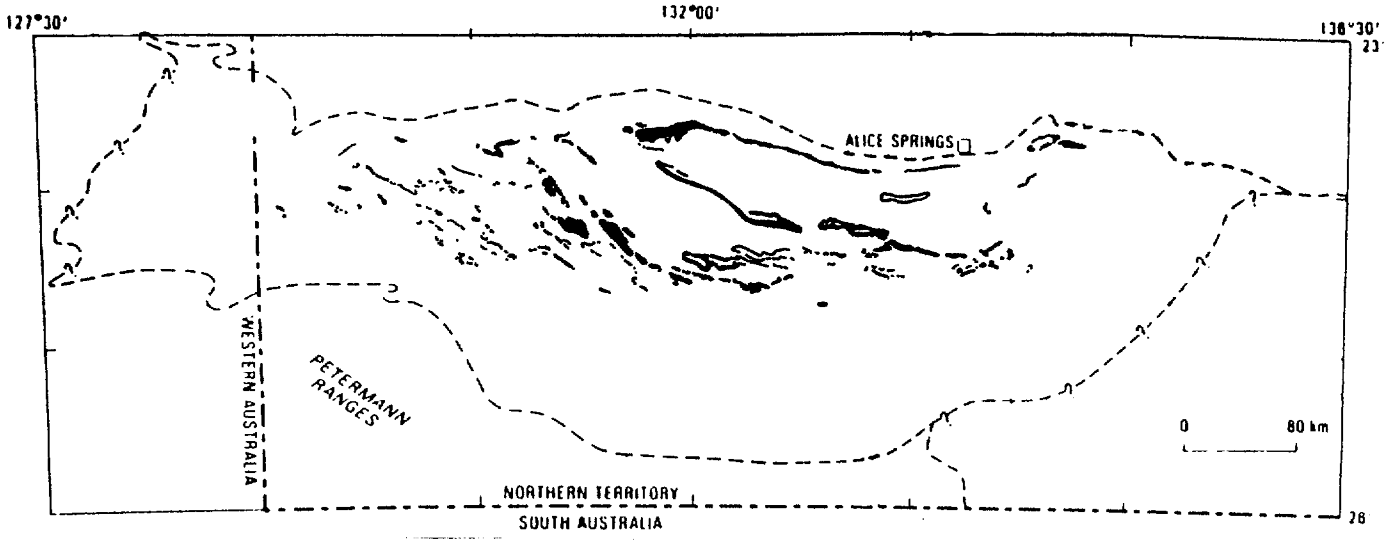


Figure 2. Outcrop of the Horn Valley Siltstone.

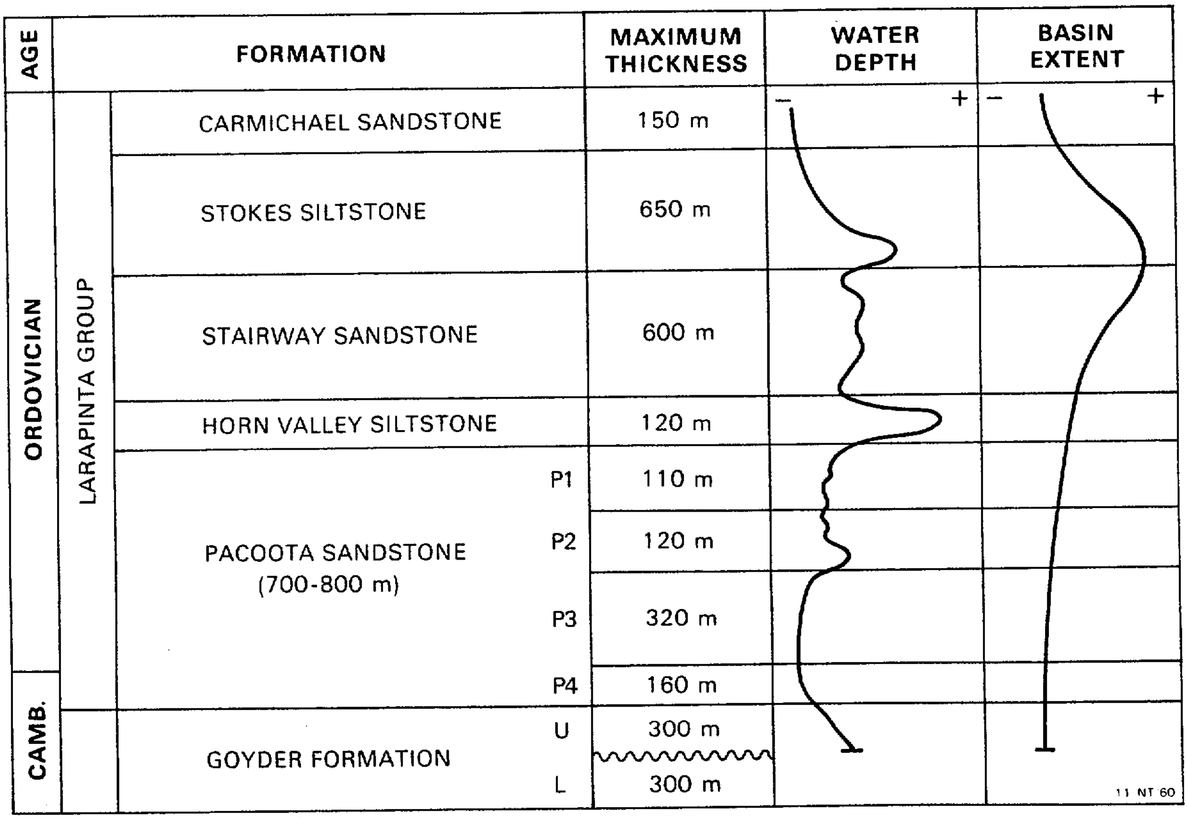


Figure 3. Formations of the Larapinta Group and intepretation of their relative water depth and aerial extent (from Nicoll, 1986).

gastropods and conodonts. These have been described by numerous authors (see summary by Shergold, 1986). Added to this list are previously undescribed trace fossils.

In most localities throughout the basin, the Horn Valley Siltstone is poorly exposed and for this reason few lithostratigraphic studies have been carried out. Prior to 1982, only one core (BMR Lake Amadeus #1; Barrie, 1964) provided a continuous record of this formation. Since then, Pancontinental Petroleum Limited and the BMR have engaged in an active drilling program, which includes the following wells:

- BMR Rodinga #6 (Owen & Morris, 1985)
- BMR Henbury #4 (Owen & Morris, 1985)
- BMR Henbury #6 (Owen & Morris, 1985)
- BMR Mt Liebig #2 (Owen, 1986)
- Tempe Vale #1 (Marsden and others, 1983)
- Tent Hill #1 (Marsden and others, 1984)
- Mt Winter #2A (Gorter, 1986)

Interest has also focussed on the geochemical studies which have been conducted on the Horn Valley Siltstone, the source of most of the discovered hydrocarbons in the Amadeus Basin (Gorter, 1984; Jackson and others, 1984; Schroder & Gorter, 1984).

SUMMARY OF REGIONAL GEOLOGY AND STRUCTURAL SETTING

The Amadeus Basin is the structural remnant of an intracratonic depression which contains a thick succession of Late Proterozoic to Middle Palaeozoic sediments. The basin lies in the southern portion of the Northern Territory and extends partly into Western Australia. It has an east - west length of 800 kilometres, an area of about 170 000 square kilometres, and a maximum preserved thickness of about 14 kilometres. The basin is bounded to the north by the Proterozoic Arunta Complex, and to the south by the Musgrave - Mann Complex and the Olia Gneiss. The sedimentary section thins westwards over an arch of basement rocks and perhaps merges with the Canning Basin. The eastward extension is overlapped by Mesozoic sediments of the Great Artesian Basin (Pearson & Benbow, 1976).

Tectonic movements in the Proterozoic established the shape of the basin, and formed the structural framework within which subsequent movement took place. Commencing with Late Proterozoic clastics, which rest on an older basement of metamorphic and igneous rocks, the basin has had a long and diversified history of sedimentation. Following Late Proterozoic sedimentation, rocks of Cambrian, Ordovician, possibly Silurian, Devonian and Permian age were deposited. Depositional and climatic conditions varied greatly 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 deposition in the Late Proterozoic and Cambrian. Two periods of glaciation also occurred in the Late Proterozoic. Silurian?-Devonian sandstones, 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.

During accumulation of the Larapinta Group from Late Cambrian to mid-Late Ordovician, the Amadeus Basin was covered by a shallow fluctuating sea. Ocean current circulation in the Larapinta Sea was probably restricted, although there appears to have been a partially sustained westward connection to the open sea (Canning Basin) and possibly also an eastern seaway to the Georgina Basin.

Tha Amadeus Basin may have been elongated NW-SE during the Ordovician, rather than E-W as at present and was probably within 10° or 15° of the equator and the climate would have been hot (carbonates, minor evaporites) and less certainly humid (Webby, 1978).

Two major transgressions occurred during the Larapinta episode of sedimentation. The first of these sea level maxima corresponds with the deposition of the Horn Valley Siltstone, the second with the Stokes Siltstone. The formations underlying and overlying the Horn Valley Siltstone (ie the Pacoota and Stairway Sandstones) were deposited in intertidal to mainly subtidal environments. Both of these formations were intensively bioturbated and contain evidence of a high energy depositional environment, in the form of current bedding, scouring and phosphorite development.

DISTRIBUTION

The Horn Valley Siltstone has a distribution (Fig. 2) across the Amadeus Basin which is much the same as that of the underlying Pacoota Sandstone. The formation underlies a considerable area, but it rarely crops out in the deep alluvium-covered strike valleys. The best outcrop exposures are in the western MacDonnell Ranges, the Ochre Hill area, Mount Olifent, and on the flanks of some of the anticlines west of Tempe Downs homestead (Wells and others, 1970).

Like the Pacoota Sandstone, the Horn Valley Siltstone thickens northwards, but has been truncated in the east by thinning and erosion associated with the pre-Mereenie Rodingan diastrophism. This affected mainly the eastern portion of the basin (east of longitude 133° 30'E), leading to the removal of a large thickness of the Larapinta Group. Around the southern basin margin, it is a condensed carbonate dominated section, whilst in the central north, at Mt Liebig #2, fine clastics predominate with only thin interbedded limestone preserved. The proportion, ordering and thickness of beds of these lithologies depends upon location within the basin. Most of the cored sections indicate an increase in proportion of limestone upwards in the Horn Valley Siltstone. The palaeo-shoreline is assumed to have been located along the southern margin of the basin, although its precise location in not known. The present northern margin of the basin does not correspond to the basin edge in Larapinta times and sediments there have been truncated by uplift and erosion on the Arunta Block.

The validity of previously established thickness and facies distributions is undermined by poor data point control and problems associated with delineating the boundaries of the Horn Valley Siltstone.

The problem of poor outcrop has been partially alleviated by the coreholes which have been drilled both by exploration companies and the Bureau of Mineral Resources. These together with the main outcrop exposures are depicted in Figs 1 and 2. A listing of the wells and their locations in the Amadeus Basin is given in Appendix 1.

STRATIGRAPHIC RELATIONSHIPS

The Horn Valley Siltstone rests conformably on the Pacoota Sandstone, except in a small area in the south (eg in the Seymour Range and Maloney Creek areas), where it rests disconformably on the Goyder Formation or Jay Creek Limestone. It is generally overlain by the Stairway Sandstone, except to the east, where it is unconformably overlain by the Mereenie Sandstone (Wells and others, 1970).

The Pacoota Sandstone - Horn Valley Siltstone and Horn Valley Siltstone - Stairway Sandstone boundaries are both mostly gradational, and furthermore, facies variation occurs in all three formations. The result is that boundary delineation has been very subjective. Given that the Horn Valley Siltstone is a relatively thin formation, the errors in formation thickness may be quite large as a result of the uncertainities in defining the formation boundaries.

Gorter (1984) discusses the history and problems associated with the definition of the Horn Valley Siltstone. For the purpose of this paper, I have adopted his definition, in that the top of the Pacoota Sandstone is represented by the top of the prominent gamma ray and sonic log spike. The lithology of the unit which causes the spiky gamma ray and sonic log character is generally either glauconitic, sandy dolomitic limestone or dolomitic sandstone. In other words the base of the Horn Valley Siltstone should be placed at or near the appearance of the first carbonate above the Pacoota Sandstone. This approach has the practical advantages of the contact being relatively easy to recognise in drill cores and also provides a means of correlation with seismic sections from throughout the basin. As discussed in Gorter (1984), this approach may also result in a substantial amount of siltstone with thin, often glauconitic sandstone beds being placed above the last major sand body of the Pacoota Sandstone. Thus a workable definition such as the boundary between the Horn Valley Siltstone and the Pacoota Sandstone is defined as near the base of the first prominent limestone bed above the siliciclastic Pacoota sequence (Gorter, 1984) is useful if correlations are to be made from seismic sections, drill core samples and outcrop sections. However, a definition which incorporates the noticable changes which can be detected in the activities of bioturbating animals and the presence or absence of other fossil groups, may also be useful. This concept will be discussed more fully below.

The top of the Horn Valley Siltstone is marked by a gradual upward transition from black shale and siltstone to interbedded carbonate and siltstone, and finally fine sandstone. This interval may be up to 10m thick. The boundary with the overlying Stairway Sandstone is arbitrarily placed where the sand component becomes dominant. This transition from "the less resistive but sandy beds to more resistive sandstones" is readily apparent on the electric logs of petroleum wells (Gorter, 1984); the base of the Stairway Sandstone is defined as the sharp base of an upward coarsening sand body clearly demarcated in both the gamma ray and sonic logs. Once again, a defintion which incorporates the fossiliferous component of the rocks, would be useful. This too will be discussed later.

AGE

Evidence for the age of the Horn Valley Siltstone, based on conodont, graptolite and trilobite fauna, has been discussed by Jones (1971, p53), Pojeta & Gilbert-Tomlinson (1977) and references cited therein, Pojeta and others (1977) and Cooper (1981). All are in agreement that a late Early Ordovician (Arenigian) age is most plausible.

Numerous publications describe body fossils in the Horn Valley Siltstone. These papers deal with taxonomy, functional morphology, or are simply lists of taxa which have been cited in this formation. For a summary of this literature, refer to Shergold (1986).

FACIES AND DEPOSITIONAL ENVIRONMENT

The facies of the underlying (Pacoota Sandstone) and overlying (Stairway Sandstone) formations of the Horn Valley Siltstone, as well as the Horn Valley Siltstone, will be included in the following discussion, due to the transitional nature of the formation boundaries. These facies have been defined using lithological, sedimentological and palaeontological observations from Henbury #4, Henbury #6, Rodinga #6, Tempe Vale #1, Tent Hill #1 and especially Mt Liebig #2. Additional information relating to facies distribution was obtained by outcrop sections which were measured by R. S. Nicoll and J. R. Laurie. Each of the facies has been depicted on the well logs and measured sections and are presented in Appendices 7, 8 and 9. Photographs of the facies are contained in Plates 1 and 2.

Data relating to the distribution of fossils was largely obtained from wells as poor exposure makes observations in the field difficult. Within the cores examined, a rich and varied biota was observed and provided much needed information about depositional environments such as the presence or absence of body fossils, mode of preservation, species associations within groups of fossils and presence or absence of bioturbating organisms.

The presence or absence of bioturbating organisms (trace fossils) proved to be a useful tool despite being confined to a few facies only. Their distribution has been plotted in the well logs (Appendix 7). Studies of modern depositional environments have shown that burrowing and scavenging activities of benthic organisms are controlled largely by the concentration of oxygen in the bottom water (Theede and others, 1969; Rhoads and Morse, 1971). From this it can be inferred that the amount and composition of organic matter preserved in the sediment was determined largely by the concentration of oxygen in the bottom water and the extent to which the sediment was disrupted by burrowing organisms. This concept will be discussed more fully later.

PACOOTA SANDSTONE

Huckaba (1970) subdivided the Pacoota Sandstone into four informal members, P1 (uppermost) to P4, which reflect vertical lithofacies variations in a clastic dominated shallow marine environment. I shall only discuss the lithofacies of the uppermost member of the Pacoota Sandstone, P1. This interpretation is that of Nicoll and others (1986) and is repeated here, due to its transitional nature with the overlying Horn Valley Siltstone.

The 'P1' member consists of interbedded siltstone, sandstone and shale. Outcrops are commonly poorly exposed and covered by talus. However, a number of coarsening upward cycles can be observed in this unit. The sandstone beds usually contain vertical burrows of *Diplocraterion* and have indistinct cross bedding, whereas the siltstones and shales are dominated by elements of the *Cruziana* ichnofacies, or are strongly bioturbated by non-diagnostic burrows. Shelly fossils are rare. The presence of a *Skolithos* ichnofauna in the sandstones suggests that shallow water conditions prevailed, but the interbedded silty to shaly beds containing elements of the *Cruziana* ichnofauna indicate deeper water conditions existed in some areas. The overlying Horn Valley Siltstone is the culmination of this trend toward greater water depth.

HORN VALLEY SILTSTONE

The Horn Valley Siltstone consists of four main lithologies:

(1) A medium to dark grey mudstone which is organic rich and may be thin to thick bedded. It is commonly fossiliferous, containing trilobites and graptolites. It is also characterised by the

presence of cryptic lamination and has abundant carbonate concretions in some sections;

(2) A laminated calcilutite consisting of light grey carbonate lenticles and laminae in a medium grey siltstone. This lithology is characterised by wavy to lenticular bedding and may be bioturbated and fossiliferous;

(3) Silty or nodular limestone. It has a variable silt content (up to 50%) and has abundant fossils. It is also characterised by its irregular and wavy bedding with limestone pods separated by siltstone laminae;

(4) Coquinas rich in fossils (trilobites, brachiopods, gastropods, etc) and sometimes dominated by single species. They normally have a sharp lower boundary and low silt content.

The proportion, ordering and thickness of beds of the different lithologies depends upon location within the basin. Carbonate content is highest around the southerly margin of the basin, and decreases northwards as the shale content increases. Most of the core sections indicate an increase in the proportion of carbonate upwards in the Horn Valley Siltstone.

A classification of shales (Fig. 4) based on such features as presence or absence of trace fossils, body fossils and sedimentological features was devised by Morris (1979) for the Lower Jurassic shales of Yorkshire, Great Britain. Such a classification scheme can be applied to the Horn Valley Siltstone. A "normal shale" is a unit which contains homogenous bioturbated sediments often with sideritic nodules or horizons. Trace fossils are abundant and benthic body fossils are abundant and diverse. A "restricted shale" consists of poorly laminated sediments with scattered calcareous concretions. Bioturbation is generally sparse, with thin discrete pyritic burrows, while the benthic fauna is dominated by deposit feeding protobranch bivalves. Finally, a "bituminous shale" is a finely laminated sediment with pyritic calcareous concretions, little or no bioturbation, and a benthic fauna which is sparse and entirely epifaunal.

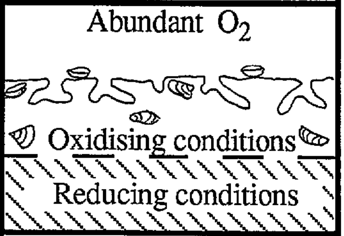
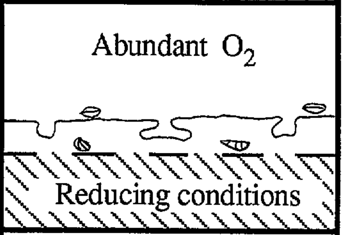
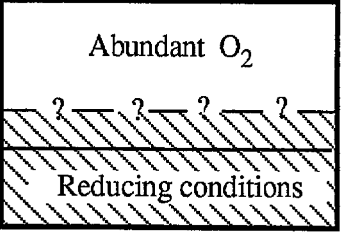
FACIES	BIVALVE GROUPS	TRACE FOSSILS	CONCRETIONS	HORN VALLEY SILTSTONE	ENVIRONMENTAL INTERPRETATION
Normal Shale	Epifaunal and infaunal suspension, infaunal deposit	Abundant Chondrites horizontal burrows	Sideritic and Calcareous	HV1, HV2	 Abundant O_2 Oxidising conditions Reducing conditions
Restricted Shale	Dominant infaunal deposit	Few unbranched horizontal burrows	Calcareous	HV4	 Abundant O_2 Reducing conditions
Bituminous Shale	Dominant epifaunal suspension	None	Pyritic calcareous	HV5, HV6, HV7	 Abundant O_2 ? ? ? ? Reducing conditions

Figure 4. Summary and interpretation of shale facies (modified from Morris, 1979)

I have subdivided the Horn Valley Siltstone into ten informal members, HV1 (lowermost) to HV10, which reflect vertical lithofacies variations within a shallow marine shelf environment. The distribution and relationship of these members will be discussed below.

HV1 This member consists of a black pyritic mudstone interlaminated with a thin medium grey siltstone which in some wells are fissile and brittle. The sedimentary laminae are wispy and discontinuous in places due to minor bioturbation. The silty parts of this sequence have been more extensively burrowed and reworked than the muddier parts, with horizontal burrows being the main type of trace fossil preserved in this facies; a possible vertical burrow was noted at Mt Liebig #2. There are three distinct types of burrows:

(1) The first type consists of straight to gently curved burrows more or less parallel to stratification. The burrows are up to 6mm in width and extend the full width of the drill core. In transverse section the burrows range form equidimensional to rounded or somewhat flattened parallel to the bedding plane. The burrow fill is the same as the enclosing sediment. No signs of branching were noted, although these burrows do display signs of minor vertical movement, which was probably in response to sediment influx. This burrow type would be either *Palaeophycus* or *Planolites;*

(2) Rare *Chondrites* -type burrows were also observed. These burrows are simple, smooth and up to 5mm in width. They appear to branch and radiate in numerous directions. It is difficult to tell if these branches are confined to the one bedding plane or if they have penetrated down from the overlying sequence because most of the burrow network appears to be parallel to the bedding plane and often extends beyond the drill core. The composition of the burrow fill appears to differ from the enclosing sediment;

(3) Thin non-descript unbranched horizontal burrows, lying parallel to bedding are also preserved. These burrows have smooth walls with burrow diameters commonly 1-2mm and a maximum of 5mm. The burrow fill appears to be the same as the enclosing sediment and is similar to *Palaeophycus.*

HV1 is characterised by the absence of body fossils and was deposited under conditions similar to those of many modern shelf muds. It represents the onset of the marine transgression. It was probably deposited under reasonably quiet conditions, in a well oxygenated environment which was actively reworked by a benthic macrofauna moving in a horizontal sense only. The burrows do not show signs of vertical movement in response to rapid sediment influx. HV1 would be classified as a "normal shale" in Morris (1979) classification scheme. The sediments may have been deposited in a two layer substrate (Sellwood, 1971) consisting of an upper oxidising layer extending from the sediment-water interface to a depth of about 0.25m, with reducing conditions extending below this depth (see Fig. 4). Such conditions are apparently common in modern shelf muds (Frenchel, 1969).

HV2 This member consists of strongly bioturbated dark grey mudstone and light grey siltstone which is calcareous in places. This grades upwards into a silty very fine grained sandstone and siltstone. The sandy zones are light grey coloured and strongly calcareous. Pyrite is scattered throughout. Glauconite becomes more common towards the top. Bioturbation is intense to complete, with remnant sedimentary lamination only occasionally visible. The pronounced reworking has resulted in giving this unit a striking bioturbated texture which is mottled in appearance. Although innumerable biogenic structures can be recognised, very few are distinctive and well enough preserved to be ascribable to individual ichnogenera or ichnospecies. Thus general descriptions only can be given.

Thin, straight to gently curved burrows up to 3mm in width, more or less parallel to one another, are common throughout this member. In transverse section, the burrows are rounded and the burrow fill is the same as the enclosing sediment. These unbranched burrows appear to intersect one another frequently.

A more common type of burrowing structure in this member has probably resulted from the animal's response to an increase in sedimentation rate. These burrows are commonly less than 10mm in diameter, with the average about 4mm and a maximum reworked depth of 15cm. They may be inclined or curved and some have been infilled with pyrite. These burrows are tube-like in shape and have spreite-like marks which curve upwards and thus parallel the base of the burrow. This suggests the animal has had to move upwards quickly through the sediment, resulting in a burrow which is of diameter equal to the animal's width (rather than being tapered).

Bioturbation in the form of much wider burrows, up to 20mm in width, has been noted. These burrows also suggest that the organism had to move upwards in response to sediment influx. However, their larger size suggest they may represent feeding or dwelling traces from shelly organisms.

Most of the burrows in this member display movement upwards rather than displaying signs of lateral sediment reworking (ie horizontal branching). Many burrows have either been reworked or truncated by other burrowing organisms.

Vertical and U-burrows represent only a minority of the structures in this member. They are generally 1-2mm in width, with smooth burrow walls. Their depth of sediment penetration is a maximum about 10mm, and some are truncated by much larger burrows.

This unit generally lacks body fossils, but in some wells there are remains of rare trilobites and shells. Perhaps due to the localised nature of these fossil deposits, they may represent storm type deposits. The sediments were deposited more rapidly than HV1, in a well oxygenated environment, and the burrows do not show signs of lateral sediment reworking, but rather the organisms have burrowed upwards quickly through the sediment as a response to sediment influx. This has resulted in some burrows being truncated. This facies would also be regarded as a "normal shale" by Morris (1979).

HV 3 The culmination of the initial transgression is represented by member HV3. This member commences with a massive, coarsely crystalline limestone which grades into a grey micritic nodular limestone with wavy black mudstone laminae. However, in some wells it is white to pale greyish brown and dolomitic. The mudstone and finer siltstone units generally have undisturbed or complete sedimentary laminae. Pyrite is disseminated throughout and may be preserved in the form of veins or concretions.

This member contains no signs of trace fossils, but contains fragmental shell debris, which appears to be mainly confined to the mud units which drape over and around the limestone. In Mt Liebig #2, the shells are fragmented and lath like in appearance, measuring up to 10mm in length, but more commonly 3-4mm. These shells are aligned subhorizontally, paralleling the laminae in the muddy units. The non-random nature of the shells suggests that in the northern part of the basin, debris flows may have occurred. However, this depositional pattern is not exhibited in all the cores. For the majority of the basin, the shells appear randomly oriented. They represent a slowing in the sedimentation rate and a shallowing in water depth, where a profilic infauna reworked the sediments and allowed precipitation of micritic nodular limestone. This carbonate unit is very distinctive and provides a useful marker bed throughout the basin. It is this member that is often cited in boundary definitions between the Pacoota Sandstone and the overlying Horn Valley Siltstone (eg Nicoll & Jakeman, 1986).

HV 4 HV4 is gradational with the underlying and overlying members and consists of minor micritic limestone nodules in a well bedded shale-siltstone. The siltstone is dark greenish-grey in colour whilst the shale is medium to dark grey. It has a blocky-conchoidal fracture and is very friable. In some wells the limestone units are represented as non-nodular dolomitic horizons which are light to medium brown grey to grey in colour. The dolomite is crypto-crystalline and contains a sparse conodont fauna of poor diversity (R. S. Nicoll, pers. comm, 1988). Randomly oriented fossil fragments of brachiopods and nautiloids are contained within the limestone nodules, towards the top of the member. Occasional trilobites and thin calcareous concretions were noted in the shaly horizons of this member in Tent Hill #1 well. Nodular and disseminated pyrite occur also.

This member is characterised by a marked decrease in the intensity of bioturbation (with possible burrows recognised in only one well), the absence of deep burrowing organisms, and the domination of the benthic macrofauna by infaunal deposit feeding organisms (brachiopods, nautiloids and trilobites). These factors suggest this member was deposited in a deeper environment than HV3 and a gradual deterioration of bottom conditions prevailed. This would have resulted in the loss of the oxidising layer in the sediment, with reducing conditions extending almost up to the sediment surface. The reducing conditions within the sediment and a gradual reduction in the amount of dissolved oxygen in the bottom waters would have caused an increase in environmental stress, leading to a decrease in the abundance and diversity of deep burrowing organisms. This facies is considered to belong to the "restricted shale" facies of Morris (1979).

HV 5 The deterioration in bottom conditions seen in HV4 is exemplified in the overlying members HV5, HV6 and HV7. HV5 consists predominantly of very finely laminated, dark grey to black, pyritic, fossiliferous mudstone with rare, thin, micritic limestone-dolomite beds. This member displays little or no signs of bioturbation, with the mudstone and finer siltstone units generally having undisturbed or complete sedimentary laminae whilst the more calcareous parts of this unit contain body fossils. Trilobites and graptolites are the dominant fauna in this member. The fossils are well preserved, are not fragmented and appear to have a shiny black coating on them. Some have been filled or replaced by pyrite.

The low diversity of fossils, consisting almost entirely of epifaunal feeders (with infaunal types being rare or absent) and their extremely good preservation, suggests euxinic conditions prevailed on the sea bottom. The reducing conditions probably extended up to, if not at times above, the sediment surface (Fig. 4). This facies would be classified as a "bituminous shale" by Morris (1979).

HV 6 Overlying HV5 is another "bituminous shale", consisting also of a black, pyritic, calcareous, highly fossiliferous mudstone. A fairly common grey muddy limestone is interbedded with the mudstone. The pods and lenses of limestone vary greatly in size and shape, and appear to consist of fine shell debris. Some of the smaller pods (up to 4cm thick) may even represent amorphous carbonate concretions. The mudstone is medium to dark grey in colour and fissile. Possible small burrows in the calcareous mudstone were noted toward the top of HV6 but in general no trace fossils were observed in this member. This member is very fossiliferous with trilobites, graptolites and indeterminate shell debris being mainly confined to the mudstone beds.

HV6 can be distinguished from HV5 by the rapid increase in the amount of carbonate contained in it. This increase in carbonate content suggests a shallowing in depositional environment upwards from HV5.

HV 7 Gradationally overlying HV6 is another "bituminous shale". It can be recognised by the sudden change in shale to carbonate ratio, with shale now the dominant rock type. In Tent Hill #1, the boundary between HV6 and HV7 is marked by the appearance of a thin brecciated layer containing fine white calcareous fragments. HV7 is predominatly a black, pyritic, highly fossiliferous mudstone with occasional thin beds of muddy, grey, micritic limestone. The mudstones are very dark grey to black in colour, very friable, pyritic and calcareous. Pyrite occurs both as disseminated crystals and nodules up to 1cm across. This member displays little to no sign of bioturbation. The mudstone and finer siltstone units generally have undisturbed sedimentary laminae. Excellently preserved body fossils, sometimes with a shiny black coating, can be found on the bedding planes in the mudstone sequences. Trilobites dominate and range in width from 3mm up to 3-4cm. Minor graptolites and occasional shell fragments are also preserved. The light grey limestone, which is usually fossiliferous, has gradational contacts with the enclosing mudstone. The unbioturbated mudstone, the excellently preserved fossils and the reduction in carbonate content upwards suggests these beds were deposited in a deepening environment hostile to benthic organisms.

Preservation of organic matter, such as in members HV5, HV6 and HV7, is an important element in the formation of organic, carbon rich, black shales. The origin of organic carbon rich sediments throughout the geologic column is still controversial. Several authors (eg Brumsack, 1980) favour "stagnation" of deep water, ie an extremely reduced deep-water circulation, as the main cause for the deposition of black shales (Fig. 5A). Extremely reduced vertical circulation prevents a sufficient ventilation of the deep-water sphere, resulting in basin-wide oxygen deficiency. If the oxygen demand required for the oxidation of organic matter exceeds the already reduced oxygen supply, anoxic conditions in the water column would occur and would enhance the preservation of organic matter in the sediment. The modern Black Sea is often referred to as the type example for organic carbon deposition in anoxic environments (eg Stein and others, 1986).

The shales of the Horn Valley Siltstone have been interpreted (eg Jackson and others, 1984) as having accumulated in a restricted marine shelf environment, with the surface waters being well aerated and the bottom conditions euxinic. The surface waters are considered to have supported nektonic and planktonic organisms, which ultimately sank through the water column after death and were preserved from degradation by the highly reducing conditions on the sea floor. However, the presence of extensively burrowed and oxidised sediments above and below the black shales in this ocean argue against such bottom-water anoxia being extensive in either volume or duration.

An alternative scenario leading to greater preservation of organic matter calls for the midwater oxygen minimum zone (oxygen-depleted intermediate waters) to become intensified and perhaps expanded through sluggish circulation or enhanced influx of organic matter (eg Demaison &

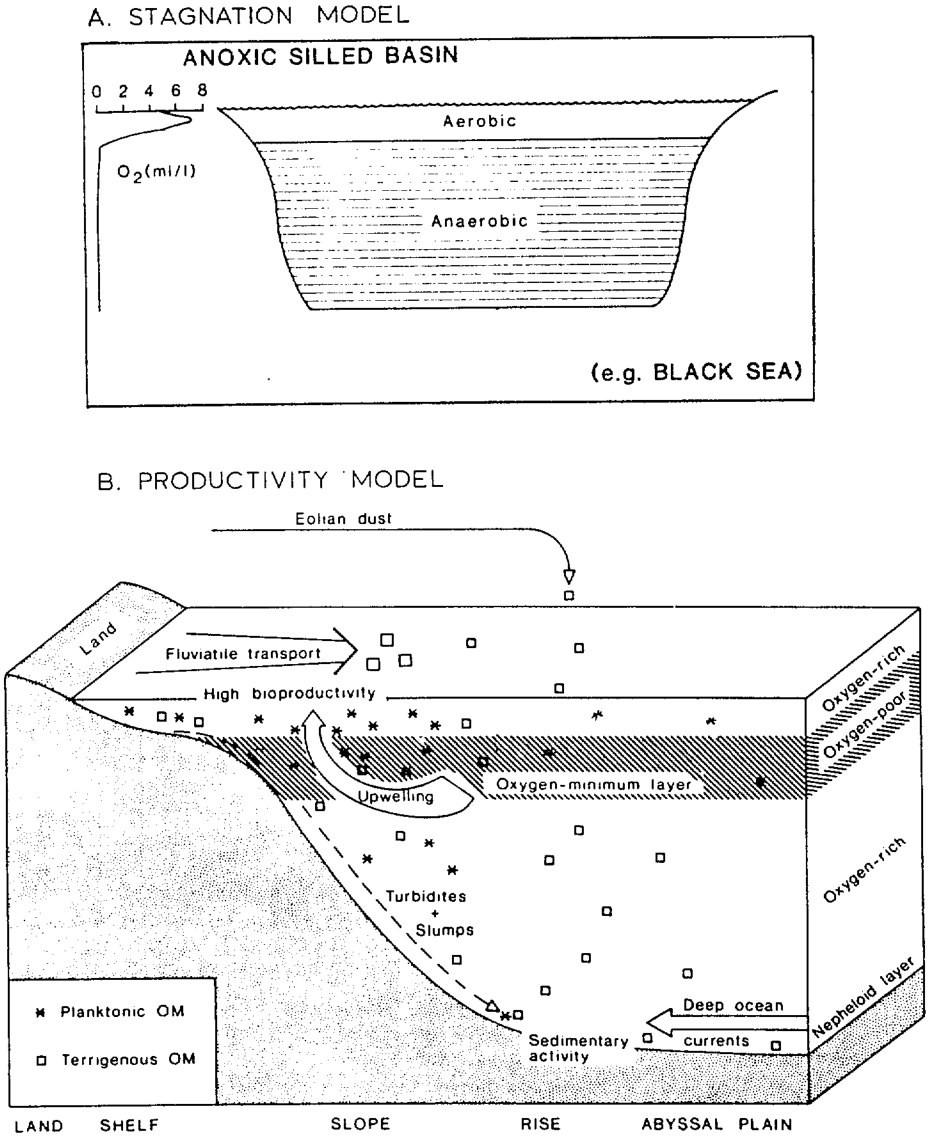


Figure 5. General models for the deposition of organic carbon rich sediments.

(A) Stagnation model of the type "Black Sea"

(B) Productivity model, including influences of oxygen - minimum layer, terrigenous input and turbidity currents (from Stein and others, 1986).

Moore, 1980; Waples, 1983; Stein and others, 1986). Where a midwater anoxic layer intercepts the ocean bottom, sediments rich in organic matter can accumulate (Fig. 5B). The dissolved oxygen values may approach zero where the oxygen minimum layer impinges on the continental slope under highly fertile and productive surface waters, ie in upwelling areas (Fig. 5B). This may result in high organic carbon concentrations in the sediments and high accumulation rates. In contrast to the "stagnation" model where anoxic deep-water conditions are the cause for increased preservation and accumulation of organic carbon, distinctly increased flux rates of marine organic matter may cause anoxic sedimentary environments in areas of very high productivity (eg Morris and others, 1984). Such a scenario may be possible for the Horn Valley Siltstone.

A third scenario for the preservation of organic-rich deposits in the deep-sea environment, does not necessarily require oxygen-minimum or euxinic basin settings nor conditions related to water column stratification, upwelling or high organic productivity. Further important parameters that favour the accumulation of organic-carbon-rich sediments according to Stanley (1986) and Stein and others (1986) are:
(1) increased supply of terrestrial organic matter;
(2) increased bulk sedimentation rates;
(3) turbidite flow and slumping.
These parameters are affected by depositional processes as well as conditions at the site of accumulation. The effect of processes (2) and (3) above involves rapid burial which facilitates the preservation of organic matter in some deep non-euxinic marine basin settings and thus reduces its residence time in zones of bioturbation and oxic decomposition. Evidence from other members of the Horn Valley Siltstone (HV1, HV2 and parts of HV3) point to rapid sedimentation rates and gravity induced depositional transport processes; such processes may also have existed during the deposition of members HV5, HV6 and HV7. This would explain the restriction in both volume and duration for bottom water anoxia. Thus the organic rich mudstones and fossiliferous carbonates imply episodic high productivity and accumulation of organic matter in a generally oxic

depositional environment.

HV8 This member sees a return to less hostile bottom conditions and the start of the regressive phase of deposition in the Horn Valley Siltstone. HV8 consists of a series of thin beds of silty fossiliferous limestone, sometimes marly, which is overlain by a black pyritic mudstone. Occasional pyrite can be found in the limestone but it is mainly disseminated throughout the mudstone. The shelly limestone beds appear to have cut down irregularly into the underlying mudstone beds, perhaps representing a series of storm related deposits, with shell debris at the base, capped by fine muds which have settled from suspension. The fossils appear to be mainly confined to the limestone-marl units. In some wells, the shelly fossils are not fragmented and are well preserved with both valves still joined at the hinge line. The relatively good preservation in the coquinas indicate any one of the following scenarios:

(1) the shelly organisms may have been covered by sediment before, during or very soon after death;

(2) little current or wave action prevailed;

(3) rapid accumulation or limited transportation of the organisms from the site of accumulation.

HV9 The regressive phase of sedimentation continued with the deposition of HV9. This member, like HV8, consists of a dark grey to black, finely laminated, pyritic mudstone with thin interbeds of grey, calcareous siltstone, and fossiliferous, white to light grey limestone. Most of the limestones in this sequence are bioclastic and wispy in shape and are composed largely of shell debris. These beds contain no signs of bioturbation. They are overlain by a series of cyclic sediments. Each cycle begins at the base with a shelly limestone (coquina) which has a sharp irregular base and fines rapidly upwards where it is almost silt free. It consists mainly of brachiopods, nautiloids and trilobites. It is then gradationally overlain by a marl. This weakly laminated calcilutite has possible cross bedding at the base of the unit becoming horizontal towards the top of the unit. The cycle is completed with the deposition of a mudstone unit. The mudstone is medium to dark grey in colour, well sorted, very fissile and has a gradational lower boundary. The only fossils found in the upper part of the cycle were a single sideritic? trilobite and an indeterminate shell fragment. These cycles are only apparent in member HV9 and are well developed in Tempe Vale #1 well. In some places the full cycle is not represented and the upper mudstone unit or the marl may be absent. This is typical in Tent Hill #1. Cone-in-cone structures are present in this member and could be confused with some shelly fossils.

These cycles may represent gravity flows, storm deposits or a combination of both. The sharp bases of the coquinas, their thickness and their association with the marl-mudstone tops of the cycles, all suggest an origin related to storm activity. However, the precise mechanism of storm origin is uncertain. Possibly shells, carbonate mud and silt were transported some distance by a mechanism such as a turbidity current. In this case the lower limestone unit consisting of shell fragments probably has been transported from shallower water and represents a shell lag deposit. The marl (calcilutite) is probably generically related to the limestone and would represent the final settling stage of the carbonate mud from the gravity-flow or storm generated currents after the coarse shelly debris has settled out. The overlying mudstone would represent the normal background sedimentation on a shallow marine shelf. Alternatively, storm current activity winnowed out the mud, thereby concentrating the shells. This second mechanism would be consistent with the single species dominance of some coquinas, as it requires virtually no transport and mixing of communities. However, the former mechanism better accounts for the very sharp bases and absence of silt in the coquinas. Irrespective of the exact mechanism of origin, the inferred association with storm activity indicates that the coquinas accumulated within a shallow environment.

HV10 The deposition of the Horn Valley Siltstone terminates with HV10. This member commences with a black mudstone interbedded with a medium grey, non-calcareous, fine siltstone. It then merges into a fine grained sandstone. The sandstone has been reworked by burrowing organisms. They are sparse and few well defined burrows are to be found. Minor shell fragments are only present in some wells. This could indicate deposition was rapid and the organisms had little time for sediment reworking; they had to keep pace by moving upwards with the aggrading sediment. However, there are no signs of vertical burrowing in the sequence. Alternatively, it might mean that deposition was excessively fast, resulting in total smothering of the organisms, followed by excessive erosion to wash them out of the substrate. This situation could occur in a rapidly changing environment such as a lower to upper shoreface environment. The Horn Valley Siltstone then grades into the overlying Stairway Sandstone.

STAIRWAY SANDSTONE

The Stairway Sandstone has been broadly subdivided into three units, as outlined in Cook (1986). I will only discuss the lithofacies of the lower unit which directly overlies the Horn Valley Siltstone. This unit, called SS1 informally here, is characterised by an abundance of sedimentary structures including ripple marks and cross beds as well as ichnofossils.

SS1 This unit is quite variable at different localities. In most wells it can be recognised as the first clean sandstone overlying the muddy sequences of the Horn Valley Siltstone. However, in some wells (eg Mt Liebig #2) it consists of fine interbeds of light grey siltstone and dark grey mudstone. Visually, this member is very similar to HV1, although in SS1, siltstone rather than mudstone predominates and scattered phosphate grains (some up to 1mm) are present. But, common to all wells, is its presence of bioturbation.

Trace fossils are common in SS1, with horizontal burrows being the dominant style of bioturbation. Simple, smooth, cylindrical burrows, up to 5mm in width (but more commonly 1-3mm wide) are preserved parallel to bedding planes. The burrow fill is the same as the enclosing sediment. Possible branching was noted, although it is difficult to tell if these branches are confined to one bedding plane or if they have penetrated down from the overlying sequence, because most of the burrow network appears to be preserved in the one bedding plane. This burrow is of the *Phycodes-Treptichnus* type and indicates that the sediments were actively reworked by infaunal, deposit feeding animals. It was initially deposited in a shallow (intertidal-subtidal) environment (Cook, 1986).

ORGANIC GEOCHEMISTRY

Organic geochemical data are widely used to characterise crude oils and evaluate petroleum source rocks. With appropriate sampling, the amount and composition of organic matter preserved in sedimentary rocks have shown to be useful indicators of environment of deposition, palaeoclimate and palaeo-oceanographic conditions (Tissot and others, 1980). Rock-Eval analysis was carried out on samples from two wells, Tempe Vale #1 and Tent Hill #1. This involved a whole-rock pyrolysis technique to identify the type, quantity and maturity of the organic matter and to detect petroleum potential and oil shows in the source rock. Substantial differences were evident in the amount and type of organic matter between the predominantly laminated lithofacies (HV5, HV6, HV7) and the predominantly nonlaminated lithofacies (HV2, HV3, HV8). Many samples of the Horn Valley Siltstone, encompassing all major lithofacies, were selected for organic geochemical study. These analyses were conducted by Dr Barbara Jakeman whilst working for the BMR. Data obtained includes: Productivity Index [PI=S1/(S1+S2)]; Petroleum Potential [PC=k(S1+S2) where k=0.083]; Hydrogen Index [HI=S2/Corg]; Oxygen Index [OI=S2/Corg]; Total Organic Carbon [TOC] and Thermal Maturation [Tmax]. The results of these analyses are listed in Appendices 5, 6 and 8.

Pratt (1984) showed that sedimentological and geochemical data from the Greenhorn Formation, Pueblo, Colorado indicate that the amount and type of organic matter in the various lithofacies correlated strongly with the extent to which the sediment was bioturbated. The relationship between bioturbation and composition of organic matter is shown most clearly on a plot of hydrogen indices versus oxygen indices (Pratt, 1984, Fig. 5). She showed that limestone samples have low hydrogen indices and variable oxygen indices. The marlstone and calcareous mudstone samples plot along a vertical trend and have intermediate hydrogen indices. The shale samples have high hydrogen indices and plot along a vertical trend. The same three groups of samples could be distinguished using the ratio of pyrolitic hydrocarbon yield, (S1+S2) to C_{org}. Similar trends have been observed in the Horn Valley Siltstone cores.

Samples that are predominantly laminated, shaly and containing occasional well preserved fossils, like trilobites and graptolites, have high hydrogen indices. This group is represented by members HV5, HV6, HV7, HV10, SS1. Lower hydrogen indices were noted in the predominantly nonlaminated samples, which are either moderately bioturbated (marlstone, mudstone) or highly bioturbated (limestone). These nonlaminated samples have either had their bedding structures totally obliterated by burrowing organisms or have been scavenged by shelly type organisms (eg bivalves, brachiopods and nautiloids) and graptolites. The facies which have lower hydrogen indices are represented by HV1, HV2, HV3, HV4, HV8 and HV9.

The distribution of facies in relation to hydrogen and oxygen indices is displayed in Fig. 6. Various degrees of bioturbation are distinguished in the Horn Valley Siltstone members. Each field is inferred to reflect the oxygen concentration in the bottom water during and shortly after deposition. The definition of each of these fields has been modified from Pratt (1984). Highly burrowed strata are strata which have been extensively disrupted by vertical and horizontal burrows greater than 5mm in diameter or have been disrupted by scavenging shell type organisms and are considered indicative of well oxygenated bottom water. Moderately burrowed strata are strata which have been partially disrupted by horizontal burrows less than 5mm in diameter and are non laminated. These are considered indicative of moderately oxygenated bottom water. Laminated strata are thinly layered strata that have not been disrupted by horizontal burrows. They can contain rare, well preserved, body fossils, which have been deposited in the sediments and were not bottom dwelling. They are considered indicative of poorly oxygenated (anoxic) bottom water.

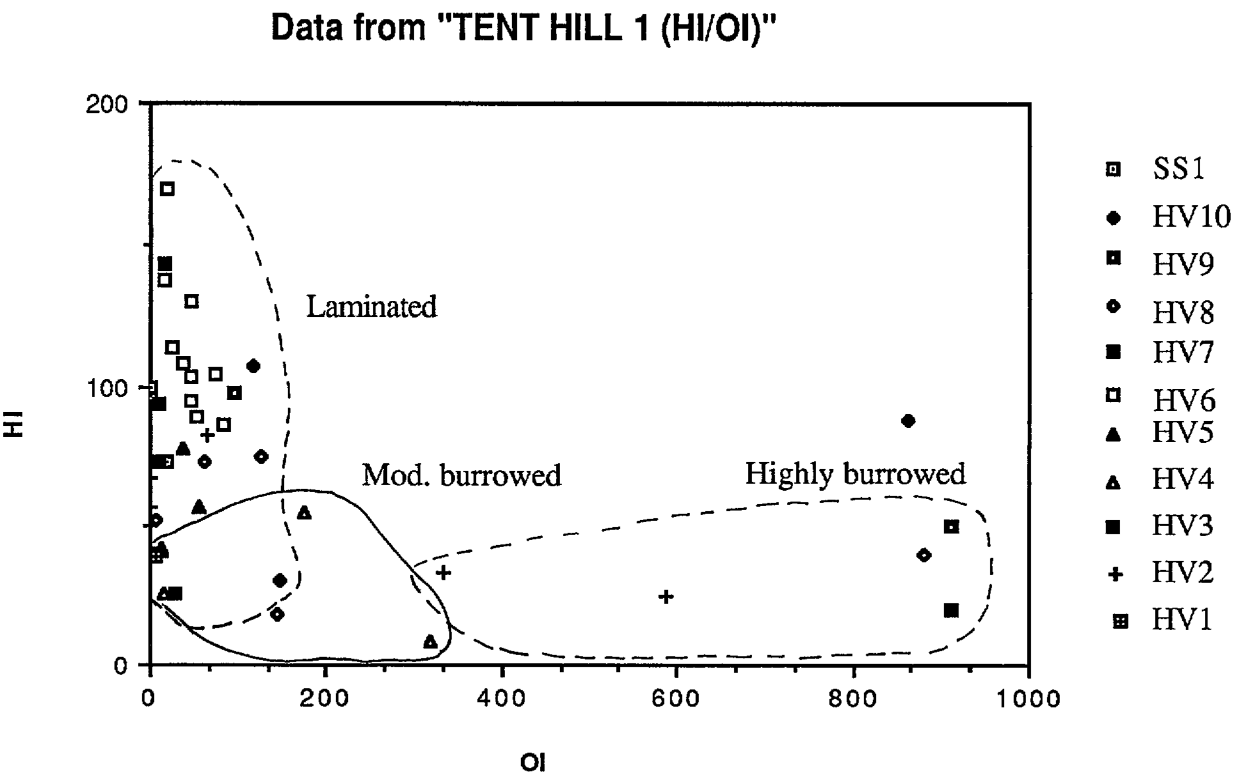


Figure 6. Plot of Hydrogen Index vs Oxygen Index for Tent Hill #1. Members HV2, 3, 8 & 9 represent highly macroburrowed sediments. HV1 & HV4 represent moderately burrowed sediments and HV5, 6, 7, 10 & SS1 are mainly laminated sediments.

As seen in the Horn Valley Siltstone cores, with decreasing bioturbation there is a decrease in the abundance of current-induced sedimentary features such as lenses and laminae of well sorted calcarenite-calcisiltite and scour-and-fill features. The lack of current-induced structures indicates little mixing of the bottom water and slow advection of oxygen during times when laminated sediments rich in organic matter were deposited. The close association between current-induced sedimentary features, degree of bioturbation, and C_{org} suggests that a major control on the amount of organic matter preserved in the sediment was the rate at which oxygen was supplied to the bottom water by currents. With increasing bioturbation there is a marked decrease in the hydrogen richness of organic matter remaining in the sediment (Fig. 6).

In the moderately and highly burrowed members of the Horn Valley Siltstone (HV2, HV3, HV8), scavenging by burrowing organisms and associated oxidative processes appear to have removed nearly all of the organic matter from the sediment as it passed through the bioturbated zone. In the underlying anoxic zone, the residual organic matter would have been further decomposed by a microbial assemblage that included sulfate-reducing bacteria. This can be seen by low TOC values in these members. The fate of organic matter in the laminated members (HV5, HV6, HV7) would have been quite different than in the burrowed members. There is little evidence of scavenging activities in the laminated sediments and any organisms that were present must have been inefficient and restricted to the uppermost few millimeters. This is further reinforced by high TOC values.

Thus sedimentological and geochemical data from Tent Hill #1 and Tempe Vale #1 wells indicate that the amount and type of organic matter in the various members correlate strongly with the extent to which the sediment was bioturbated. It can also be inferred that the amount and composition of organic matter preserved in the sediment was determined largely by the concentration of oxygen in the bottom water and the extent to which the sediment was disrupted by bioturbating organisms. Further, the close association between abundance of current-induced sedimentary structures, extent of bioturbation, and amount of organic matter suggests that the strength and frequency of benthic currents determined the rate at which oxygen was supplied to the bottom water rather than by the rate of oxygen consumption in the benthic environment.

Ordovician sediments and oils possess unusual hydrocarbon profiles which are related to the abundance of *Gloeocapsomorpha prisca,* a cyanobacterium associated with oil formation (Foster and others, 1986). Its distribution and associated sedimentary environment can be obtained from TOC and TMAX data. These data were derived for Tent Hill #1 and Tempe Vale #1 wells, the samples being processed and analysed by Dr Barbara Jakeman. This was not only useful from a geochemical and sedimentary environment point of view, but was also of interest in determining the association of *G. prisca* with other fossils, both body and trace fossils.

Reed and others (1986) described the typical occurrence of *G. prisca* in thin, organic rich laminae within bioturbated limestones. They concluded that these organisms formed benthic "mats" on the shallow sea floor. On the other hand, Foster and others (1986), studying similar *G. prisca* rich beds, concluded that the organism was planktonic and "bloomed" periodically before settling to the bottom to produce kerogenite beds. Calcareous algae occur in limestones associated with the younger beds, but are missing in the fossil-rich limestones associated with the lower kerogenites. This suggests that *G. prisca* could accumulate in a variety of water depths, both above and below the photic zone (Longman & Palmer, 1987).

The transition between HV6 and HV7, which can be recognised by the sudden change in shale to carbonate ratio, coincides with the presence of highly organic rich sediments, with TOC values of up to 6.30% being recorded. This interval coincides with the *G. prisca* blooms and the main source of hydrocarbons in this formation.

CONCLUSIONS

The Horn Valley Siltstone was deposited during a transgressive-regressive episode, with the paleoshoreline assumed to have been located along the southern margin of the basin, although its precise location is unknown. The increase in carbonate upwards in the Horn Valley Siltstone, indicates shoaling upwards in the formation.

The organic-rich, black mudstones in the Horn Valley Siltstone may not necessarily have accumulated in a restricted marine shelf environment where surface waters were aerated and bottom conditions euxinic. The presence of extensive burrowed and oxidised sediments above and below the black mudstones in this ocean argue against such bottom-water anoxia being extensive in either volume or duration. Instead these conditions probably represent short episodes of rapid burial which facilitated the exceptional preservation of organic matter and thus reduced its residence time in zones of bioturbation and oxic decomposition. The interbedded limestones and mudstones show poorer preservation and were probably deposited within turbulent, better oxygenated and shallower shelf settings. Limited evidence also exists for the existence of hardgrounds in this shallow marine shelf with burrowing in the silty (nodular) limestone and in some marls.

The most organic rich sediments, with high TOC values, tend to occur at the transition of facies HV6 and HV7. Explanations for this episodic yet high organic matter productivity are speculative. Biological nutrients could have been supplied by periodic upwelling or by rivers draining into the area. But, changes in environmental factors and sedimentation rates more likely were responsible.

REFERENCES

BARRIE, J., 1964. Phosphate drilling, Amadeus Basin. *Bureau of Mineral Resources, Australia, Record, 1964/195,* 22p.

BRUMSACK, H. J., 1980. Geochemistry of Cretaceous black shales from the Atlantic Ocean (DSDP Legs 11, 14, 36 and 41). *Chemical Geology, 31(1/2),* 1-25.

CHEWINGS, C., 1935. The Pertatataka series in central Australia, with notes on the Amadeus sunkland. *Transactions of the Royal Society of South Australia, 59,* 141-163.

COOK, P. J., 1986. Stairway Sandstone *in* Late Proterozoic and Early Palaeozoic depositional facies of the northern Amadeus Basin, central Australia (Kennard, J. M. & Nicoll, R. S. eds.) Field Excursion 25B, Amadeus Basin, 12th International Sedimentological Congress, Canberra, 1986, 54-55.

COOPER, B. J., 1981. Early Ordovician conodonts from the Horn Valley Siltstone, central Australia. *Palaeontology, 24(1),* 147-183.

DEMAISON, G. J. & MOORE, G. T., 1980. Anoxic environments and oil source bed genesis. *The American Association of Petroleum Geologists, Bulletin, 64(8),* 1179-1209.

FORMAN, D. J. & SHAW, R. D., 1973. Deformation of the crust and mantle in central Australia. *Bureau of Mineral Resources, Australia, Bulletin, 144,* 20p.

FOSTER, C. B., O'BRIEN, G. W. & WATSON, S. T., 1986. Hydrocarbon source potential of the Goldwyer Formation, Barbwire Terrace, Canning Basin, Western Australia. *The Australian Petroleum Exploration Association Journal, 26(1),* 142-155.

FRENCHEL, T., 1969. The ecology of marine microbenthos. Structure and function of the benthic ecosystem, its chemical and physical factors and the microfauna communities with special reference to the ciliated protozoa. *Ophelia, 6,* 1-182.

FROELICH, A. J. & KREIG, E. A., 1969. Geophysical - geologic study of northern Amadeus Trough, Australia. *The American Association of Petroleum Geologists Bulletin, 53(9),* 1978-2004.

GORTER, J. D., 1984. Source potential of the Horn Valley Siltstone, Amadeus Basin. *The Australian Petroleum Exploration Association Journal, 24(1),* 66-90.

GORTER, J. D., 1986. Mt Winter 2A, Well Completion Report, Amadeus Basin, OP178, Northern Territory. *Pancontinental Petroleum Limited, PPL Report 204* (Unpublished).

HUCKABA, W. A., 1970. Thickness and porosity of the Pacoota Sandstone in the Mereenie Field, Northern Territory, Australia. *Report for Magellan Petroleum (NT) Pty Ltd* (unpublished).

JACKSON, K. S., McKIRDY, D. M. and DECKELMAN, J. A., 1984. Hydrocarbon generation in the Amadeus Basin, central Australia. *The Australian Petroleum Exploration Association Journal, 24(1),* 42-65.

JONES, P. J., 1971. Lower Ordovician conodonts from the Bonoparte Gulf Basin and the Daly River Basin, northwestern Australia. *Bureau of Mineral Resources, Australia, Bulletin, 117,* 80p, 9pls.

KENNARD, J. M., NICOLL, R. S., & OWEN, M., 1986. Late Proterozoic and Early Palaeozoic depositional facies of the northern Amadeus Basin, central Australia. *Field Excursion 25B, 12th International Sedimentological Congress, Canberra,* 125p.

LONGMAN, M. W. & PALMER, S. E. 1987. Organic Geochemistry of Mid-Continent Middle and Late Ordovician Oils. *The American Association of Petroleum Geologists Bulletin, 71(8),* 938-950.

MADIGAN, C. T., 1932. The geology of the Western MacDonnell Ranges, central Australia. *Quarterly Journal of the Geological Society of London* , *88*, 672-711, pls. 41-46.

MARSDEN, G. R., FENTON, G. G., SCHRODER, R. J. & GORTER, J. D., 1983. Tempe Vale No. 1, Well Completion Report, Amadeus Basin, OP 175, Northern Territory. *Pancontinental Petroleum Limited, 1983, PPL Report, 95* (Unpublished).

MARSDEN, G. R., SCHRODER, R. J. & GORTER, J. D., 1984. Well Completion Report, Tent Hill No. 1, OP 175, Amadeus Basin, Northern Territory. *Pancontinental Petroleum Limited, 1984, PPL Report, 97* (unpublished).

McNAUGHTON, D. A., QUINLAN, T., HOPKINS, R. M. & WELLS, A. T., 1968. Evolution of salt anticlines and salt domes in the Amadeus Basin, central Australia. *The Geological Society of America, Special Paper 88,* 229-247.

MORRIS, K. A., 1979. A classification of Jurassic marine shale sequences: An example from the Toarcian (Lower Jurassic) of Great Britain. *Palaeogeography, Palaeoclimatology, Palaeoecology, 26,* 117-126.

MORRIS, R. J., McCARTNEY, M. J. & WEAVER, P. P. E., 1984. Sapropelic deposits in a sediment from the Guinea Basin, South Atlantic. *Nature (London), 309(5969),* 611-614.

NICOLL, R. S., 1986. Ordovician Larapinta Group *in* Late Proterozoic and Early Paleaozoic depositional facies of the northern Amadeus Basin, central Australia (Kennard, J. M., Nicoll, R. S., & Owen, M. eds.) Field Excursion 25B, Amadeus Basin, 12th International Sedimentological Congress, Canberra, 1986, 46-49.

NICOLL, R. S., GORTER, J. D. & HAINES, P. W., 1986. Pacoota Sandstone *in* Late Proterozoic and Early Palaeozoic depositional facies of the northern Amadeus Basin, central Australia (Kennard, J. M., Nicoll, R. S., Owen, M. eds.) Field Excursion 25B, Amadeus Basin, 12th International Sedimentological Congress, Canberra, 1986, 50-52.

NICOLL, R. S. & JAKEMAN, B. J., 1986. Horn Valley Siltstone *in* Late Proterozoic and Early Palaeozoic depositional facies of the northern Amadeus Basin, central Australia (Kennard, J. M., Nicoll, R. S. & Owen, M. eds.) Field Excursion 25B, Amadeus Basin, 12th International Sedimentological Congress, Canberra, 1986, 52-53.

OWEN, M., 1986. BMR Stratigraphic drilling in the Amadeus Basin, Northern Territory, 1985. *Bureau of Mineral Resources, Australia, Record, 1986/8,* 36p.

OWEN, M. & MORRIS, D. G., 1985. BMR Stratigraphic drilling in the Amadeus Basin, Northern Territory, 1983. *Bureau of Mineral Resources, Australia, Record, 1985/9,* 38p.

PEARSON, T. R. & BENBOW, D. D., 1976. Amadeus Basin *in* LESLIE, R. B., EVANS, H. J.

& KNIGHT, C. L., (EDS) *Economic Geology of Australia and Papua and New Guinea, 3. Petroleum.* Australian Institute of Mining and Metallurgy, Monograph 7, 216-225.

POJETA, J. & GILBERT-TOMLINSON, J., 1977. Australian Ordovician pelecypod molluscs. *Bureau of Mineral Resources, Australia, Bulletin, 174,* 64p, 29pls.

POJETA, J., GILBERT-TOMLINSON, J., & SHERGOLD, J. H., 1977. Cambrian and Ordovician rostroconch molluscs from northern Australia. *Bureau of Mineral Resources, Australia, Bulletin 171,* 54p, 27pls.

PRATT, L. M., 1984. Influence of Paleoenvironmental Factors on Preservation of Organic Matter in Middle Cretaceous Greenhorn Formation, Pueblo, Colorado. *The American Association of Petroleum Geologists Bulletin, 68(9),* 1146-1159.

PRICHARD, C. E. & QUINLAN, T., 1962. The geology of the southern half of the Hermannsburg 1:250 000 Sheet. *Bureau of Mineral Resources, Australia, Report 61,* 39p, 2pls.

REED, J. H., ILLICH, H. A. & HORSFELD, B., 1986. Biochemical evolutionary significance of Ordovician oils and their sources *in* Advances in Organic Geochemistry 1985 (D. Leythaeuser, D. and Rullkötter, J. eds.) 347-358. Pergamon Press, Oxford.

RHOADS, D. C. & MORSE, J. W., 1971. Evolutionary and ecologic significance of oxygen-deficient marine basins. *Lethaia, 4,* 412-428.

SCHRODER, R. J. & GORTER, J. D., 1984. A review of the recent exploration and hydrocarbon potential of the Amadeus Basin, Northern Territory. *The Australian Petroleum Exploration Association Journal, 24(1),* 19-41.

SELLWOOD, B. W., 1971. The genesis of some sideritic beds in the Yorkshire Lias (England). *Journal of Sedimentary Petrology, 41(3),* 854-858.

SHERGOLD, J. H., 1986. Horn Valley Siltstone *in* Review of the Cambrian and Ordovician palaeontology of the Amadeus Basin, central Australia. *Bureau of Mineral Resources, Australia, Report 276,* 9-10.

STANLEY, D. J., 1986. Turbidity current transport of organic-rich sediments: Alpine and Mediterranean examples. *in* (P. A. Meyers and R. M. Mitterer, eds.), Deep Ocean Black Shales: Organic Geochemistry and Paleoceanographic Setting. *Marine Geology, 70,* 85-101.

STEIN, R., RULLKÖTTER, J. & WELTE, D. H., 1986. Accumulation of organic-carbon-rich sediments in the Late Jurassic and Cretaceous Atlantic Ocean - A synthesis. *Chemical Geology, 56,* 1-32.

TATE, R., 1896. Palaeontology. *in* (B. Spencer, ed.) - Report on the work of the Horn Scientific Expedition to central Australia. Part III - Geology and Botany. *Melville, Mullen & Slade, Melbourne,* 26-75.

THEEDE, H., PONAT, A., HIROKI, K. & SCHLIEPER, C., 1969. Studies on the resistance of marine bottom invertebrates to oxygen-deficiency and hydrogen sulphide. *Marine Biology, 2,* 325-337.

TISSOT, B. DEMAISON, G., MASSON, P., DELTEIL, J. R. & COMBAZ, A., 1980. Palaeoenvironment and petroleum potential of middle Cretaceous black shales in Atlantic basins. *The American Association of Petroleum Geologists Bulletin, 64(11),* 2051-2063.

WAPLES, D. W., 1983. Reappraisal of anoxia and organic richness, with emphasis on Cretaceous of North Atlantic. *The Americam Association of Petroleum Geologists Bulletin, 67(6),* 963-978.

WEBBY, B. D., 1978. History of the Ordovician continental platform shelf margin of Australia. *Journal of the Geological Society of Australia, 25(1),* 41-63.

WELLS, A. T., FORMAN, D. J., & RANFORD, L. C., 1965. The geology of the north-western part of the Amadeus Basin, Northern Territory. *Bureau of Mineral Resources, Australia, Report, 85,* 45p, 11pls.

WELLS, A. T., FORMAN, D. J., RANFORD, L. C. and COOK, P. J., 1970. Geology of the Amadeus Basin, central Australia. *Bureau of Mineral Resources, Australia, Bulletin 100,* 216p.

WELLS, A. T., RANFORD, L. C., STEWART, A. J., COOK, P. J. & SHAW, R. D., 1967.

Geology of the north-eastern part of the Amadeus Basin, Northern Territory. *Bureau of Mineral Resources, Australia, Report, 113*, 93p.

APPENDICES

APPENDIX 1: LOCATIONS OF WELLS INTERSECTING THE HORN VALLEY SILTSTONE

WELL	COMPANY	LOCATION
DINGO 1	PANCON	24° 13' 36"S, 133° 53' 46"E
DINGO 2	PANCON	24° 13' 53"S, 133° 52' 26"E
EAST JOHNNY'S CREEK 1	EXOIL	24° 11' 00"S, 131° 37' 55"E
EAST MEREENIE 1	EXOIL	24° 00' 31"S, 131° 33' 51"E
EAST MEREENIE 2	EXOIL	24° 02' 47"S, 131° 38' 50"E
EAST MEREENIE 4	EXOIL	24° 01' 57"S, 131° 37' 48"E
EAST MEREENIE 6	OILMIN	24° 04' 21"S, 131° 40' 58"E
EAST MEREENIE 10	OILMIN	24° 04' 39"S, 131° 41' 16"E
HENBURY 1 (AP2)	BMR	24° 33'S, 132° 15'E (APPROX)
HENBURY 2 (AP3)	BMR	24° 20'S, 132° 58'E (APPROX)
HENBURY 4	BMR	24° 33' 33"S, 132° 14' 38"E
HENBURY 6	BMR	24° 30' 00.5"S, 133° 15' 00.5"E
LAKE AMADEUS 1 (AP1)	BMR	24° 17'S, 131° 41'E (APPROX)
LAKE AMADEUS 2 (AP4)	BMR	24° 56'S, 131° 55'E (APPROX)
MT LIEBIG 2	BMR	23° 54' 12"S, 131° 50' 05"E
MT WINTER 1	PANCON	23° 51' 57"S, 130° 47' 41"E
MT WINTER 2A	PANCON	23° 51' 51"S, 130° 47' 49"E
PALM VALLEY 1	MAGELLAN	24° 00' 00"S, 132° 46' 20"E
PALM VALLEY 2	MAGELLAN	24° 00' 03"S, 132° 38' 47' E
PALM VALLEY 3	MAGELLAN	24° 00' 44"S, 132° 37' 00"E
PALM VALLEY 4	MAGELLAN	23° 59' 13"S, 132° 38' 51"E
PALM VALLEY 5	MAGELLAN	24° 04' 15"S, 132° 51' 04"E
PALM VALLEY 6	MAGELLAN	24° 00' 10"S, 132° 42' 20"E
RODINGA 6	BMR	24° 22' 46"S, 133° 42' 12"E
TEMPE VALE 1	PANCON	24° 00' 48"S, 131° 18' 29"E
TENT HILL 1	PANCON	24° 13' 45"S, 132° 02' 30"E
WEST MEREENIE 1	EXOIL	23° 56' 57"S, 131° 24' 44"E
WEST MEREENIE 2	EXOIL	23° 58' 49"S, 131° 32' 22"E
WEST WALKER 1	PANCON	24° 10' 21"S, 131° 54' 24"E
WEST WATERHOUSE 1	MAGELLAN	24° 00' 00"S, 133° 06' 30"E

APPENDIX 2: LOCATIONS OF MEASURED SECTIONS INTERSECTING THE HORN VALLEY SILTSTONE

FIELD NO	AREA	LOCATION
* 84-2003	OCHER HILL, APPROX LINE OF LAC7	24° 13' 10"S, 131° 27' 50"E
* 84-2004	ADJACENT TO MALONEY CREEK	24° 30' 50"S, 133° 15' 40"E
* 84-2008	EASTERN JAMES RANGE	24° 22' 50"S, 133° 42' 10"E
* 85-2013	EAST OF MT OLIFENT	24° 08' 15"S, 131° 11' 20"E
* 85-2014	EAST OF MT OLIFENT	24° 08' 15"S, 131° 11' 20"E
* 85-2014/2013	EAST OF MT OLIFENT	24° 08' 15"S, 131° 11' 20"E
* 85-2017	SOUTH OF SEYMOUR RANGE	24° 52' 55"S, 132° 53' 30"E
* 85-2021	HORSE GAP, GARDINER RANGE	23° 55' 25"S, 131° 54' 57"E
* 86-2023	ELLERY CREEK - TYPE SECTION	23° 49' 03"S, 133° 03' 45"E
* 86-2027	NEAR MRW1, SE MT RENNIE SHEET	23° 51' 00"S, 130° 25' 00"E
# HYR4	NEAR AREYONGA	24° 09'S, 132° 17'E
# LAC7	OCHRE HILL	24° 13'S, 131° 27'E
# HyC1	JAMES RANGE	24° 11'S, 132° 58'E
# LAR2	PARANA HILL ANTICLINE	24° 25'S, 131° 59'E
# LAR1	PARANA HILL ANTICLINE	24° 19'S, 131° 57'E
# LAC12	WEST	24° 17'S, 131° 16'E
# LAR3	WEST	24° 22'S, 130° 38'E
# LAC8	GEORGE HILL RANGE	24° 28'S, 131° 57'E
# HYR7	THE SISTERS	24° 43'S, 133° 19'E

** No Horn Valley Siltstone outcrops south of 24° 40'S

* Measured sections by R. S. NICOLL, M. OWEN & J. R. LAURIE (unpublished data)

Measured sections detailed in RANFORD, L. C., COOK, P. J., & WELLS, A. T., (1965)
(Locations taken from the enclosed geological maps)

APPENDIX 3: THICKNESSES OF THE HORN VALLEY SILTSTONE

(taken from well completion reports)

WELL	COMPANY	THICKNESS (M)
DINGO 1	PANCON	40m
DINGO 2	PANCON	
EAST JOHNNY'S CREEK 1	EXOIL	57 (187ft)
EAST MEREENIE 1	EXOIL	67.7 (222ft)
EAST MEREENIE 2	EXOIL	61.3 (201ft)
EAST MEREENIE 4	EXOIL	64.6 (212ft)
EAST MEREENIE 6	OILMIN	64 (210ft)
EAST MEREENIE 10	OILMIN	64 (210ft)
HENBURY 1 (AP2)	BMR	incomplete
HENBURY 2 (AP3)	BMR	incomplete
HENBURY 4	BMR	46.03 (151ft)
HENBURY 6	BMR	34.7 (113.9ft)
LAKE AMADEUS 1 (AP1)	BMR	60.7 (199ft)
LAKE AMADEUS 2 (AP4)	BMR	
MEREENIE 1	EXOIL	70.1 (230ft)
MT LIEBIG 2	BMR	135.77 (445.4ft)
MT WINTER 1	PANCON	62 (203.4ft)
MT WINTER 2A	PANCON	61.9 (203.1ft)
NW MEREENIE 1	MAGELLAN	
PALM VALLEY 1	MAGELLAN	98.8 (324ft)
PALM VALLEY 2	MAGELLAN	113.7 (373ft)
PALM VALLEY 3	MAGELLAN	100.6 (330ft)
PALM VALLEY 4	MAGELLAN	84.1 (276ft)
PALM VALLEY 5	MAGELLAN	
PALM VALLEY 6	MAGELLAN	81.1 (266ft)
RODINGA 6	BMR	37.55 (123.2ft)
TEMPE VALE 1	PANCON	80 (262.5ft)
TENT HILL 1	PANCON	72 (236.2ft)
WEST MEREENIE 1	EXOIL	78.6 (258ft)
WEST MEREENIE 2	EXOIL	70.7 (232ft)
WEST WALKER 1	PANCON	64.5 (211.6ft)
WEST WATERHOUSE 1	MAGELLAN	75 (246ft)

APPENDIX 4: THICKNESS OF THE HORN VALLEY SILTSTONE TAKEN FROM MEASURED SECTIONS

FIELD NO	LOCATION	THICKNESS (M)
* 84-2003	OCHER HILL, APPROX LINE OF LAC7	117 (384ft)
* 84-2004	ADJACENT TO MALONEY CREEK	46 (151ft)
* 84-2008	EASTERN JAMES RANGE	9 (30ft)
* 85-2014/2013	EAST OF MT OLIFENT	17 (56ft)
* 85-2017	SOUTH OF SEYMOUR RANGE	8.5 (28ft)
* 85-2021	HORSE GAP, GARDINER RANGE	130 (427ft)
* 86-2023	ELLERY CREEK - TYPE SECTION	80 (262ft)
* 86-2027	NEAR MRW1, SE MT RENNIE SHEET	54 (177ft)
# HYR4	NEAR AREYONGA	106.7 (350ft)
# LAC7	OCHRE HILL	86.9 (285ft)
# HyCl	JAMES RANGE	73.2 (240ft)
# LAR2	PARANA HILL ANTICLINE	71.6 (235ft)
# LAR1	PARANA HILL ANTICLINE	61.0 (200ft)
# LAC12	WEST	48.8 (160ft)
# LAR3	WEST	24.4 (80ft)
# LAC8	GEORGE HILL RANGE	44.2 (145ft)
# HYR7	THE SISTERS	24.4 (80ft)
++	WESTERN MACDONNELL RANGES	426.7 (1400ft)

** No Horn Valley Siltstone outcrops south of 24° 40'S

++ BARRIE, 1964. BMR RECORD, 1964/195 (NB This value seems to be too high)

* Measured sections by R. S. NICOLL, M. OWEN & J. R. LAURIE

Measured sections detailed in RANFORD, L. C., COOK, P. J., & WELLS, A. T., 1965.

APPENDIX 5: GEOCHEMICAL DATA FROM TENT HILL #1

(data collected by B. Jakeman, unpublished)

UNIT	DEPTH (m)	TMAX (°C)	ORG C (%)	HI (S2/Corg)	OI (S3/Corg)	G.P. (S1+S2)	PI [S1/(S1+S2)]
SS1	1060.1	436	0.15	40	0	0.07	0.14
SS1	1062.3	319	0.11	73	18	0.11	0.27
SS1	1096.9	440	0.35	97	0	0.46	0.26
SS1	1112.9	426	0.10	100	0	0.18	0.44
HV10	1117.8	327	0.27	30	148	0.10	0.20
HV10	1119.2	276	0.08	88	863	0.09	0.22
HV10	1122.2	433	0.45	107	116	0.69	0.30
HV9	1123.9	419	0.08	75		0.11	0.45
HV9	1125.0	341	0.10	50	910	0.10	0.50
HV9	1130.0	443	0.42	98	95	0.72	0.43
HV8	1131.9	450	0.26	73	62	0.26	0.27
HV8	1132.6	452	0.05	40	880	0.05	0.60
HV8	1133.4	390	0.12	75	125	0.15	0.40
HV8	1134.9	452	0.27	52	7	0.22	0.36
HV8	1136.0	444	0.11	18	145	0.06	0.67
HV7	1138.3	415	0.27	26	26	0.13	0.46
HV7	1140.1	460	0.51	73	10	0.60	0.38
HV7	1140.8	456	0.78	94	9	1.20	0.39
HV7	1145.1	457	1.15	143	16	3.10	0.47
HV6	1146.9	450	0.50	104	74	1.01	0.49
HV6	1148.9	453	0.40	95	45	0.66	0.42
HV6	1150.9	454	1.01	137	15	2.52	0.45
HV6	1151.2	451	0.36	86	83	0.72	0.57
HV6	1157.6	455	2.74	170	19	8.81	0.47
HV6	1160.7	451	0.90	89	52	1.41	0.43
HV6	1163.2	456	1.03	130	46	2.42	0.45
HV6	1165.3	450	0.76	103	47	1.41	0.45
HV6	1166.6	456	0.91	108	38	1.71	0.43
HV6	1168.0	455	1.14	114	23	2.39	0.46
HV5	1172.3	453	0.42	57	55	0.46	0.48
HV5	1173.7	453	0.49	78	37	0.67	0.43
HV4	1174.4	461	0.11	9	318	0.07	0.86
HV4	1175.1	452	0.45	42	13	0.36	0.47
HV4	1178.7	463	0.27	26	15	0.15	0.53
HV4	1181.4	452	0.27	41	11	0.16	0.31
HV4	1183.3	403	0.22	55	173	0.22	0.45
HV3	1184.1	237	0.05	0		0.02	1.00
HV3	1184.6	273	0.10	20	910	0.08	0.75
HV2	1184.9	273	0.08	25	588	0.05	0.60
HV2	1186.8	302	0.12	33	333	0.08	0.50
HV2	1193.8	323	0.11	82	64	0.42	0.79
HV2	1195.9	383	0.18	67	0	0.20	0.40
HV2	1196.6	455	0.28	50	0	0.20	0.30
HV2	1198.5	437	0.21	57	0	0.17	0.29
HV1	1199.6	403	0.18	39	6	0.09	0.22

APPENDIX 6: GEOCHEMICAL DATA FROM TEMPE VALE #1

(data collected by B. Jakeman, unpublished)

UNIT	DEPTH (m)	TMAX (°C)	ORG C (%)	HI (S2/Corg)	OI (S3/Corg)	G.P. (S1+S2)	PI [S1/(S1+S2)]
HV10	360.8	436	0.42	188	29	1.18	0.33
HV10	362.6	440	1.43	320	1	5.23	0.13
HV10	363.0	435	1.15	288	15	3.90	0.15
HV9	367.8	441	0.72	222	31	2.18	0.27
HV9	368.6	439	0.75	220	53	2.38	0.31
HV9	368.7	443	3.73	342	23	19.56	0.35
HV9	369.4	442	0.49	129	92	0.87	0.28
HV9	373.3	450	0.15	33	347	0.08	0.38
HV9	374.6	445	0.33	67	58	0.29	0.24
HV9	378.3	439	0.39	82	31	0.40	0.20
HV9	378.5	437	0.28	64	46	0.24	0.25
HV9	380.5	448	0.45	91	38	0.57	0.28
HV9	383.3	445	0.68	162	21	1.61	0.32
HV8	384.5	439	0.22	68	91	0.24	0.38
HV8	388.5	440	0.23	43	30	0.14	0.29
HV8	392.4	384	0.12	58	92	0.10	0.30
HV8	397.6	445	0.27	59	15	0.23	0.30
HV8	398.3	446	0.27	44	11	0.17	0.29
HV8	400.4	447	0.42	124	21	0.78	0.33
HV7	401.2	452	0.81	181	12	2.24	0.34
HV7	403.7	450	0.95	161	9	2.17	0.29
HV7	404.2	446	0.39	74	23	0.43	0.33
HV7	407.6	448	4.09	297	17	19.16	0.37
HV7	409.6	450	6.30	328	13	28.06	0.26
HV6	416.8	442	1.22	308	86	5.71	0.34
HV6	417.0	435	0.95	260	133	4.27	0.42
HV5	420.1	451	0.72	143	76	1.68	0.39
HV5	423.0	445	0.48	90	71	0.81	0.47
HV5	425.7	448	0.40	70	50	0.41	0.32
HV4	426.6	444	0.37	59	35	0.31	0.29
HV4	428.5	447	0.45	71	22	0.44	0.27
HV4	430.1	448	0.42	69	0	0.41	0.29
HV4	432.1	449	0.35	54	0	0.26	0.27
HV4	433.4	448	0.30	53	0	0.22	0.27
HV4	435.8	441	0.23	35	0	0.11	0.27
HV4	437.4	446	0.30	47	0	0.19	0.26
HV4	438.4	446	0.57	128	2	0.93	0.22
HV3	440.3	431	0.22	132	341	0.45	0.36

APPENDIX 7

LITHOLOGIC LOGS

LEGEND FOR LITHOLOGIC LOGS

LITHOLOGY

⁙	SANDSTONE
┅	SILTSTONE
▤	MUDSTONE, SHALE
▦	INTERBEDDED MUDS
▩	LIMESTONE
▨	DOLOMITE

BEDDING

	PLANAR	CROSS-BEDDED
V. THICK	▭̸	⁄▭
THICK	▭	⁄▭
MEDIUM	⊏	⁄⊏
THIN	=	⁄=
LAMINATED	≡	⁄≡

FOSSILS

BURROWS	b
GRAPTOLITE	g
MOLLUSC	m
NAUTILOID	n
TRILOBITE	t

MINERALS

GLAUCONITE	gl
PHOSPHATE	ph
PYRITE	py

BEDDING STRUCTURES

BIOTURBATED	⊖
STYLOLITES	
RIPPLES	
MUD PELLETS	
CALC. NODULES	

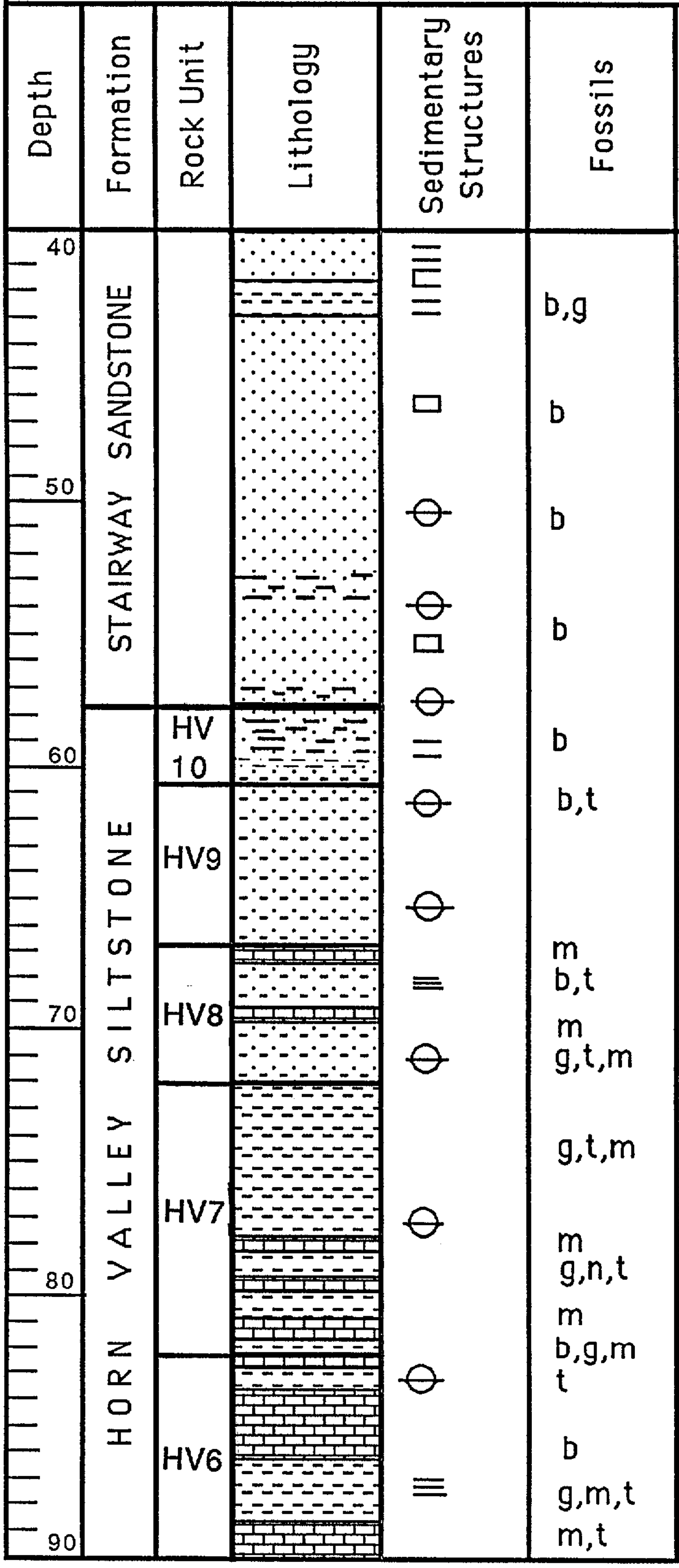
Basin: AMADEUS

Well: HENBURY #4

Sheet: 1 of 2

Location: 132° 14' 38"E, 24° 33' 33"S

Core No: 13-34



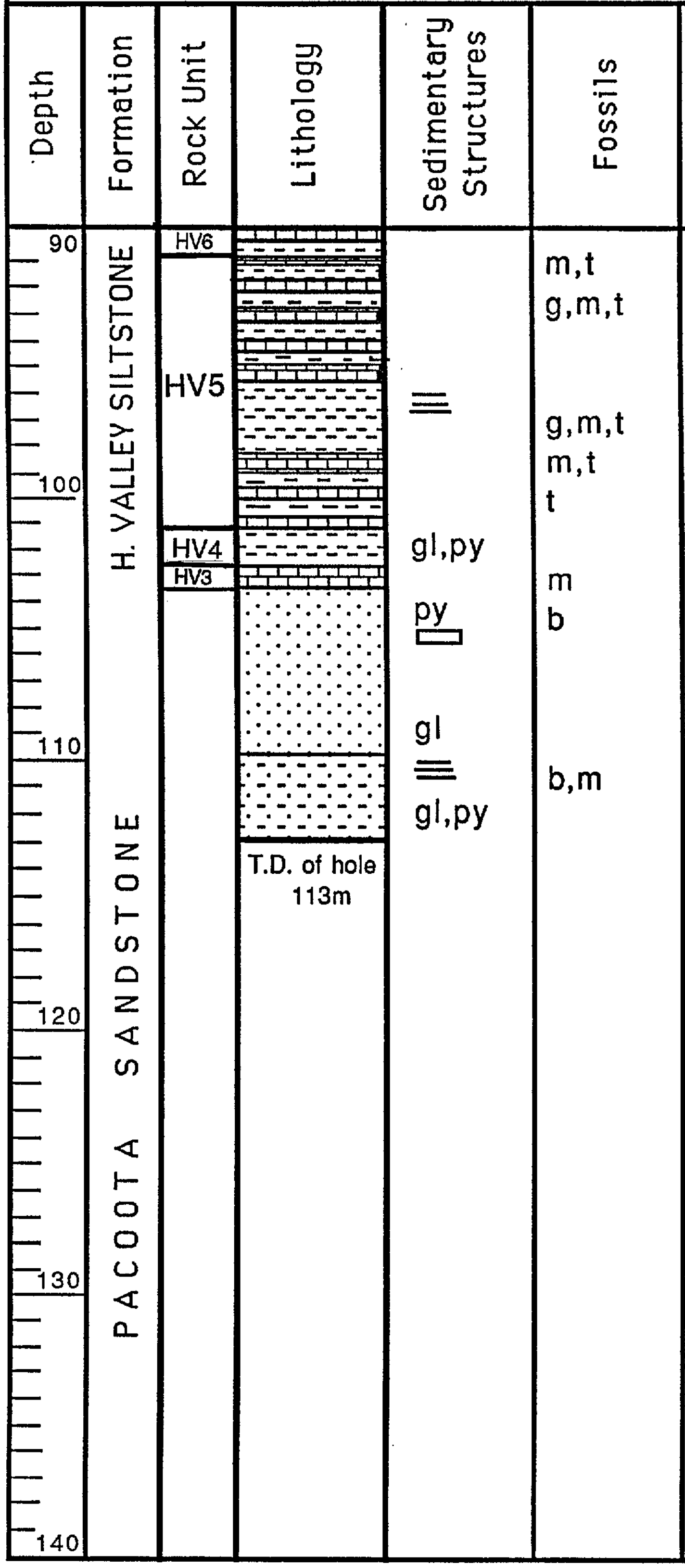
Description

40-40.22 Coarse sandstone, poorly sorted
40.22-40.70 Coarsening upwards med to fine ss
40.70-42.18 Med - coarse ss, light grey to grey green clay pellets and partings
42.18-43.22 Interlaminated siltstone & ss (med) bioturbated, current ripples near top, grad LB
43.22-48.70 FU coarse-med ss, l gy with dk br mottlings. Clay pellets. Fracturing towards base
48.70-50.22 Ss as above. Dk red br (haematite)
50.22-57.8 Med-v. crs ss, poorly sorted, dark yellow grey, br clay matrix & partings. Interbeds of siltstone. Bioturbated. Cruziana.
57.8 TOP OF HORN VALLEY SILTSTONE
57.8-60.95 Mainly med ss, clay interbeds, yl -br interlaminated silts, bedding indistinct. Bioturb.
60.95-82.73 Thinly interbedded mudstone and fine to med grained sandstone, in parts dolomitic. Dark grey to black mudstone, light grey ss. Interbeds of shell fragments (calcirudite) Strongly bioturbated (vertical & inclined burrow) in parts very fossiliferous (graptolites, shells, trilobites, ?nautiloids)
Very irregular laminations with diffuse lenticles and laminations of sandstone possibly due to bioturbation as well as storm deposits.
66.65 Shell fragment calcirudite (storms?)
68.42 Shell fragment calcirudite (storms?)

72.50-73.93 Abundant fossils - graptolites, trilobite fragments (pygidium) & brachiopods. Slight uneven subhorizontal lamination.
73.93-74.8 Common trilobites, minor graptolites
77.25-78.8 Shell fragment calcirudite

82.04-90 Interbedded dk grey to black mudstone with interbeds and nodules of calcilutite. Mudstone laminae deformed around carbonate bed. Carbonate units contain shell fragments. Mud units are bioturbated with burrows, also trilobites, graptolites and brachiopods.

Basin: AMADEUS	Well: HENBURY #4	Sheet: 2 of 2
Location: 132° 14' 38"E, 24° 33' 33"S		Core No: 34-45



Description

90-101.86 Same as for interval 82.04-90
90.30 Abundant shell fragments, irreg bedding
90.92 Abundant trilobite, graptolites, shell fragments in muddy unit
91.64 Shell fragment calcirudite
92.23 Trilobite & graptolite fragments in mud

101.86-103.81 Silty limestone. Light greenish grey. Glauconitic. Thin carbonaceous mudstone laminae. Pyrite common. Abundant fossil fragments (random orientation of shells)
103.81-104.14 Med - coarse sandstone, pyritic calcareous. Shell fragments at top. Bioturbated (escape burrows?)

104.14-109.69 Fine to medium sandstone, greenish grey to dark greenish grey. Strongly bioturbated (sand filled escape burrows - several cm long - Skolithos)

109.69-109.82 Fine to med grained sandstone and interbedded mudstone. Fossiliferous.
109.82-112.59 Fine grained sandstone and interbedded siltstone. Fossiliferous (lenses of shell debris and infilled burrows). Glauconitic.

112.59 - 113.00 Coarse dark grey to green sandstone. Massive. Glauconitic. Bioturbated. Pyrite common.

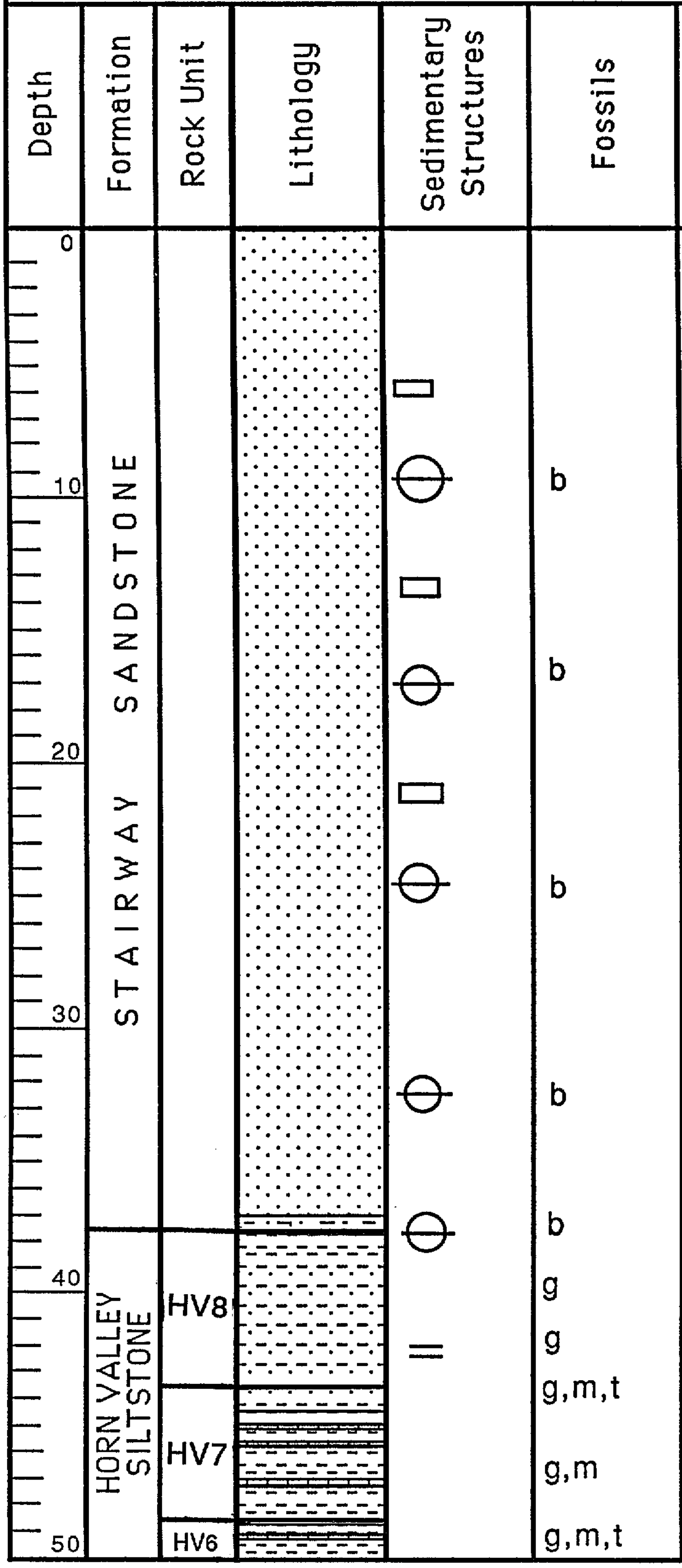
Basin: AMADEUS

Well: HENBURY #6

Sheet: 1 of 2

Location: 133° 15' 00.5", 24° 30' 00.5"

Core No: 1–24



Description

0-19 Medium to coarse grained sandstone. Light yellow grey to dark yellow brown in colour. Thick bedded, bioturbated places. Gradational contact with underlying unit.

19-37.0 Medium grained sandstone. Yellowish brown with dark yellowish brown and purplish red mottling. Bedding been disturbed due to bioturbation.

37.0-37.6 Siltstone and fine grained sandstone. Mottled greyish orange and dark yellowish orange. Tracks and trails are common. Grades into unit below.

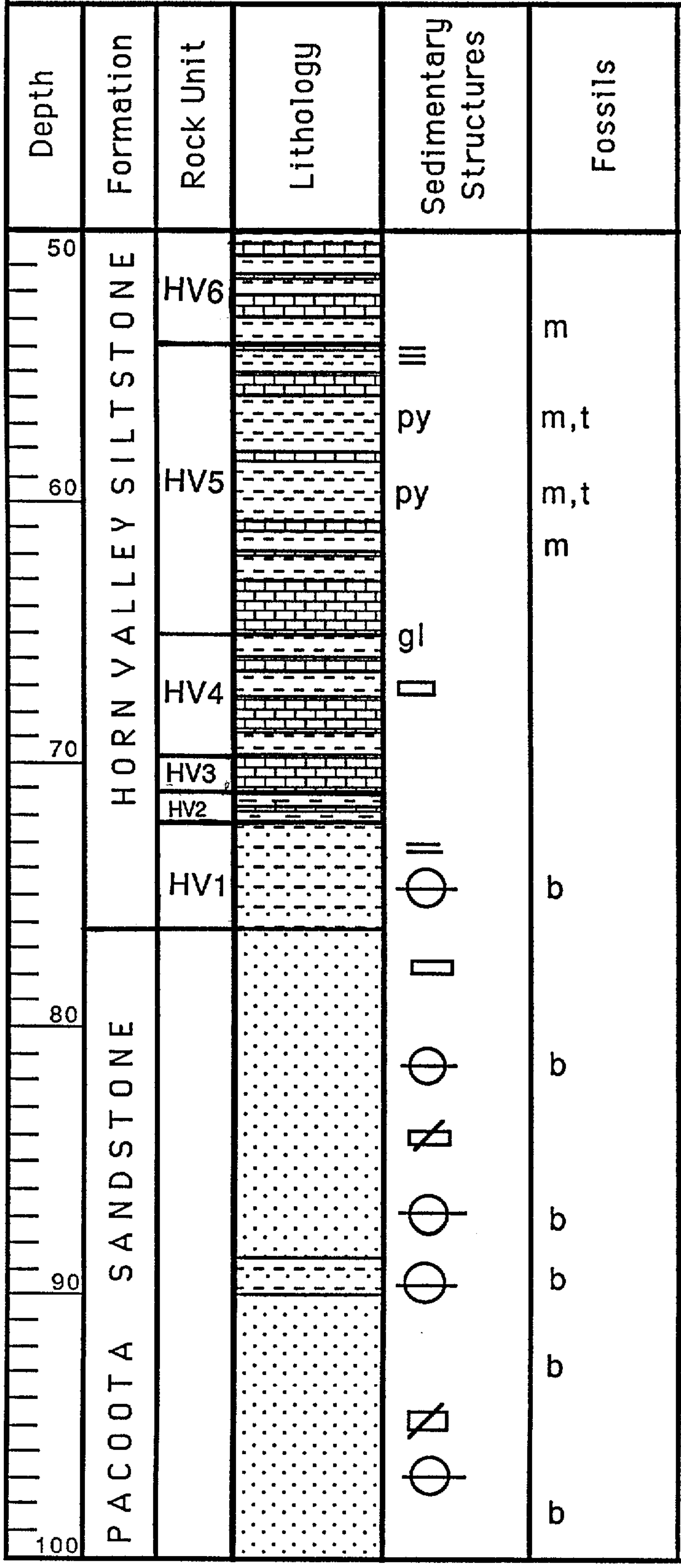
37.6-43.5 Alternating beds of mudstone and siltstone. Dark grey to greyish black. Very carbonaceous. Weathered to greyish orange in parts. Thinly bedded unit. Graptolites common throughout.

43.5-44.2 Mudstone with minor thin interbeds of calcareous siltstone. Brachiopods common. Minor trilobites and graptolites.

44.2-48.25 Medium grey to dark grey mudstone with minor interbeds and nodules of calcilutite and coquinite. Graptolites abundant. Pyritic.

48.25-51.8 Interbedded mudstone and limestone. Coquinite common. Nodular calcilutite. Abundant graptolites & trilobites. Carbonaceous. Pyritic.

Basin: AMADEUS	Well: HENBURY #6	Sheet: 2 of 2
Location: 133° 15' 00.5"E, 24° 30' 00.5"S		Core No: 24 – 41



Description

51.8-53.55 Shelly limestone. Coquinite with micrite and mudstone matrix.

53.55-61.2 Medium dark grey to dark grey mudstone containing nodules of carbonate. Interbeds of coquinite are common. Fossiliferous. Abundant trilobites, minor brachiopods. Pyritic.

61.2-63.94 Interbedded mudstone and shelly calcarenite. Shells are preserved as fragments. Dark greenish grey in colour.

63.94-72.3 Interbedded mudstone and sandy limestone. Limestone is dusky yellow green to light olive grey and pale olive in colour. Glauconitic thin pale olive mudstone.

72.3-76.08 Interbedded siltstone, shale and fine grained sandstone. Mottled dusky yellow and light olive brown. Carbonate in matrix. Strongly bioturbated.

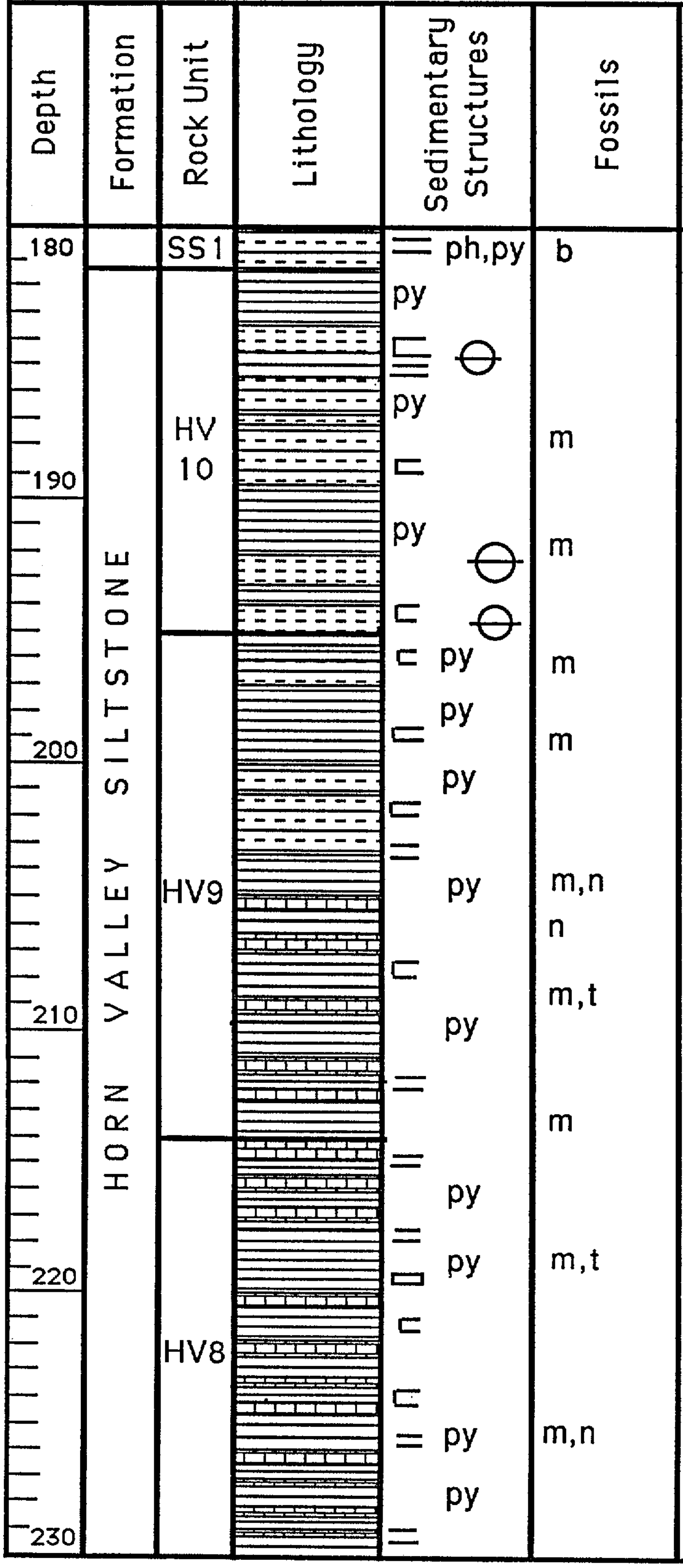
76.08-79.1 Fining upwards coarse through to fine grained sandstone. Yellowish grey to dusky yellow with minor red mottlings. Minor light olive grey clay partings.

79.1-88.76 Coarse to very coarse grained sandstone. Mottled dusky red in colour. Minor dark greenish grey clay partings. Very thick bedded. Strongly bioturbated with clay lined burrows.

88.76-89.5 Interbedded fine to medium grained sandstone and siltstone. Thinly laminated, dusky red to dark yellowish orange. Minor bioturbation.

89.5-100.00 Coarse to very coarse grained sandstone. Pebbly in places. Dusky red in colour with minor greyish green clay matrix and small pellets.

Basin: AMADEUS	Well: MT LIEBIG #2	Sheet: 1 of 3
Location: 23° 54' 12"S, 131° 50' 05"E		Core No: 60–79



Description

180-181.41 Interbedded dk grey mdst & lg gy sltst. Strongly bioturbated.
181.41 TOP OF HORN VALLEY SILTSTONE (grad.)
181.41-193.70 Interbedded black pyritic mdst & grey fine sltst. Bioturbated. Minor shell fragments, rare burrows.

187.5-189.5 Shell fragments

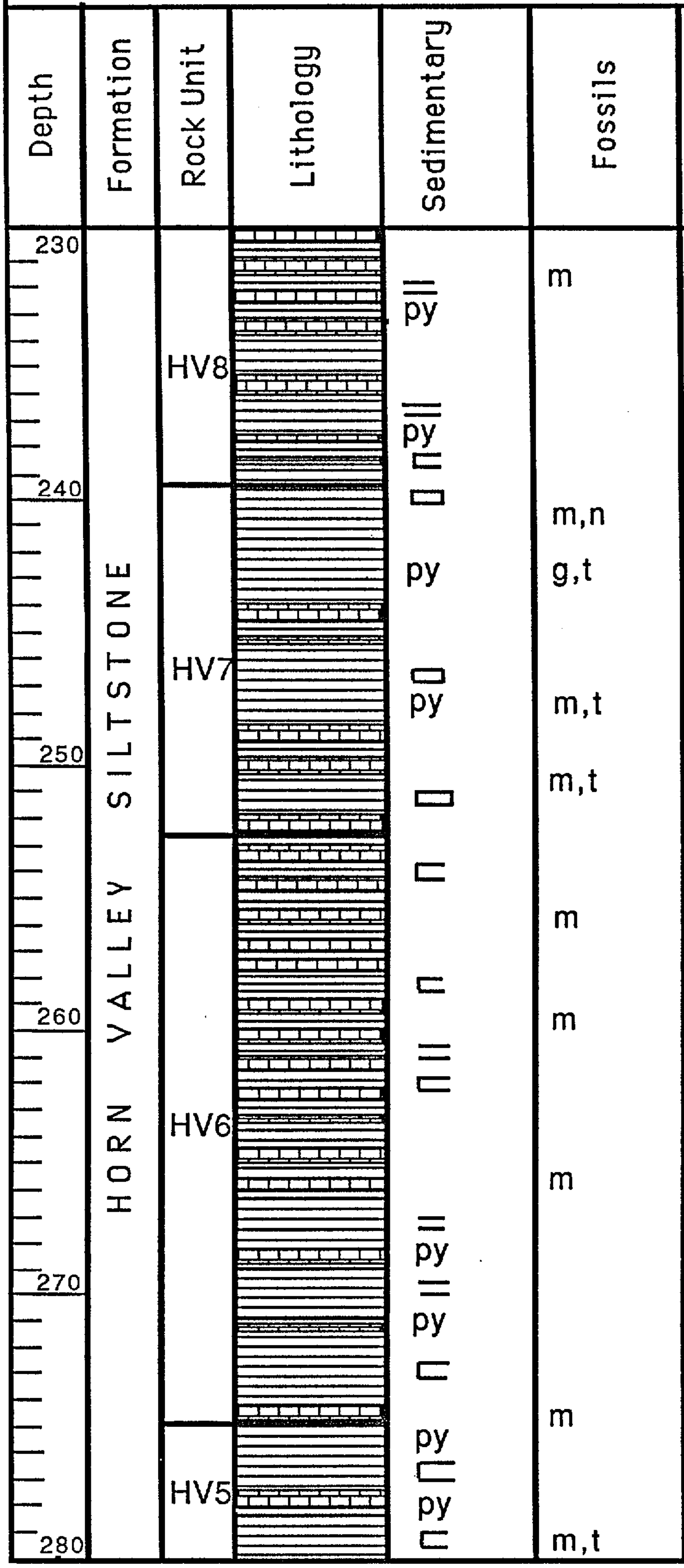
191.80-192.30 Predominantly silt with shell fragments.

193.70-195.20 Transitional boundary with overlying unit. Strongly bioturbated grey sltst.

195.20-213.93 Black pyritic mudstone with thin interbeds of gy calcareous sltst and fossiliferous grey lst. Fossils common throughout, especially in silty lst, and below 208m. Finely laminated in places, not bioturbated. Mainly calcitic shell valves (lag like deposit) and trilobites.

213.93-239.55 Black pyritic mdst with frequent thin beds of silty fossiliferous lst. Mdst has little internal lamination and is highly fossiliferous (trilobites and both valves of shells are still attached and have been preserved - quiet conditions prevailed). No signs of trace fossils.
226.1 nautiloids

Basin: AMADEUS	Well: MT LIEBIG #2	Sheet: 2 of 3
Location: 23° 54' 12"S, 131° 50' 05"E		Core No: 79–96



Description

213.93-239.55 Black pyritic mdst with frequent thin beds of silty fossiliferous lst. Mdst has little internal lamination, and is highly fossiliferous. Mainly well bedded and not much bioturbation. Graditional contact with underlying unit.

239.55-252.30 Black pyritic highly fossiliferous mudstone with occasional thin beds of muddy grey micritic limestone. Limestone usually fossiliferous and often has gradational top and bottom with the mudstone. Pyritic. Graptolites present in the finely laminated silt. Many trilobites (range in size from 3mm up to 3-4cm across). Black shiny coating on fossils.

252.30-274.60 Black pyritic highly fossiliferous mudstone with fairly common grey muddy limestone beds. Dirtier looking unit. Fossils mainly as abraded shell fragments in muddy unit. No signs of trace fossils. Muddy units seem slightly siltier than in other sections.

274.60-302.00 Black pyritic fossiliferous mudstone, very finely laminated, with rare thin micritic limestone beds. No signs of trace fossils. Fossils include - trilobites and shells. Body fossils are well preserved and not fragmented. Fossils have shiny black coating on them. Top limestone unit is mainly composed of shell fragments which are randomly arranged ie not alligned.

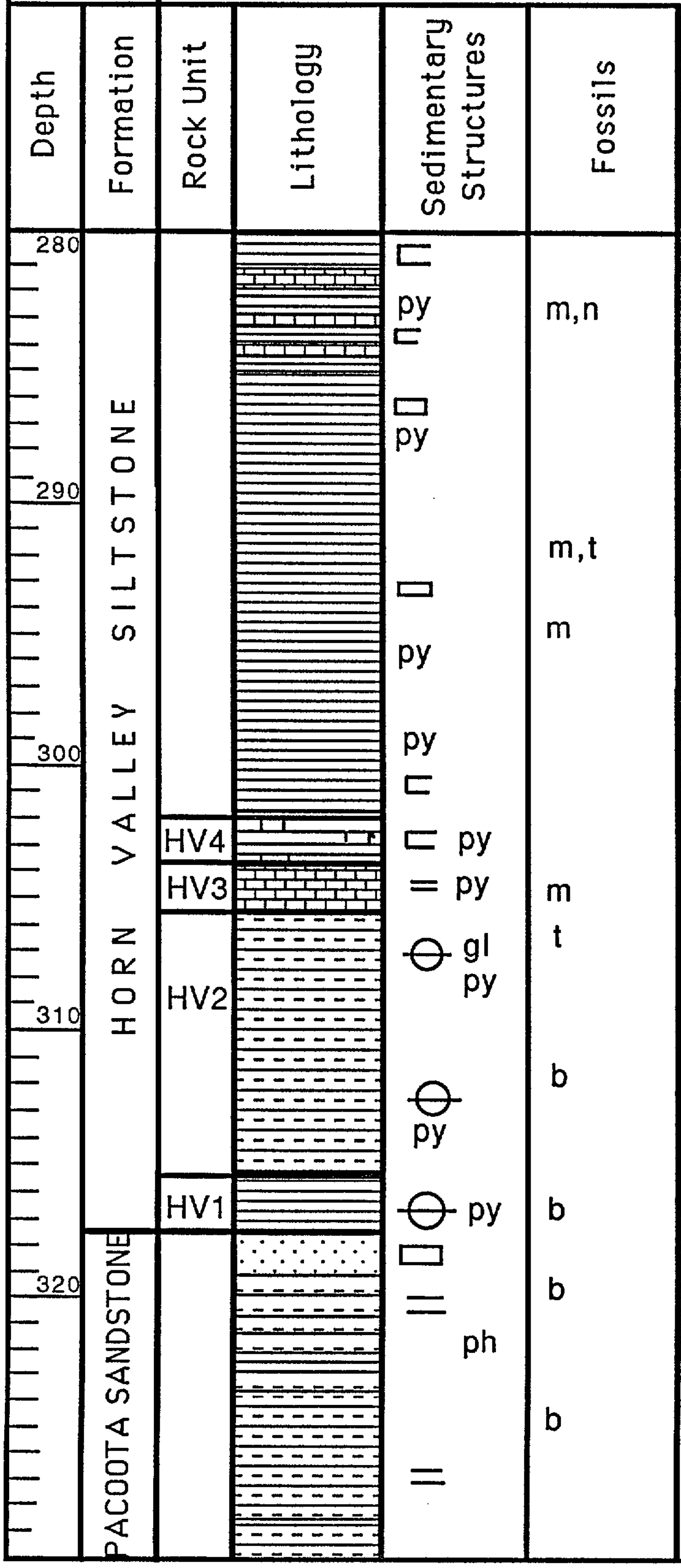
Basin: AMADEUS

Well: MT LIEBIG #2

Sheet: 3 of 3

Location: 23° 54' 12"S, 131° 50' 05"E

Core No: 96–113



Description

274.60-302.00 Black pyritic fossiliferous mudstone, very finely laminated, with rare thin micritic limestone beds. No signs of trace fossils. Shells well preserved and not fragmented. Fossils have shiny blak coating on them.

302.00-303.48 Micritic limestone nodules in well bedded mudstone. No trace fossils in this unit. Rare pyritic body fossils (nautiloid).

303.48-305.50 Grey micritic nodular limestone with wavy black mudstone laminae. Fragmental fossil debris mainly in the mud unit and shells alligned lengthways as if to represent a debris flow of shells over limestone. Scattered pyrite throughout. No trace fossils.

305.50-315.45 Strongly bioturbated light grey siltstone and dark grey mudstone with only remnant lamination remaining. Active burrowing, horizontal burrows which have adjusted to changes in sedimentation rates. Diameter of burrows 4mm - max length or depth of burial 15mm. Rare trilobite. Pyritic & glauconitic.

315.45-317.18 Black pyritic mudstone with thin grey siltstone laminae. Bioturbation is not intense, with sedimentary lamination being little disturbed. Pred. thin horizontal burrows. Possible vertical burrow. Rare Chondrites.

317.18-319.22 Light grey fine ss coarsening up.
319.22-323.30 Interbedded muds and silts. Phosphate nodules towards base of unit.

323.30-330 Thinly bedded black mudstone and light grey siltstone.

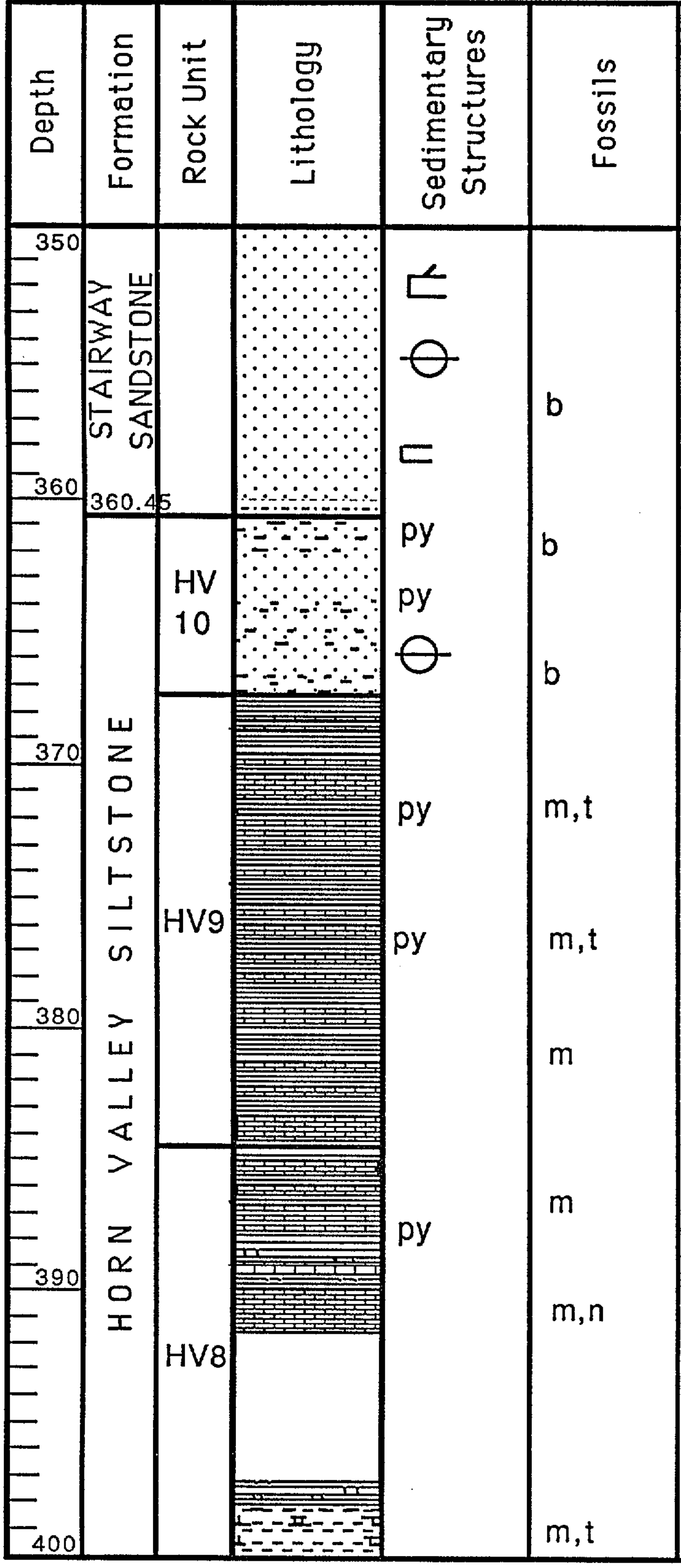
Basin: AMADEUS

Well: TEMPE VALE #1

Sheet: 1 of 2

Location: 24° 00' 48"S, 131° 18' 29" E

Core No: NA



Description

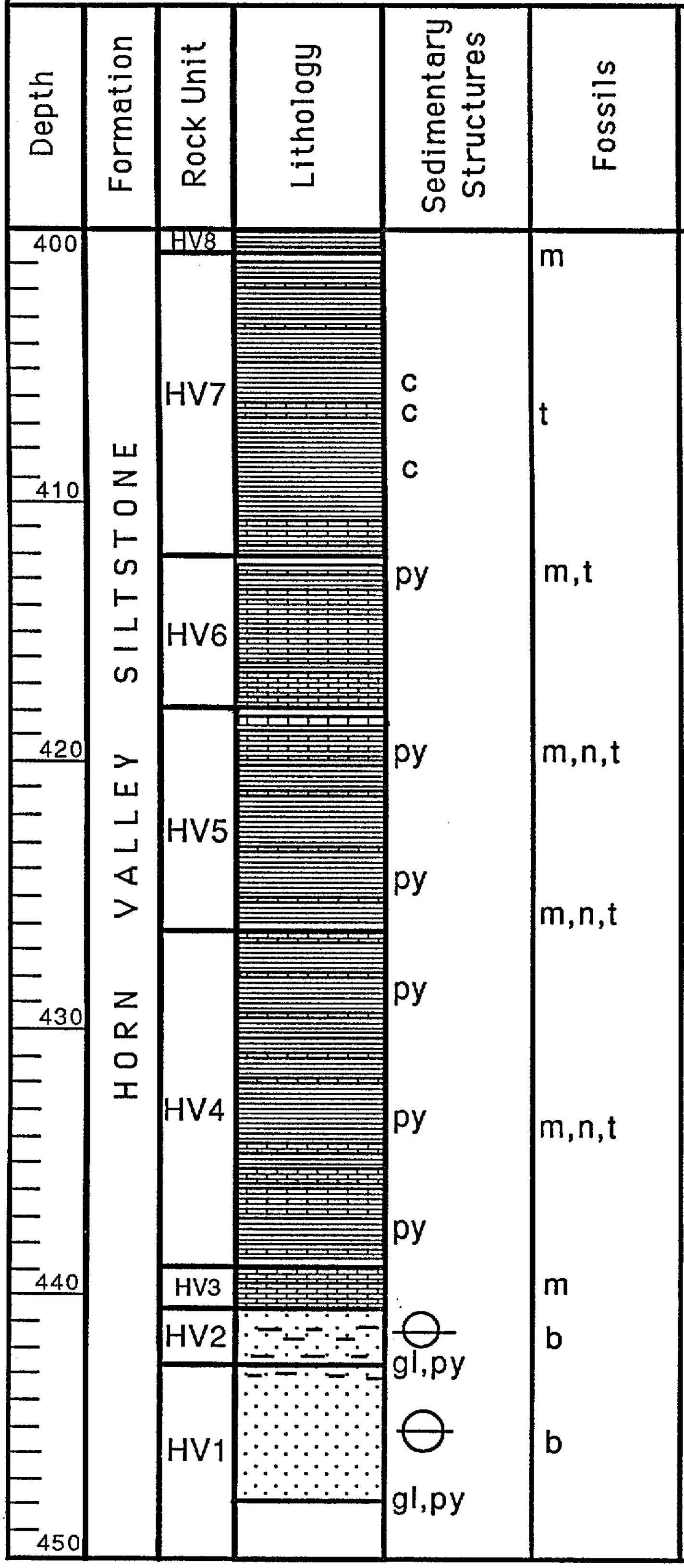
350-356.81 Med grained light grey to white sandstone. Silty in places. Well sorted except towards the base which is strongly bioturbated. Cross bedding towards top otherwise horizontal.
356.81-358.28 Silty fine-med light grey to dirty white ss, strongly bioturbated. Sand filled, silt lined burrows.
358.28-360.45 Interbedded v. fine ss and bioturbated silty fine ss. Sharp transition (by gradation) to underlying unit.
360.45 TOP OF HORN VALLEY SILTSTONE
360.45-367.32 Interbedded sltst and sandstone. Varies from dark grey to grey green in colour. Minor pyrite. Bioturbated (sand filled burrows). Siliceous cement, vey low porosity. No fossils.

367.32-384.43 Consists of alternating beds of shelly limestone overlain by well bedded calcilutite and finally overlain by a well sorted fossiliferous and pyritic med. grey mudstone. This cycle is repeated several times. The lower limestone unit consists of abraded shell debris and other fossils including trilobite fragments and nautiloids. The calcilutite is generally well bedded and so too is the overlying mudstone which contains blebs of pyrite and the occasional well preserved trilobite. This cyclic sequence may represent debris/gravity flows associated with storms.
384.43-386.56 Nodular limestone. Nodules of shelly lst separated by laminae of sltst. Bedding wavy and irregular. Pyrite.

386.56-392.86 Alternating sequence of shelly limestone beds overlain by calcilutite with occasional mudstone bed.

392.86-397.54 Core of box 10 not logged because it had been dropped and core appears to be missing.
397.54-400.63 Alternating beds of light grey calcilutite and fossiliferous mudstone (trilobites, shells).

Basin: AMADEUS	Well: TEMPE VALE #1	Sheet: 2 of 2
Location: 24° 00' 48" S, 131° 18' 29" E		Core No: NA



Description

400.63-400.69 Shelly limestone bed.
400.69-412.07 Med dark grey shale. Carbonate laminae towards top, very pure shale towards base. Smells strongly of HC when fractured. Conchoidal - blocky fracture. Trilobite fragments abundant to occasional in places. Very fissile, several diffuse carbonate concretions and cone-in-cone structures. Pyritic.

412.07-418.00 Interbedded limestone and shale. Limestones are in the form of concretions and shelly lenses. The shales are med grey and contain trilobites and pyrite blebs.

418.00-426.20 Med-dark grey shale with variable conchoidal/blocky uneven fracture with abundant well rounded carbonate concretions throughout, usually containing fossil fragments of brachs, bivalves, nautiloids, trilobites but no graptolites observed. Some fossils filled/replaced by pyrite.

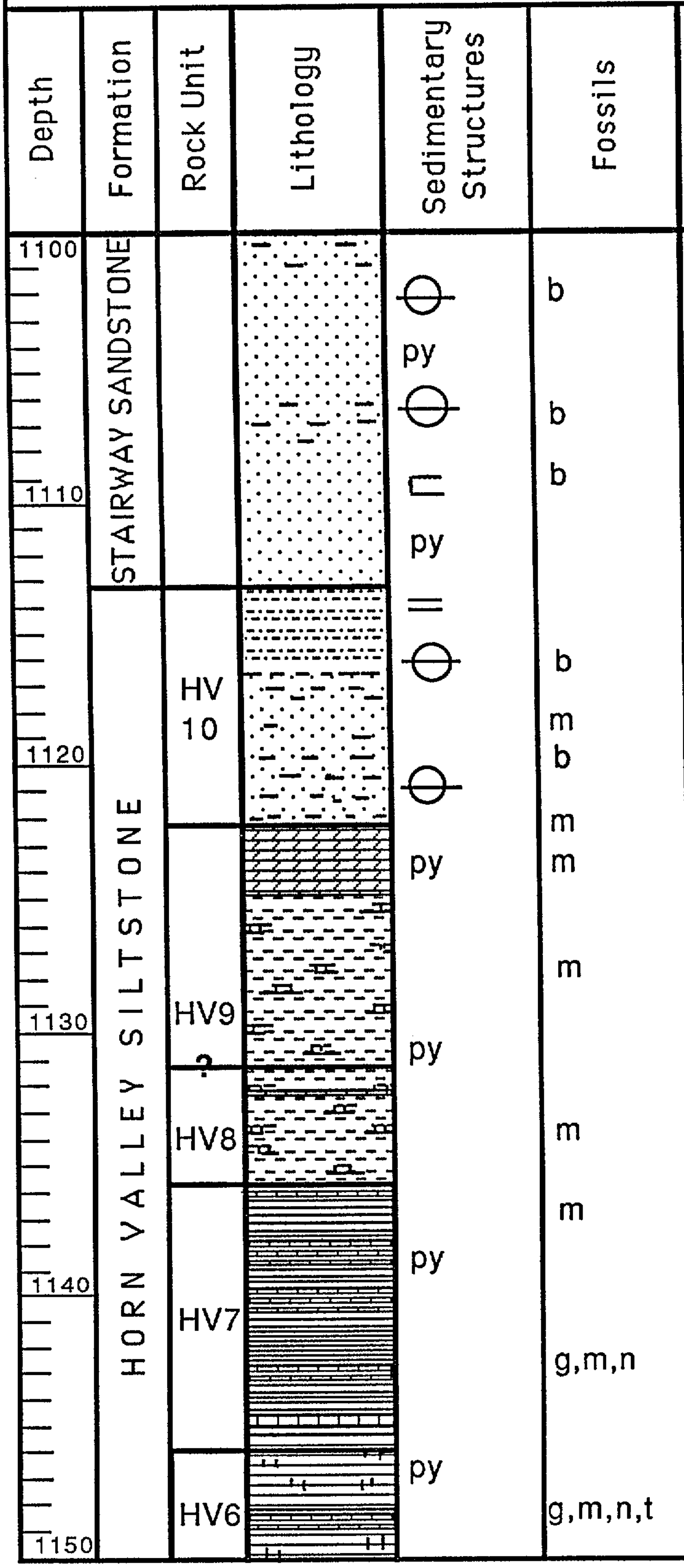
426.20-438.86 Dark grey shale, very fissile, planar horizontal bedding plane, abundant calcareous nodules & thin limestone layers (1-2cm thick). Carbonate "concretions" less abundant than in overlying unit. White fossil fragments including nautiloids, brachipods. Pyritic

438.86-440.28 Shelly limestone with minor silty laminae. Appears to be consist of shell fragment welded together - extensive recrystallisation. Irregular bedding.

440.28-442.64 Bioturbated sltst/sst. Pyritic & glauconitic (glauconite throughout but concentrated near the top). Bedding disturbed by burrowing. Uncommon fossil fragment (nautiloid)

442.64-447.75 Silty sandstone. Strongly bioturbated, glauconitic & pyritic.
447.75 End of logging

Basin: AMADEUS	Well: TENT HILL #1	Sheet: 1 of 2
Location: 23° 13' 45" S, 132° 02' 30" E		Core No: NA



Description

1100-1107.91 Alternating beds of silty fine sandstone with beds of medium grained sandstone. Silty sst has shale shards, pyrite nodules and is strongly bioturbated. Medium sst is light grey to white in colour and is also strongly bioturbated with long escape type burrows, pyrite and styolites present in places.

1107.91-1112.99 Medium to coarse sandstone, light grey to white in colour. Bioturbated towards top, with long escape burrows otherwise horizontal bedding. Pyritic. Styolites.

1112.99-1116.34 Very inhomogenous unit. Silty fine sst. Strongly bioturbated. Small shale clasts in sandier sections.

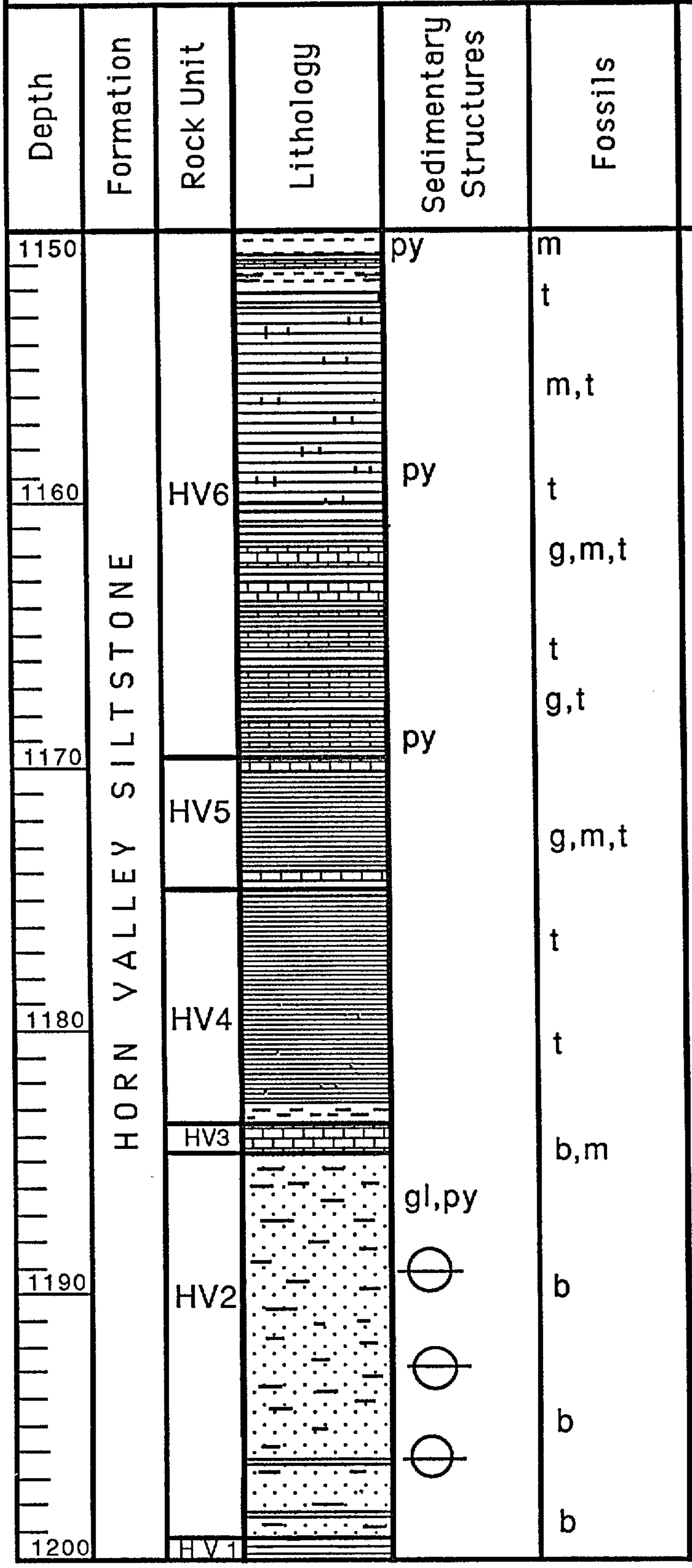
1116.34-1122.40 Predominantly siltstone with thin horizons of calcilutite. Siltstone is strongly bioturbated with silt lined burrows, pyritic. Small shell fragments with occasional whole shell preserved in the silty limestone bands.

1122.40-1124.80 Dolomite silty in places. Shell fragments scattered throughout. Pyritic.

1124.80-1136.55 Interbedded shelly limestone (dolomitic in places) and laminated calcareous siltstone. Limestone composed largely of shell fragments and calcareous siltstone contains small burrows and is pyritic in places.

1136.55-1146.64 Predominantly shale, silty in part, firm to hard, fissile to subfissile. Shale is very carbonaceous and bituminous in parts with minor pyrite. Dark grey to black occasionally white/tan in colour. Well preserved disarticulate shells, trilobite fragments, graptolites and nautiloids. Occasional silty limestone bands which in places are dolomitic.

Basin: AMADEUS	Well: TENT HILL #1	Sheet: 2 of 2
Location: 23° 13' 45" S, 132° 02' 30" E		Core No: NA



Description

1146.64-1153.65 Laminated calcareous siltstone. Shelly fragments, nautiloids. Pyritic.
1153.65-1169.78 Shale with irregular limestone and in places dolomitic lenses. Shale is medium to dark grey in colour, slight uneven lamination. Fractures readily but unevenly. Contains mainly trilobites but also graptolites and is pyritic. Shale, gradational to siltstone in part. Limestone consists of predominantly fragmented shells and is dolomitic in places. Dolomite is cryptocrystalline and dark grey brown in colour. Silty in part, moderately hard. Rarely fossiliferous with occasional sharp contacts.
1169.78-1174.56 Shale with abundant trilobites graptolites, minor brachiopods, pyrite blebs. Interbedded silty limestone with shell fragments.
1174.56-1183.00 Fossiliferous shale, brittle, with calcareous concretions. Mainly trilobites.

1183.00-1183.50 Silty limestone (irregular nodules enclosed by trilobite & shelly rich silt)

1183.50-1184.80 Slightly silty nodular to massive limestone. Shell fragments.

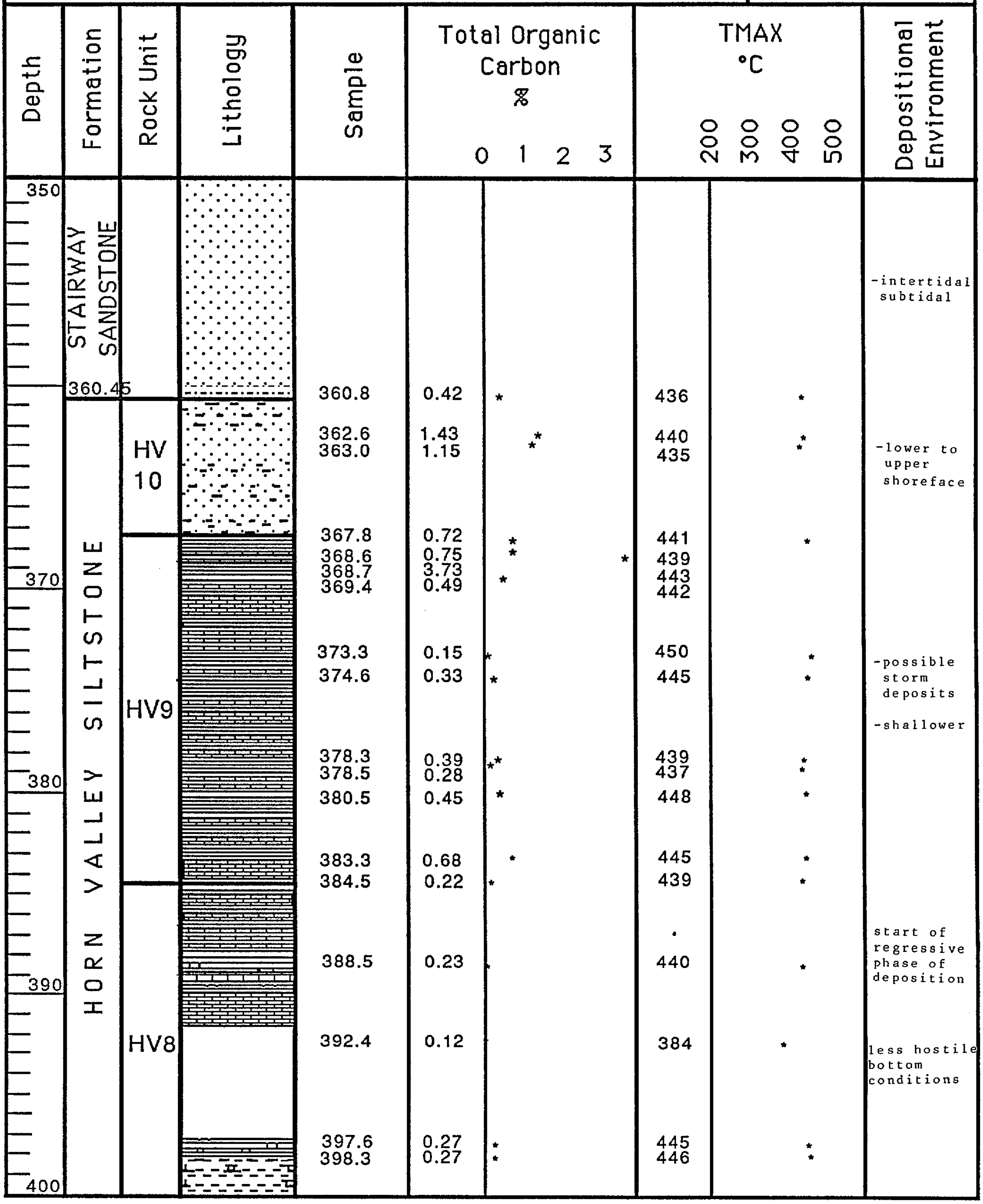
1184.80 -1199.57 Interbedded siltstone and very fine to fine sandstone. Sandstone is well cemented with dolomite and occasionally silica, very fine to extremely fine grained. Very glauconitic and a trace pyritic. Hard, subangular and grades to siltstone in part. Siltstone is medium to dark grey, grading through to extremely fine sandstone as above. Dolomitic, micromicaceous, glauconitic and blocky. All very thinly interbedded and are heavily bioturbated.

1199.57-1199.80 Medium grey shale, extremely fissile, with pyrite blebs. Horizontal bedding. No fossils. Sharp lower boundary.
1199.80-1200.42 Transitional zone into the Pacoota Sandstone. (Silt and sands)
1200.42 Pacoota Sandstone proper (sandstones).

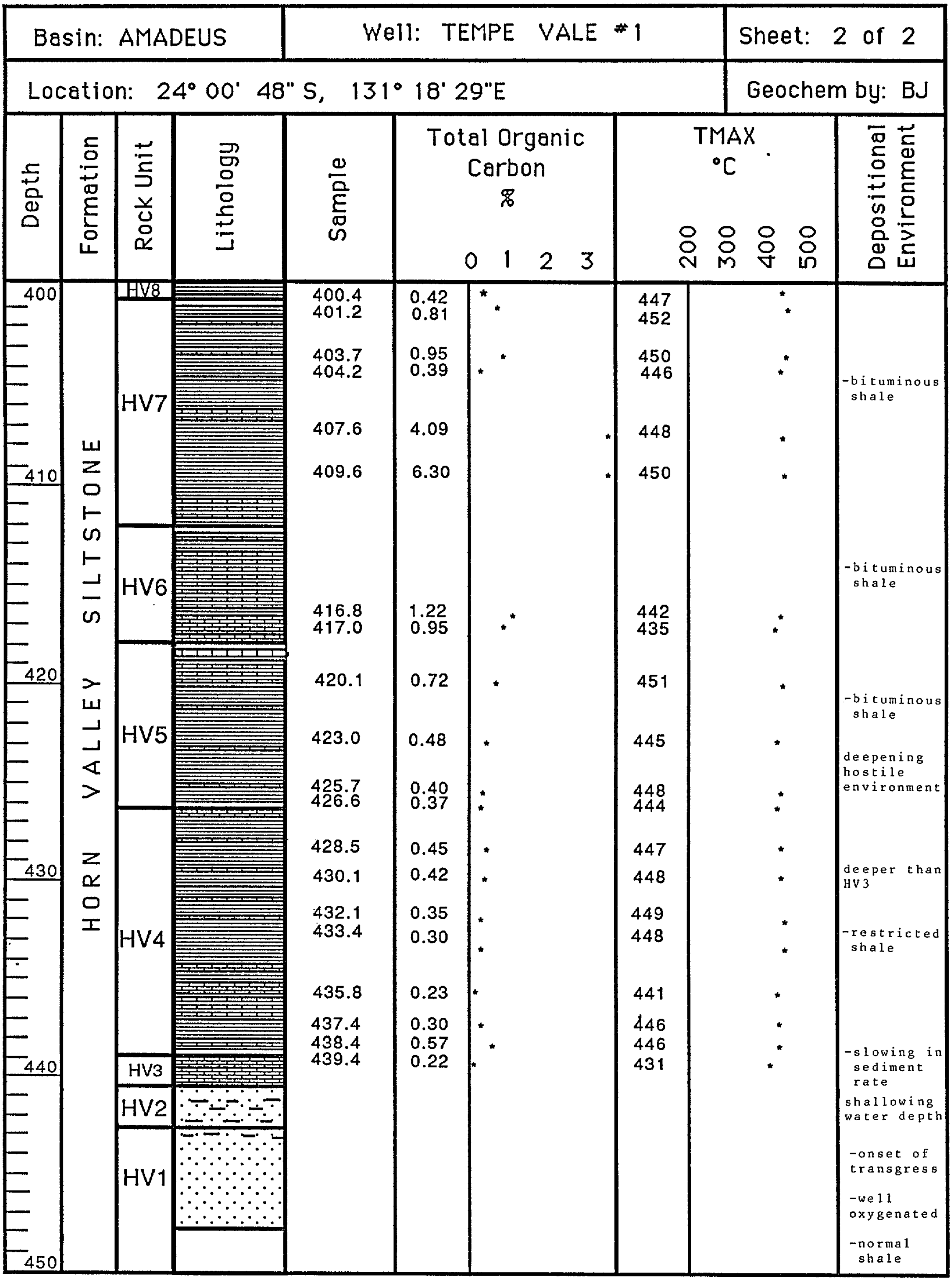
APPENDIX 8

GEOCHEMICAL LOGS

Basin: AMADEUS	Well: TEMPE VALE #1	Sheet: 1 of 2
Location: 24° 00' 48" S, 131° 18' 29"E		Geochem by: BJ



Sample	Total Organic Carbon %	TMAX °C
360.8	0.42	436
362.6	1.43	440
363.0	1.15	435
367.8	0.72	441
368.6	0.75	439
368.7	3.73	443
369.4	0.49	442
373.3	0.15	450
374.6	0.33	445
378.3	0.39	439
378.5	0.28	437
380.5	0.45	448
383.3	0.68	445
384.5	0.22	439
388.5	0.23	440
392.4	0.12	384
397.6	0.27	445
398.3	0.27	446



Sample	Total Organic Carbon %	TMAX °C
400.4	0.42	447
401.2	0.81	452
403.7	0.95	450
404.2	0.39	446
407.6	4.09	448
409.6	6.30	450
416.8	1.22	442
417.0	0.95	435
420.1	0.72	451
423.0	0.48	445
425.7	0.40	448
426.6	0.37	444
428.5	0.45	447
430.1	0.42	448
432.1	0.35	449
433.4	0.30	448
435.8	0.23	441
437.4	0.30	446
438.4	0.57	446
439.4	0.22	431

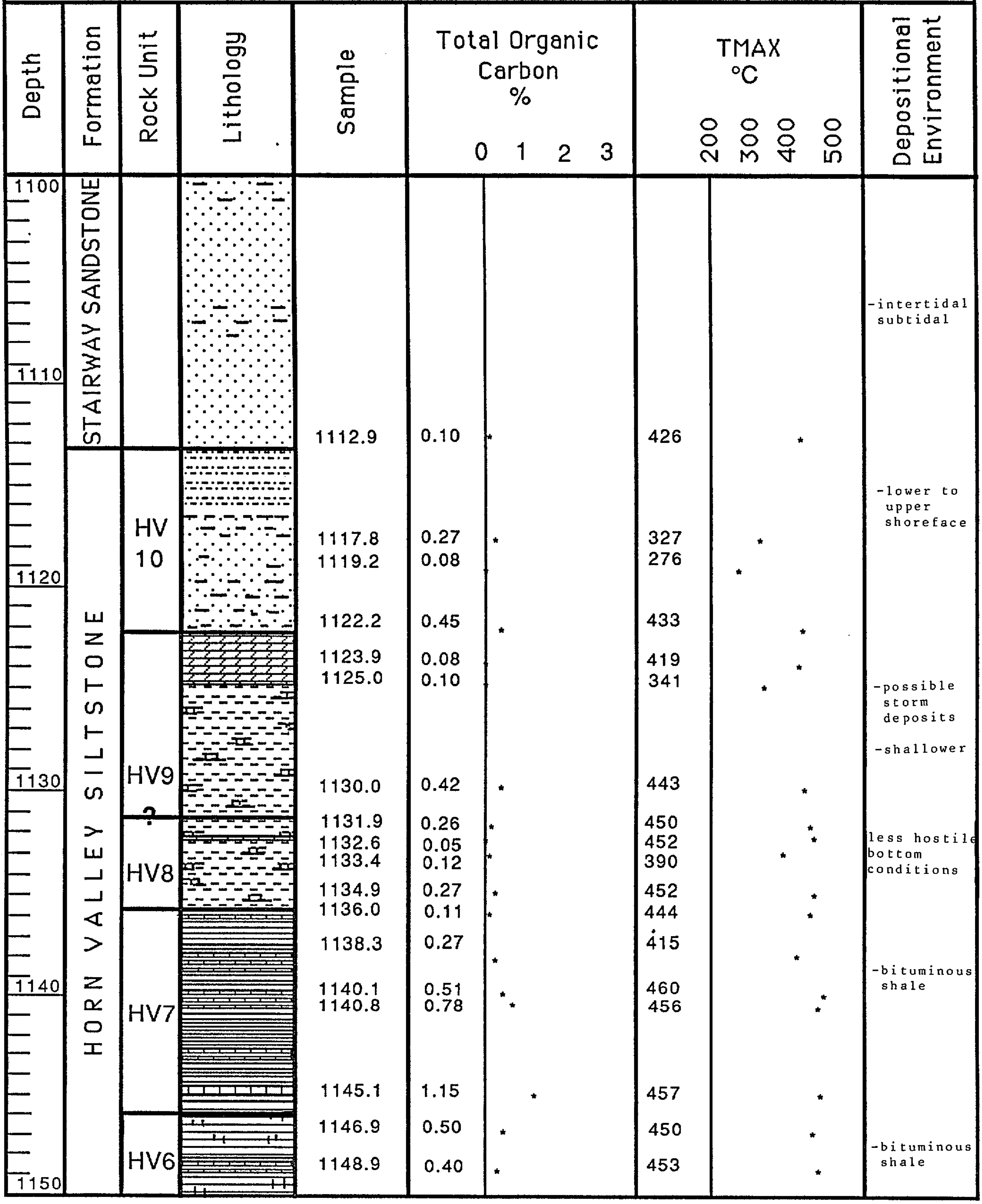
Basin: AMADEUS

Well: TENT HILL #1

Sheet: 1 of 2

Location: 23° 13' 45" S, 132° 02' 30" E

Geochem by: BJ



Sample	Total Organic Carbon %	TMAX °C
1112.9	0.10	426
1117.8	0.27	327
1119.2	0.08	276
1122.2	0.45	433
1123.9	0.08	419
1125.0	0.10	341
1130.0	0.42	443
1131.9	0.26	450
1132.6	0.05	452
1133.4	0.12	390
1134.9	0.27	452
1136.0	0.11	444
1138.3	0.27	415
1140.1	0.51	460
1140.8	0.78	456
1145.1	1.15	457
1146.9	0.50	450
1148.9	0.40	453

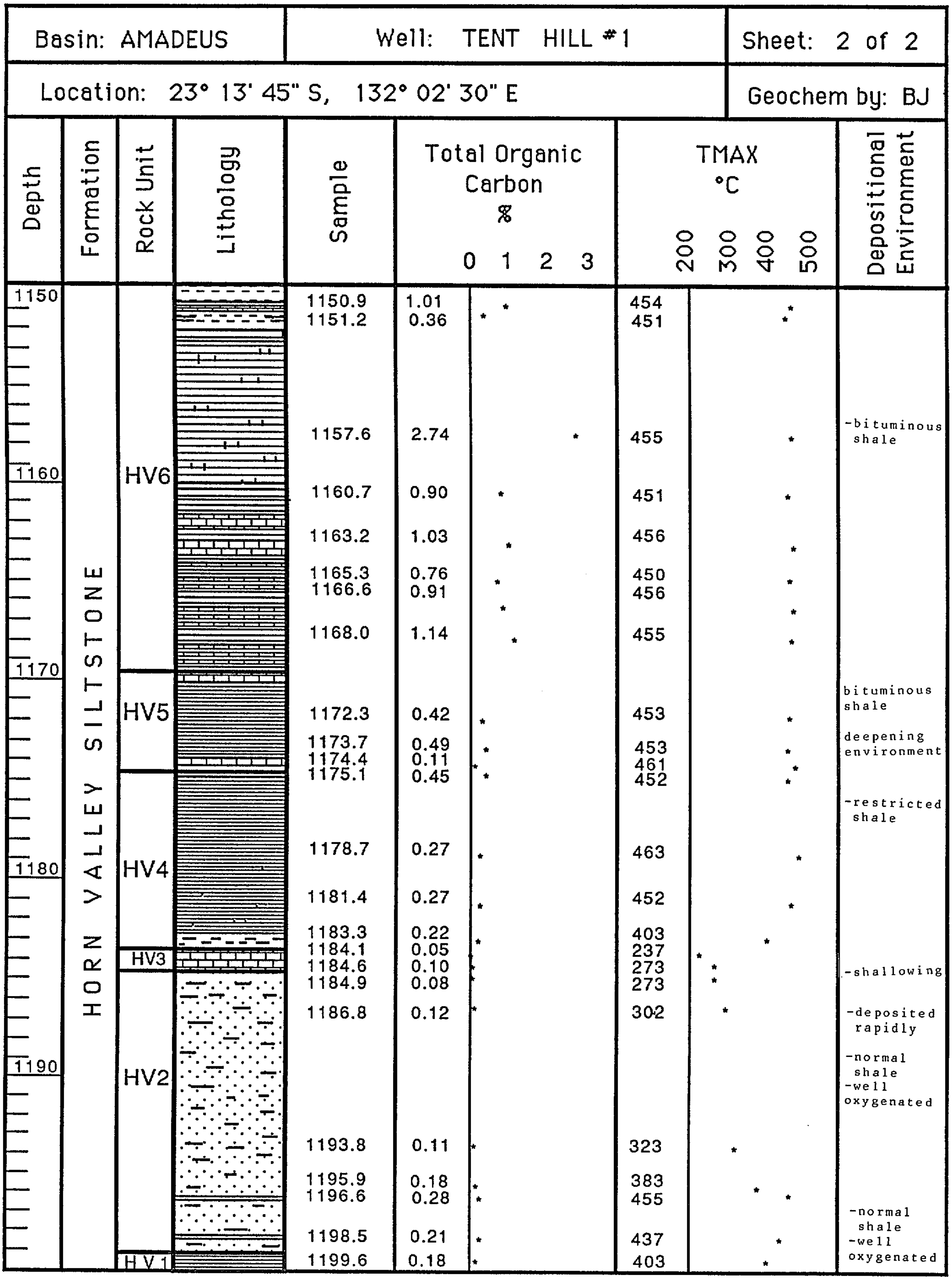
Basin: AMADEUS

Well: TENT HILL #1

Sheet: 2 of 2

Location: 23° 13' 45" S, 132° 02' 30" E

Geochem by: BJ



Sample	Total Organic Carbon %	TMAX °C
1150.9	1.01	454
1151.2	0.36	451
1157.6	2.74	455
1160.7	0.90	451
1163.2	1.03	456
1165.3	0.76	450
1166.6	0.91	456
1168.0	1.14	455
1172.3	0.42	453
1173.7	0.49	453
1174.4	0.11	461
1175.1	0.45	452
1178.7	0.27	463
1181.4	0.27	452
1183.3	0.22	403
1184.1	0.05	237
1184.6	0.10	273
1184.9	0.08	273
1186.8	0.12	302
1193.8	0.11	323
1195.9	0.18	383
1196.6	0.28	455
1198.5	0.21	437
1199.6	0.18	403

-bituminous shale

bituminous shale

deepening environment

-restricted shale

-shallowing

-deposited rapidly

-normal shale
-well oxygenated

-normal shale
-well oxygenated

APPENDIX 9

MEASURED SECTIONS

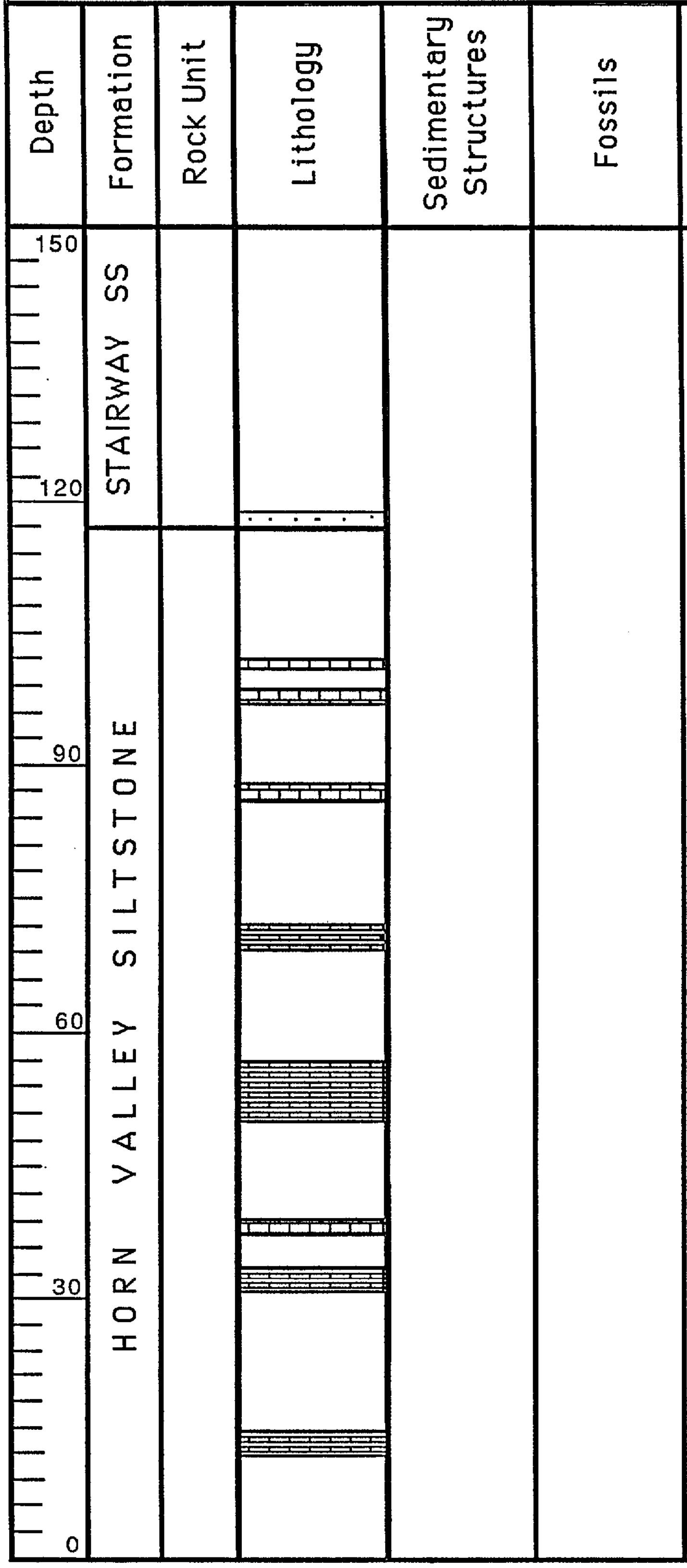
Basin: AMADEUS

Section: 84 - 2003

Sheet: 1 of 1

Location: Approx line of LAC7 (Ochre Hill)

Measured by: RSN

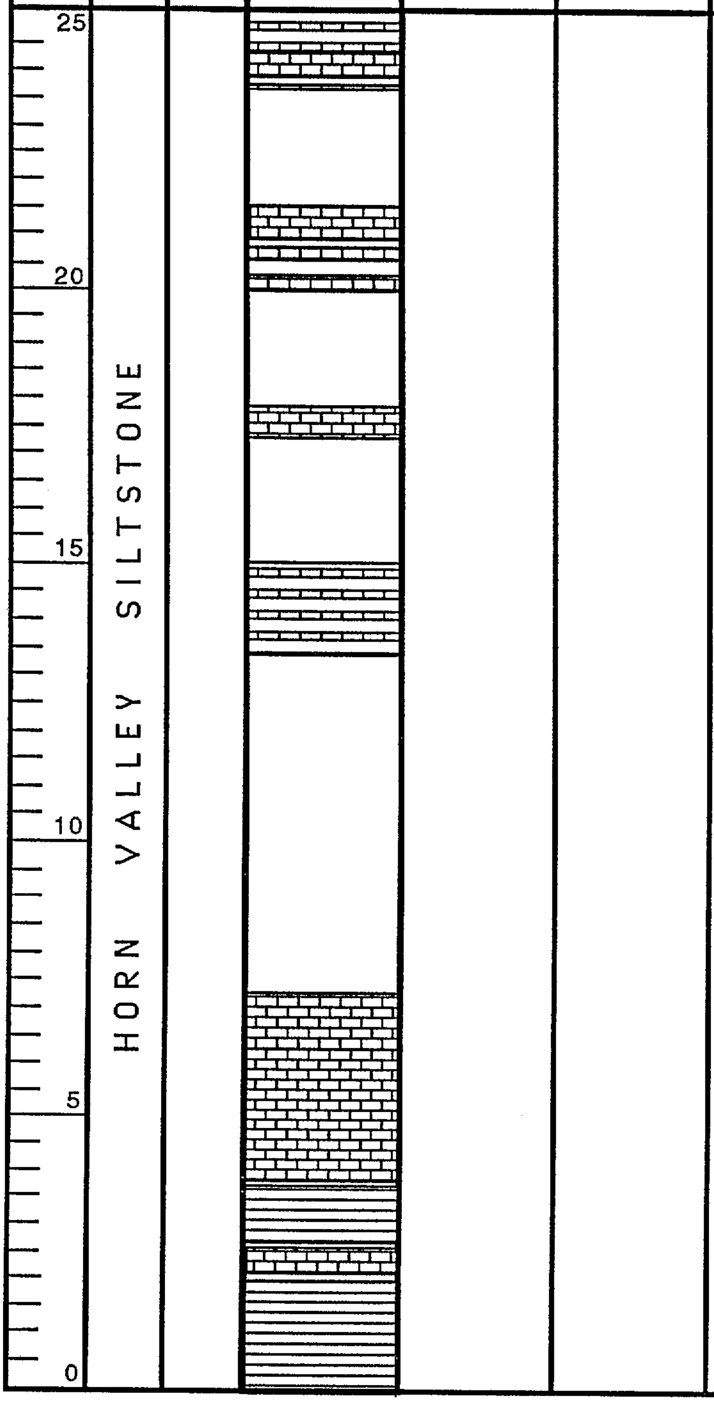


Description

UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE

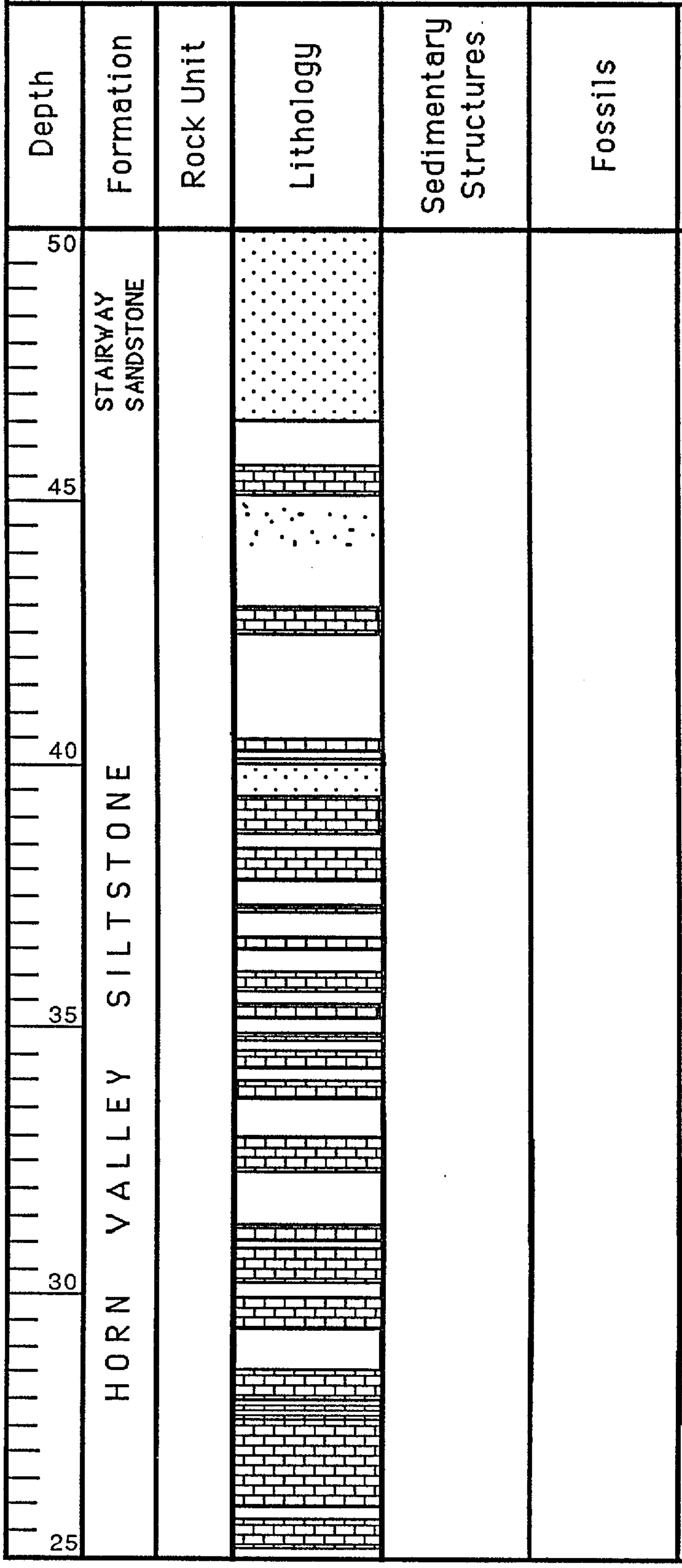
Basin: AMADEUS	Section: 84 - 2004	Sheet: 1 of 2
Location: Maloney Creek		Measured by: RSN

Depth	Formation	Rock Unit	Lithology	Sedimentary Structures	Fossils	Description



UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE

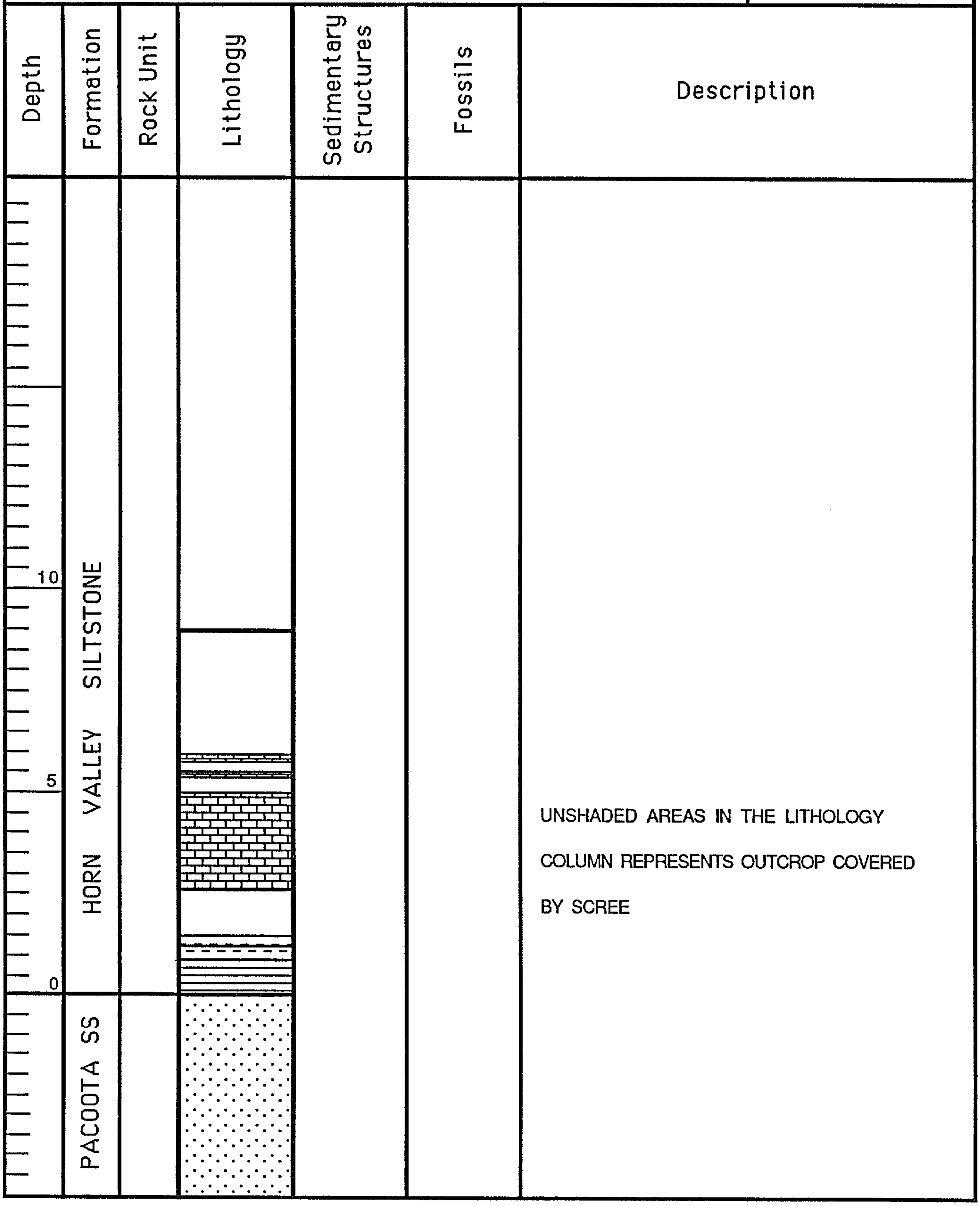
Basin: AMADEUS	Section: 84 - 2004	Sheet: 2 of 2
Location:		Measured by: RSN



Description

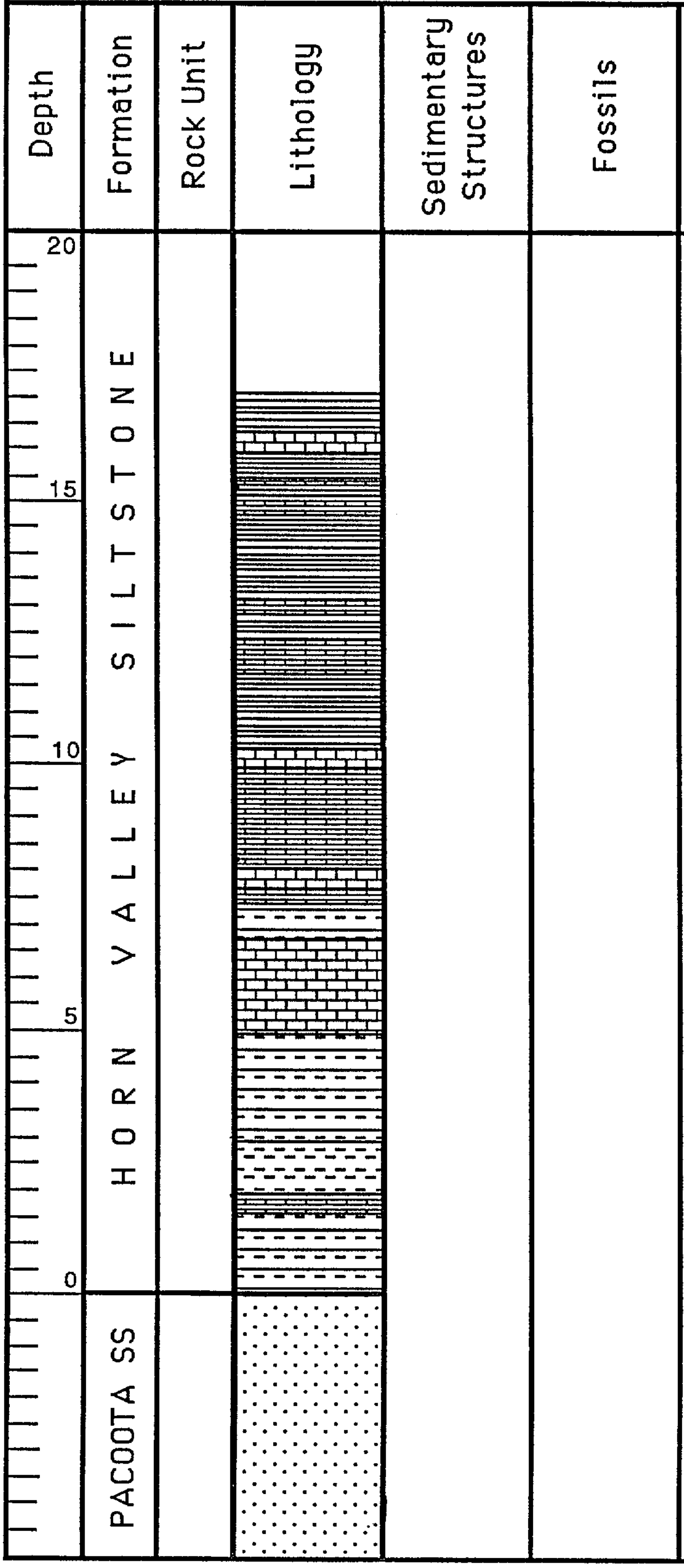
UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE

Basin: AMADEUS	Section: 84 - 2008	Sheet: 1 of 1
Location: EASTERN JAMES RANGE		Measured by: RSN



UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE

Basin: AMADEUS	Section: 85 - 2013 / 85 - 2014	Sheet: 1 of 1
Location: Mount Olifent area		Measured by: RSN



Description

UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE

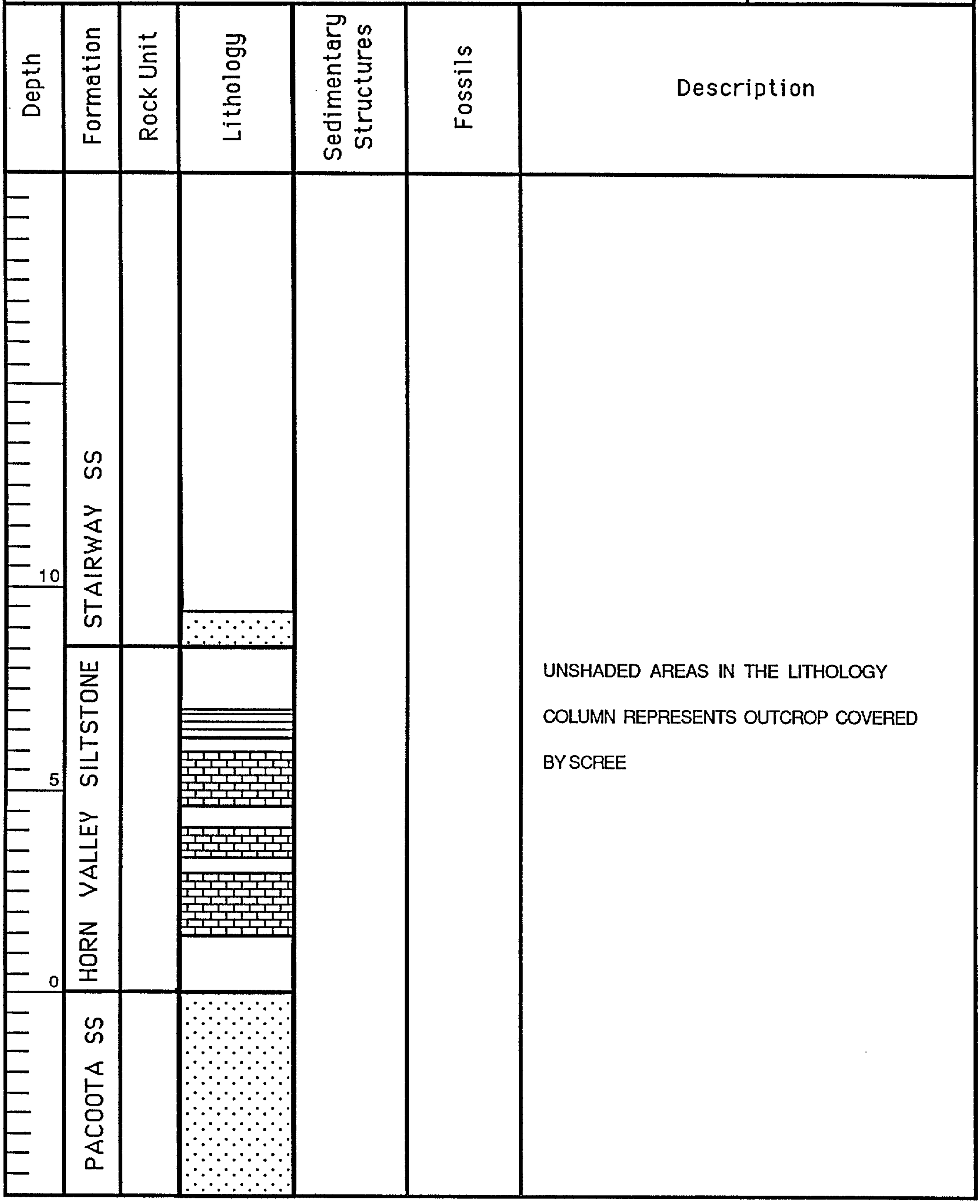
Basin: AMADEUS

Section: 85 - 2017

Sheet: 1 of 1

Location: unnamed range south of Seymour Range

Measured by: RSN



UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE

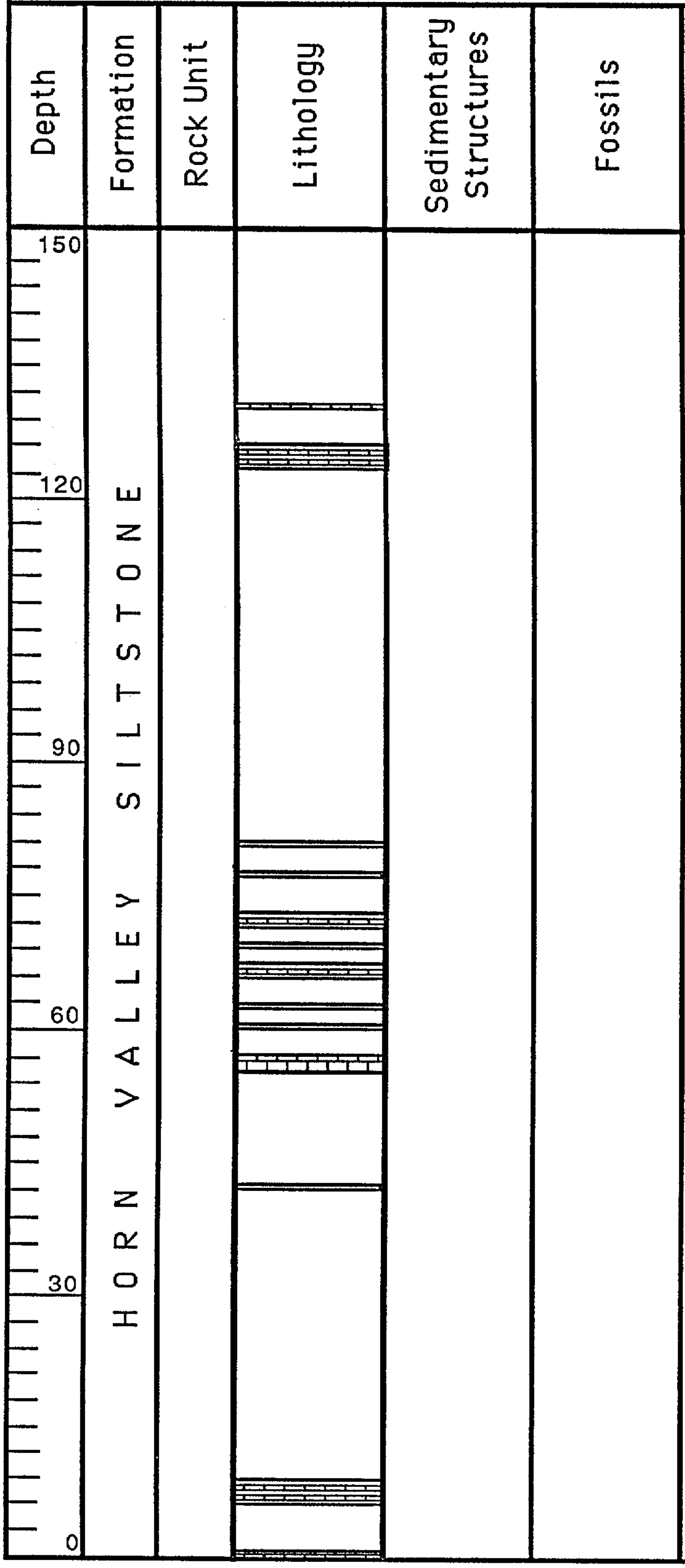
Basin: AMADEUS

Section: 85 - 2021

Sheet: 1 of 1

Location: " Horse Gap " - Gardiner Range

Measured by: RSN



Description

UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE.

Basin: AMADEUS

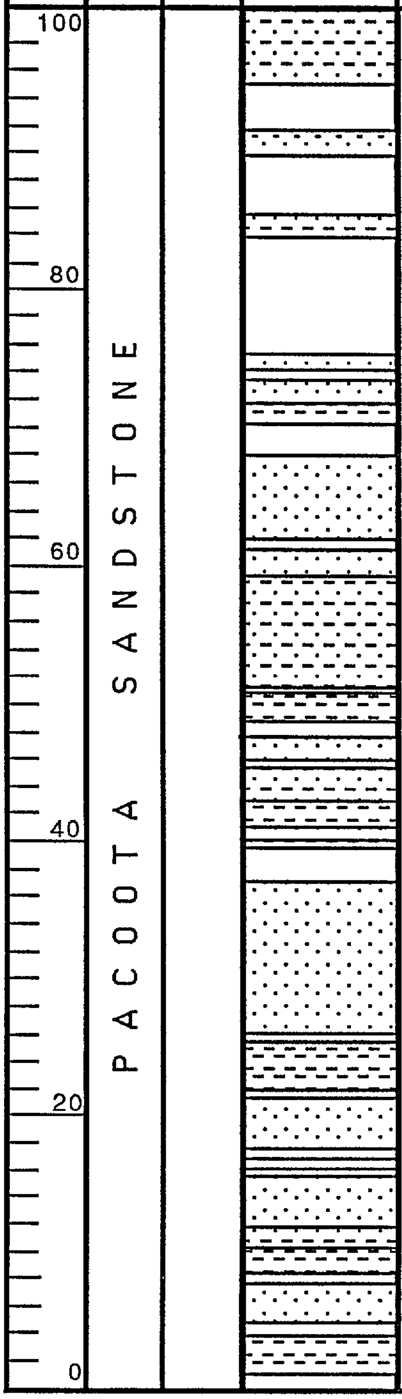
Section: 86 - 2023

Sheet: 1 of 2

Location: Ellery Creek

Measured by: RSN

Depth	Formation	Rock Unit	Lithology	Sedimentary Structures	Fossils	Description



UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE

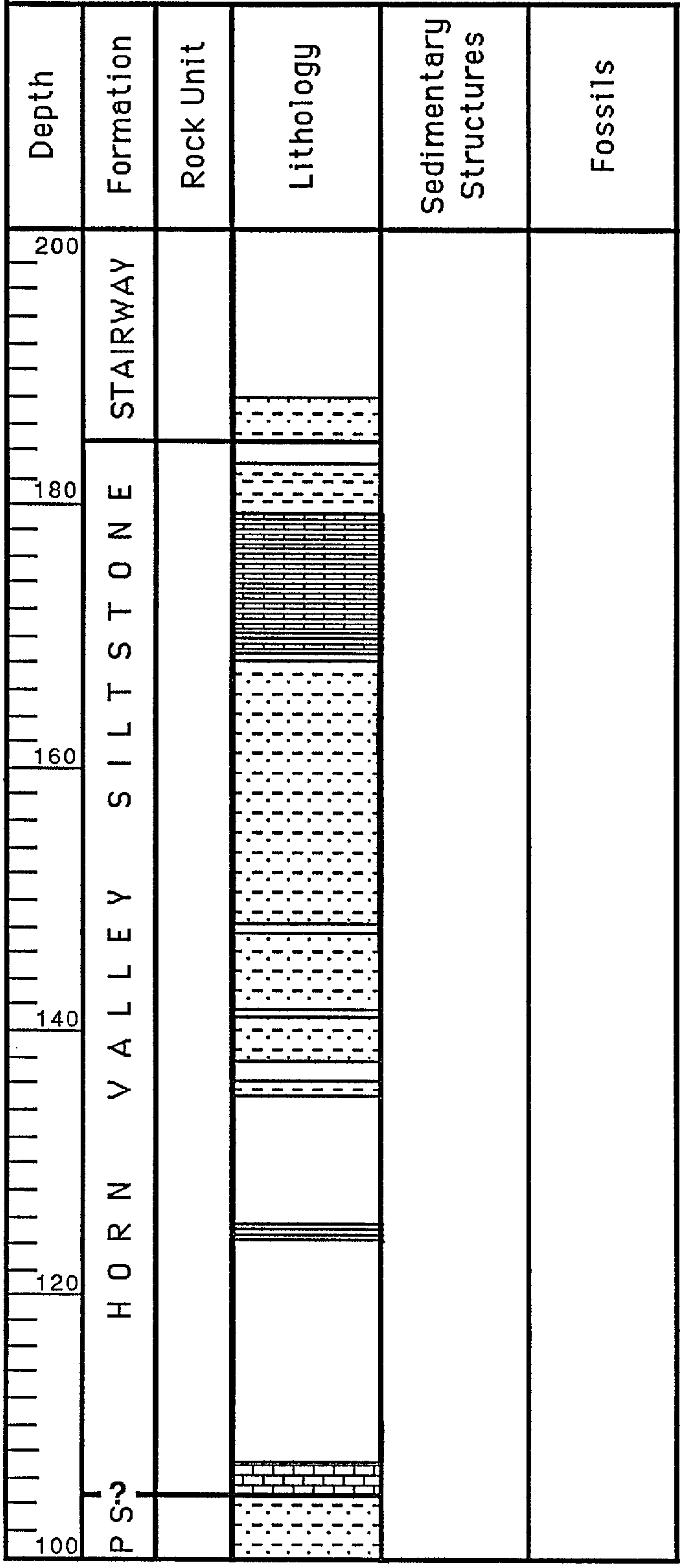
Basin: AMADEUS

Section: 86 - 2023

Sheet: 2 of 2

Location: Ellery Creek

Measured by: RSN



Description

UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE

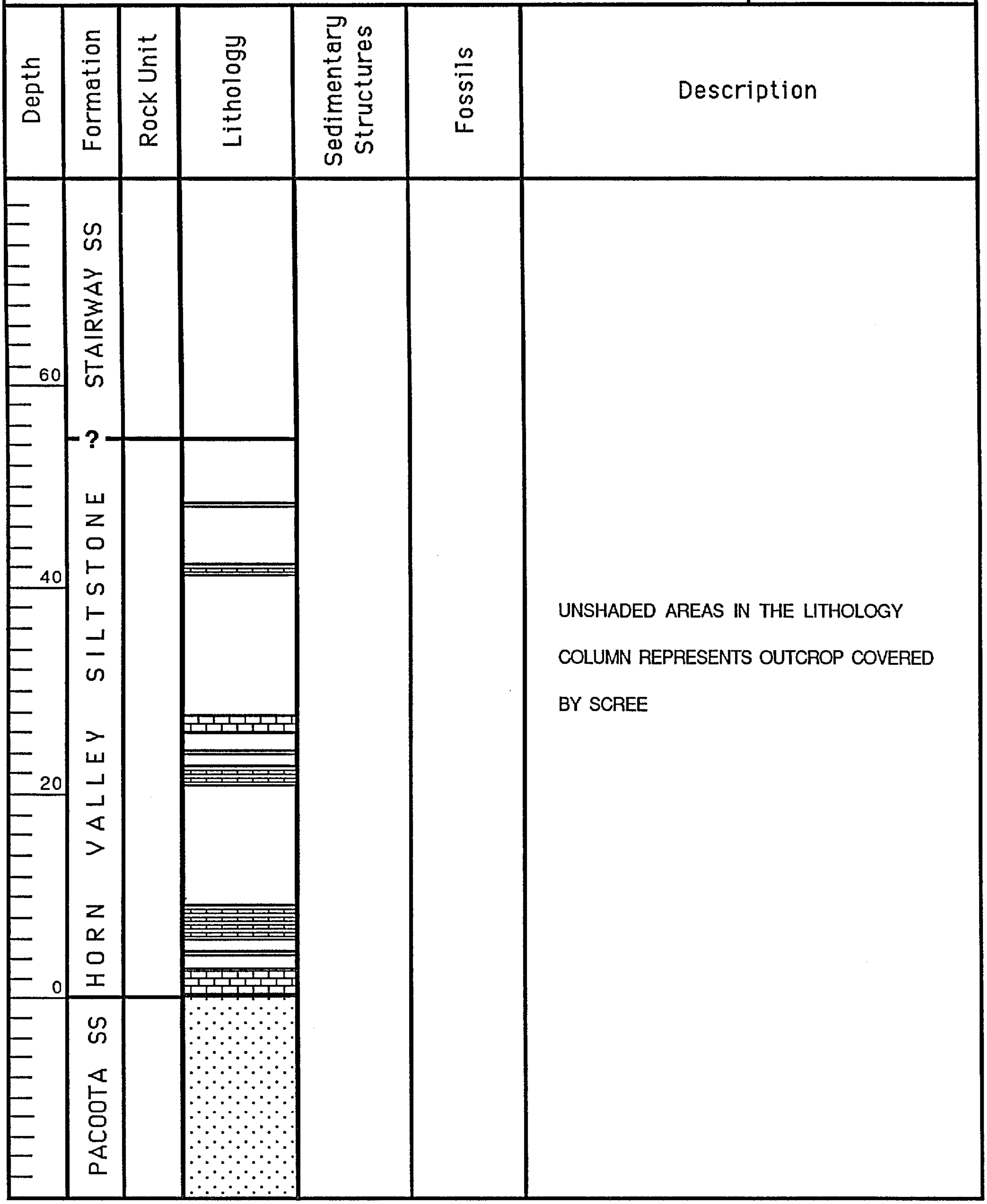
Basin: AMADEUS

Section: 86 - 2027

Sheet: 1 of 1

Location: Approximately that of MRW 1

Measured by: RSN



UNSHADED AREAS IN THE LITHOLOGY COLUMN REPRESENTS OUTCROP COVERED BY SCREE

PLATES

PLATE 1

Fig. A Interbedded black pyritic mudstone with thin medium grey siltstone. The sedimentary laminae are "wispy" and discontinuous in places due to minor bioturbation. Cross sections of small horizontal burrows can be noted in this core. This is indicative of HV1.

Fig. B Horizontal unbranched burrow (6mm in width) in HV1, resembling the ichnogenera *Palaeophycus* or *Planolites*.

Fig. C Branching burrows (up to 5mm in width) in HV1, of the *Chondrites* -type.

Fig. D Strongly bioturbated dark grey mudstone and light grey siltstone of facies HV2. Physical stratification is almost absent. Predominantly horizontal burrows which have burrowed upwards through the sediment quickly in response to sediment influx.

Fig. E HV3 consists of micritic nodular limestone with wavy black mudstone laminae. The shells are fragmented and lath like in appearance (up to 10mm in length) and are aligned lengthways, paralleling the laminae in the muddy units which flow over and around the limestone.

Fig. F A well preserved pyritic nautiloid lying parallel to bedding in HV4.

Fig. G HV4 consists predominantly of a well bedded mudstone with minor micritic limestone nodules. Above this nodule is the end view of the nautiloid depicted in Fig. F.

Fig. H HV6 consists of a black pyritic and highly fossiliferous mudstone with a grey muddy limestone interbedded. Pods of limestone consisting of fine shell debris are also common.

Figs A - H are all x1. Figs A, D, E, G and H are oriented with increasing depth downwards, whilst Figs B, C and F have no particular orientation. All of these core samples have been taken from Mt Liebig #2.

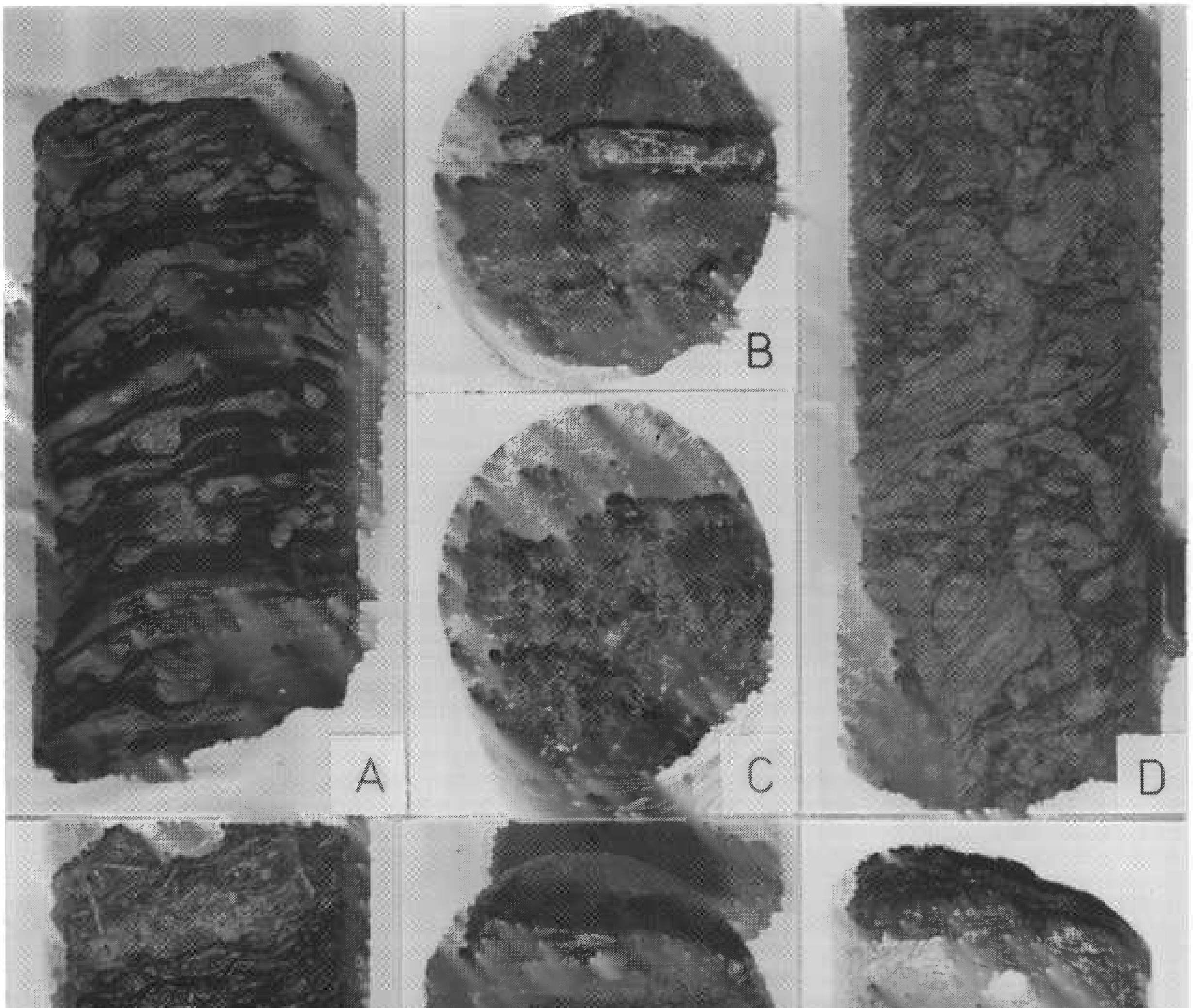

A
B
C
D
E
F
G
H

PLATE 2

Fig. A A silty fossiliferous limestone in HV8. Here the shells are not fragmented and have been preserved with both valves still attached. The infilling material in these shells appears to be different to the surrounding host rock.

Fig. B HV9 consists of a dark grey finely laminated pyritic mudstone with thin interbeds of grey calcareous siltstone and fossiliferous light grey limestone.

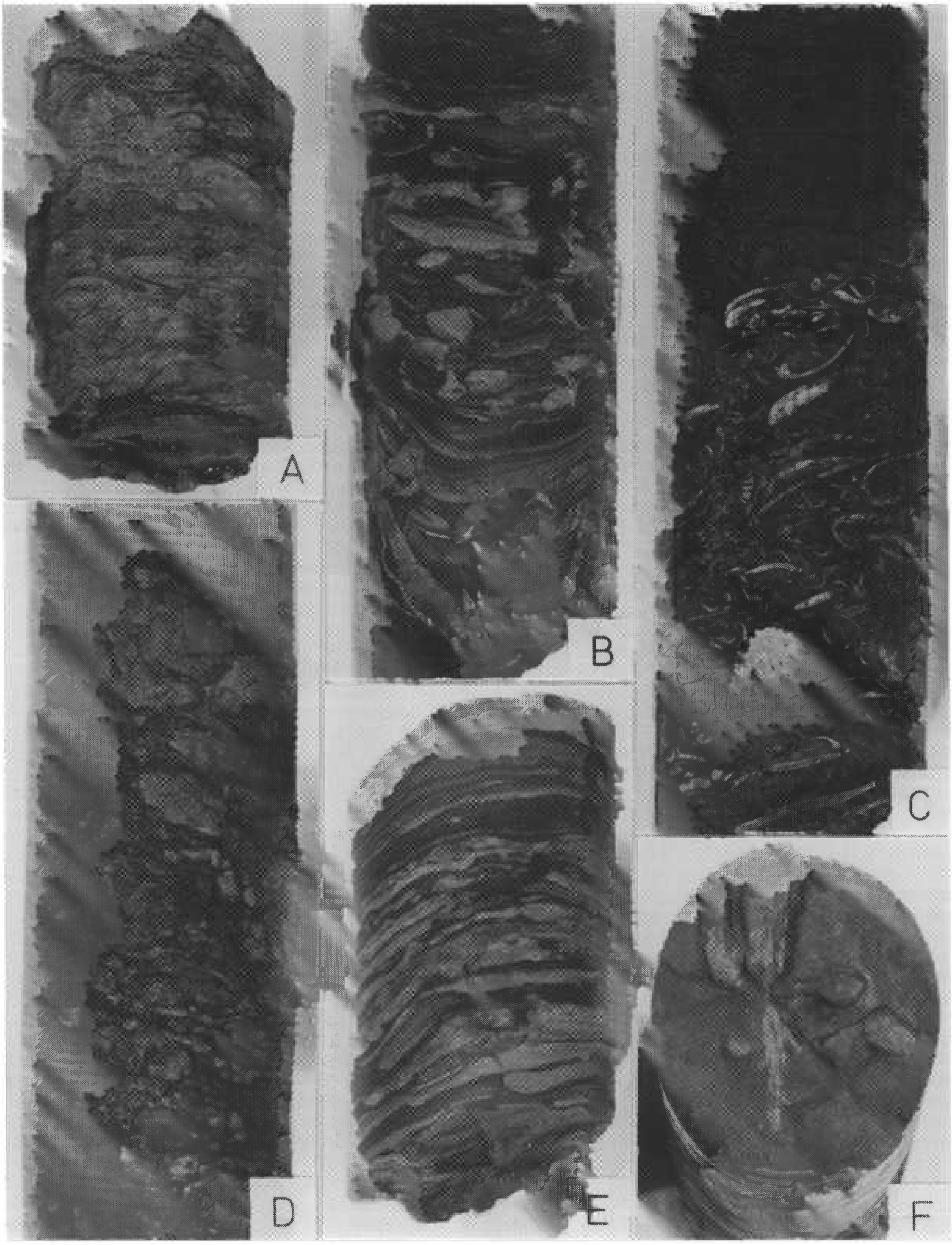
Fig. C This cycle is one of many depicted in HV9. The cycle begins with a shelly limestone (coquina) which has a sharp and irregular base. It consists mainly of brachiopods, nautiloids and trilobites. It is then overlain by a marl or mudstone. This association suggests an origin related to storm activity.

Fig. D HV10 consists of a black mudstone with interbeds of medium grey, non clacareous, fine siltstone. The sequence has the appearance of being bioturbated and reworked by burrowing organisms.

Fig. E Fine interbeds of light grey siltstone and dark grey mudstone which are bioturbated are common to SS1 (lowest beds of the Stairway Sandstone).

Fig. F Trace fossils are common in the Stairway Sandstone (SS1). A *Phycodes* like burrow is preserved lying parallel to the bedding plane.

Figs A - F are all x1. Figs A, B, C, D and E are oriented with increasing depth downwards, whilst Fig. F has no particular orientation. All of these core samples have been taken from Mt Liebig #2.


A
B
C
D
E
F