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LUCAS HEIGHTS RESEARCH LABORATORIES

DEMONSTRATION OF AN INITIAL SCREENING PHASE FOR SITE SELECTION FOR LOW LEVEL RADIOACTIVE WASTE BURIAL - AN EVALUATION OF RELEVANT IAEA GUIDELINES

by

Environmental Science Division
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FOREWORD

There are two basic options for the disposal of low level radioactive waste - shallow ground burial and ocean dumping. Many factors are involved in choosing one method over the other, with geographical size of the nation being one of them. International practice varies: for example, the United Kingdom uses both methods of disposal; Russia, USA and Canada presently use only shallow ground burial; and Japan is proposing ocean dumping.

The International Atomic Energy Agency (IAEA), through its Safety Series publications, provides guidance on many aspects of atomic energy. Three such guides published recently cover the following topics

- Basic guidance on underground disposal of radioactive wastes,
- Development of regulatory procedures for the disposal of radioactive waste in deep, continental formations, and
- A guide to shallow ground disposal of radioactive wastes.

This report is concerned only with the third of these IAEA publications. The Environmental Science Division of the AAEC was involved, through IAEA advisory group meetings, in the drafting of this guide, and a study to test the applicability of the IAEA guidelines under Australian conditions was carried out by the Division using data from NSW which were readily available. This report is the result of that study.

Elements of subjectivity were involved in several aspects of the IAEA approach to site selection. This was particularly so with respect to the derivation of the hydrogeological characteristics of the candidate sites and the ranking of them. Several officers, both within and outside Commission employ, were involved in reaching a consensus. Particular thanks are due to Mr D. Hawley, Mr J. McManus, Mr A. Camilleri and Dr A.I.M. Ritchie.

Thanks too are due to the AAEC editorial and drafting staff who willingly worked on a series of drafts as the report asymptotically approached consensus.

D.R. Davy
Chief, Environmental Science Division

ABSTRACT

Low level radioactive wastes, arising from the use of radioisotopes in medicine and industry are accumulating, close to their point of use, throughout Australia. The rate of accumulation has not been large and storage of these wastes close to the point of use has proved practicable to date, but consideration must now be given to a central repository or repositories for these low level wastes. Ocean dumping and shallow ground burial are the two basic options for disposal. This report considers the question of selecting a site suitable for disposal of wastes by shallow ground burial.

The selection of sites for the burial of low level radioactive waste depends on a number of factors including hydrogeology, biology, land use and status, and social and economic values. In its guidebook to shallow ground disposal of radioactive waste, the IAEA suggests guidelines to be used in site selection. The approach is an iterative, evaluative process, which includes a map-literature survey, preliminary reconnaissance, intermediate reconnaissance and, finally, detailed site analysis, with unsuitable sites being rejected at each stage and carrying forward only those sites which appear to be suitable for additional investigation.

The work reported here is an attempt to assess the practicability of using the hydrogeological and other factors suggested by the IAEA for the initial 'office review' phase of site screening. For convenience, since the data used were readily available, the study was limited to areas within the state of New South Wales which was considered large enough to provide a variety of potential sites and to expose any problems in evaluating the data required in the screening process. The purpose of the study was to evaluate the site selection technique, and the resulting ranking of areas of NSW in this 'office review' does not imply the overall suitability of any site for waste burial. This would require detailed hydrogeological studies of the sites selected.

The screening process described has essentially two stages. In the first, NSW was divided into broad structural units and these ranked in order of suitability. In the second stage, survey sites in which thick clay beds outcropped were delineated in the five highest ranking structural units. These survey sites were ranked on the basis of various geomorphological properties which largely described the hydrogeology of the site. Three survey sites - Yellow Mountain, 70 km north-west of Condobolin, Pine Creek, 80 km south of Broken Hill and Taringo Downs, 100 km south-west of Cobar ranked highest in this second stage.

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The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS: Manual for Indexing) and IAEA-INIS-13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

GEOLOGY; GROUND DISPOSAL; HYDROLOGY; LOW-LEVEL RADIOACTIVE WASTES; NEW SOUTH WALES; RADIOACTIVE WASTE DISPOSAL; SITE SELECTION

CONTENTS

(Continued)

1. INTRODUCTION

Radioactive materials are used frequently throughout Australia for a wide variety of purposes [Boyd 1968]. Their best known use is in medicine, where radionuclides are used as both diagnostic and therapeutic tools [Andrews 1977; Boyd and Lane 1973]. Radionuclides, however, are also used in many other areas, such as engineering where applications include their use in thickness gauges [Evans 1977] and in determining erosion and sediment transport in rivers and harbours [Airey 1978]; in agriculture, for forest nutrition studies [Brown 1969] and sterilisation of crop pests [Osborne et al. 1966]; and in the mining industry for precise determination of element concentrations for mining [Watt and Gravitis 1973]. Since the properties of the radionuclide chosen for a particular application (such as its physical and chemical forms, its half-life and its activity) will vary according to the detailed requirements of the application, radionuclides in use span most of the periodic table and have half-lives ranging from minutes to thousands of years. In many applications, where the activity of the radioactive source used has dropped to a level that would require inefficiently long counting times for its further use, it must be replaced by a new source. The old source then becomes scrap but as radioactive waste it cannot be disposed of as normal waste. In addition, the waste material (glassware, tissues, reagents, etc.) that arises from the day-to-day handling of radionuclides may be radioactive and also cannot be disposed of as normal waste. This waste material takes a wide variety of forms such as powders, liquids and solids, and is stored in containers and buildings close to the point of use.

The volume of waste is not very great at the present time. For example, low level waste at the AAEC Research Establishment currently occupies some 420 m^3 and is increasing at the rate of about 26 m^3 a year. Storage of waste close to a point of use and preparation is therefore a viable option for the short term, but clearly consideration must soon be given to selecting a central repository or repositories for disposal of Australia's low level radioactive waste material.

There are two basic options for the disposal of low level radioactive waste - shallow ground burial and ocean dumping. Many factors are involved in choosing one method over the other, geographical size of the nation being one of them. International practice varies; for example, the United Kingdom uses both methods of disposal; Russia, USA and Canada presently use only shallow ground burial, and Japan is proposing ocean dumping. This report is concerned only with the shallow ground burial option; in particular the question of selecting a site suitable for shallow burial disposal of low level radioactive waste. The question of the type of material to be disposed of in such a repository will not be discussed as such discussion belongs properly to the time when regulation of the repository is being considered.

The IAEA has produced a guide [IAEA 1981] for selection of a shallow ground disposal site. This guide describes an iterative screening process that rejects unsuitable sites and carries forward, for further investigation, those sites which are apparently suitable. The work reported here is an attempt to apply the approach, as outlined in the guide, to site selection in an Australian context. The IAEA guide describes the various elements that need to be considered in selection of a site and it ranks, in qualitative terms, the factors that make up these elements. However, the factors it lists are not exhaustive nor does it suggest how the various factors should be combined. In this report, a trial screening was carried out using, as an overall suitability index for a potential site, the sum of suitability indices applied to the various factors considered. For convenience, the selection process was limited to areas within the state of NSW. It was considered that NSW is large enough in area to provide a variety of potential sites and to expose any of the problems that might arise in acquiring and evaluating the data required for the exercise. As such, the study illustrates the site selection technique but does not, and cannot, at the office review stage, imply the suitability of any region for waste disposal. What is significant is the fact that, on the basis of the factors considered, this trial screening shows unequivocally those areas that are unsuitable as sites for a repository and indicates areas which are worth studying in further detail should a disposal site be required.

The initial screening phase described in this report, has essentially two stages. In the first stage, NSW was divided geologically into broad structural units (SU) (see definition later) and these ranked as possible areas for shallow ground disposal repositories, using criteria based on both the IAEA guide and on a report prepared by the US Academy of Science [National Research Council 1976]. This part of the exercise is described in Section 2. The second stage was to take the five SUs of highest rank and select, in each unit, one or more areas where clay beds of greater than 15 m depth crop out. These areas were then ranked according to weights applied to various geomorphological properties which largely describe the hydrogeology of each area. This initial screening phase is in essence the 'office review' phase of site screening defined in the IAEA guide to shallow ground disposal of low level radioactive waste. The 'survey' sites which ranked highest in this phase would be suitable for selection as candidate areas for further screening based on field reconnaissance and detailed soil analysis.

2. FIRST STAGE SCREENING

2.1 Description of Structural Units

Included in the 1:1 000 000 Geology of New South Wales printed in 1972 is a 1:6 000 000 scale map of SUs. A structural unit (SU) can be defined as an area which contains an assemblage of rocks of a particular geological age range and which has experienced a distinct and separate tectonic (structural) history relative to the surrounding area. It is a useful entity to employ when screening an area for sites suitable for shallow ground disposal of radioactive waste. Since, however, some of the SUs in the eastern half of NSW, as defined represent a rather small area at a 1:6 000 000 scale, adjacent small or narrow SUs were combined to give minimum sized areas larger than 25 000 km^2 or equal to at least 3 per cent of the total area of the State. In addition, the 300 000 km^2 area of the Lachlan Fold Belt which has a complex tectonic history, may be subdivided into meridional zones of greater and lesser deformation. Specifically, the Lachlan Fold Belt has been subdivided in the following way, using NSW Department of Mineral Resources nomenclature:

(a) The eastern edge of the Darling Depression has been bounded by the relatively undeformed Devonian far-west boundary of the Lachlan Fold Belt.

(b) The West Lachlan Fold Belt incorporates the Cobar and Mineral Hill synclinorial zones and the Girilambone - Wagga anticlinorial zones.

(c) The Central Lachlan Fold Belt includes the Bogan Gate and Cowra - Yass synclinorial zones and the Forbes anticlinorial zone.

(d) The East Lachlan Fold Belt includes the Molong - South Coast anticlinorial zone, together with the Hill End and Captain's Flat - Goulburn synclinorial zones.

In addition, in the eastern half of the state:

(a) The New England Fold Belt includes the Woolamin - Texas Block and the Tamworth synclinorial zone.

(b) East Coast Blocks and Basins include the Brisbane, Demon, Nambucca, Emu Creek, Kempsey and Port Macquarie Blocks and the Lorne and Clarence - Moreton Basins.

Figure 1 illustrates the way in which NSW was subdivided into eleven SUs, each containing an assemblage of rocks of comparable geological age and structure.

2.2 Rating System for the Structural Units

2.2.1 Resource variables

Australia's official visual description of natural and man-made resource variables, goods and services has been compiled and updated from industry and government data since 1953 as the Atlas of Australian Resources (see Appendix C). This atlas, published by the Department of National Development, contains some twenty-nine 1:6 000 000 scale maps. These resources are defined in terms of a number of variables such as rainfall, crop production, railways and so on, and the maps quantify these variables in each part of the continent. The variables were grouped into four categories as follows:

A. Natural Resources: climate, temperature, rainfall, surface water resources, groundwater, landforms and relief, geology, soils, natural vegetation and grasslands.

B. Man-made Resources: mineral deposits, water use, land use, forest resources, livestock, sheep and wool, crop lands, crop production, fish and fisheries, and manufacturing industry.

C. Introduced Services: roads and aerodromes, railways, electricity, health services, ports and shipping.

D. Government Administration: State Government and Local Government areas of responsibility, and population distribution.

Since low level waste is essentially a worthless material that must be transported from the place where it has been used to a repository, Category E 'Distance' was added to the above for this survey. This category includes the distance of an SU from major urban and rural areas of population and from major mining and industrial areas.

2.2.2 Weighting of resource variables

Each variable was given a weighting 3, 2 or 1 depending on whether it scored a high, medium or low rating on the basis of the criteria set out in the IAEA guide to shallow ground disposal, and in the report of the Panel of the US National Academy of Sciences (see Appendix A). The variables, their categories as described above and the weights given to each of them are listed in Appendix B.

The object of the first stage screening was to define, at 1:6 000 000 scale, those SUs in NSW that are worth examining in more detail as prospective sites for shallow ground disposal. It was therefore considered that, although the assignment of weight to a variable, in the manner described, was largely subjective, the large number of variables evaluated for each SU allowed a credible evaluation to be made of the relative merits of the SUs as prospective sites for shallow ground disposal.

2.2.3 Ranking of structural units

Since each variable in each SU could be categorised using the information in the Atlas of Australian Resources, and since each variable could be given a weight as described above, a table was drawn up (Table 1) presenting the weight assigned to each variable for each SU. From such a table the SUs can be ranked just by summing the weights given to each of the variables. It should be stressed that each map in the Atlas of Resources is updated over a period of about five years in the light of new data collected from government and industry sources. Hence the categorisation of each resource variable is time-dependent and the ranking of each structural unit reflects its current categorisation. Appendix C lists the date of publication of each of the maps used to categorise the variables. If a more detailed screening of the optimum sites indicated in this report were to be conducted, more up-to-date information would be necessary for some variables.

A straight summing of the weights assigned to each variable in a given SU to determine the rank of an SU assumes equal importance for all 32 variables. Alternatively, equal importance could be given to the five categories but since there are twice as many variables in the category 'National Resources' as in the category 'Introduced Services', a straight sum of weights given to each variable could give a biased result. Therefore the average weight in each category was also evaluated and the average weight for an SU was found by averaging over the category weights (see Table 1).

2.3 Results

The results of this stage of the screening exercise at a scale of 1:6 000 000 are summarised in Table 1. Clearly, whether the five categories or the 32 variables within those categories are given equal or unequal weights, the conclusion that SUs in western NSW are better prospective sites for the next stage of the screening exercise remains unaltered. The SUs which ranked highest and which have been selected for the next screening stage are, from geologically oldest to youngest (see Figure 1(a)):

1. Kanmantoo Fold Belt (far west);
2. West Lachlan Fold Belt (east margin of Western Division);
3. Darling Depression (situated between 1 and 2);
4. Great Australian (Artesian) Basin (north);
5. Murray Basin (south).

3. SECOND STAGE SCREENING

The IAEA guide to shallow ground disposal ranks hydrogeology above all other site screening elements in determining the optimum site for low level radioactive waste disposal. Since there are no accepted measurements of the relative importance of hydrogeological factors, the IAEA ranks the following in decreasing order of importance:

1. Water and its potential to contact the wastes,

2. Physical isolation of the wastes by distance from man and water,
3. Factors which could alter conditions at the burial site, and
4. Other factors which should be known but are considered less important.

3.1 Data Source

Information for NSW groundwater hydrology was obtained from the Water Resources Commission, North Sydney. Their hydrogeological data, collected from waterbores over a 70-year period, are stored on magnetic tapes, microfiche files, a tabulated card index system, State graticule waterbore locality maps and bore register (lithology description) volumes.

For a rapid and accurate perspective of the site selection problem, a computer program was designed to recall from magnetic tape, those waterbores, in western NSW, with at least 15 m thickness of continuous clay in the first 50 m of the hole, and to print out

- the thickness and vertical position, within the selected holes, of all aquifers; and
- the boreholes' approximate geographic locations (in graticule code).

The program [Garrard 1979] selected 5000 waterbores and produced enough information to enable the screening procedure outlined below to be carried out.

3.2 Screening of Areas of Surface Clay

First-pass inspection of the program print-out plus reference to locality maps indicated areas within each structural unit where several adjacent waterbores contained thick surface clays. Reference was made to the Water Resources Commission's 1:2 mile and 1:4 mile maps to plot locations of these and surrounding waterbores. This procedure delineated from two to four promising separate clay areas within each SU. Next, further details on bore type, dates of commencement and completion, well head levels, water quality, aquifer depths and lithology description were obtained from the Water Resources Commission card-index system and bore register volumes.

To determine one or two representative surface clay areas in each SU, given that several areas were indicated in each SU by the above procedure, closer attention was paid, in descending order of importance, to the following considerations:

- surface clay thickness and distribution,
- position of water-bearing strata and depth of water level below the surface,
- depth and type of the unconsolidated sediment and depth and type of the basement geology,
- earthquake risk
- the nearest surface water and estimate of flood frequency,
- interstate transport access and position,
- nearest country town or mine (for site support and communication), and
- present land-use and nearest farm or human settlement.

This approach presented one major problem: greater waterbore information implied that the surface clay was on property productive enough to justify the waterbore investment; on the other hand, the fewer the bores, the poorer was the country and the less likely the clash between existing land-use and use of the land for a repository, but also the less waterbore information on which to base an assessment. For example, there is much waterbore information on the Murray and Great Australian (Artesian) Basins which enabled a clear picture to emerge of the clay and aquifer distribution. In the far west areas, however, which are hot, dry and largely uninhabited, there is little waterbore information with which to identify both surface clay or potential disposal sites. Since, however, these areas, with marginal to poor farming and low level of human settlement, could be more attractive as prospective burial sites, the areas of surface clay in these SUs must of necessity be picked on the basis of poorer information than, for example, clay areas in the Murray and Great Australian (Artesian) Basin.

In the Great Australian (Artesian) Basin and Murray Basin SUs, the various surface clay alternatives had very similar hydrogeology components and final choice was influenced by interstate highway or railway access. In the Darling Depression SU, the hydrogeology components were so variable that, to be representative, three sites had to be chosen. In the Kanmantoo Fold Belt and West Lachlan Fold Belt SUs the relative absence of information on surface clays made choice very restrictive and difficult. This was largely because of poor groundwater quality and the resultant scarcity of waterbores. Mineral exploration has not added any information on the extent of clays in these areas.

The screening of these areas of surface clay, as described above, led to the choice of eight 'survey' sites, as prospective burial sites, within the five SUs left after the first stage screening. The survey sites are shown in Figure 1a. The area of each survey site is much larger than that required for a burial site but small enough, compared to the area of the SUs, to enable a clear picture of hydrogeological properties to be obtained from waterbore and other data in the way described in the next section.

3.3 Data Use

For each survey site a waterbore locality map was constructed showing the bore number, thickness of surface clay and the depth of water-bearing strata in the bore (see Figures 2 to 8 in Appendix D). A 'representative' lithological cross section was constructed for each of the survey sites (Figures 2a to 9a of Appendix D) to assist in assessing the extent of surface clay layers and the relationship of water-bearing strata to those layers. To clarify these relationships, the geology and hydrogeology of both the SUs which contain the survey sites and the survey sites themselves were examined and some interpretations made. This study, together with information on surface topography, climate and mineral resources where these were deemed necessary, is contained in Appendix D. Isopach maps were drafted for each of the survey sites to indicate the extent and thickness of surface clays. There is a degree of subjectivity in delineating the isopachs and in tracing water-bearing strata on the lithological cross sections due to the incompleteness of some of the information from the water bores. However, the accuracy of the information is sufficient for this 'office review' phase of site selection.

Table 2 is a compilation of data for the eight survey sites. The data are grouped into three major headings: locality, hydrology and geology, and the subheadings of each group were formulated on the basis of information available from the Water Resources Commission. Subheadings that may need elaboration are

- settlement concentration - the number of farm homesteads located within the survey area;
- estimated 50-year flood area - a qualitative estimate of the area of the survey site affected in a 50-year flood; this estimate was based on surface topography, groundwater depths and discussion with Water Resources Commission flood mitigation personnel;
- erosion surface depth - a buried palaeo- (fossil) erosion surface between two geological ages that (because of its coarse uneven nature) frequently forms an aquifer surface (which may include buried stream systems);
- aquifer control - the geological or geomorphological factors - such as adjacent stratigraphy and granulometric variations - which help control the horizontal and vertical dimensions of groundwater.

3.4 Ranking of Survey Sites

Ranking of the survey sites was carried out in a manner analogous to ranking of the structural units. A number of factors (see Table 3) were considered which could be grouped under the four headings listed at the start of this section. Factors (which come under the heading 'water and its potential to contact wastes') which the IAEA guide gives the highest ranking in the hydrogeological element, were accorded the highest rank and given weights 4, 2, 1 depending on whether a particular survey site was considered to score well, fairly or poorly. Factors which came under the headings 'physical isolation of the wastes by distance from man and water' and 'factors which could alter conditions at the burial site' were lumped in a set 'medium rank' and given weights 2, 1, $\frac{1}{2}$. The last two factors listed in this set in Table 3 come under the second of these headings and should, on the basis of the IAEA guide, be ranked rather lower than the other factors in the set. It is considered that, at this office review phase of screening for suitable waste disposal sites, the application of a somewhat lower weight to these two factors to reflect the lower ranking would not alter the final order of ranking of the survey sites.

The last set of factors which are in the set 'lower rank' in Table 3 were given weights 1, $\frac{1}{2}$, $\frac{1}{4}$. These factors reflect the likely land-use, on the basis of water availability and quality, as well as ease of access to the survey sites and their distance from major centres. The actual weights assigned to all factors for each of the survey sites were largely based on the data for the survey sites given in Table 2.

3.5 Results of Ranking Survey Sites

Table 3 shows the weights given to each factor, in this phase of the screening exercise, for each of the survey sites. Cumulative totals are given for each of the three high, medium and low ranking groups of factors as well as a grand total for all factors. Hence, from the results in Table 3, the eight survey sites can be ranked on the basis of factors which largely reflect the hydrogeological properties of the survey sites.

As in the case of the structural units, some survey sites are clearly more suitable than others as prospective disposal areas. Table 3 shows that two survey sites score much better than the others with respect to the high ranking factors, with a further set of three survey sites grouped closely together some distance behind the first two. Inclusion of the medium ranking factors leaves the first two survey sites as the highest ranking sites but shows that one of this set of three is better than the other two. Inclusion of the low ranking factors does not change the position that the Pine Creek, Yellow Mountain and Taringo Downs survey sites are the best prospects, the Greenough's Hill, Conoble Lake, Willandra Creek and Forrest Creek survey sites form a second ranking group, while the Warrego River survey site is the least optimal site.

It is apparent from Table 3 that, as a result of screening the eight survey sites on the basis of factors which largely highlight the hydrogeological properties of the areas under consideration, the Pine Creek, Yellow Mountain and Taringo Downs survey sites are the best choices.

4. SUMMARY AND CONCLUSIONS

A two-stage initial screening process for site selection, based largely on an IAEA guide to shallow ground disposal of low level radioactive waste, has been applied to NSW as a geographic area in order to illustrate the technique.

Data culled largely from the Atlas of Australian Resources were sufficient to show that, on the criteria adopted for the first stage of the screening process, areas in the eastern half of NSW were clearly less suitable as waste repositories than areas in the western half of the State. In the second stage, waterbore data available from the NSW Water Resources Commission, were used to help identify eight 'survey sites' in the western region, each with an area between 2000 and 6000 km^2 and each with clay beds thicker than 15 m at or very close to the surface. Lithological and hydrological results from the waterbore data were interpreted in terms of the geology of regions surrounding these survey sites and used to indicate the proximity, size and the direction of flow of water in the water-bearing strata.

These survey sites were screened on the basis of criteria which again drew largely on the IAEA guide but emphasised the hydrological properties most suitable for a low level waste repository. The survey sites which ranked highest in this phase of the screening exercises were:

1. Yellow Mountain in the West Lachlan Fold Belt structural unit;

2. Pine Creek, in the Kanmantoo Fold Belt structural unit,

3. Taringo Downs in the Darling Depression structural unit.

These survey sites and the approximate position of the thick clay areas in them are shown in Figure 1a.

The size of each of these clay areas (10 to 250 km^2) is very much larger than the area of about 1 km^2 needed for a repository. Nevertheless, the results do illustrate that the technique can be used to determine areas worthy of further study and that it does delineate those areas that are far less suitable for a waste repository. Clearly, in any real study, a further screening phase would involve on-the-ground investigation of the survey sites that have emerged from this initial screening phase to determine more precisely the hydrological properties of the sites and to delineate within the sites the areas most suitable for a repository. At about the same time, a closer investigation would have to be made of present, and possibly future, land-use within the survey sites.

In NSW there are enough data on land-use, the distribution of surface clay deposits and the hydrology near these clay deposits to enable the use of the IAEA guidelines to the selection of survey sites suitable for location of a low level waste repository. If similar data exist on other States to the same level then the same two-stage screening process could be applied.

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APPENDIX A
IAEA FAVOURABLE SITE CHARACTERISTICS

The objective for shallow ground disposal is to prevent harmful amounts of radioactivity from reaching man by isolating radioactive substances within a site for the period of time that the substances remain hazardous. International Atomic Energy Agency [IAEA 1981] favourable site characteristics on which the qualitative weights in Table 1 were designed are listed below.

1. The natural hydrogeological characteristics of a site should contain the waste.

2. Minimisation of exposure and overland transport of nuclides by normal erosion processes, floods and earthquakes.

3. Minimisation of transport of dissolved nuclides upward to the soil zone by capillary flow. Minimisation of transport of nuclides by gases generated by bacterial reduction of organic waste material and containers.

4. Minimisation of dispersal following intrusion by animals or deep rooted plants.

5. No intrusion by man (fencing, fire precautions, etc.).

6. Minimisation of accident during handling of disposal operations.

7. The land surface should be devoid of surface water and generally stable geomorphologically.

8. The disposal zone should be separated from fractured bedrock by a thickness of geological materials sufficient to retard migration of radionuclides into the fracture zone.

9. The predicted residence time of radionuclides within the groundwater flow system must be long enough for sufficient decay to occur.

10. The natural water table, at its highest level, should be below the disposal zone by at least a few metres and the hydrological setting be such that large water table fluctuations are unlikely.

11. Waste disposal site commits this tract of land to the exclusion of all other uses as long as the wastes remain hazardous.

12. The disposal site should be located on public land to ensure the long term control of ownership.

13. The choice of shallow ground disposal should be based on the requirements of radiation protection as recommended by ICRP.

14. Telecommunications are important for choosing a site, because a detailed keeping of records and consistent submission of returns to the licensing regulatory body is normal operating procedure.

The National Research Council [1976], administering a US National Academy of Sciences Panel, listed the following as favourable site characteristics:

(1) A desert climate.

(2) A deep groundwater table.

(3) A low population

(4) A slow erosion rate.

(5) Land unsuitable for agriculture.

(6) No potentially valuable mineral deposits.

(7) Availability of inexpensive and abundant building materials.

(8) Topography suitable for easy movement of heavy machinery.

(9) Absence of special environmental attractiveness.

Both the IAEA and the other US publications referenced to give details on measurements necessary after a particular site is selected.

APPENDIX B
EXPLANATION OF QUALITATIVE RATING OF GEOGRAPHIC VARIABLES IN TABLE 1

A. NATURAL RESOURCES

Variable	Qualitative Rating 3	 2	 1
Climate	Hot and dry Evaporation > Precipitation	Extreme diurnal variation Evaporation Precipitation	Cool, wet and humid Precipitation > Evaporation
Temperature	Seasonal Range >10°C - >30°C	-10°C - >35°C	>0°C - 25°C
Rainfall	< 400 mm p.a.	400-800 mm p.a.	> 800 mm p.a.
Surface Water Resources	Nil. Bores for water	Dams, irrigation schemes and windmills	Perennial streams
Groundwater	Bored for extensively	Shallow wells to supplement supply	Not used because of surface water supply
Landforms and Relief	Gently undulating. Valleys slopes < 5°, Hills < 100 m local relief. No floods	Flat plains, subject to occasional flooding	Rugged country. Valley slopes > 5°, Hills > 100 m
Geology	Simple structure, homogeneous rock type	Up to 5 different rock types	Complex structure and lithology
Soils	Infertile sand, salt and clay	Partly fertile for agriculture and livestock	Good fertile soils used in agriculture
Natural Vegetation	Stunted, xerophytic shrubs mainly annuals. Few trees	Semi-cleared shrubland and open forestland	Good, permanent forests with a wide variety of vegetation types
Grasslands	Poor to no development because of climate	Grasslands dependent on rainfall	Permanent development of natural grasslands

APPENDIX B (Continued)

B. MAN-MADE RESOURCES

	Qualitative Rating		
Variable	3	2	1
Mineral Deposits	No mineral resources that could be economically developed	Old mining area or mining project planned for future	At least one operating mine in production
Water Use	Little to no use of meagre water supply	Poor usage of abundant water supply	Extensive use of low to medium water supply for rural, urban or industrial pursuits
Land use	No economically viable land use	One or possibly 2 or 3 dominant land uses	Highly competitive number and many variable land uses
Forest Resources	Nil	Low quality timber, little to no exploitation	Good resources presently exploited
Livestock	Low to nil	Extensive grazing	High carrying capacity
Sheep and Wool	Too wet and humid for sheep	Extensive sheep grazing < one sheep per hectare	Intensive sheep and wool production > one sheep per hectare
Croplands	Rainfall too low, erratic and unreliable	High rainfall and humidity but rough topography and poor soil	Dam and irrigation control. Low-medium reliable rainfall
Crop Production	Low to nil	Small-medium scale	Large scale
Fish and Fisheries	Absent	Small scale in rural areas of dams and rivers	Coastal areas with lakes, rivers and sea
Manufacturing Industry	Moderate distance because of complementary use of facilities in manufacturing industry	Close to urban area but land use conflict with industry expansion	Remote from industry with related high transport costs

APPENDIX B (Continued)

C. INTRODUCED SERVICES

	Qualitative Rating		
Variable	3	2	1
Roads and Aerodromes	A few main access roads and bush strips	Absent or sparsely distributed	Dense concentration of road network, several aerodromes
Railways	At least one railroad in the area	Railroads absent	Heavy traffic network of variable purpose railroads
Electricity	Electricity, telephone and TV lines available for communication	Absent or State electricity grid	Heavy mesh of State electricity line grid
Health Services	A wide variety of specialised hospitals available	Hospitals located in most towns > 1000 people	At least one hospital within 200 km radius. Service locations
Ports and Shipping	Within 200 km of site area	Coastal area with major ports and ships	No ports or ships in inland area

APPENDIX B (Continued)

D. GOVERNMENT ADMINISTRATION

	Qualitative Rating		
Variable	3	2	1
State and Local	Very close government supervision of economic life	Moderate to low government supervision	Little or no government interference in economic life
Immigration	Few immigrants settled in area	Small pockets of immigrants in area	Large concentration of ethnic or immigrant groups
Population	Very few inhabitants	Low to medium	High concentration

E. DISTANCE

	Qualitative Rating		
Variable	3	2	1
From Major Urban Area	Medium distance because of transport costs	Close to an urban area and alternative methods of transport	Remote from an urban area with poor transport access
From Major Rural Area	Medium distance so will not compete with present land use	Close to rural area for choice of transport and cost	Remote from rural area. Transport costs high
From Major Mining Area	Medium distance so will not compete with present transport	Close so that present infrastructure can be used	Remote from mining area
From Major Industrial Area	Medium distance so will not compete with present industry	Close so that present infrastructure and perhaps work sites can be used.	Remote from industrial area. Transport costs high

APPENDIX C
MAP SHEET DATES FOR THE ATLAS OF AUSTRALIAN RESOURCES
2nd SERIES (1:6 000 000 SCALE)

Publication Date	Title
1973	Climate
1973	Temperature
1970	Rainfall
1967	Surface Water Resources
1973	Groundwater
1973	Landforms and Relief
1966	Geology
1963	Soils
1976	Natural Vegetation
1970	Grasslands
1970	Mineral Deposits
1974	Water Use
1973	Land Use
1967	Forest Resources
1970	Livestock
1968	Sheep and Wool
1970	Croplands
1968	Crop Production
1965	Fish and Fisheries
1974	Manufacturing Industry
1977	Roads and Aerodromes
1974	Railways
1969	Electricity
1957	Health Services
1971	Ports and Shipping
1975	State and Local Government
1975	Federal Government
1959	Immigration
1975	Population Distribution

APPENDIX D

CONTENTS

APPENDIX D
STRUCTURAL UNIT DESCRIPTION

1. KANMANTOO FOLD BELT - PINE CREEK SURVEY SITE

[Refer Figures 2, 2(a)]

1.1 Location and Area

In the far west of the State surrounding the mining centre of Broken Hill (32°S, 141°30'E) is the Willyama Inlier [Thomson 1975] which extends into South Australia. In New South Wales the inlier forms an elevated, partly fault-bounded, irregularly shaped area with maximum north northeast - east southeast dimensions of 150 km and 800 km respectively. Highly fractured and metamorphosed rocks of Lower Proterozoic age crop out in the area. Located approximately 900 km west of Sydney, 700 km northwest of Melbourne and 400 km northeast of Adelaide, Broken Hill is well connected by major road, rail and air services. The survey site is 80 km south of Broken Hill and is intersected by the all-weather Silver City Highway, which joins Broken Hill to Wentworth and thence Melbourne and Adelaide. With a 1978 population of 27 640 [NSW Pocket Year Book, 1979], Broken Hill is the only settlement of concentration nearby and is surrounded by a rugged, desert hinterland with sparse to marginal sheep grazing.

1.2 Topography

The Willyama Inlier is situated on a vast plain. Rocks of the New South Wales portion of the Willyama Inlier and Adelaidean rocks form the northerly trending, partly fault-controlled, fractured and eroded Barrier Ranges. The Ranges, which have local relief of up to 150 m, are flanked by plains consisting of Cainozoic clay and sands with underlying Paleozoic rocks in places. The survey site is located just south of the main Barrier Range in Cainozoic clays and sands.

The surface topography surrounding the survey site is nearly flat with a low, southeast to south dip on the Quaternary land surface. The dip is apparent in waterbore lithologs as outwash clays and sands 50 to 80 m thick, overlying a 5 to 10 m Tertiary eroded land surface of silicified 'sandstone' and coarse gravels. These buried gravels were deposited by past erosion of the exposed Barrier Ranges that now crop out 30 km to the north. Fringing the present surface expression of the Barrier Ranges are several coalescing, low-angled alluvial fans, composed of mechanically sorted sands and gravels.

Thirty kilometres east of the eastern margin of the survey site is the permanently flowing, freshwater Darling River, plus several overflow salt lakes in low-lying depressions. The Menindee Lakes recreation area and Kinchega National Park are located about 60 km to the east northeast of the survey site, but there is no drainage from the chosen survey site to any of the surface water catchments described.

1.3 Climate

Broken Hill experiences a dry desert, continental climate of hot summers (mean average temperatures above 25°C), mild to cold winters (below 10°C), with a low and erratic rainfall of 250 mm per annum and an extremely high evaporation of over 2000 mm per annum.

1.4 Geology

The Kanmantoo Fold Belt is the name [NSW Dept. Min. Res. and Devel. 1974] given to a regional scale, post-Cambrian geological province, which extends from Kangaroo Island, south of Adelaide, for nearly 1000 km in a north-northeast direction to Tibooburra in the northwest corner of NSW. Within the exposed Kanmantoo Fold Belt, the Willyama Inlier [Thomson 1975] forms an older basement ridge which separates the Precambrian Adelaide geosyncline to the west from the Palaeozoic Darling Depression to the east. The Willyama Inlier rocks in the Broken Hill area are early Precambrian gneiss and schist, representing a moderate to high grade of regionally metamorphosed sandstones, shales, limestones and igneous rocks. These rocks have been studied in extreme detail in the near vicinity of the massive Ag-Pb-Zn deposit at Broken Hill.

1.5 Mineral resources

Since 1883, the Broken Hill deposit has produced in excess of 120 million tons of ore, grading from 4 to 20 per cent Pb, 14 to 20 per cent Zn and 30 to 340 grams per ton Ag [Stevens et al. 1974]. All mining has originated from a stratabound lode which extends in six main superimposed lenses in the south to two lenses in the north, from the surface to more than 1500 m depth and along an 8 km discontinuous ('eroded coathanger') surface expression over a northeast trending line of lode [Vernon 1969]. On the line of lode's southern limit, New Broken Hill Consolidated is working at a depth of about 915 m. In 1976 North Broken Hill Ltd announced additional reserves at about 1600 m depth on the northern limit of the lode. An estimated 60 million tons of ore of similar grade remains to be extracted from the main line of lode [Johnson and Klinger 1975].

Away from the main line of lode, intensive exploration over many years by prospectors and mining companies has located hundreds of surface mineral occurrences but failed to find another major orebody. Collectively, all other areas mined have contributed less than 0.0001 per cent to total economic production figures. Just southwest of Broken Hill, pegmatites are mined on a small scale for good quality feldspar. Most small Ag-Pb-Zn mines have been abandoned as uneconomic prospects; the small tin fields to the north of Broken Hill were worked out many years ago. Limestone and gypsum deposits were once mined as flux for the old Broken Hill smelters but most other mineral occurrences, such as the pegmatite uranium minerals, are only of mineralogical interest. There are no mineral occurrences or prospects in the near vicinity of the survey area.

1.6 Survey Site Hydrogeology

[Refer Figure 2, 2(a) for locations]

Because of the low rainfall, high evaporation and/or poor soils, the Willyama Inlier and surrounding plains have attracted only sparse habitation, related to sheep grazing for wool. Except for the permanently flowing Darling River just to the east, all other water courses are ephemeral, flowing only after the occasional heavy storm. A widely spaced pattern of waterbores has tested most rock and soil types, with generally poor results, the best aquifers being located in Quaternary sands and clays. Several deep (> 60 m) aquifers in Quaternary sands are narrow and local with low water flows of poor quality water that is used to supplement stock water supplies.

Unconsolidated sediments in the Pine Creek survey site are believed to be both Tertiary and Quaternary sediments on the north-eastern margin of the Murray Basin. Tertiary sediments have been dated by Mines Administration in uranium exploration 150 km to the northwest along the southern margins of the Frome Embayment in South Australia [Brunt 1978]. The precise lithological contact boundary between Tertiary and Quaternary sediments in the map survey area is unknown on waterbore information. What appears in the waterbore lithologs to be a sandstone-gravel erosion surface, extends from a depth of 55 m in the north to 130 m, 75 km to the south. If it is assumed that there is only one such erosion surface in the survey site area, it is not known whether this depth difference is attributable to Tertiary tectonic movements along older fault structures, a complex stratigraphy, or merely an old land surface depositional slope. The northeast trending Darling River lineament with known Tertiary movement [Sprigg 1961] lies adjacent to the southern boundary of the survey area. Lithologies differ in adjacent waterbores in the southern portion of the survey area. To the north of the Pine Creek survey site is the Redan lineament, which parallels the Darling River lineament.

If this waterbore-indicated, erosion surface is the boundary between the Tertiary and Quaternary, then the latter, in the Pine Creek survey area, contains a 55 to 130 m thick sequence of predominantly surface clays and underlying sands of about equal thickness. This sequence is underlain by the 5 to 10 m silicified boulder-erosion surface (of uncertain age) below which is a predominantly sand to silty sequence. No basement rock was intersected in any waterbore.

The Pine Creek survey area's surface clay of 200 km^2 is located about 60 km west of Menindee Lakes and the Darling River. In general, for areas with a thick surface clay segment (20 to 60 m) the sand/gravel semi-confined aquifer beds lie at depths of between 40 and 80 m. Near the southern end of the survey area waterbore information indicates deep confined aquifers at depths of over 135 m with static water levels of around 30 m depth. Data reported by Gibbons et al. [1972] indicate that groundwater flow in the survey area is towards the east to southeast.

Denham et al. [1979] and McEwin et al. [1974] show the area is adjacent to a known but weakly active earthquake zone - The Adelaide Geosyncline, which exhibits Tertiary and post-Tertiary movements along the Darling River lineament. Evidence of post-Tertiary movement is documented from other areas [Firman 1966].

2. WEST LACHLAN FOLD BELT - YELLOW MOUNTAIN SURVEY SITE

[Refer to Figures 3, 3(a)]

2.1 Location and Area

Located between 30°10'S and 36°S and 145°30'E and 148°E, the West Lachlan Fold Belt of 40 000 km^2 straddles the eastern border of the Western Lands Division. The Yellow Mountain survey site is approximately 400 km west-northwest of Sydney, 600 km north of Melbourne, 800 km northeast of Adelaide and 800 km southwest of Brisbane. Access is via the Parkes-Condobolin road or Sydney-Broken Hill railway to Condobolin and thence along a trunk road to Cobar for 70 km in a north-northwest direction.

2.2 Topography

The Cobar peneplain is bounded on the south by the Lachlan River and Willandra Creek, on the west by a line running northward from Roto and on the northeast by the Bogan River. It is a nearly level Tertiary land-surface defined by David [1950] as the most westerly portion of the Western Slopes, which extend from Albury in the south to Goondiwindi in the north. The peneplain contains several altitude-controlled duricrust remnants on the folded Palaeozoic rocks, with topography greatly influenced by lithology and structure. For example, narrow ranges are controlled by the strike and dip of resistant rock types such as sandstones, quartzites and granites, while depressions are formed on eroded siltstone, limestone, schist and phyllite [Brunker 1969 and 1973]. In the north of the West Lachlan Fold Belt, the Darling River forms a boundary in a region of low, undulating local relief between 150 and 300 m altitude. In the centre, around Cobar, higher country occurs, with general local relief above 300 m but few peaks exceeding 450 m. In the south, the large west-flowing Lachlan River contains a 10 km wide swampy floodplain as it issues forth from the 300 m Cobar peneplain onto the Western Plains of the Murray Basin.

Near the Yellow Mountain survey site, the land surface is gently undulating in the south to hilly in the north, along an uplifted northwest fault structure, with the Yellow Mountain at 575 m altitude the dominant landform. This fault structure forms the drainage divide separating stream tributaries that flow north to the Barwon River (a tributary of the upper Darling) from those flowing south to the Lachlan River. The major south flowing tributaries, Crowie and Tinda Creeks, drain a wide variety of rock types.

2.3 Climate

The climate of the area is semi-arid continental; warm and dry with high diurnal temperature variations. Average temperature ranges from 5°C in winter to 30°C in summer. Average annual rainfall varies from 300 to 400 mm, while the annual evaporation rate is close to 1800 mm. The variability of rainfall is high, averaging about 30 per cent when expressed as a mean departure from the average [Dept. of Nat. Devel. 1957-1977].

2.4 Geology

The West Lachlan Fold Belt SU forms the western part of the larger scale Tasman geosyncline which extends from Tasmania to far northeast Queensland. The geology of this SU can be subdivided into the Palaeozoic basement, composed of lightly metamorphosed, folded, faulted and igneous-intruded geosynclinal sediments, and the younger, mantling, partly consolidated Tertiary and Quaternary sands and clays. Because of the West Lachlan Fold Belt's complex sedimentation and structural history, there is a wide diversity of rock types cropping out in any one area.

The dominant Palaeozoic basement structural trend is sub-meridional. The oldest rocks of Ordovician age have been regionally metamorphosed to low-medium grades by repeated tectonic movements. Although they have a regional north-northwest trend, the Ordovician sediments' precise distribution is obscure, as they have been isoclinally folded over three deformations and, as metamorphic grade increases, the crenulation cleavage develops into a metamorphically differentiated layering [Pogson and Felton 1978] with transposed bedding generally sub-vertical and sub-parallel to the regional trend. The Silurian sediments did not experience the Benambran Orogeny [Packham 1969] and true bedding is recognisable. However, the sediments have been tightly folded into synclines and anticlines along north and north-northwest axes by the Bowning Orogeny of lower Devonian age. Individual beds dip 30 to 70° and can be traced around the noses and keels of folds which in general, plunge north and south. Small scale transverse faulting, crushing and stretching of conglomerate beds and development of schistosity in the finer grained units are smaller scale features [Brunker 1969]. The contact with the older Ordovician rocks is invariably faulted. The mid to upper Devonian rocks experienced only the Kanimblan Orogeny of Lower Carboniferous age and formed broad, open-folded, large-scale anticlines and synclines. Because of this younger uplift and erosion, there was no deposition of late Palaeozoic rocks in the West Lachlan Fold Belt. There were two ages of granite intrusion: the earlier in the lower Silurian and the later in the lower Devonian. Accompanied by orogenic earth movements and comagmatic volcanic contribution, the granites help explain the structural variations in rocks of different age described above.

During the Cainozoic Era, the West Lachlan Fold Belt experienced a slow 100 m uplift (from 90 million years to present [Wellman 1979]) associated with the Kosciusko uplift, which developed the present Eastern Highlands [Packham 1969]. Over this period, the exposed and eroded surface was covered by a variety of alluvial fan conglomerates, gravels, sand and clay outwash deposits under a predominantly wet, warm, chemical weathering palaeo-climate that witnessed silcrete formation and laterite development on exposed surfaces [Dury and Langford-Smith 1964]. Further erosion of the Tertiary surface in the Quaternary led to residual and colluvial deposits of reworked rock fragments, ironstone pebble, quartz talus and sand in depressions. In places, these are overlain by undulating plains of red and brown clayey sand, loam and lateritic soil. Overlying these deposits along the Western Plains boundary are occasional east-west trending aeolian sand dunes, interspersed with internal drainage playas, clay pans and salt lakes of grey silts and clays with anhydrite halite and gypsum accumulations [Brunker 1973]. The youngest Quaternary stratigraphic unit comprises alluvium accumulations along the major creeks and rivers which are all post-Tertiary in age (e.g. Lachlan River) and generally follow older structures along which smaller, prior streams had developed [Pels 1974].

The geology of the Yellow Mountain survey site, as mapped by Kennecott Explorations [Dow 1973] consists of a basement of schist, phyllite and sandstone (Girilambone Beds) intruded by the Yellow Mountain granite. These rocks are overlain by the Babinda Volcanics (acid pyroclastics and dacites) which are unconformably overlain by arkoses of the upper Devonian, Hervey Group. The volcanics form a gently south-plunging synclinal fold which is down-faulted by two northwest trending zones of shearing. Low grade base metal mineralisation occurs and 4.7 million tons of mineralised material, containing low grade base metals, exists within the volcanics between 4 and 6 km north of Yellow Mountain. The metal grades are 0.29 per cent Cu, 0.99 per cent Pb, 1.47 per cent Zn and 0.92 oz Ag/ton. Although the grades are low and subeconomic further exploration in the Yellow Mountain area and changed economic circumstances could result in use of the area for mining.

2.5 Mineral Resources

Copper was discovered at Cobar in 1869 in the northern part of the West Lachlan Fold Belt. From 1871 to 1921, both copper and gold were mined from shallow depths in the region about Cobar. With low world copper prices, the major mines closed from 1921 to 1935, then re-opened because of high gold prices that occurred in the pre-war economic depression and World War II, but they closed again in 1952 [Gilligan 1974]. In 1965, Broken Hill South Ltd began working new copper discoveries north of Cobar along the main line of lode and subsequent investment in new plant again witnessed moderate production. Since then, there have been many extensive exploration programs carried out in the surrounding area by overseas and local exploration and mining companies. One explorer, Electrolytic Zinc Company (Australasia) Ltd, announced in 1973 the discovery of Elura, a relatively large, base metal orebody, 45 km northwest of Cobar, which contained 27 million tons of ore at an average grade of 8.4% zinc, 5.8% lead and 130 grams per ton of silver [Electrolytic Zinc Industries 1978 Annual Report].

In summary, contained metal production figures from Cobar from 1871 to 1973 have been approximately: copper 205 000 tons, gold 38 tons, silver 118 tons, lead 16 500 tons and zinc 40 000 tons [Brooke 1975]. Production came from three distinct north-northwest lines of lode over a 28 km distance, each distinguished by a similar stratigraphic position in slates of Silurian age.

The association of mineralisation with zones of deformation has yielded steeply plunging, elongate lenticular orebody shapes, which vary from 15 to 180 m in width and 450 m in length [Gilligan 1974].

Besides the mines mentioned above, there existed a few small to medium sized producers such as the Mt Boppy gold mine - 50 km to the east, and the base metal mines at Nymagee and Mineral Hill - 80 and 165 km southeast of Cobar, respectively. This southeast zone embraces the Yellow Mountain area and has witnessed intense exploration since 1968. Many other small, low to medium grade base metal occurrences have been prospected and worked on a very small scale in the past but none are current producers. A re-evaluation of past geological mapping northwest of Cobar, has been completed by the NSW Department of Mineral Resources and Development as a result of the 1973 discovery at Elura [D. Pogson, NSW Dept. Min. Res. Devel., private communication, 1979].

2.6 Survey Site Hydrogeology

[Refer Figure 3, 3(a) for locations]

A search of the computer printout followed by one of the file card index, failed to locate any widespread area of thick clay development in the West Lachlan Fold Belt. An inspection of hydrogeologic data relating to the area within Graticule 48 revealed only isolated waterbores with surface clay over 15 m. One reason for the apparent lack of surface clay is the West Lachlan Fold Belt's historical record of poor quality groundwater, which has over 14 000 $\mu g\ g^{-1}$ total dissolved salts [Water Resources Commission 1970]. This poor quality groundwater has resulted in low waterbore density and stock carrying capacity, and sparse, marginal settlement. Hence information on which to base further studies is very limited and this may initially count against the area, unless a field inspection is made.

The only clay development indicated by the hydrogeologic data is near Yellow Mountain (32°29'S, 146°50'E) in the northern portion of the Yellow Mountain survey site. Two bores 13 km apart contained isolated Quaternary surface clay thicknesses of 12 and 16 m. In nearby bores, the surface clay thickness decreased to 4 and 5 m. During recent mineral exploration (1968-75) companies did not record the presence of clays in drill holes.

These isolated clay pockets are located stratigraphically above basement rocks at a high altitude and probably represent remnants of an eroded laterite profile, or simply residuum and colluvial waste that masks much of the outcrop in the area, as documented by Brunker [1969]. The residuum/colluvium usually grades into aeolian and alluvial sand, and clay cover away from outcrop areas.

West of Yellow Mountain, water is found in what has been interpreted as highly weathered, fractured and faulted Ordovician basement schist and quartzite at depths of between 30 to 80 m. East of Yellow Mountain water bores have probably tapped Devonian sandstone and conglomerate aquifer beds of the Hervey Group at depths of about 70 m [Brunker 1969].

Further south around Kerein Hills, there are several bores located in elevated country in colluvium near Silurian basement volcanics and granite, and also in flat sand/clay cover areas away from the hills. These bores probably tap groundwater in weathered granite and volcanics at depths up to 85 m. Some of the bores further away from basement outcrop may be intersecting sand aquifers in the Quaternary sand cover.

3. DARLING DEPRESSION - GREENOUGHS HILL, TARINGO DOWNS AND CONOBLE LAKE SURVEY SITES

[Refer to Figures 4, 4(a), 5, 5(a), 6, 6(a)]

3.1 Location and area

Geographically located between the two previously described structural units, i.e. the Kanmantoo and West Lachlan Fold Belts, the Darling Depression also forms the divide between the Great Australian (Artesian) Basin to the north and the Murray Basin to the south. It is an irregularly shaped, roughly circular area of approximately 75 000 km^2 located either side of the southwest-flowing Darling River. The only towns within this structural unit are Wilcannia on the river, accessed via the Barrier Highway linking Cobar with Broken Hill, and Ivanhoe in the extreme southeast corner, accessed by the Sydney-Broken Hill railway line.

3.2 Topography

The topography on the 1:1 000 000 scale Geology Map (Geological Survey of NSW 1972) appears to be simple. The extensive Darling River flood plain is filled with post-Tertiary unconsolidated sediments which include alluvium, eluvium, and aeolian materials in complex associations. Hence there are many areas of surface clays indicated on the computer printout, but they exhibit wide variability and complexity in unconsolidated and lithified sub-surface geology and in hydrology. The Darling Depression is a low-lying depression relative to the two older, uplifted, exposed and eroded structural units to the west and east. The Darling Depression basement is between 150 and 350 m altitude where exposed from under the extensive river alluvium, sand dunes and laterite loam, and is of Devonian age, with a simple structure and stratigraphy disturbed only by occasional faulting. The major geological structure - the Darling River lineament - has a history of fault movement from Precambrian times. The Darling River follows this major fault lineament.

3.3 Climate

The climate of the area is semi-arid continental, with hot summers (mean average temperature above 25°C) and mild to cool winters (mean below 10°C). Average annual rainfall varies between 300 mm (in the east) to 200 mm (in the west), while the average annual evaporation rate is 2000 mm. Rainfall is erratic and occurs in sudden storms, causing local flash floods and transport difficulties in the extensive low-lying areas. The floods along the Darling River are due more to precipitation levels in the Eastern Highlands along the New South Wales/Queensland border, and in the large Western Slopes catchment, rather than heavy rain in the Darling Depression. The river has flooded three times in the past ten years, but in the 20-year period before, only one big flood was recorded. The floods inundate large areas around the Darling and the water usually remains for periods of days to weeks, depending upon the volume of rainfall-runoff discharge. Towards the east of the Darling Depression, the Devonian basement crops out in a series of low hills and ridges which are generally free from floods and constitute 50 per cent by area of the Darling Depression [J. Millington, 1979 - personal communication on flood frequencies, Water Resources Commission].

3.4 Geology

The Darling Depression is structurally bounded on the east and west by ancient crystalline basement massifs. To the west is located the Kanmantoo Fold Belt of Middle Cambrian to Early Ordovician age. Within this belt are some Precambrian inliers of schist and gneiss. About 280 kilometres to the east of the Kanmantoo Fold Belt, the Palaeozoic, West Lachlan Fold Belt, composed of meta sediments and granites, crops out as an uplifted northwest-trending inlier. The geological basement within the Darling Depression is Devonian age. Although depressed relative to the rocks on the east and west margins, the Darling Depression forms an uplifted divide relative to the younger, Mesozoic Age, Great Australian (Artesian) Basin to the north and the Cainozoic Age, Murray Basin to the south.

Firman [1966] reported that large scale down-warping of the crust along the Precambrian Darling River lineament was reactivated during the Mesozoic and reached maximum development before the late Cretaceous with the development of the 'Darling Corridor' [Sprigg 1961] or Darling Depression (1:1 000 000 Regional Geology Map of NSW, Geological Survey 1972). A period of uplift and non-deposition followed and the Mesozoic sediments were almost completely eroded from the Darling Depression, exposing the Devonian basement. In the early Tertiary, this area and the Murray Basin subsided and marine sedimentation ensued. Late Tertiary uplift saw the development of the Darling River, with Quaternary fluviatile deposition masking the Tertiary sediments.

3.5 Mineral Resources

Apart from water use from the river and adjacent water bores by pastoralists, there are few other economic mineral resources. Locally, gravels for council road maintenance are quarried from Devonian quartzite outcrops and Tertiary laterites. In the southeast corner of the Darling Depression at Ivanhoe, adjacent to the railway line joining Sydney to Broken Hill, several playa salt lakes have been mined for gypsum.

3.6 Survey Site Hydrogeology

Surface water is used extensively from the Darling River and its billabongs for both human and stock consumption. Groundwater bores are most heavily concentrated close to the river as water quality rapidly deteriorates away from it, with the exception of some areas which contain Devonian quartzite inliers, with near surface aquifers and springs. Much of the area close to the Darling River is low-lying and subject to flood. To obtain a truly representative survey site for radioactive waste disposal in the Darling Depression structural unit, three survey sites were chosen which covered a variety or range of features desirable for disposal of low level waste. These sites are described separately below by local survey site name.

3.7 Greenough's Hill Survey Site

[Refer to Figures 4, 4(a) for locations]

The Greenough's Hill survey site is southeast of the Darling River and located near the margins of the flood plain, 100 km east of Wilcannia, in very flat to gently undulating dunal sand and clay plains country containing numerous drainage flats, playa lakes and small clay pan Devonian sandstones. Quartzite, shales and siltstone crop out along the eastern margin of the survey area forming hills and ridges with about 50 m of local relief.

Water bores in the survey site area penetrate any of the following, or combinations of the following, depending on their locations; Quaternary flood plain or outwash deposits of clayey silt and sand, playa lake or clay pan clay and silt, aeolian sands, clayey sand, loam and lateritic soil and residual or colluvial deposits of sand and gravel. Some of the water bores in the south eastern part of the survey site appear to have penetrated Devonian basement sediments, which crop out nearby (see cross section in Figure 4(a)), at depths between 40 to 80 m.

Depth to the standing water level, usually corresponding to the top of the Quaternary semi-confined sand aquifer, is quite variable. However, it is generally around 20 m adjacent to the Darling River and deepens to between 60 and 80 m towards the east. In areas near Devonian basement outcrop, the water-bearing horizons appear to be Devonian sandstones, conglomerate and slate or colluvial residual conglomerates on a tertiary erosional surface at depths of around 40 m.

Surface drainage from the elevated areas in the east and runoff on the sand plains is concentrated towards the numerous clay pan and drainage flats areas that lie between sand dunes. Groundwater movement is probably towards the west, i.e. towards the Darling River.

3.8 Taringo Downs Survey Site

[Refer Figures 5, 5(a) for locations]

Located 120 km northeast of Ivanhoe in the southeast corner of the Darling Depression, the Taringo Downs survey site is away from any major river or stream. Access is via the Ivanhoe-Cobar or Roto-Cobar roads, which pass through the west and east margins of the gently undulating survey area. The area is contained within an elliptical north-trending basin structure, completely surrounded by low hills of low dipping Devonian quartzites conglomerates, sandstones and siltstones which form a syncline or basin filled with younger sediments.

Within the Devonian basin a thick sequence of poorly consolidated Tertiary sandstones, shales and conglomerates is developed and is overlain by around 20 to 30 m of Quaternary sands, gravels and clays. In places, outcropping tertiary sediments are silicified and form silcretes or duricrust.

There are two areas of thick surface clays (20-50 m) indicated in waterbore logs in the area. One area is in a northerly trending zone immediately east of Keewong homestead in Quaternary dunal clay and sand plain country which contains numerous claypans forming the internal drainage system. Gently dipping Devonian basement sandstones, siltstones, shale and conglomerate crop out immediately west of this part of the survey area (Ivanhoe 1:250 000 Geological Survey of NSW Map, 1968).

The other part of the survey area in which waterbore logs indicate a thick sequence of surface clay is situated on hills of Devonian basement rock which form the eastern margin of the Devonian basin near Taringo Downs homestread. These clays are probably residual and colluvial deposits over the westerly dipping Devonian sediment basement sequence. The water bores in this part of the survey are probably tapping water from consolidated Devonian aquifers at depths of between 20 and 80 m.

Water bores in the western clay zone near Keewong intersected sand and gravel (conglomerate) aquifers at depths between 70 and 100 m. These aquifers could be of Tertiary age or, in some cases, conglomerates of the Devonian basement rocks. The Ivanhoe 1:250 000 geological map shows waterbore 3361 as having penetrated the Devonian basement. A gravel horizon at 30 to 40 m depth, in half the waterbores may indicate the boundary between unconsolidated Quaternary sand and clays, and the Tertiary sequence.

Surface drainage for the clay zone near Keewong is directed towards very small to quite long (up to about 4 km) narrow clay pans situated between low east-west trending sand dunes. Ephemeral and intermittent streams form a dendritic drainage pattern off the hills at the clay zone near Taringo Downs.

These drainage channels end up at clay pans/playa lakes on the sand plain area near the centre of the Devonian basin. Groundwater would make its way via the deep sandstone/conglomerate towards the basin centre south of the clay areas.

3.9 Conoble Lake Survey Site

[Refer Figures 6, 6(a) for locations]

Located 55 km east of Ivanhoe, near the southern margin of the Darling Depression, the Conoble Lake survey site is only 10 km north of the Sydney-Broken Hill railway. The area is composed of flat to gently undulating plains of red and brown clayey, sandy loam and lateritic soils, interspersed with outwash areas and flood plains of internal drainage with black and red clay, silt and sand. There are a number of playas, clay pans and salt lakes containing calcrete, halite and gypsum. Gypsum is mined from three of the lakes up to 20 km northeast of Ivanhoe within 10 km of the railway line.

The waterbore logs indicate that the area contains from 20 to 70 m thickness of unconsolidated Quaternary calcareous gypsum-bearing clays, silts, sands, calcretes and gravels. The gravel beds probably mark the base of the Quaternary sequence. Underlying the Quaternary are sandstones, shales and conglomerates probably of Tertiary age.

In general, standing water level coincides with the top of the uppermost semi-confined aquifer beds at depths between 30 and 40 m. The aquifers are usually thin, unconsolidated sandy beds in the Quaternary sequence or gravel beds near the Quaternary/Tertiary disconformity. Deeper aquifer beds are located in the consolidated Tertiary sandstone beds. Data presented by Gibbons et al. [1972] indicate that groundwater movement in the survey area is directed towards the southwest.

The Conoble Lake survey site is located on the margins of the Murray Basin and Darling Depression, some 30 km north of Willandra Creek which is the nearest surface water. The survey site contains no streams, just a series of shallow clay pans, calcrete lakes and hollows which hold water briefly after rain. After rain in this area of nearly flat topography, surface drainage moves southeast.

4. THE GREAT AUSTRALIAN (ARTESIAN) BASIN - WARREGO RIVER SURVEY SITE

[Refer Figures 7, 7(a)]

4.1 Location and Area

The Great Australian (Artesian) Basin occupies about 250 000 km^2 of northern NSW. It extends over most of Queensland and also into the southeast of the Northern Territory and the northeast of South Australia, covering a total area of 1 700 000 km^2. The Warrego River survey site is located 100 km north of Bourke (at 29°15'S, 145°30'E) and is intersected by the Mitchell Highway which connects Bourke with Cunnamulla in Queensland.

4.2 Topography

The Great Australian Basin forms a vast, flat area of sands, clays and salt lakes in northern NSW and contains lateritised sandstone ridges with local relief only appearing along lineament margins and basement inliers, where prior and present drainage channels are developed. The surface topography of the survey area is composed of subdued ridges and wide alluviated valleys flanking the southerly-flowing Warrego River, a tributary of the upper Darling. The horizontal ridges trend east-west and form an outline of eroded Cretaceous sandstone, capped with remnant laterite profiles. The pediments are composed of lateritised and silicified Cretaceous eluvial material, prior stream gravels, calcretes and silts. Within the valleys red-brown sands and clays from a reworked Tertiary landscape surround the present ephemeral stream tributaries.

4.3 Climate

The climate may be described as temperate continental with hot summers (mean average temperature over 25°C) and mild to cold winters (mean temperature below 15°C). Average annual rainfall is highly irregular, varying from 300 mm in the east of this structural unit to 150 mm in the west, while the annual evaporation rate is 2500 mm. The southerly flowing headwater tributaries of the Darling River provide little to no surface water to support human, animal or crop land use. Most water is from the numerous artesian and sub-artesian bores, which provide plentiful supplies of good quality groundwater.

4.4 Geology

The northern New South Wales portion of the basin on a regional scale is composed of undeformed, weakly metamorphosed rocks deposited as fine to coarse grained sediments within the Surat and Eromanga sub-basins. The basement in the west is composed of rocks of the Palaeozoic Kanmantoo Fold Belt, which in places has internal massifs of Precambrian Wonominta Beds while the basement in the central and eastern parts is composed of Ordovician to Early Carboniferous Lachlan Fold Belt rocks. The central, unexposed basement highs of the Eulo Ridge and Cunnamulla Shelf (which includes the survey area) are composed of Palaeozoic granites and low grade metamorphics [Hawke et al. 1974]. These features were noted in waterbore lithology from waterbores 4591 and 4414 researched for this report from the NSW Water Resources Commission lithologs.

The Great Australian Basin was initiated by a gentle down-warping during the late Triassic, and sedimentation was continuous from then until mid-Cretaceous times. The survey site lies between the Eulo Range and Cunnamulla Shelf which are units of the Eromanga Basin. Throughout the Eromanga Basin's sedimentary sequence, a two-fold sub-division is apparent whereby a non-marine, dominantly coarse grained, fluviatile sandstone is overlain by a thick, fine grained marine sequence [Hawke et al. 1974]. The basal sequence is the Hooray Sandstone of Jurassic age and varies in thickness up to 300 m, depending on proximity to basement highs. The overlying, dominantly marine sediments constitute part of the Rolling Downs Group of Cretaceous age. This sequence is composed of marine transgressive mudstones, siltstones, and limestones, with minor sandstones. The Rolling Downs Group crops out over much of the Eromanga Basin surface where a deep weathering profile up to 70 m thick is developed. In many places, these rocks are overlain by sandy conglomeratic fluviatile deposits of Tertiary age, called the Glendower Formation [Whitehouse 1955]. Many of the horizontal beds have been silicified to form silcrete crusts and clayey interbeds which produce prominent outcrops on higher ground [Hawke et al. 1974]. In addition, most areas of the basin are covered by unconsolidated Quaternary deposits of variable thickness. They are composed of sand dunes, sand plains, fluviatile, colluvial and residual deposits, internal drainage areas and playa lakes. The combined thickness of these Cainozoic (Tertiary plus Quaternary) sediments ranges up to over 150 m.

Little is known about the structure of the basin sediments, except that they are generally flat-lying. In many areas, displacement in the sediments has probably occurred on old, resurgent basement faults [Hawke et al. 1974], while a certain amount of sedimentary draping occurs on basement highs (see below).

Within the Warrego River map survey area, from the surface to a depth of 50 m, there occurs in all holes a variable thickness of Quaternary to Recent clays, sands, gravel, calcrete, silt and drift sand. Each hole showed a different proportion of each of these components and it was difficult to subdivide a stratigraphy (perhaps because waterbore collars were at different elevations). Surface clay isopach aerial distribution indicates sparse, isolated pockets of clay accumulation up to 27 m thickness with an east-west distribution. Some of the surface clay accumulations may represent the eroded, pallid zones of exposed Tertiary laterite profiles or be located over Rolling Downs Group shales. Other surface clay accumulations of 13 m, located approximately 20 km southwest of Enngonia, lie in black soil and sandplain country adjacent to several major creeks.

The NSW Water Resources Commission artesian bore logs 11271, 4254, 4659, 4591, 4414, 4756, 3360 and 4739 indicated a horizontal Jurassic-Cretaceous sequence of from 400 to more than 600 m thickness. The sequence is composed of a basal sandstone from 80 to 120 m thick, overlain by an upper sequence of blue shales with minor interbedded siltstones 320 m thick (Rolling Downs Group). Basement was intersected in two adjacent holes along the section line of surface clay and a probable basement high was indicated. In one hole, 4414, the artesian waterbore intersected granite, while in hole 4591 a 'green soapstone' (probably a talc or chlorite schist) was intersected. The relationship of the granite to the schist is unknown, but from the Geological Survey 1:1 000 000 NSW Regional Geology Map they should both be of Palaeozoic age and form part of the Lachlan Fold Belt basement, which crops out 90 km to the southeast on the uplifted southern side of the Darling River lineament.

4.5 Mineral Resources

The Eromanga Basin is rather poorly endowed with valuable minerals. The most important mineral resource is the groundwater which has generally assisted the extensive pastoral industry in an area of low and irregular rainfall. The value of the deposits of opal at Lightning Ridge and White Cliffs make it the next most important mineral resource. The most important gypsum deposits are at Paka, while other deposits, some of which have been or are being mined, occur at Gidgea Camp Bore, Dry Lake, Currgah, Muttons Well, Bullamanta, Coorilla, Poison Point Tank and in the Mount Oxley and Wanaring areas. Petroleum, rutile and uranium have been explored for in the basin but with no significant success.

4.6 Hydrogeology

[Refer Figures 7, 7(a) for locations]

The Great Australian Basin is one of the largest artesian basins in the world and is comprised of aquifers in continental quartzose sanstones and confining beds of partly marine sandstone and siltsone of Triassic, Jurassic and Cretaceous age. The aquifer intake beds in NSW (Pilliga Sandstone) accept high rainfall along the basin's elevated eastern margin (the Western Slopes) and transmit water very slowly to the deeper parts of the basin where the confining properties of the less permeable rocks create a pressure head related to the level of the saturated aquifer in the recharge zone [AWRC 1975]. Hence in NSW, some 3500 bores at depths of from 50 to 1200 m, obtain artesian water from several aquifer horizons [Hawke et al. 1974]. Of the bores, 682 are artesian bores (water coming to the surface under its own pressure), with a combined rate of flow of about 64 million gallons (3 million hectolitres) per day [Hind and Helby 1969].

Work using radioactive tracers has indicated that movement of water over a distance of 1.6 km may take from 150 to 1000 years, depending on local hydrological conditions [P.L. Airey, Hydrology Group, Isotope Division, Australian Atomic Energy Commission - private communication 1979]. This slow rate is related to permeabilities in the aquifer which are based on 'shut-in' pressures, aquifer compactions and pressure falls over time, with additional borehole drilling affecting water transmissivity. As the water moves down dip, the salinity of the recharge waters increases, with Na increasing at the expense of Ca and Mg [AWRC 1975]. Although in NSW, the overall salt content of the groundwater is not particularly high, the high alkali content generally precludes the use of water for irrigation over all except the eastern basin margin [Hawke et al. 1974].

Within the survey area the present surface drainage system reflects a braided stream pattern on a low angle, south sloping erosion surface. The rivers are actively eroding the Quaternary sands and drift, and exhuming the Cretaceous and Tertiary landscape before issuing forth onto the Darling flood plain.

In the survey area, shallow groundwater is located at depths of from 5 to 35 m within Quaternary or Tertiary sands and gravels. These aquifers can be regarded as local semi-confined and unconfined perched aquifers of limited discontinuous distribution overlying the extensive confined sandstone aquifers in the underlying Mesozoic sequence.

The deep Mesozoic artesian aquifers are intersected at depths of between 200 and 540 m. Water levels recorded during drilling of deep wells include those encountered in the upper confining beds of the sequence which are regarded as the upper boundary of the saturated zone. A generalised contour map of the regional water table for the whole of the Great Australian (Artesian) Basin sequence developed by Habermehl [1980] indicates that the regional water table in the survey area for the Mesozoic aquifers lies between 100 and 130 m above mean sea level. Deep groundwater movement in these aquifers is directed toward the south.

5. MURRAY BASIN - WILLANDRA CREEK, FORREST CREEK SURVEY SITES

[Refer Figures 8, 8(a), 9, 9(a)]

5.1 Location and Area

The Murray Basin occupies an area of some 135 000 km^2 in southwestern NSW [Pels 1969] and extends into northern Victoria and southeast South Australia. The NSW portion of the basin is well situated relative to all southeast State capitals, with direct major access highways joining Sydney to Melbourne, Sydney to Adelaide, Melbourne to Hay, Sydney to Hay and Canberra to Hay. Hay is a central service town in the Murray Basin located next to the Murrumbidgee River.

5.2 Topography

The Darling, Lachlan, Murrumbidgee and Murray which have their source in the Eastern Highlands, drain the Murray Basin. Although they are a dominant feature of the flat basin area, they have not, in their present form, been responsible for the Quaternary Age aggradational basin topography [Pels 1974]. Except for small Recent overbank flood deposits, the Murray Basin landscape is a relict landform and has been described [Wellman 1979] as a structural basin which largely evolved in Tertiary times through block faulting related to the Kosciusko uplift. This uplift produced the Eastern Highlands (Great Dividing Range) where high erosion produced large volumes of material which infilled fringing old mature valleys to depths of 150 m. The present Murray Basin configuration has been brought about by relative subsidence, followed by active sedimentation during the Cainozoic [Pels 1969].

5.3 Climate

The Murray Basin experiences a temperate continental climate, with hot summers (above 25°C mean) and cold winters (less than 10°C). Rainfall is variable and ranges from 400 mm close to the Western Slopes in the southeast to 200 mm in the far west near Mildura. Annual evaporation averages approximately 1500 mm per annum. Occasional sandstorms, driven by strong, northwest winds in summer droughts, as well as bush fires, can cause temporary communication problems. As most of the larger rivers are regulated by authorised irrigation, flooding is usually on a small scale and restricted to such natural marshlands and swamps as occur in the middle reaches of the Lachlan River.

5.4 Geology

The 135 000 km^2 area of the Murray Basin in NSW contains a thin (0 to 640 m) accumulation of poorly cemented Cainozoic marine and continental sediments within a structurally controlled basin. The Cainozoic sediments are overlain by 0 to 90 m of Recent alluvium and aeolian sands. Encircling the basin are structural hills and buried ridges of impermeable basement rock of Precambrian to Devonian age which hydrologically isolate it from neighbouring basins.

Except for localised down-faulted grabens of Permian Coal Measures in the southeast, the basal sequence, restricted to the western part of the newly formed basin, is a 180 m thick marine and clastic sequence of Cretaceous age. In the southwest this is overlain by a 500 m thick, Tertiary sequence called the Renmark Beds [Bembrick 1974]. Because of synorogenic Tertiary faulting along the Darling lineament during deposition of the Renmark Beds, marine, estuarine, lacustrine and fluvial environments have been recognised in a transgressive west to east lateral sequence. Vertical variations range from sandy at the base, through argillaceous and carbonaceous units, to sandy clays and silts at the top, with both lateral and vertical facies changes along shifting palaeo-shorelines. The Renmark Beds are not present in the east of the basin. A parallel northeast trending structure - the Padthaway Ridge - located between the Lachlan and Darling Rivers, marks the sedimentation boundary between a western marine province with abundant fossils and an eastern province where there are no fossils and lacustrine and fluvial deposition have taken place.

Silicification and ferruginisation mark the time break (associated with the faulting) between Tertiary and Quaternary sedimentation. Sands and clays of Quaternary age, related to late Pleistocene prior streams, form an almost complete, blanket surface-cover over the Tertiary sediments of the Murray Basin. A broad aerial subdivision of older and younger landsurfaces has been recognised from waterbores in the unconsolidated sediments. In the west of the basin, an older surface marked by east-west trending, sand ridge country, depicts an aeolian landscape which unconformably overlies the Renmark Beds. In the east of the basin younger fluviatile (prior stream) sediments are known to extend to a depth of 90 m and to overlie both the older Tertiary fluviatile and lacustrine sedimentary surface there, as well as the aeolian surface further to the west.

5.5 Mineral Resources

The major mineral resource in the Murray Basin is surface water which is used for irrigation along the Lachlan, Darling, Murrumbidgee and Murray Rivers. This is by far the largest irrigation area in Australia and, through regulation by both Federal and State instrumentalities, is a productive income earner. Produce ranges from fruit and vegetables to fodder crops, lucerne, cotton, sorghum, citrus, vines, etc., and irrigation areas provide attractive open-space public recreation and tourist facilities, as well as water supplies for people and livestock.

Away from the major rivers, where the total dissolved salts content of groundwater increases and where the water table is very shallow but does not reach the surface, gypsum and celestite precipitate by fractional crystallisations; but where the water table reaches the surface, halite and epsomite precipitate [Lawrence 1975]. None of these anhydrite deposits have been worked on a commercial scale, except around Ivanhoe on the northern margin of the Murray Basin adjacent to the Sydney-Broken Hill railway (see Section 3.9 in Appendix D).

Petroleum exploration has taken place since the early 1950s, but no economic traces of hydrocarbons have been detected from 18 holes drilled in strata beneath the unconsolidated basin sediments [Bembrick 1974].

Exploration for sedimentary uranium has encountered only uneconomic uranium traces (30 $\mu g\ g^{-1}$) adjacent to the Tertiary-Quaternary unconformity in the near vicinity of Palaeozoic granite near Jerilderie in the southeast Murray Basin and in a similar stratigraphic position near Menindee in the west [B. Coles, Afmeco, personal communication 1972].

5.6 Hydrogeology

Over the greater part of the NSW section of the Murray Basin, wells and bores are the main source of water supply. Gibbons et al. [1972] have divided the NSW section of the basin into three distinct hydrogeological regions - Eastern, Northern and Southern. The Eastern region is characterised by an almost invariable occurrence of good stock water in aquifers within 60 m of ground surface; the Southern region by a general occurrence of salt waters to a depth of 100 m or more; and the Northern region by a generally patchy distribution of better quality water.

The Murray Basin is a major topographic basin bounded by essentially impervious rimrock. Thus there is little likelihood of water entering the basin by lateral underground movement from areas removed from the basin itself.

Groundwater recharge is via

- water entering the basin by soakage from rivers and lakes,
- water falling in the higher rainfall areas at the margin of the basin and soaking into the marginal sediments at an altitude above the general surface level within the area and
- water falling in the more arid areas of the basin where runoff is small and evapo-transpiration high [Gibbons et al. 1972].

The main recharge areas in the eastern zone are close to the Lachlan, Murrumbidgee and Murray Rivers in areas where they leave the highland valleys and flow over the basin. Bores yielding irrigation-quality water are scattered throughout this area.

Aquifers are located within the Quaternary and poorly consolidated Tertiary sediments. Individual aquifers are usually of limited extent and thickness, although there are also very thick and extensive aquifers in the eastern zone, e.g. Narrandera and Darlington Point.

In the NSW section of the basin, it has been found, in most bores, that the standing water level corresponds closely with the local level of the water table, so that the water table height above sea level indicates fairly accurately the total potential of the water beneath. The general direction of flow will therefore be from areas of high water table towards areas of lower water table. Thus the general direction of groundwater flow is towards the central part of the basin in NSW and then generally south, towards the Murray

River.

5.7 Survey Site Hydrogeology

As mentioned in the body of the report in Section 3.2, the various surface clay areas delineated in this structural unit have very similar hydrogeology components. To indicate the monotonous similarity of Murray Basin hydrogeology, two survey sites, 190 km apart, were chosen in southern NSW and will be described separately.

5.8 Willandra Creek Survey Site

[Refer Figures 8, 8(a) for locations]

Located 25 km south-southeast of Ivanhoe near the northeastern margin of the Murray Basin, the area contains flood-prone, flat to gently undulating plains of silts and clays surrounding Willandra Creek, a west-flowing effluent of the Lachlan River. A number of clay pans, calcrete 'fossil' drainage systems, outwash areas and lateritic areas are described on geological maps, and to the north gypsum is mined within 15 km of the railway line.

A thick Quaternary sequence, of more than 130 m, exists in the survey area. Within the waterbores, the stratigraphy is predominantly clays and silts, from the surface to approximately 30 m. Below the clays and silts a narrow (2 to 12 m), sequence of coarse sands and gravels form the shallowest aquifer zone. Beneath the aquifer, the lithology returns to clays and silts. In the three deepest bores there appears to be a second sand horizon at approximately 110 m. Its thickness is unknown and no indurated material was penetrated.

Gibbons et al. [1972] report that standing water levels in the area lie between 25 and 35 m below the ground surface, and that groundwater flow is towards the west to west southwest.

5.9 Forrest Creek Survey Site

[Refer Figures 9, 9(a) for location]

The survey area is located 65 km southwest of Hay. Hay, which is on the Murrumbidgee River, is a central service centre with a population of 3500 and is cut by the Sydney-Adelaide Sturt Highway and Melbourne-Brisbane Cobb Highway. The area is situated in nearly flat, featureless plains, composed of sands and clays with some gravels, calcrete-filled clay pans and sand ridges. Only shallow (less than 10 m) relief surrounds Forrest Creek and the area is probably subject to local flooding after heavy or prolonged rain.

Because aquifers occur close to the surface, all waterbores were shallow (less than 60 m) and intersected only the upper part of the Quaternary sequence. This is composed predominantly of clay (see Figure 8), with thin interbeds of silt, sand and drift containing very minor pebble lenses. The thickest amount of surface clay is adjacent to Forrest Creek.

An aquifer, at about 20 m depth, extends over a large part of the area. The borehole density is insufficient to permit the number, depth and importance of other nearby groundwater levels to be further discussed. Surface drainage is to the southwest, towards the Edward River. Gibbons et al. [1972] indicate the groundwater flow is generally towards the northwest.

TABLE 1
FIRST STAGE SCREENING IN SITE SELECTION

NSW Structural Units	Kammantoo Fold Belt	West Lachlan Fold Belt	Central Lachlan Fold Belt	East Lachlan Fold Belt	Darling Depression	Tamworth Sync.	New England Fold Belt	North Coast Blocks and Basins	Sydney - Bowen Basin	Great Australian Basin	Murray Basin
I <u>Equal Weight for Each Variable</u>											
A. NATURAL RESOURCES											
Climate	3	3	2	1	3	2	2	1	1	3	3
Temperature	2	2	2	1	2	2	1	3	2	3	2
Rainfall	3	3	2	1	3		2	2	1	1	3
Surface water resources	2	3	2	1	1	2	1	1	1	3	1
Groundwater	3	2	2	1	3	1	2	1	1	3	2
Landforms and Relief	3	3	1	1	2	3	1	1	1	2	2
Geology	1	1	1	1	3	1	1	1	3	2	3
Soils	3	2	1	1	2	1	1	1	2	3	2
Natural vegetation	3	3	2	1	3	2	1	1	1	3	3
Grasslands	3	2	1	2	2	2	1	1	2	3	1
	(26)	(24)	(16)	(11)	(24)	(18)	(13)	(12)	(15)	(28)	(22)
B. MANMADE RESOURCES											
Mineral Deposits	1	1	1	2	3	2	1	2	1	1	2
Water use	2	2	2	1	3	1	2	1	1	2	1
Land use	2	2	1	1	3	1	2	1	1	3	1
Forest resources	3	2	2	1	3	2	2	1	1	3	2
Livestock	2	3	2	1	3	1	2	1	1	3	2
Sheep and Wool	2	2	2	1	2	1	3	3	3	2	2
Croplands	3	2	1	2	3	1	1	2	2	3	1
Crop production	3	2	1	1	3	1	2	2	1	3	1
Fish and fisheries	2	3	2	1	3	3	2	1	1	3	2
Manufacturing industry	1	1	3	3	1	1	1	1	2	1	1
	(21)	(20)	(17)	(14)	(27)	(14)	(18)	(15)	(14)	(24)	(15)

(Continued)

C. INTRODUCED SERVICES											
Roads and aerodromes	3	3	1	1	2	3	3	3	1	2	2
Railways	3	3	1	3	3	3	2	2	1	2	3
Electricity	3	3	1	2	2	2	2	2	1	3	2
Health services	1	2	3	3	1	2	2	2	3	1	2
Ports and shipping	1	1	1	2	1	2	1	3	3	1	1
	(11)	(12)	(7)	(11)	(9)	(12)	(9)	(12)	(9)	(9)	(10)
D. GOVERNMENT ADMINISTRATION											
Local Government	2	1	2	2	1	2	2	2	3	1	2
State Government	1	1	2	3	1	2	2	2	1	1	2
Population distribution	1	1	2	2	3	2	2	2	1	3	2
	(4)	(3)	(6)	(7)	(5)	(6)	(6)	(6)	(5)	(5)	(6)
E. DISTANCE											
from major urban	1	3	3	3	1	3	1	1	2	1	3
from major rural	3	3	2	2	3	2	2	2	1	1	3
from major mining	2	2	2	2	3	1	2	2	2	2	3
from major industrial	3	1	2	3	1	3	1	1	2	1	3
	(9)	(9)	(9)	(10)	(8)	(9)	(6)	(6)	(7)	(5)	(12)
Cumulative Total Rating	71	68	55	53	73	59	52	51	500	71	65
II Equal Weights for Each Category											
A. Natural resources	2.6	2.4	1.6	1.1	2.4	1.8	1.3	1.2	1.5	2.8	2.2
B. Manmade resources	2.1	2.0	1.7	1.4	2.7	1.4	1.8	1.5	1.4	2.4	1.5
C. Introduced services	2.2	2.4	1.4	2.2	1.8	2.4	1.8	2.4	1.8	1.8	2.0
D. Government administration	1.3	1.0	2.0	2.3	1.7	2.0	2.0	2.0	1.7	1.7	2.0
E. Distance	2.2	2.2	2.2	2.5	2.0	2.2	1.5	1.5	1.7	1.2	3.0
(Σ A,B,C,D,E)/5 Ranking of SU	2.08	2.0	1.78	1.90	2.12	1.96	1.68	1.72	1.62	1.98	2.14
Equal Weight for Each Variable	2=	4	7	8	1	6	9	10	11	2=	5
Equal Weight for Each Category	3	4	8	7	2	6	10	9	11	5	1

TABLE 2
DATA FROM MAP SURVEY AREAS

Map Survey Area (Fig.1a)	A	B	C	D	E	F	G	H
1. LOCALITY								
State graticule number and local name	43 Pine Creek	48 Yellow Mt.	39 Greenoughs Hill	47 Taringo Downs	46 Conoble Lake	14 Warrego River	62 Willandra Creek	69 Forrest Creek
Nearest town and direction	Broken Hill 80 km N	Condobolin 70 km SE	Wilcannia 100 km W	Cobar 100 km NE	Ivanhoe 55 km W	Bourke 100 km S	Ivanhoe 25 km N	Hay 65 km NE
Structural unit	Kanmantoo Fold Belt	West Lachlan Fold Belt	Darling Depression	Darling Depression	Basin Margin	Gt Artesian Basin	Murray Basin	Murray Basin
Distance from								
Sydney	900	400	650	600	600	750	650	600
Melbourne	700	600	700	600	550	950	550	350
Nearest highway/ railway	Silver City intersects	Barrier 100 km N	Barrier intersects	Indian-Pacific 80 km S	Indian-Pacific 10 km S	Mitchell intersects	Indian-Pacific 25 km N	Sturt intersects
Mid point								
Lat.	32°40'S	32°30'S	31°15°S	32°15'S	32°45'S	29°15'S	33°10'S	3550'S
Long.	141°40'E	146°45'E	144°30'E	145°15'E	144°45'E	E145°30'E	144°30'E	144°15'E
Survey area km^2	2720	2200	4500	4875	200	5775	2600	2425
Settlement conc.	1	1	3	4	3	5	3	1
2. HYDROLOGY								
No. of waterbores	90	21	108	60	60	126	167	78
Borehole density/km^2	1/30	1/100	1/42	1/81	1/33	1/45	1/15	1/31
Main aquifer depth (m)	80	60	50	86	40	350	40	20

(Continued)

Other ground water levels	40,50, 100	various	20,30, 60	20,66, 75	30-35	5,15,25, 230,350,400 480,520	27,35, 53,60	various
Surface water drainage direction	S	S	SW	interior	E	S	E	SW
Surface streams number	2	2	5	3	2	5	2	2
Est. 50 year flood area	20% in E	5% in S	70% in NW	10% in centre	10% in E	40%in N	75% in S	50% in N
Water quality TDS in $\mu g\ g^{-1}$	7000-14000	>14000	7000-14000	3000-7000	3000-7000	<1000	3000-7000	1000-3000
3. GEOLOGY								
Age surface cover	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary
Type	clays	sandy clay	silts and clay	clay	clay	sandstone clays and gravel	clay	clay
Age basement rock	Tertiary	Ordovician	Devonian	Tertiary	Tertiary	Jurassic	not exposed	not exposed
Type of basement	sandstone	quartzite schist	sandstone shale	shale	sandstone	shale	-	-
Erosion surface depth	60	65	50	25	40	20	30	-
Aquifer control	tectonics erosion surface	various	erosion surface	erosion surface	stratigraphy	stratigraphy	stratigraphy	independent
Maximum site clay thickness	60	15	20-50	10-40	10-40	5-27	20-60+	20-60

(Continued)

Site clay surface area (km^2)	200	10	75	250	370	100	250	210
Est. % clay to map survey site	7	0.4	2	5	18	1.7	10	8.5
% survey site to structural unit	5	5	5	7	2	3	1	1

TABLE 3

RANKING OF SURVEY SITES

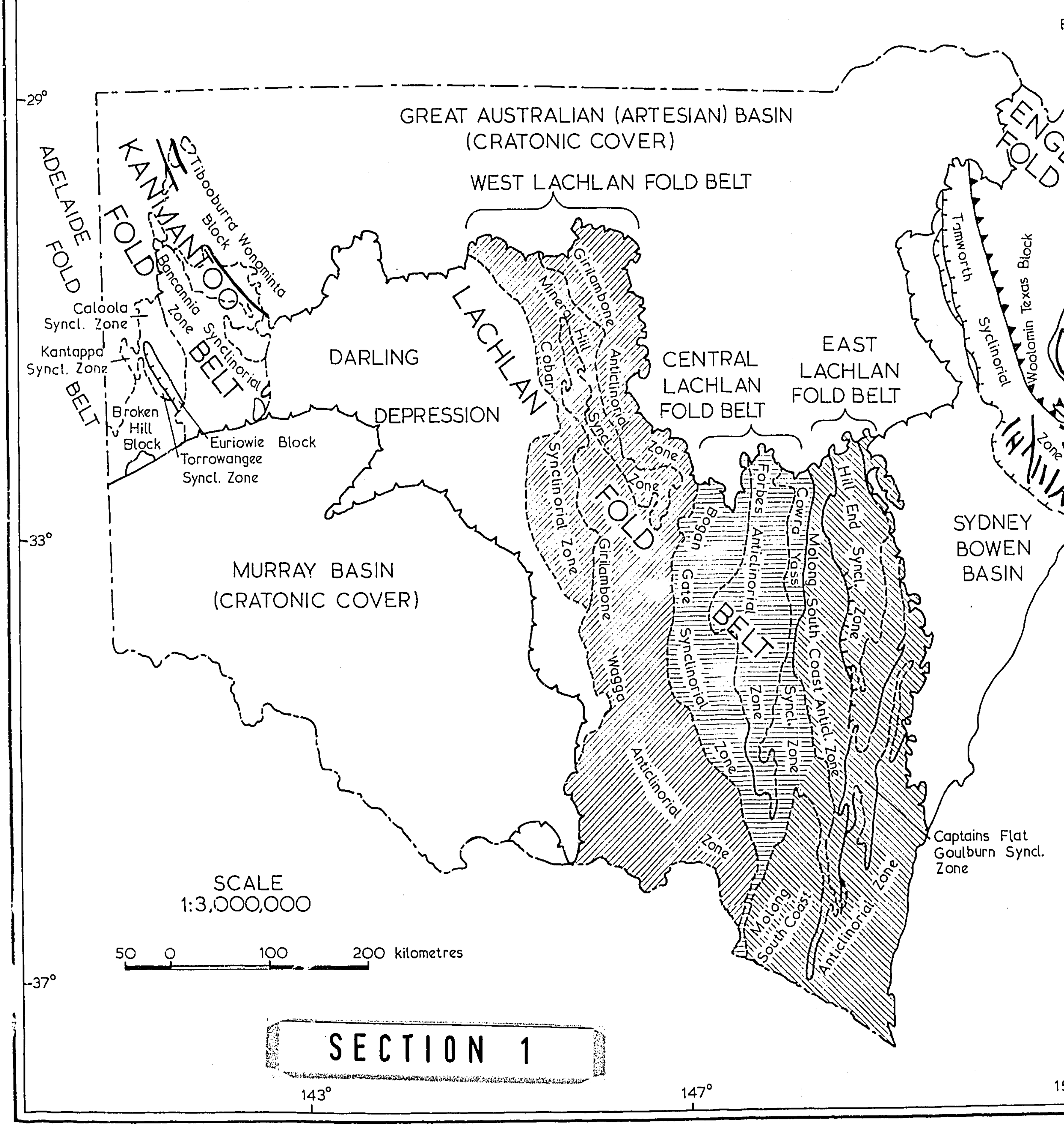
Criteria for Disposal Site	Pine Creek	Yellow Mt.	Greenough's Hill	Taringo Downs	Conoble Lake	Warrego River	Willandra Creek	Forrest Creek
HIGH RANK								
Site devoid of surface water	4	4	1	2	1	1	1	1
Site not subject to floods	4	4	1	2	1	1	1	1
Simple hydrogeologic conditions	1	1	4	2	4	4	4	4
Water table below disposal zone	4	4	4	4	4	2	1	1
Minimal water table fluctuations	2	1	1	2	2	1	2	2
Accumulated sub-totals	(15)	(14)	(11)	(12)	(12)	(9)	(9)	(9)
MEDIUM RANK								
Present use of groundwater minimal	2	1	$\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Disposal zone separated from bedrock	1	2	2	1	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Site committed to only disposal use	2	2	$\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Site physically isolated from man	2	2	2	2	$\frac{1}{2}$	1	1	1

(Continued)

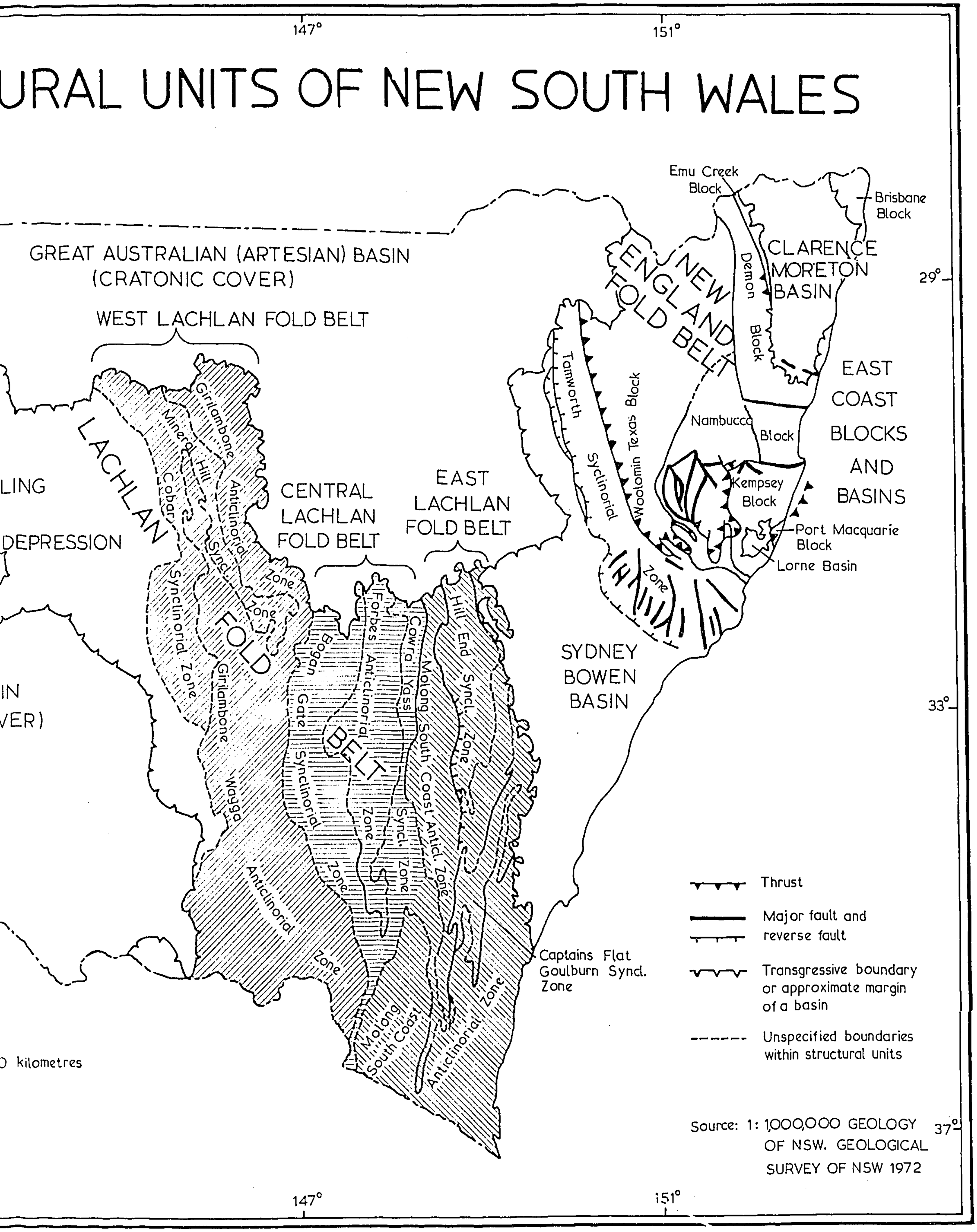
Depth-area surface clay accumulation	2	$\frac{1}{2}$	$\frac{1}{2}$	1	1	$\frac{1}{2}$	2	2
Site stable geomorphologically	1	2	$\frac{1}{2}$	2	1	1	2	2
Site away from earthquake tectonics	$\frac{1}{2}$	1	$\frac{1}{2}$	2	$\frac{1}{2}$	2	2	2
Accumulated sub-totals	($10\frac{1}{2}$)	($10\frac{1}{2}$)	($6\frac{1}{2}$)	(10)	(5)	(6)	($8\frac{1}{2}$)	($8\frac{1}{2}$)
<u>LOW RANK</u>								
Site subject to public acceptance	$\frac{1}{2}$	1	$\frac{1}{4}$	1	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$
Transport/Distance optimum costs	$\frac{1}{4}$	1	$\frac{1}{2}$	1	1	$\frac{1}{4}$	1	1
Site has present good access and service	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	$\frac{1}{2}$	1	1
Site located on public or readily resumable land	1	1	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$
Accumulated sub-totals	(2)	($3\frac{1}{2}$)	($1\frac{1}{2}$)	($2\frac{3}{4}$)	($2\frac{3}{4}$)	($1\frac{1}{2}$)	($2\frac{1}{2}$)	($2\frac{1}{2}$)
Final Total	$27\frac{1}{2}$	28	19	$24\frac{3}{4}$	$19\frac{3}{4}$	$16\frac{1}{2}$	20	20

FIGURE 1.

STRUCTURAL UNITS OF NEW SOUTH



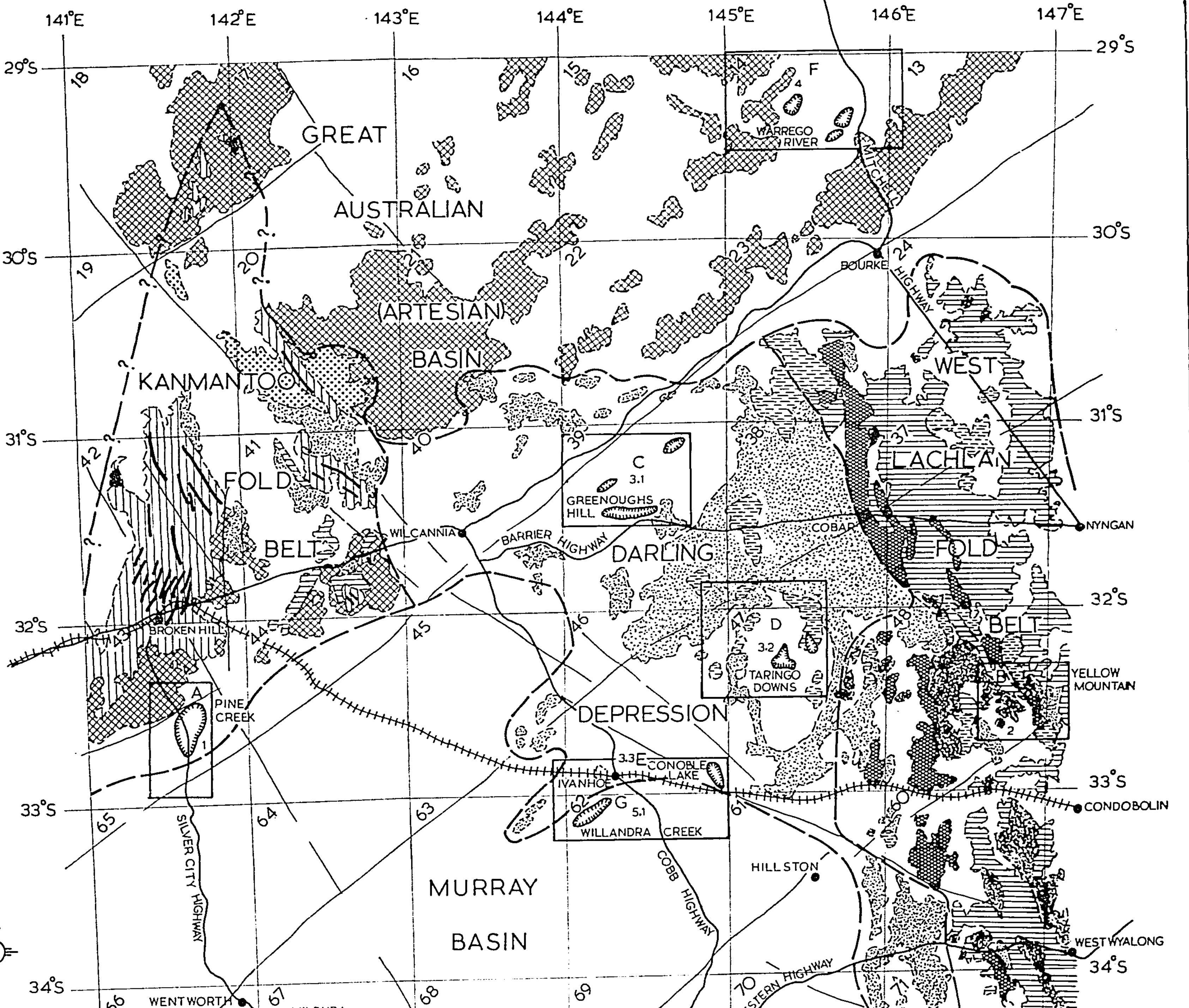
SECTION 1



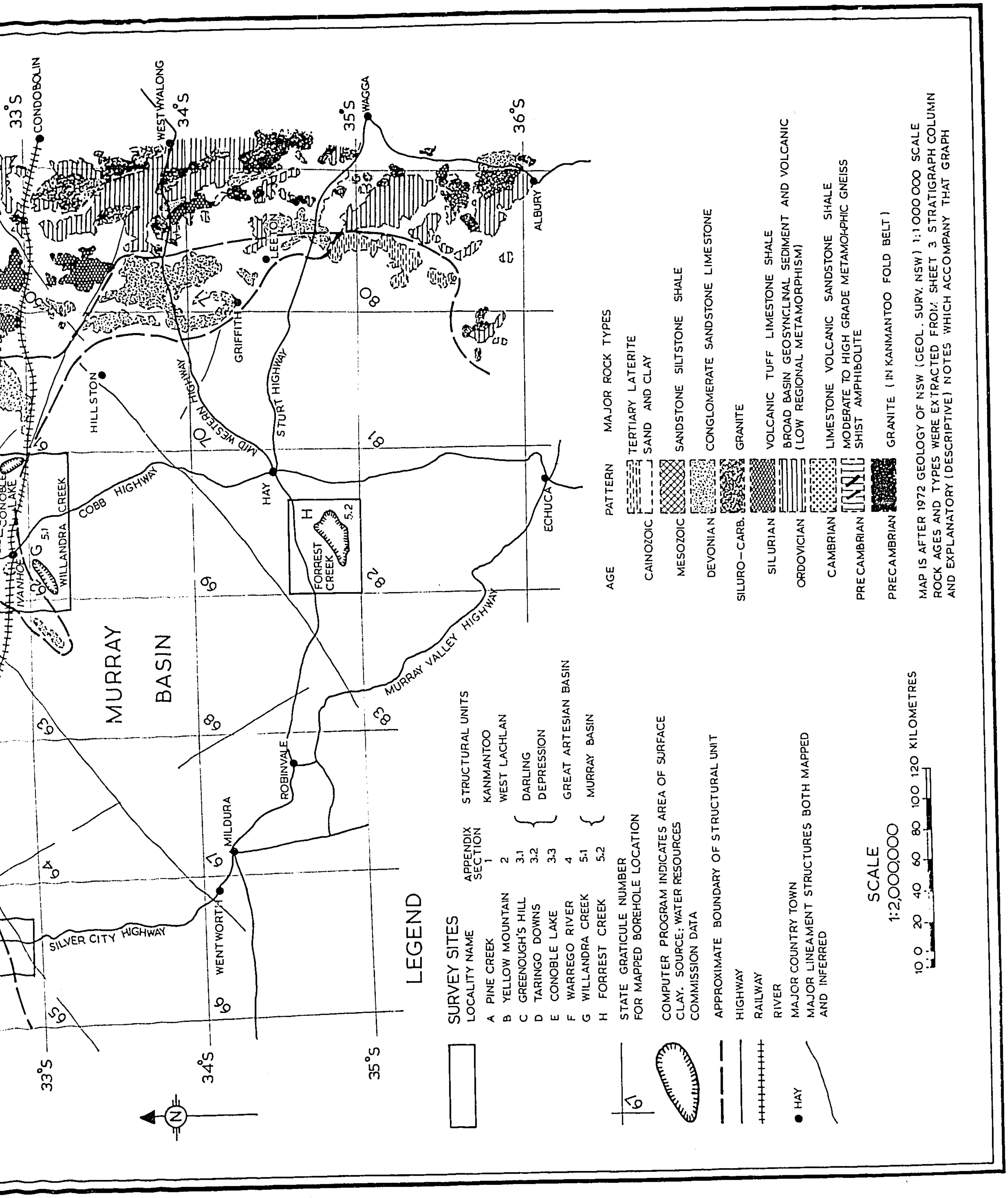
Source: 1: 1,000,000 GEOLOGY OF NSW. GEOLOGICAL SURVEY OF NSW 1972

SECTION 2

FIGURE 1a REGIONAL GEOLOGY AND AREAS SURVEYED IN DETAIL IN WESTERN NSW

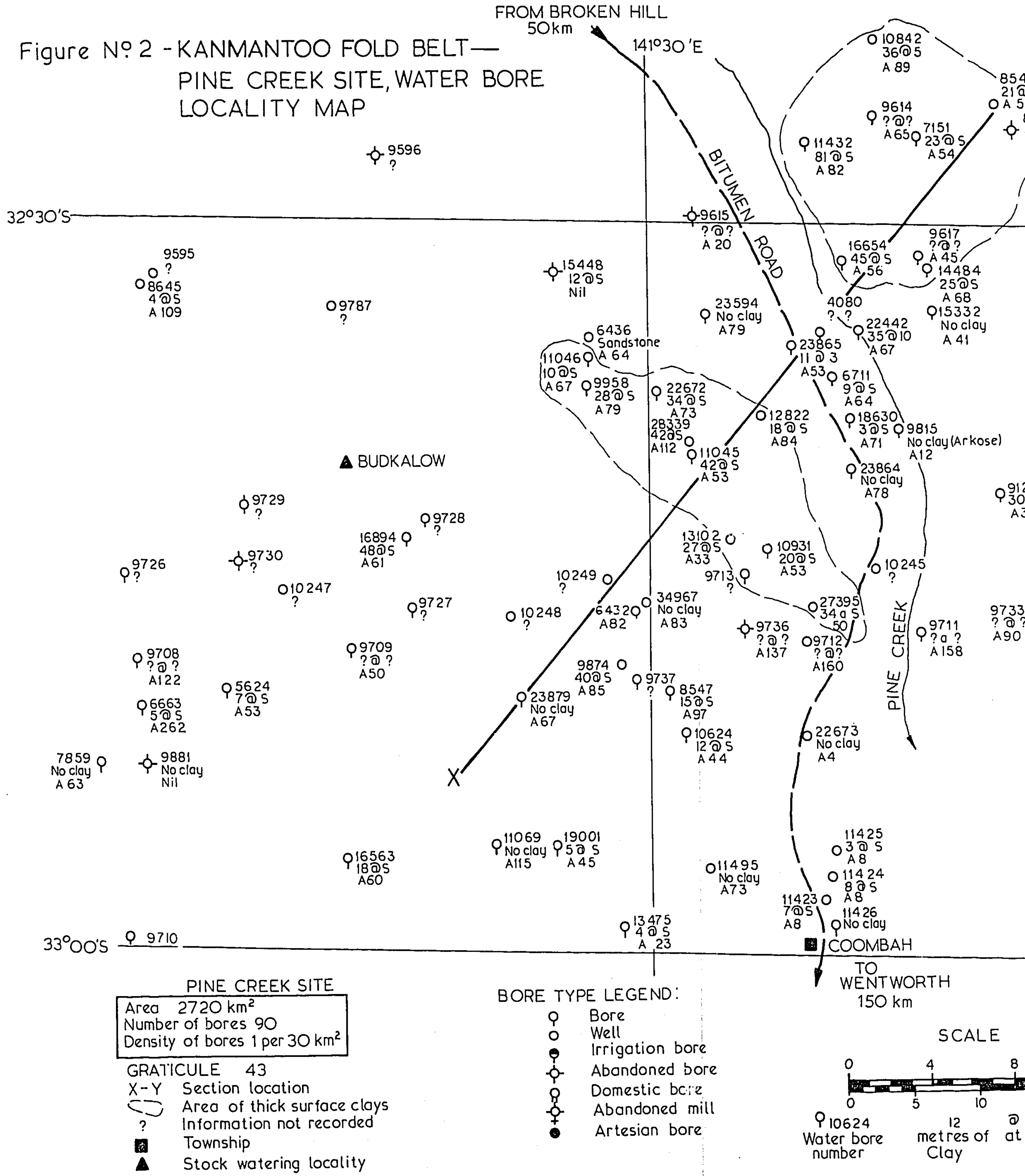


SECTION 1

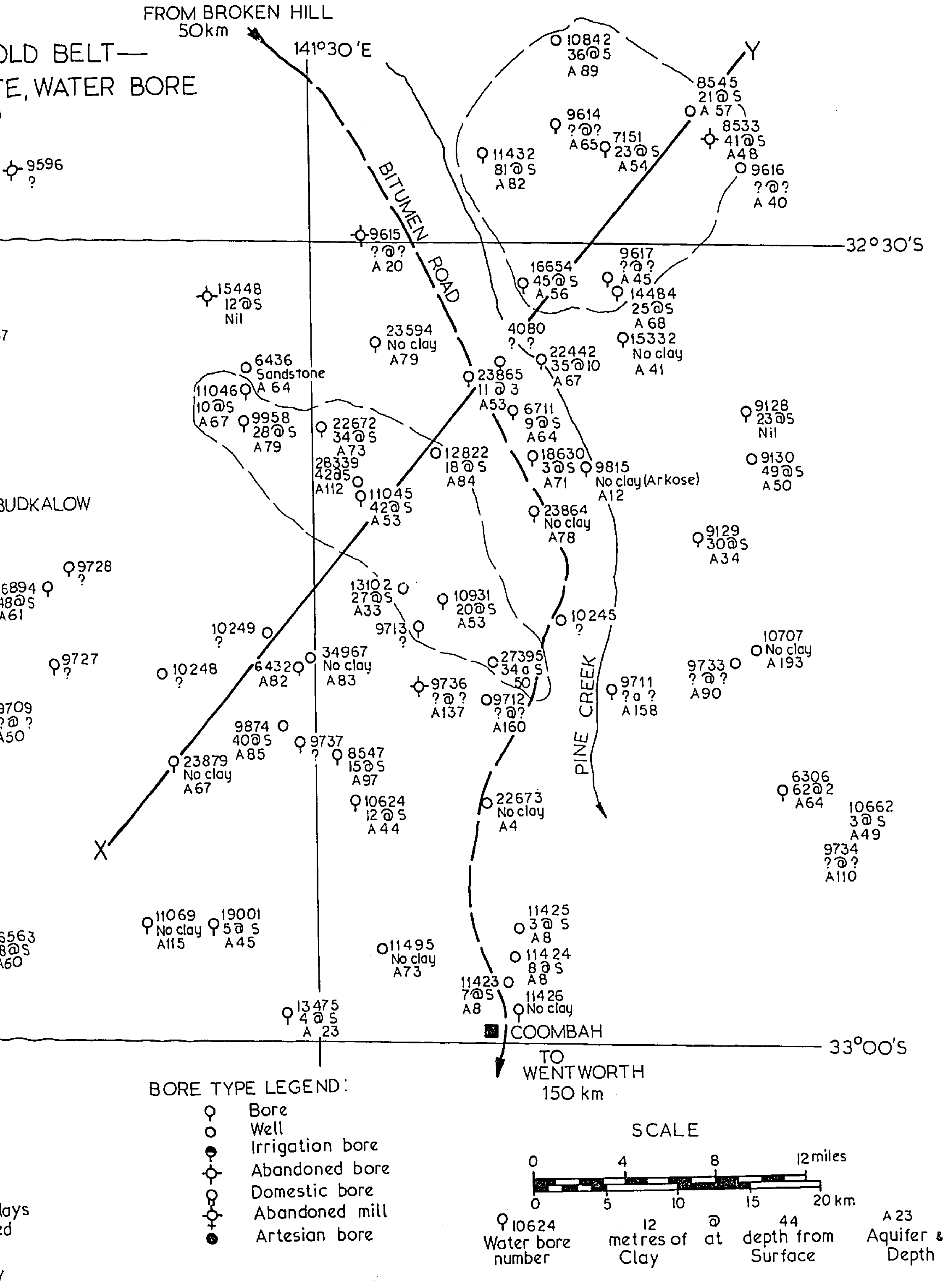

CONDOBOLIN
WEST WYALONG
WAGGA
ALBURY
LEETON
GRIFFITH
HILLSTON
HAY
ECHUCA
FORREST CREEK
IVANHOE
CONOBLE LAKE
WILLANDRA CREEK
ROBINVALE
MILDURA
WENTWORTH
MURRAY BASIN
MID WESTERN HIGHWAY
STURT HIGHWAY
COBB HIGHWAY
MURRAY VALLEY HIGHWAY
SILVER CITY HIGHWAY
33°S
34°S
35°S
36°S
G
5.1
H
5.2
63
64
65
66
67
68
69
70
80
81
82
83
N
LEGEND
SURVEY SITES
LOCALITY NAME
A PINE CREEK
B YELLOW MOUNTAIN
C GREENOUGH'S HILL
D TARINGO DOWNS
E CONOBLE LAKE
F WARREGO RIVER
G WILLANDRA CREEK
H FORREST CREEK
APPENDIX SECTION
1
2
3.1
3.2
3.3
4
5.1
5.2
STRUCTURAL UNITS
KANMANTOO
WEST LACHLAN
DARLING DEPRESSION
GREAT ARTESIAN BASIN
MURRAY BASIN
STATE GRATICULE NUMBER FOR MAPPED BOREHOLE LOCATION
COMPUTER PROGRAM INDICATES AREA OF SURFACE CLAY. SOURCE; WATER RESOURCES COMMISSION DATA
APPROXIMATE BOUNDARY OF STRUCTURAL UNIT
HIGHWAY
RAILWAY
RIVER
MAJOR COUNTRY TOWN
MAJOR LINEAMENT STRUCTURES BOTH MAPPED AND INFERRED
AGE
PATTERN
MAJOR ROCK TYPES
CAINOZOIC
TERTIARY LATERITE SAND AND CLAY
MESOZOIC
SANDSTONE SILTSTONE SHALE
DEVONIAN
CONGLOMERATE SANDSTONE LIMESTONE
SILURO-CARB.
GRANITE
SILURIAN
VOLCANIC TUFF LIMESTONE SHALE
ORDOVICIAN
BROAD BASIN GEOSYNCLINAL SEDIMENT AND VOLCANIC (LOW REGIONAL METAMORPHISM)
CAMBRIAN
LIMESTONE VOLCANIC SANDSTONE SHALE
PRECAMBRIAN
MODERATE TO HIGH GRADE METAMORPHIC GNEISS SHIST AMPHIBOLITE
PRECAMBRIAN
GRANITE (IN KANMANTOO FOLD BELT)
MAP IS AFTER 1972 GEOLOGY OF NSW (GEOL. SURV. NSW) 1:1 000 000 SCALE
ROCK AGES AND TYPES WERE EXTRACTED FROM SHEET 3 STRATIGRAPH COLUMN
AND EXPLANATORY (DESCRIPTIVE) NOTES WHICH ACCOMPANY THAT GRAPH
SCALE
1:2,000,000
10 0 20 40 60 80 100 120 KILOMETRES

SECTION 2

Figure Nº 2 - KANMANTOO FOLD BELT— PINE CREEK SITE, WATER BORE LOCALITY MAP



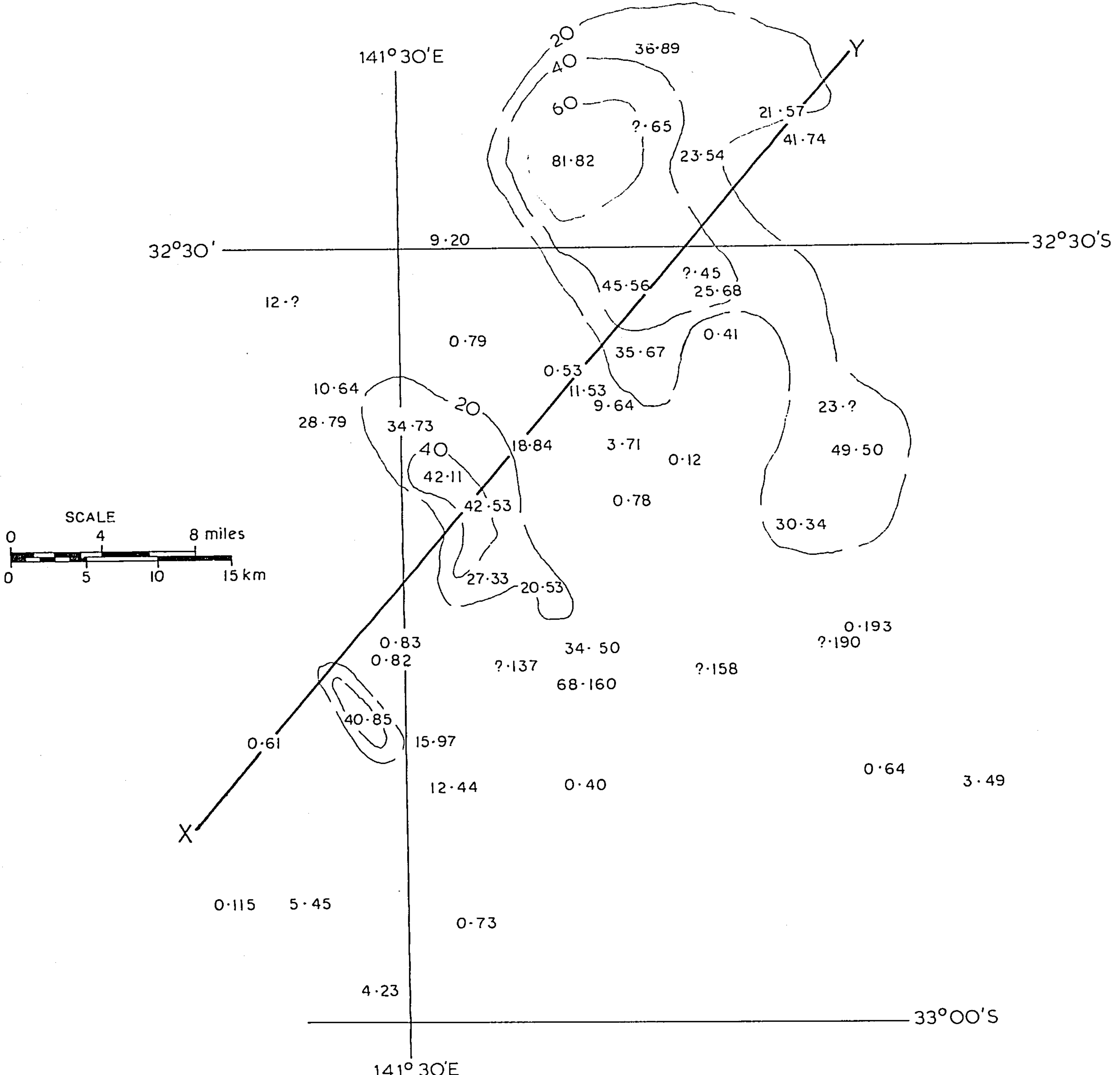
SECTION 1

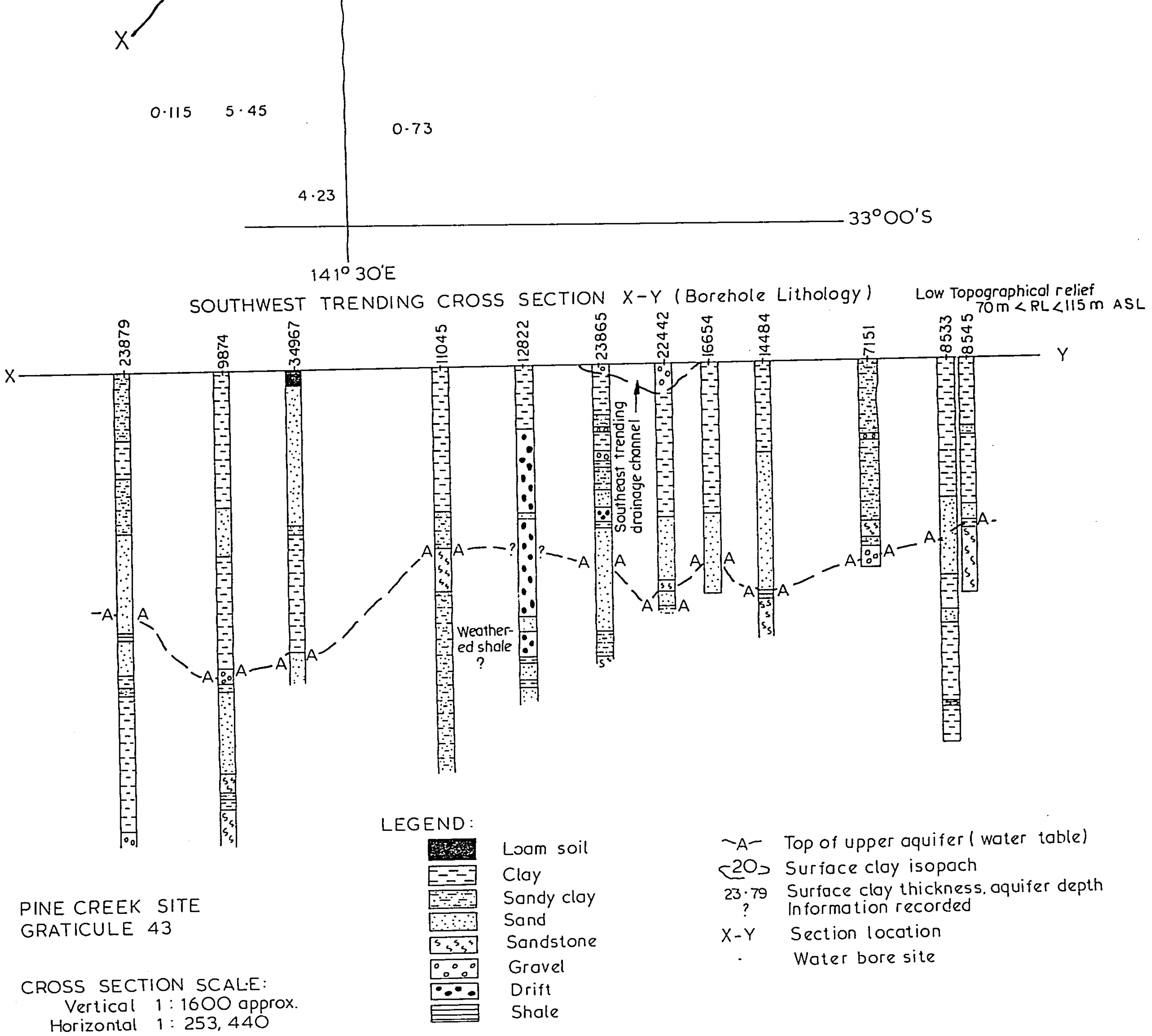

OLD BELT—
E, WATER BORE
FROM BROKEN HILL
50km
141°30'E
BITUMEN ROAD
32°30'S
33°00'S
PINE CREEK
BUDKALOW
COOMBAH
TO WENTWORTH
150 km
X
Y
10842 36@5 A 89
8545 21@S A 57
9614 ?@? A65
7151 23@S A54
8533 41@S A48
11432 81@S A 82
9616 ?@? A 40
9596 ?
9615 ?@? A 20
9617 ?@? A 45
16654 45@S A 56
14484 25@S A 68
15448 12@S Nil
23594 No clay A79
4080 ? ?
22442 35@10 A 67
15332 No clay A 41
6436 Sandstone A 64
23865 11@3 A53
11046 10@S A67
9958 28@S A79
22672 34@S A73
6711 9@S A64
9128 23@S Nil
12822 18@S A84
18630 3@S A71
9815 No clay (Arkose) A12
9130 49@S A50
28339 42@S A112
11045 42@S A 53
23864 No clay A78
9129 30@S A34
9728 ?
6894 48@S A61
13102 27@S A33
10931 20@S A53
10245 ?
10249 ?
9713 ?
10707 No clay A 193
9727 ?
10248 ?
6432 A82
34967 No clay A83
27395 34 a S 50
9733 ?@? A90
9711 ?a ? A158
9736 ?@? A137
9712 ?@? A160
9709 ?@? A50
9874 40@S A85
9737 ?
8547 15@S A97
23879 No clay A67
10624 12@S A44
22673 No clay A4
6306 62@2 A64
10662 3@S A49
9734 ?@? A110
11425 3@S A8
11069 No clay A115
19001 5@S A45
6563 8@S A60
11495 No clay A73
11424 8@S A8
11423 7@S A8
11426 No clay
13475 4@S A 23
BORE TYPE LEGEND:
Bore
Well
Irrigation bore
Abandoned bore
Domestic bore
Abandoned mill
Artesian bore
SCALE
0 4 8 12 miles
0 5 10 15 20 km
10624 Water bore number
12 metres of Clay
@ at
44 depth from Surface
A 23 Aquifer & Depth
ays
ed

SECTION 2

SECTION 1

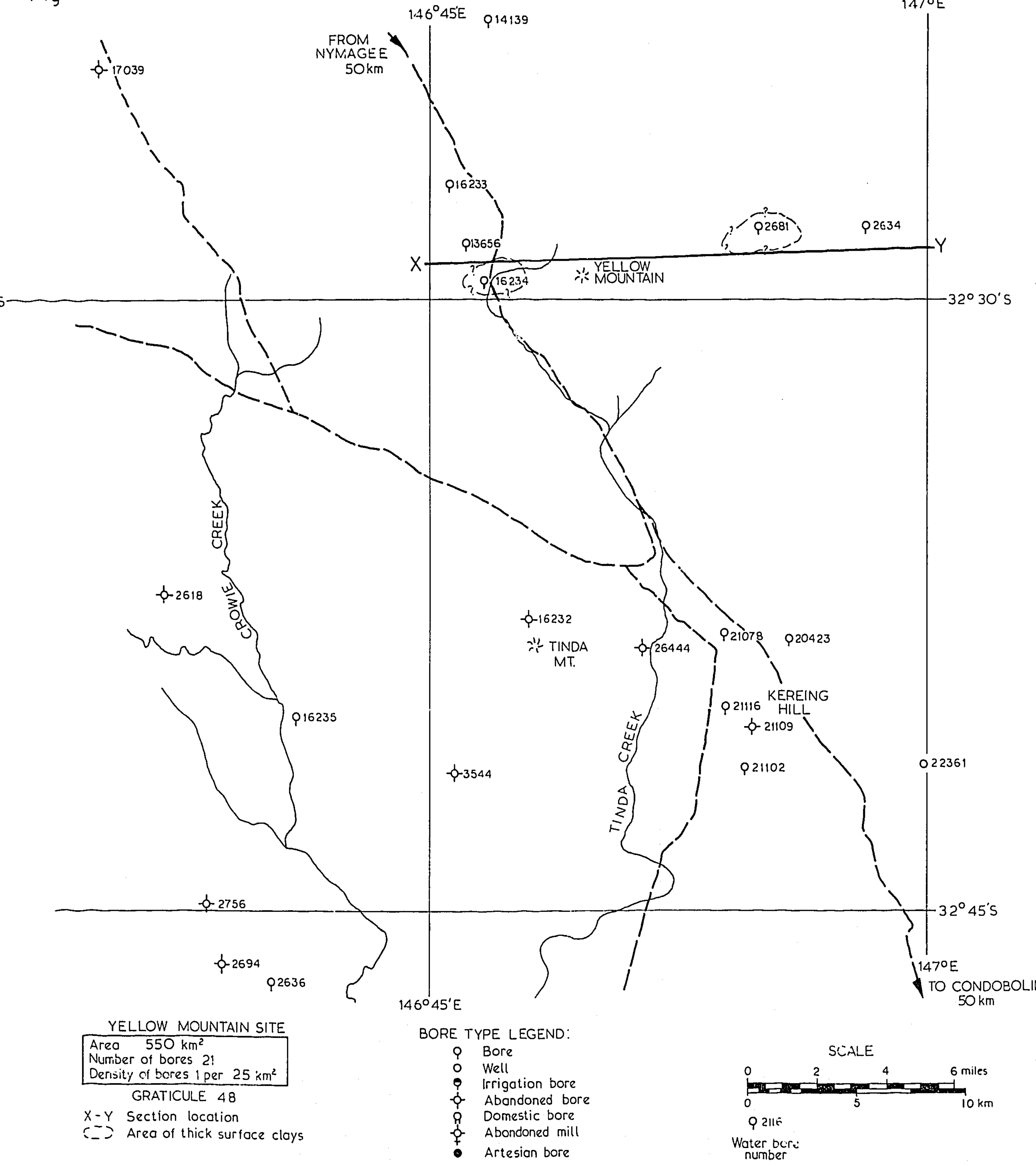
Figure Nº 2a - KANMANTOO FOLD BELT, PINE CREEK SITE, CLAY AQUIFER RELATIONSHIP




X
0·115
5·45
0·73
4·23
33°00'S
141° 30'E
SOUTHWEST TRENDING CROSS SECTION X-Y (Borehole Lithology)
Low Topographical relief
70m < RL < 115m ASL
23879
9874
34967
11045
12822
23865
22442
16654
14484
7151
8533
8545
X
Y
A
?
Weathered shale ?
Southeast trending drainage channel
LEGEND:
Loam soil
Clay
Sandy clay
Sand
Sandstone
Gravel
Drift
Shale
~A~ Top of upper aquifer (water table)
<20> Surface clay isopach
23·79 ? Surface clay thickness, aquifer depth information recorded
X-Y Section location
· Water bore site
PINE CREEK SITE
GRATICULE 43
CROSS SECTION SCALE:
Vertical 1 : 1600 approx.
Horizontal 1 : 253, 440

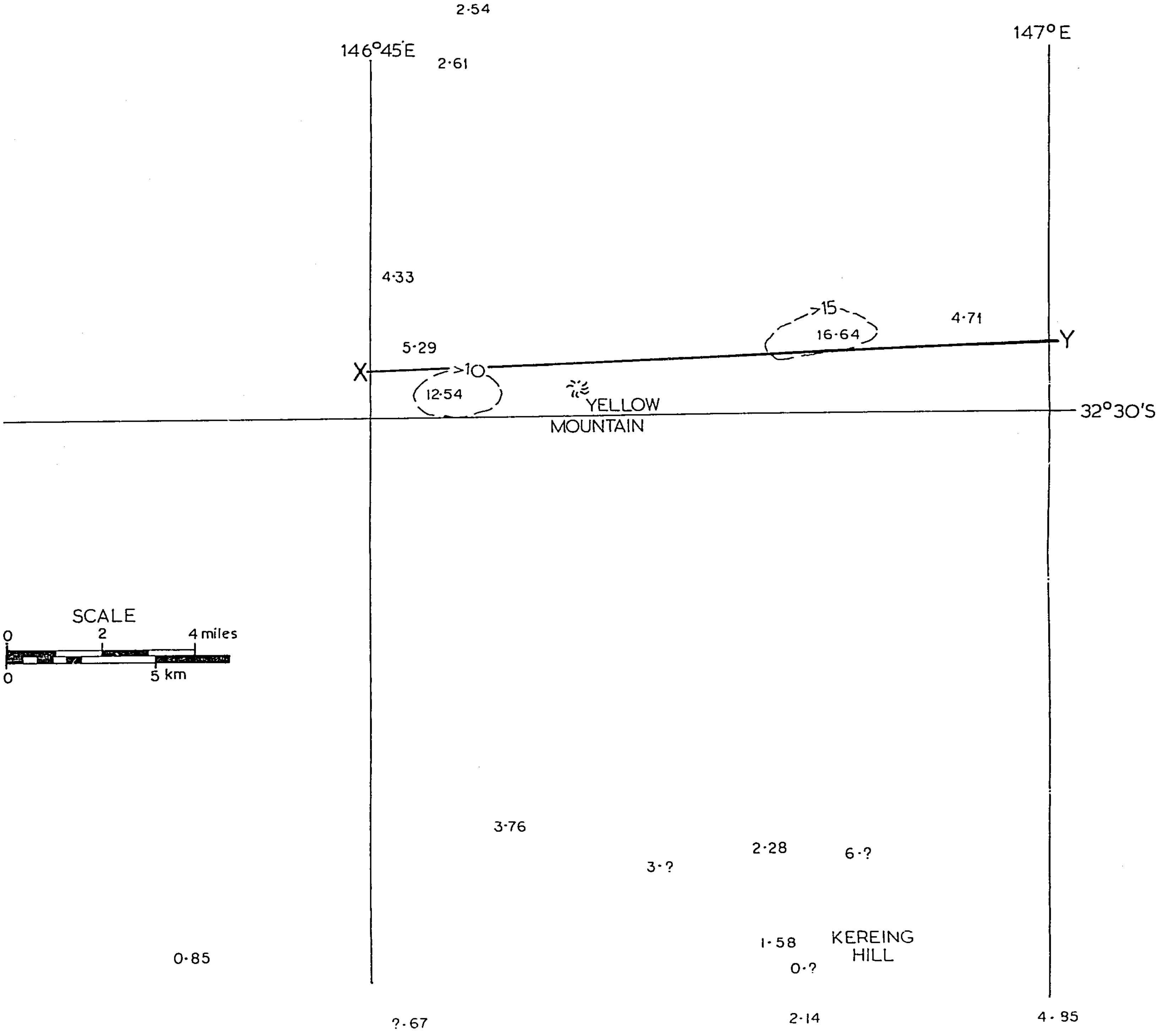
SECTION 2

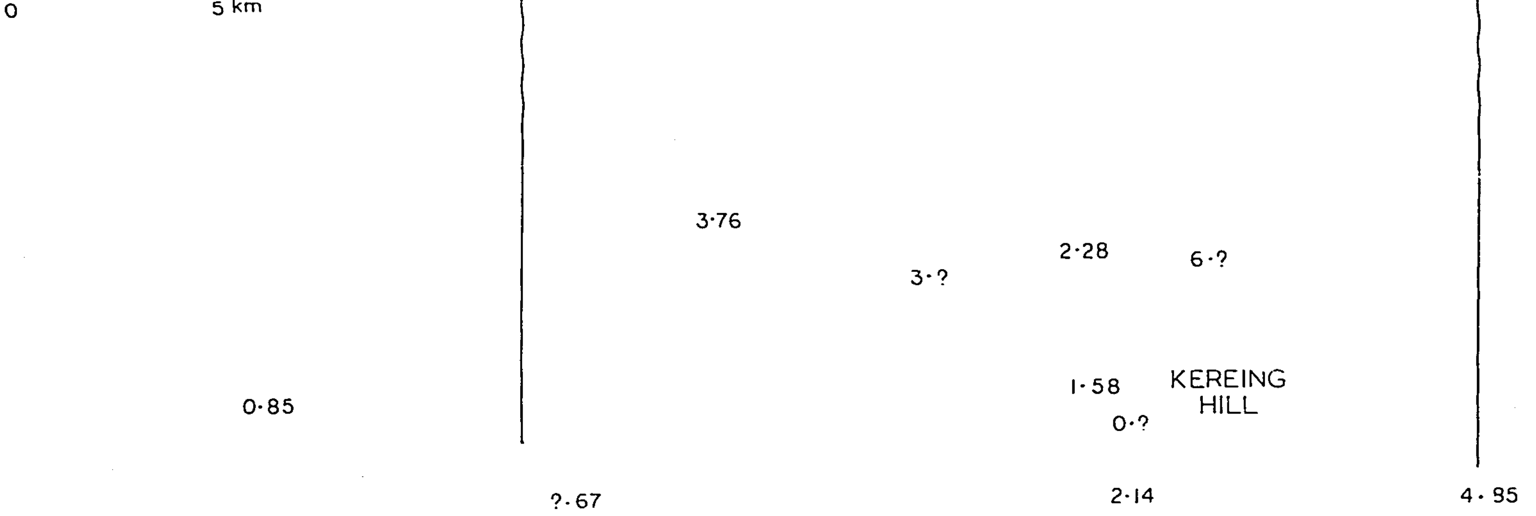
Figure No 3 - WEST LACHLAN FOLD BELT — YELLOW MOUNTAIN SITE, WATER BORE LOCALITY MAP



SECTION 1

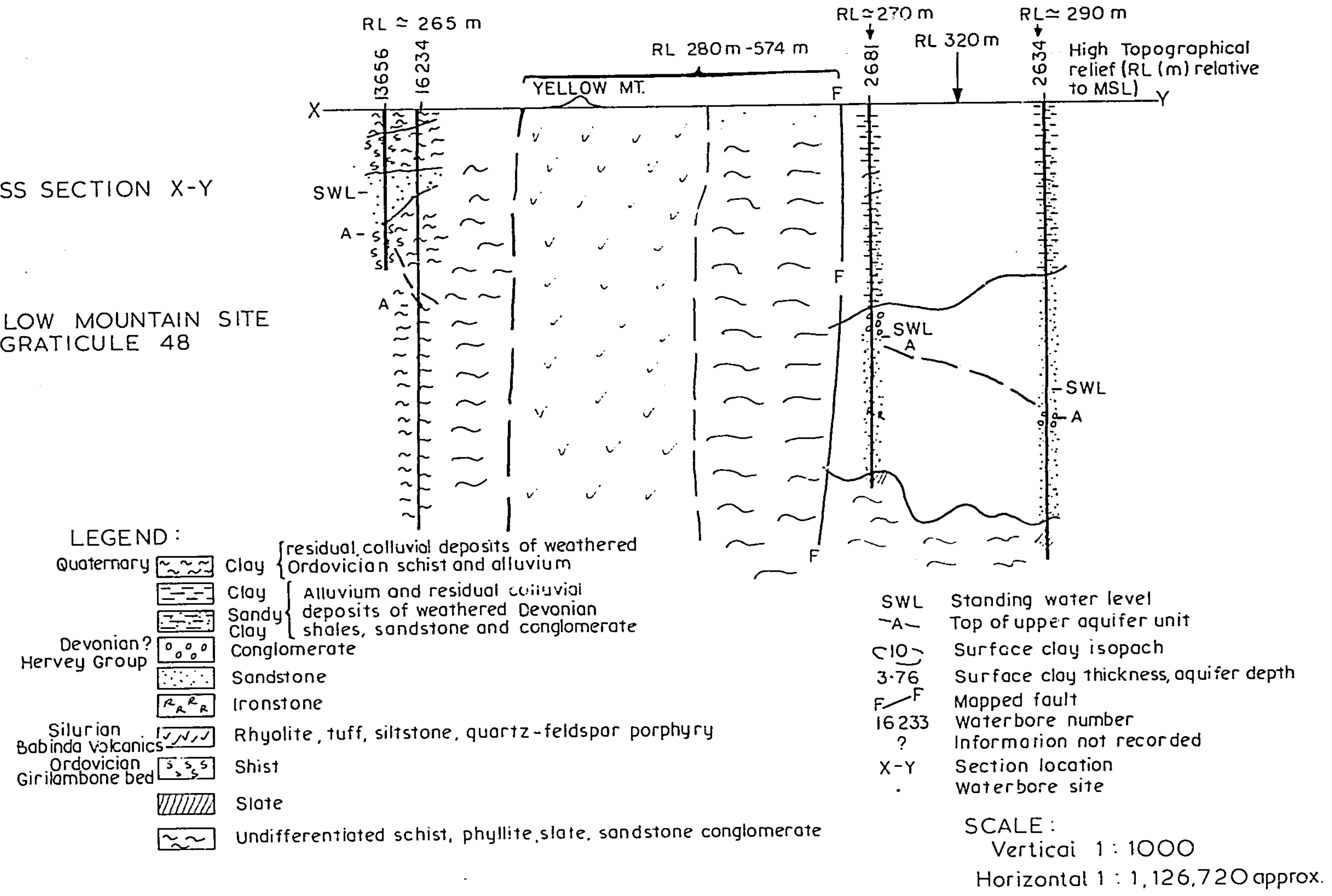
Figure Nº 3a-WEST LACHLAN FOLD BELT — YELLOW MOUNTAIN SITE, CLAY AQUIFER RELATIONSHIP





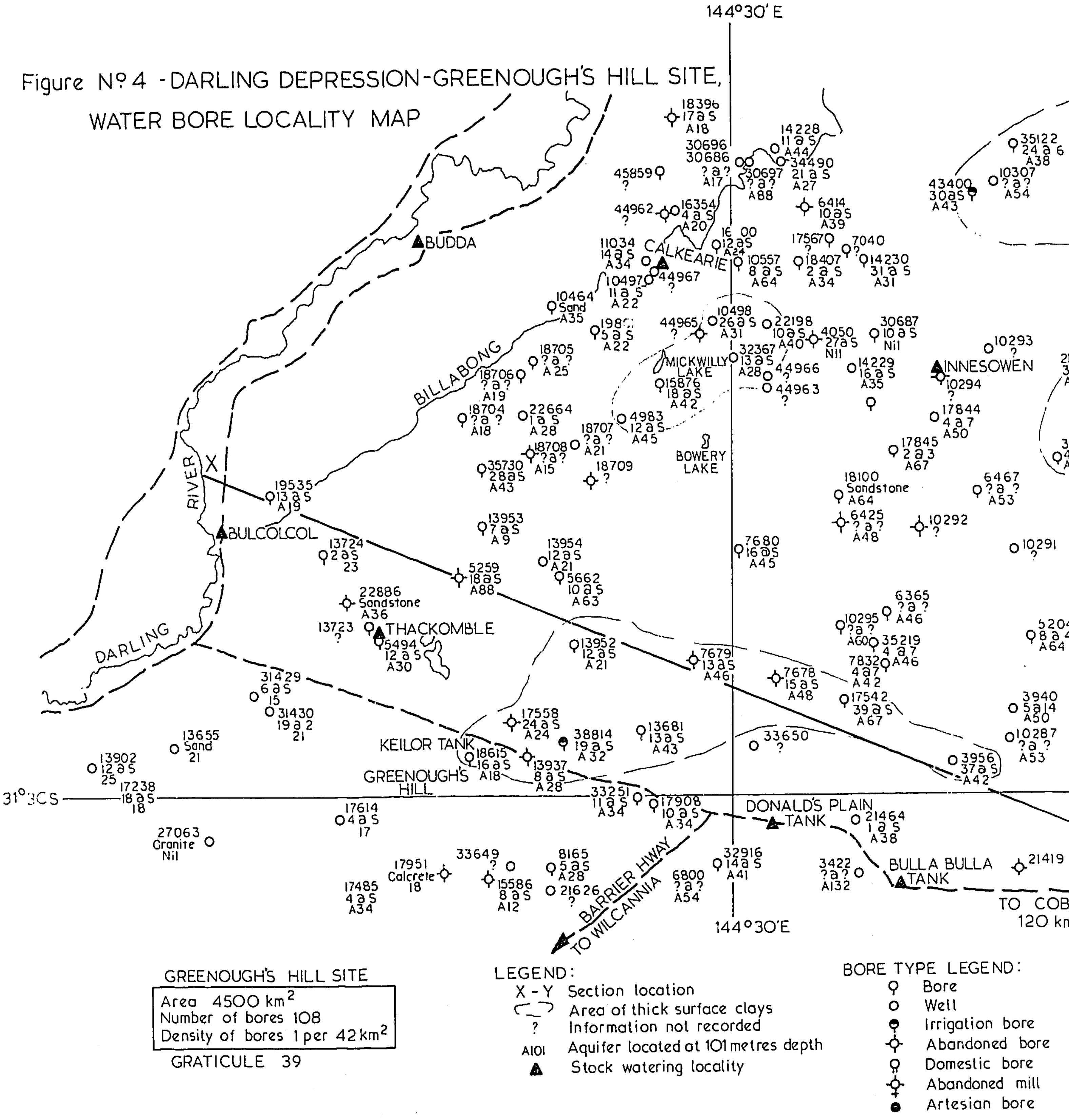
CROSS SECTION X-Y

YELLOW MOUNTAIN SITE
GRATICULE 48



SECTION 2

Figure Nº 4 - DARLING DEPRESSION-GREENOUGH'S HILL SITE, WATER BORE LOCALITY MAP



GREENOUGH'S HILL SITE

Area	4500 km^2
Number of bores	108
Density of bores	1 per 42 km^2

GRATICULE 39

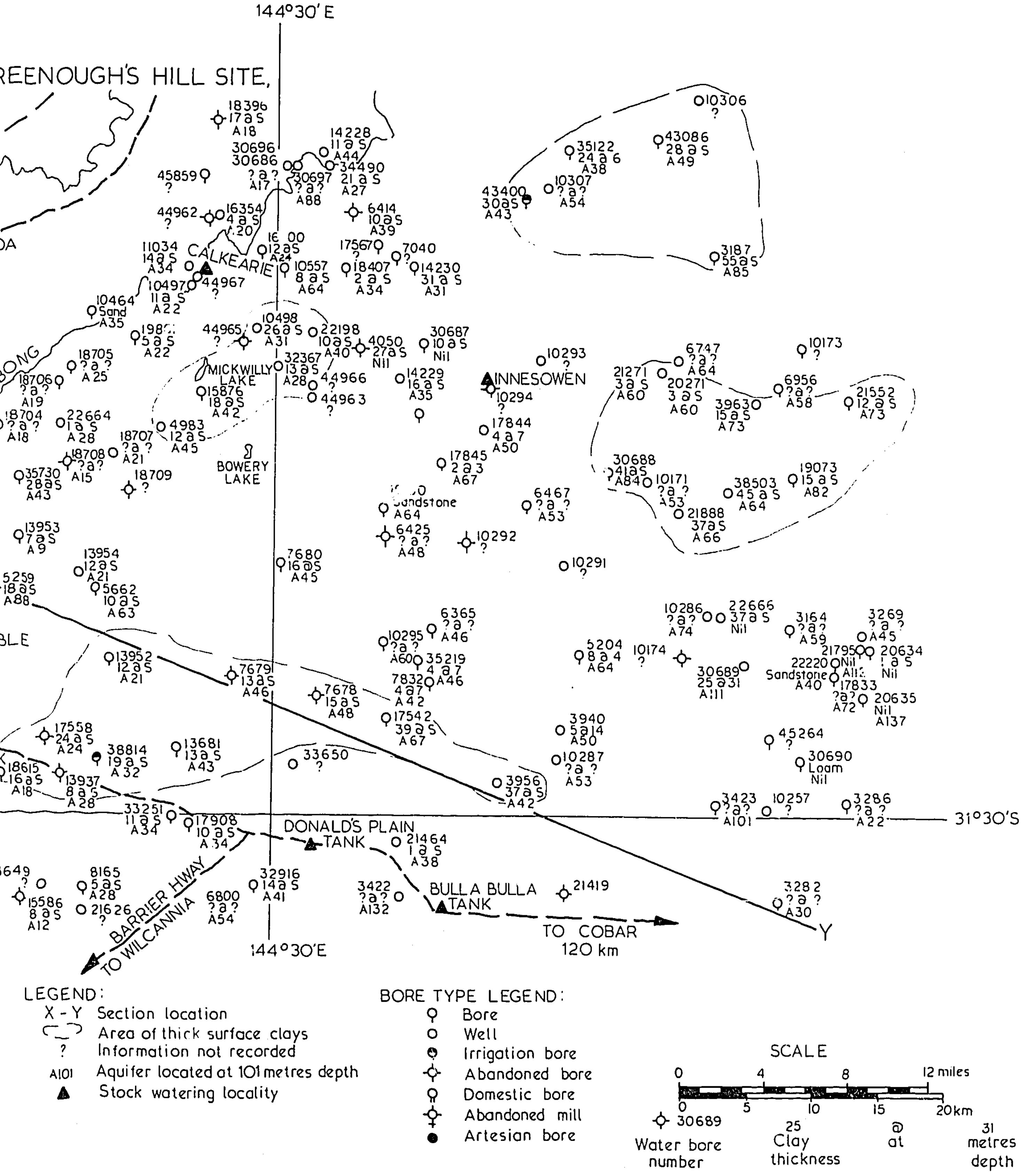
LEGEND:

X - Y	Section location
⊂_⊃	Area of thick surface clays
?	Information not recorded
A101	Aquifer located at 101 metres depth
▲	Stock watering locality

BORE TYPE LEGEND:

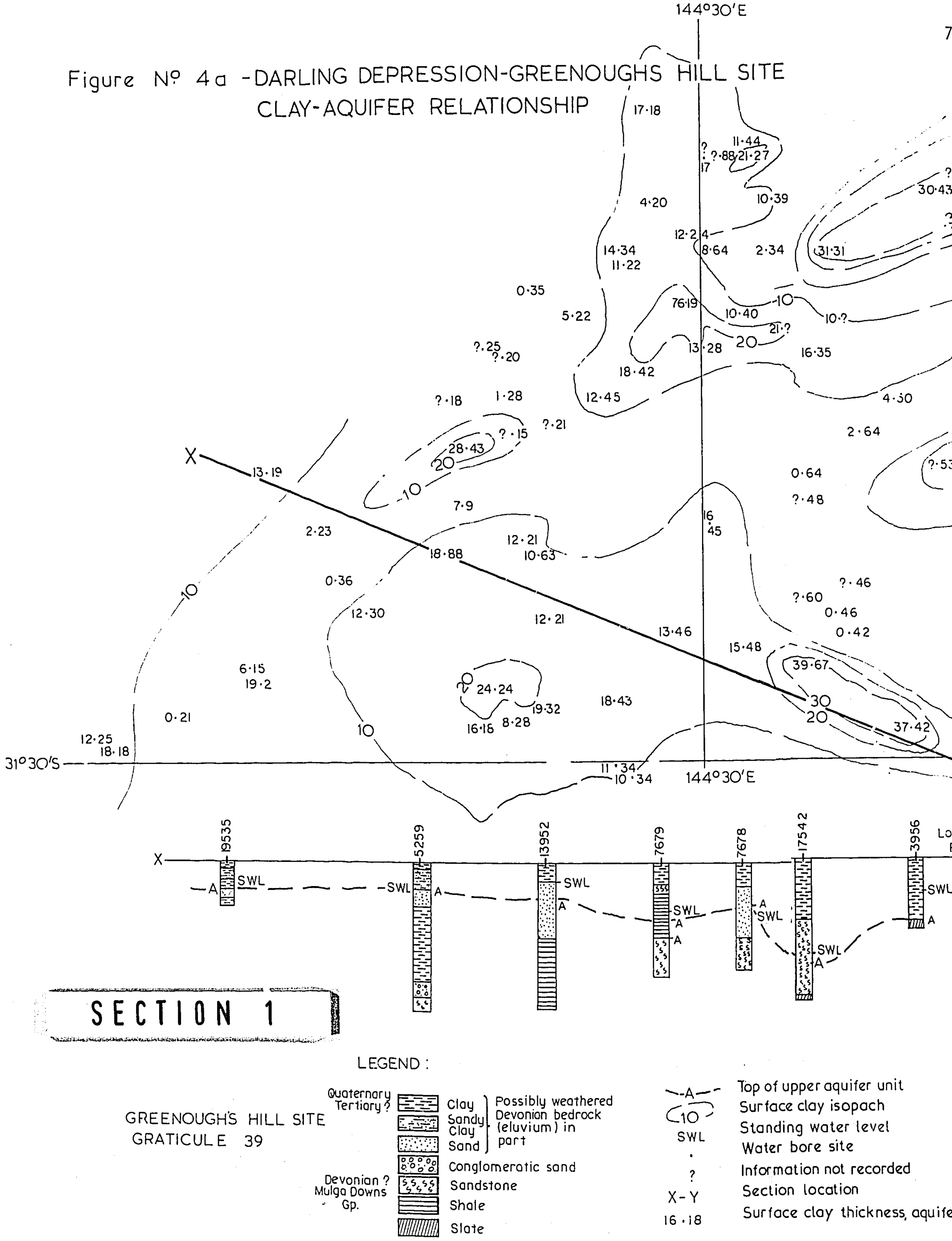
♀	Bore
○	Well
◒	Irrigation bore
-♀-	Abandoned bore
♀	Domestic bore
-♀-	Abandoned mill
●	Artesian bore

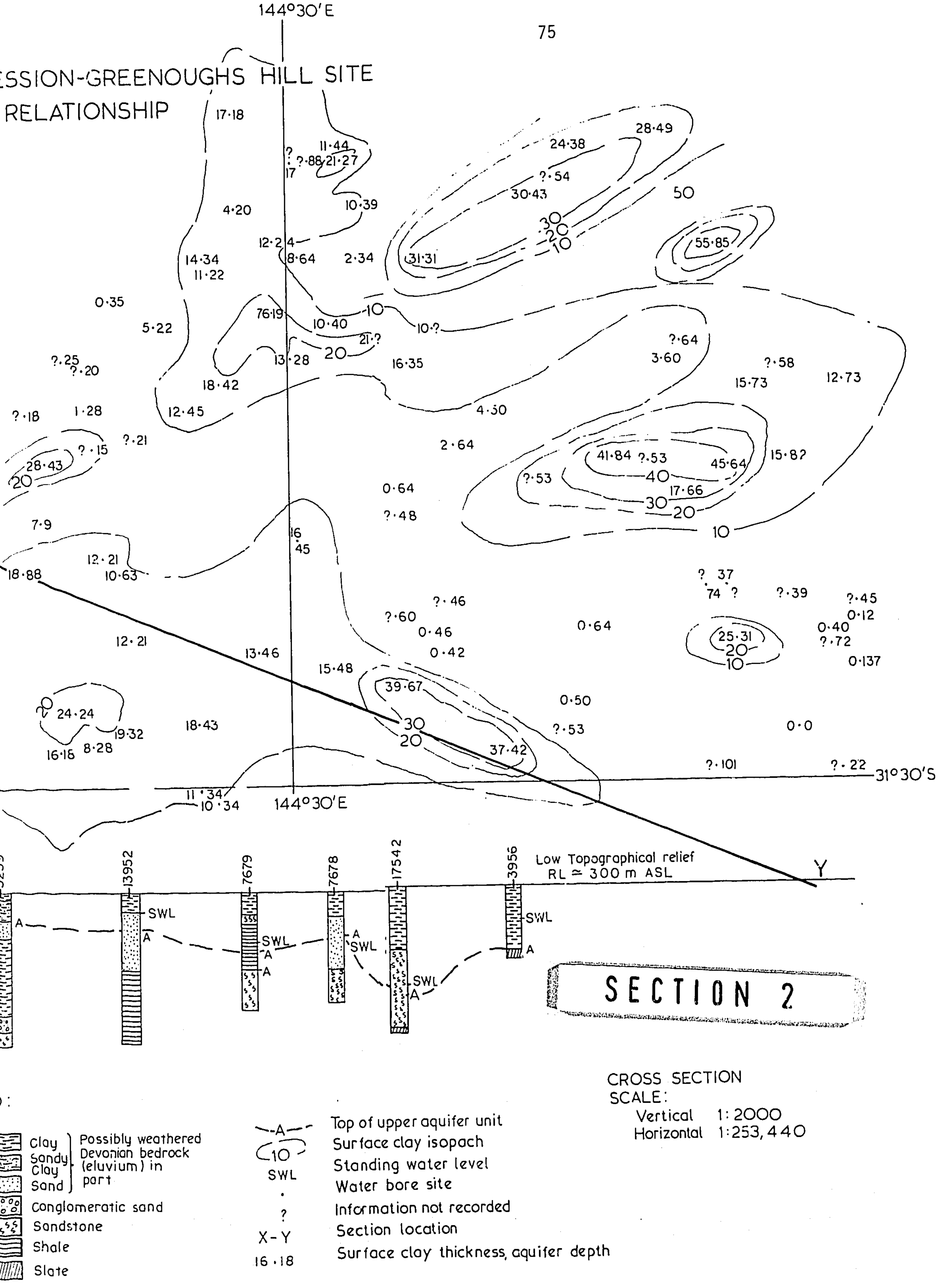
SECTION 1


REENOUGH'S HILL SITE,
144°30'E
CALKEARIE
MICKWILLY LAKE
BOWERY LAKE
INNESOWEN
DONALD'S PLAIN TANK
BULLA BULLA TANK
TO COBAR 120 km
BARRIER HWAY
TO WILCANNIA
31°30'S
Y
LEGEND:
X - Y Section location
Area of thick surface clays
? Information not recorded
A101 Aquifer located at 101 metres depth
▲ Stock watering locality
BORE TYPE LEGEND:
Bore
Well
Irrigation bore
Abandoned bore
Domestic bore
Abandoned mill
● Artesian bore
SCALE
0 4 8 12 miles
0 5 10 15 20km
30689 25 @ 31
Water bore number
Clay thickness
at
metres depth

SECTION 2

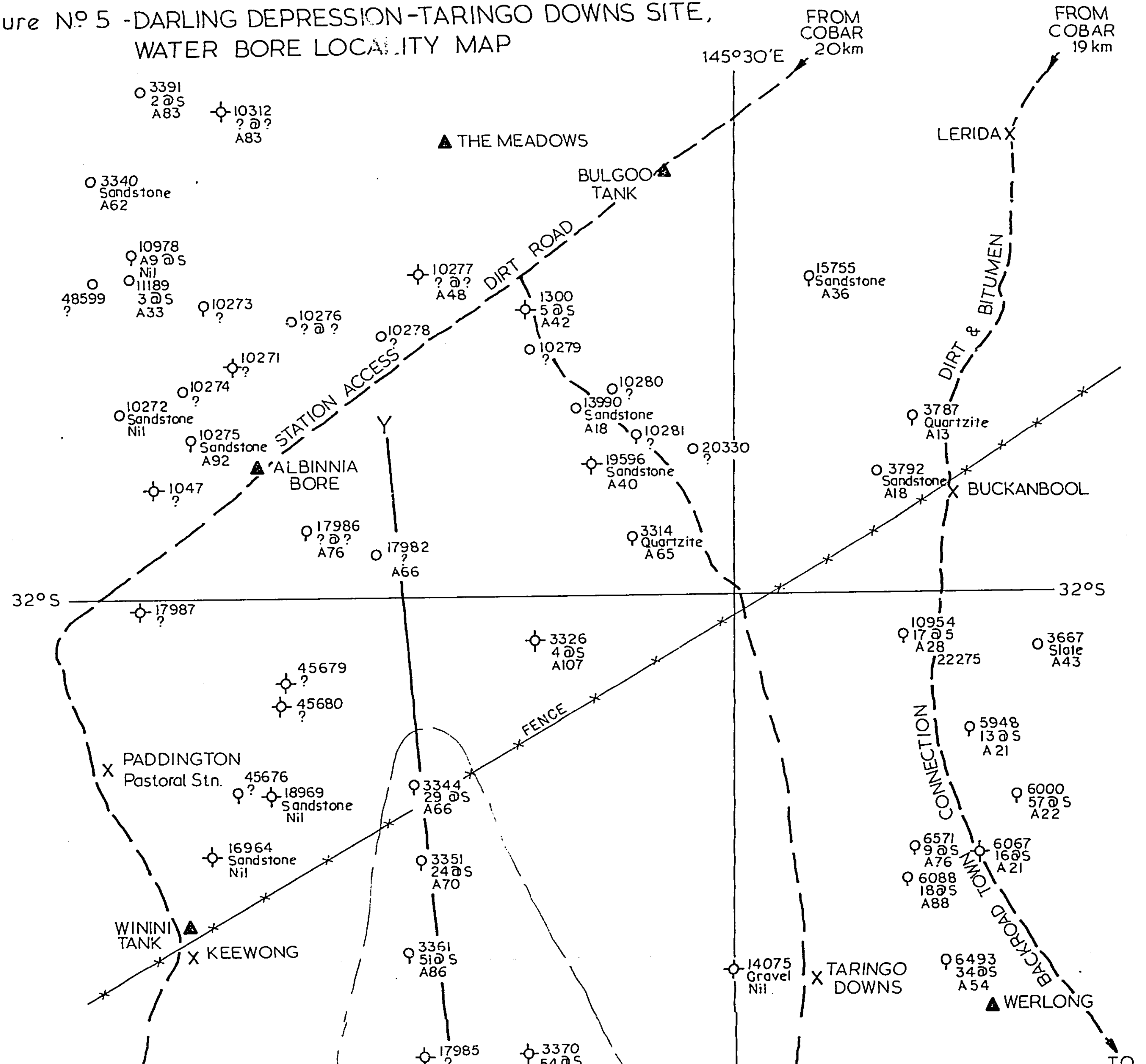
Figure Nº 4a - DARLING DEPRESSION-GREENOUGHS HILL SITE CLAY-AQUIFER RELATIONSHIP

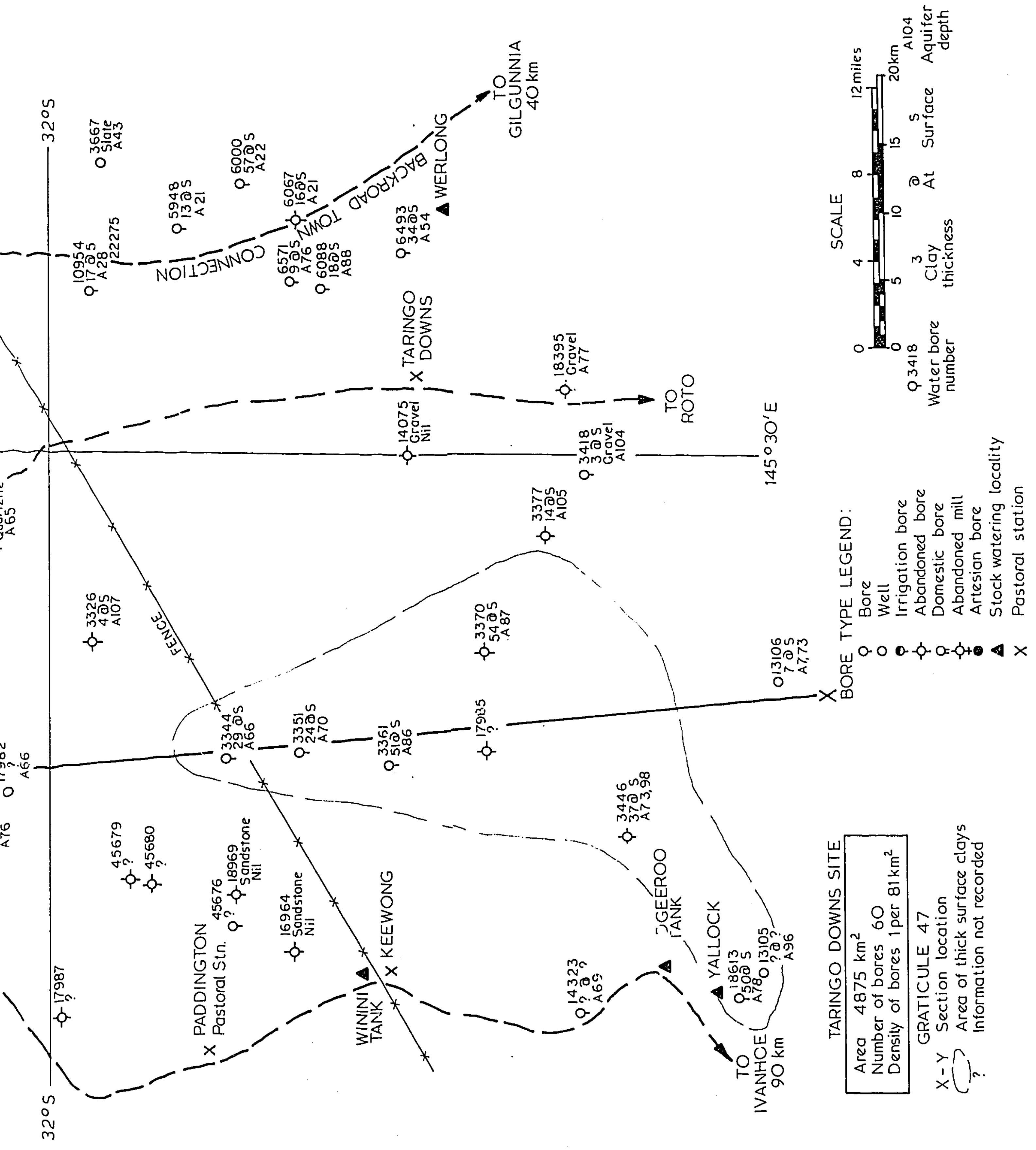



ESSION-GREENOUGHS HILL SITE
RELATIONSHIP
144°30'E
31°30'S
17·18
11·44
?·88
21·27
17
10·39
4·20
28·49
24·38
?·54
30·43
50
30
20
10
55·85
12·24
8·64
2·34
31·31
14·34
11·22
0·35
5·22
76·19
10·40
10
10·?
21·?
20
13·28
16·35
?·64
3·60
?·58
15·73
12·73
?·25
?·20
18·42
?·18
1·28
12·45
4·50
?·21
?·15
28·43
20
2·64
41·84
?·53
45·64
15·82
?·53
40
17·66
0·64
?·48
7·9
16
45
12·21
10·63
18·88
?·37
74 ?
?·39
?·45
0·12
?·46
?·60
0·46
0·42
0·64
0·40
?·72
25·31
12·21
13·46
15·48
0·137
39·67
24·24
19·32
18·43
16·16
8·28
0·50
?·53
37·42
0·0
?·101
?·22
11·34
10·34
144°30'E
13952
7679
7678
17542
3956
Low Topographical relief
RL ≃ 300 m ASL
Y
SWL
A
SECTION 2
CROSS SECTION
SCALE:
Vertical 1:2000
Horizontal 1:253,440
Clay
Sandy Clay
Sand
Possibly weathered Devonian bedrock (eluvium) in part
Conglomeratic sand
Sandstone
Shale
Slate
Top of upper aquifer unit
Surface clay isopach
Standing water level
Water bore site
Information not recorded
Section location
Surface clay thickness, aquifer depth
X-Y
16·18

SECTION 1

Figure Nº 5 -DARLING DEPRESSION-TARINGO DOWNS SITE, WATER BORE LOCALITY MAP

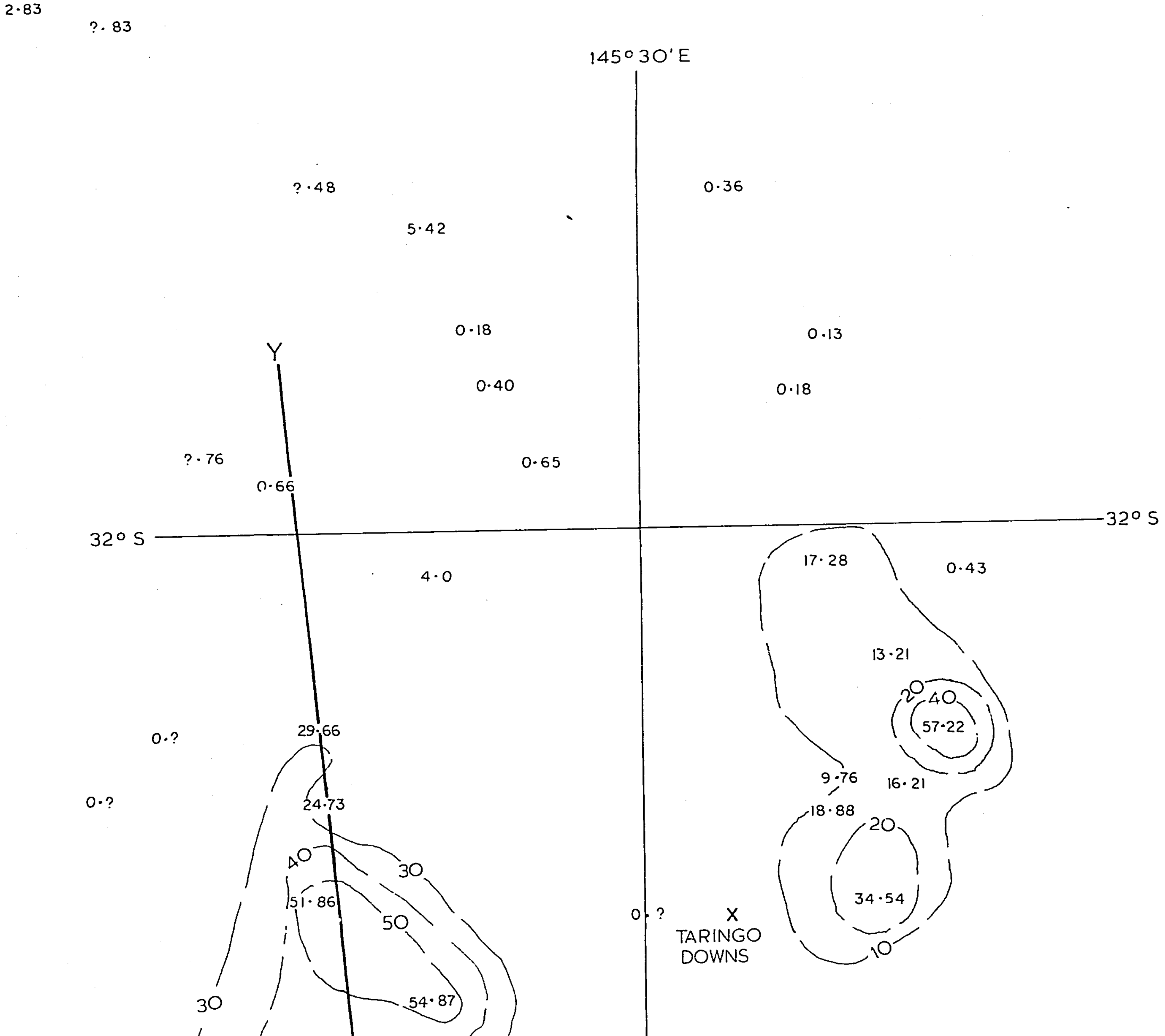


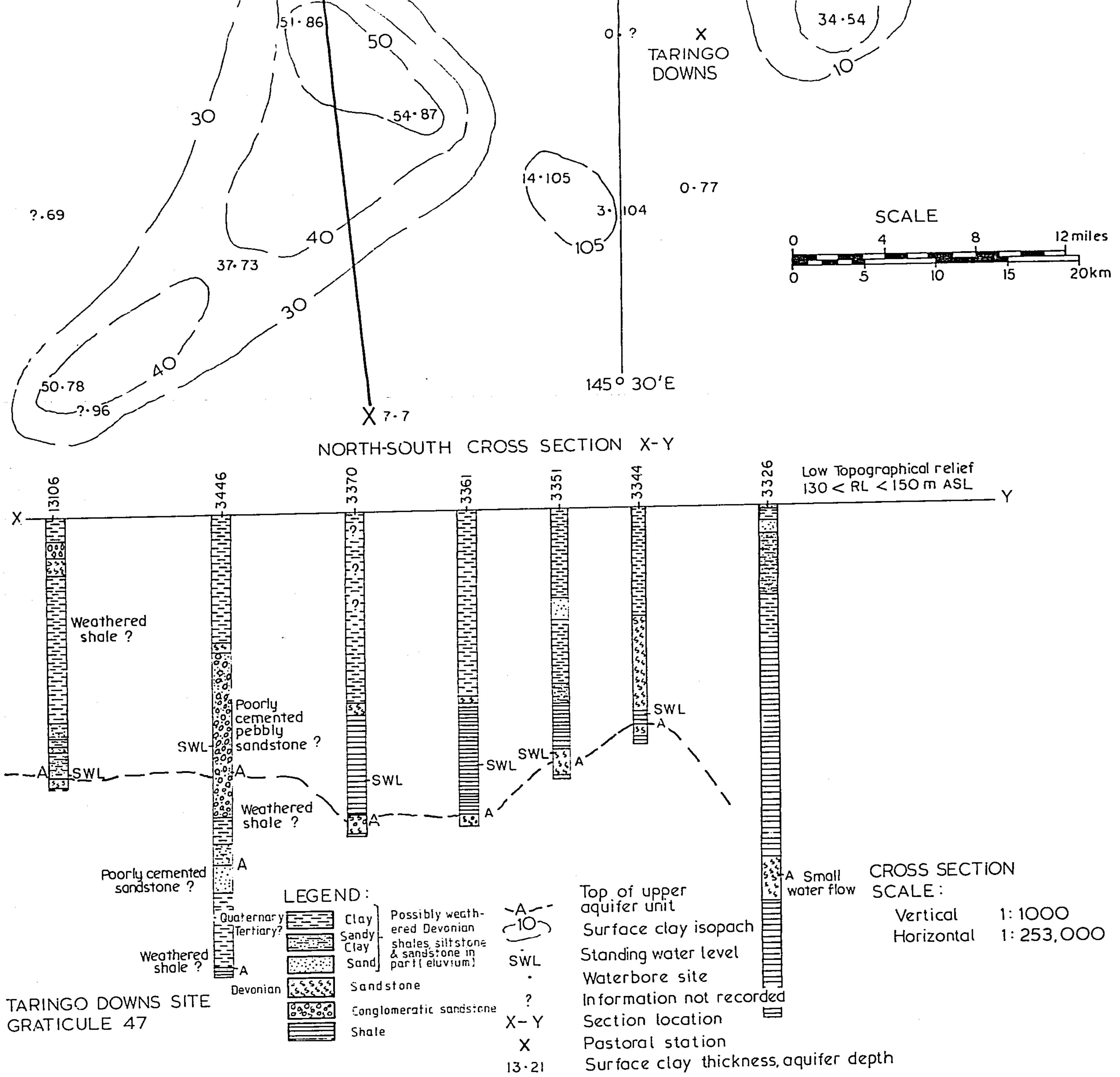

32°S
32°S
145°30'E
TO GILGUNNIA 40 km
TO ROTO
TO IVANHCE 90 km
CONNECTION TOWN BACKROAD
WERLONG
TARINGO DOWNS
FENCE
PADDINGTON Pastoral Stn.
WININI TANK
KEEWONG
YALLOCK
GEEROO TANK
3667 Slate A43
6000 57@S A22
5948 13@S A21
6067 16@S A21
10954 17@S A28
22275
6493 34@S A54
6571 9@S A76
6088 18@S A88
18395 Gravel A77
14075 Gravel Nil
3418 3@S Gravel A104
3377 14@S A105
3326 4@S A107
3370 54@S A87
13106 7@S A7,73
3344 29@S A66
3351 24@S A70
3361 51@S A86
17985 ?
17982 ? A66
A65
A76
3446 37@S A73,98
45679 ?
45680 ?
45676 ?
18969 Sandstone Nil
16964 Sandstone Nil
17987 ?
14323 ?@? A69
18613 50@S A78
13105 ?@? A96
SCALE
0 4 8 12 miles
0 5 10 15 20 km
3418 Water bore number
3 Clay thickness
@ At
S Surface
A104 Aquifer depth
BORE TYPE LEGEND:
Bore
Well
Irrigation bore
Abandoned bore
Domestic bore
Abandoned mill
Artesian bore
Stock watering locality
Pastoral station
TARINGO DOWNS SITE
Area 4875 km²
Number of bores 60
Density of bores 1 per 81 km²
GRATICULE 47
X-Y Section location
Area of thick surface clays
? Information not recorded

SECTION 2

SECTION 1

Figure Nº 5a - TARINGO DOWNS SITE, CLAY AQUIFER RELATIONSHIP

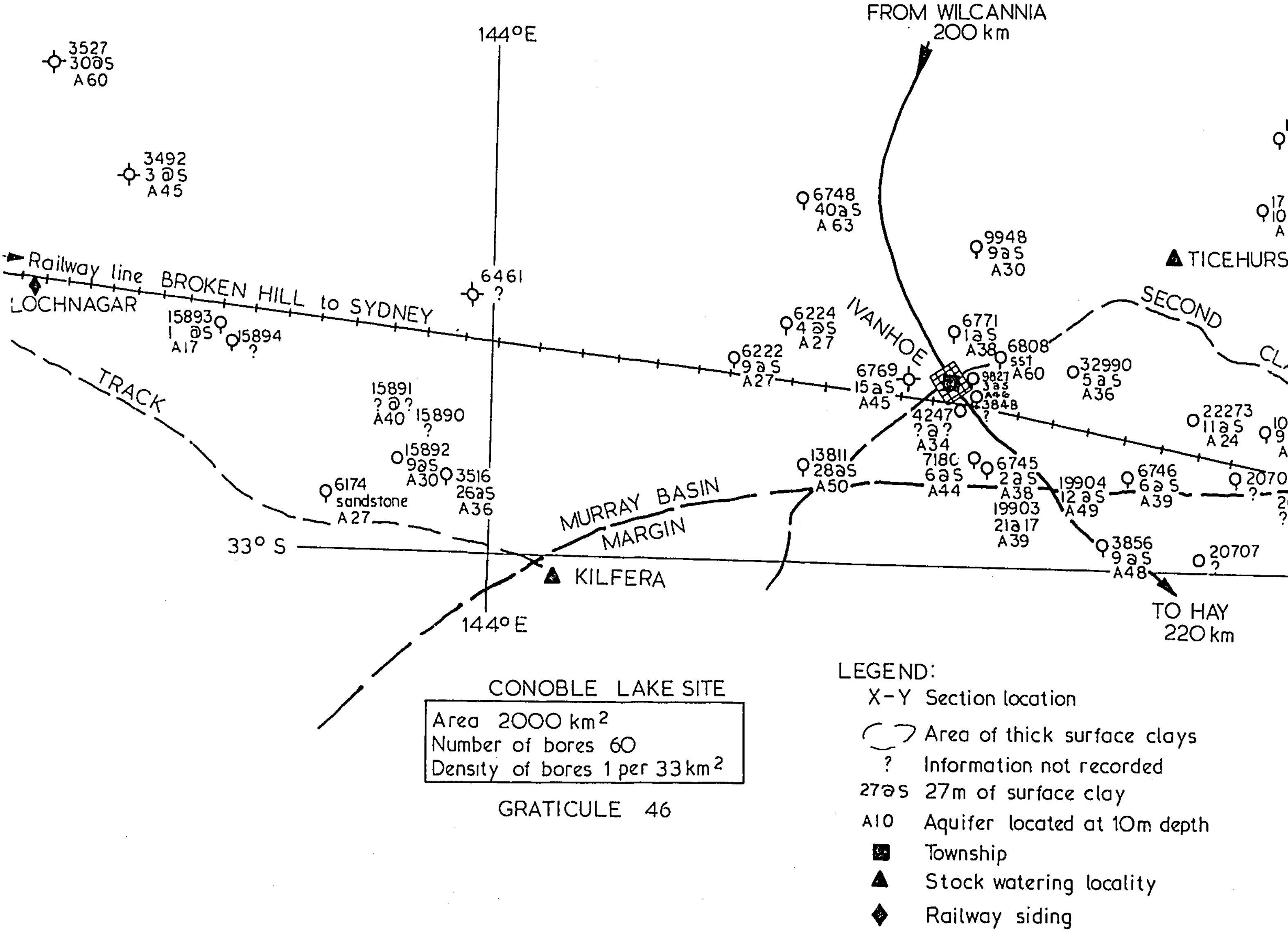




TARINGO DOWNS SITE
GRATICULE 47

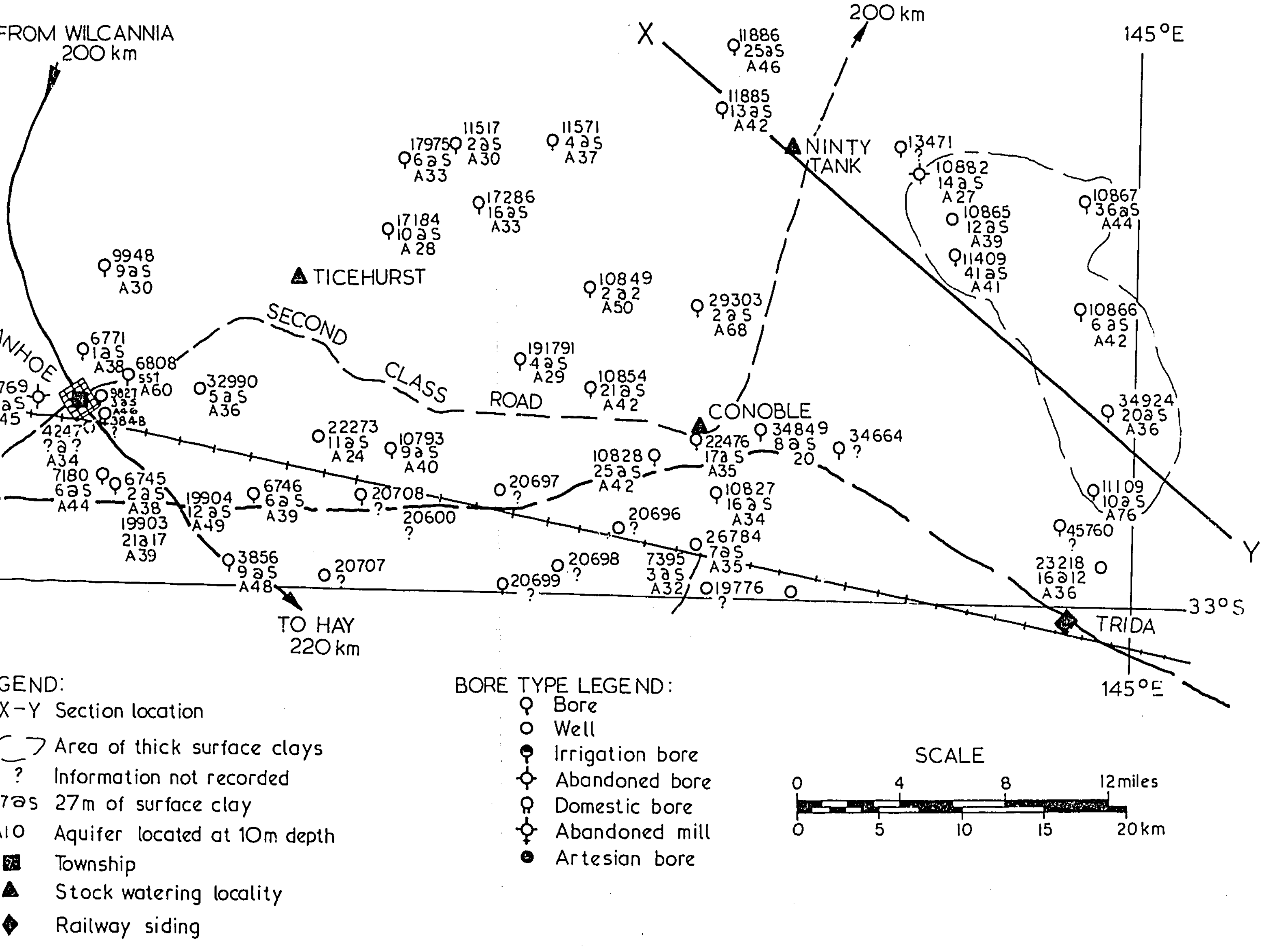
SECTION 2

Figure Nº 6 - DARLING DEPRESSION, CONOBLE LAKE SITE, WATER BORE LOCALITY MA



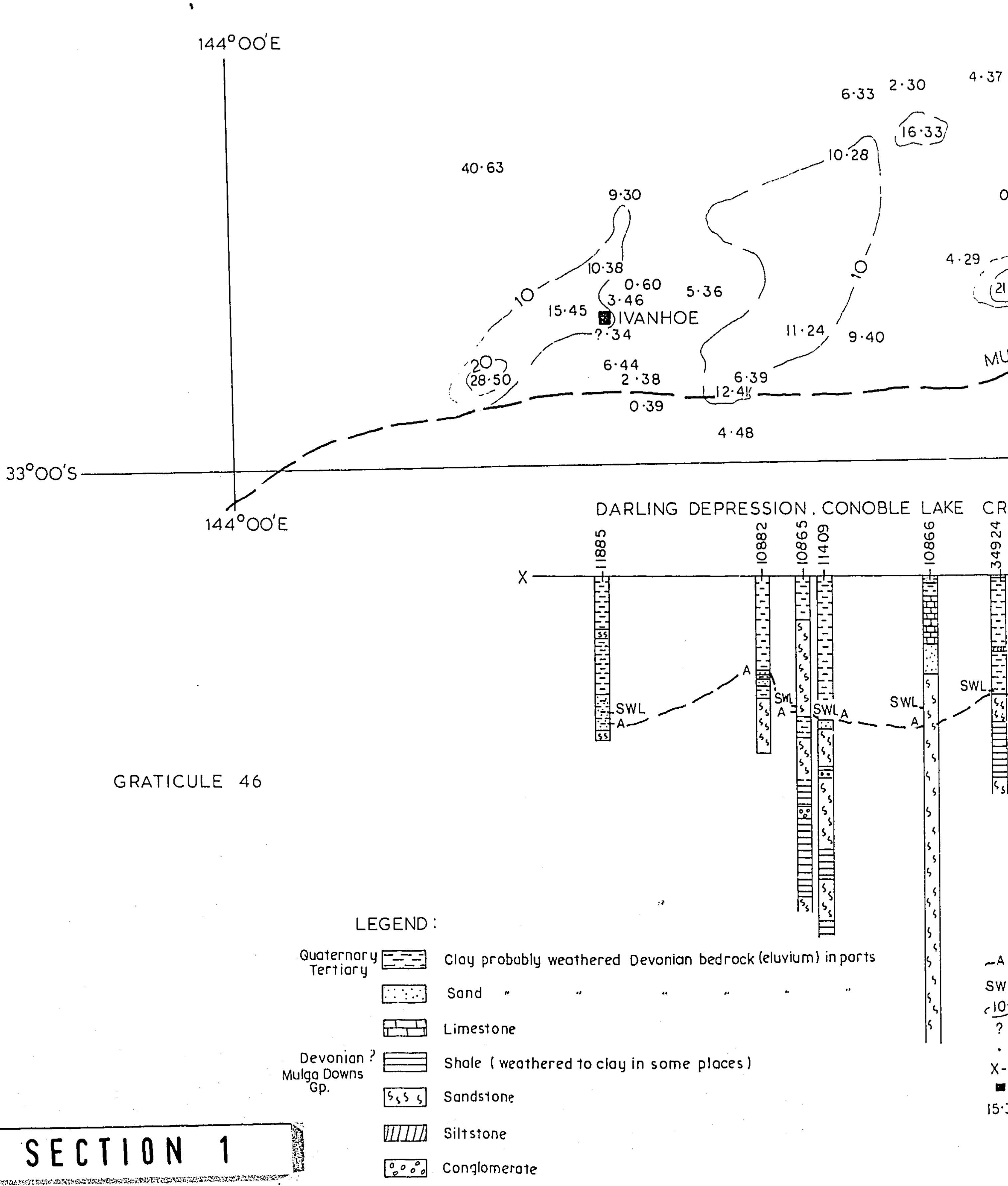
SECTION 1

,WATER BORE LOCALITY MAP



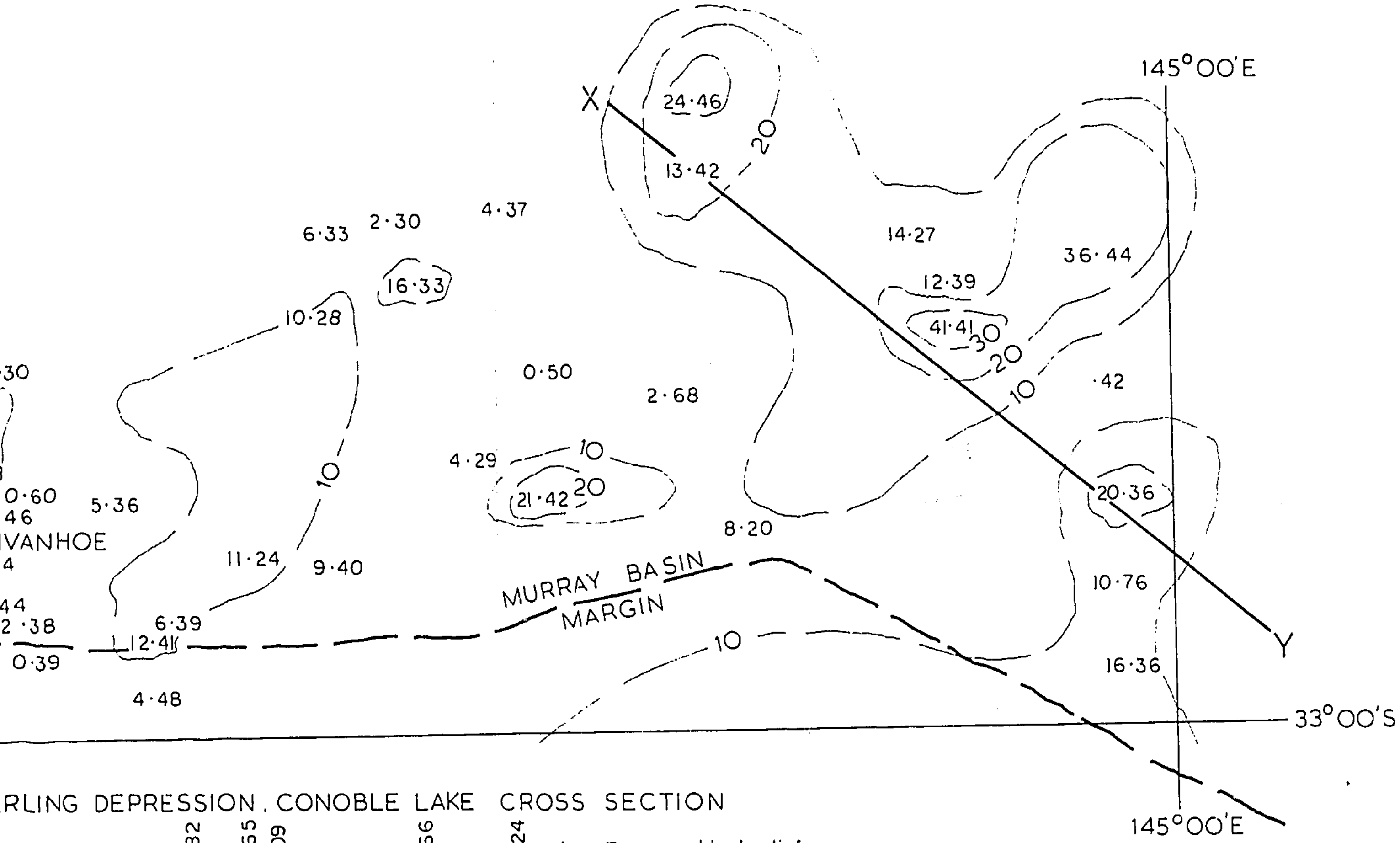
SECTION 2

Figure Nº 6a - DARLING DEPRESSION, CONOBLE LAKE SITE, CLAY AQUIFER RE

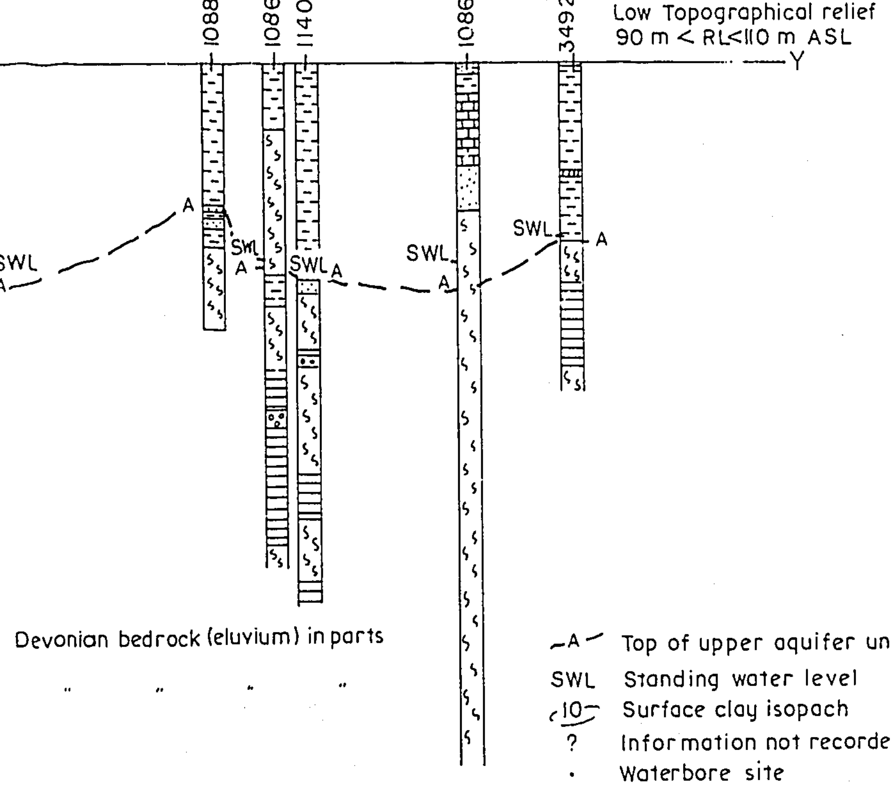


SECTION 1

LE LAKE SITE, CLAY AQUIFER RELATIONSHIP



RLING DEPRESSION . CONOBLE LAKE CROSS SECTION



SCALE:
Vertical 1:1000
Horizontal 1:253,440

Devonian bedrock (eluvium) in parts

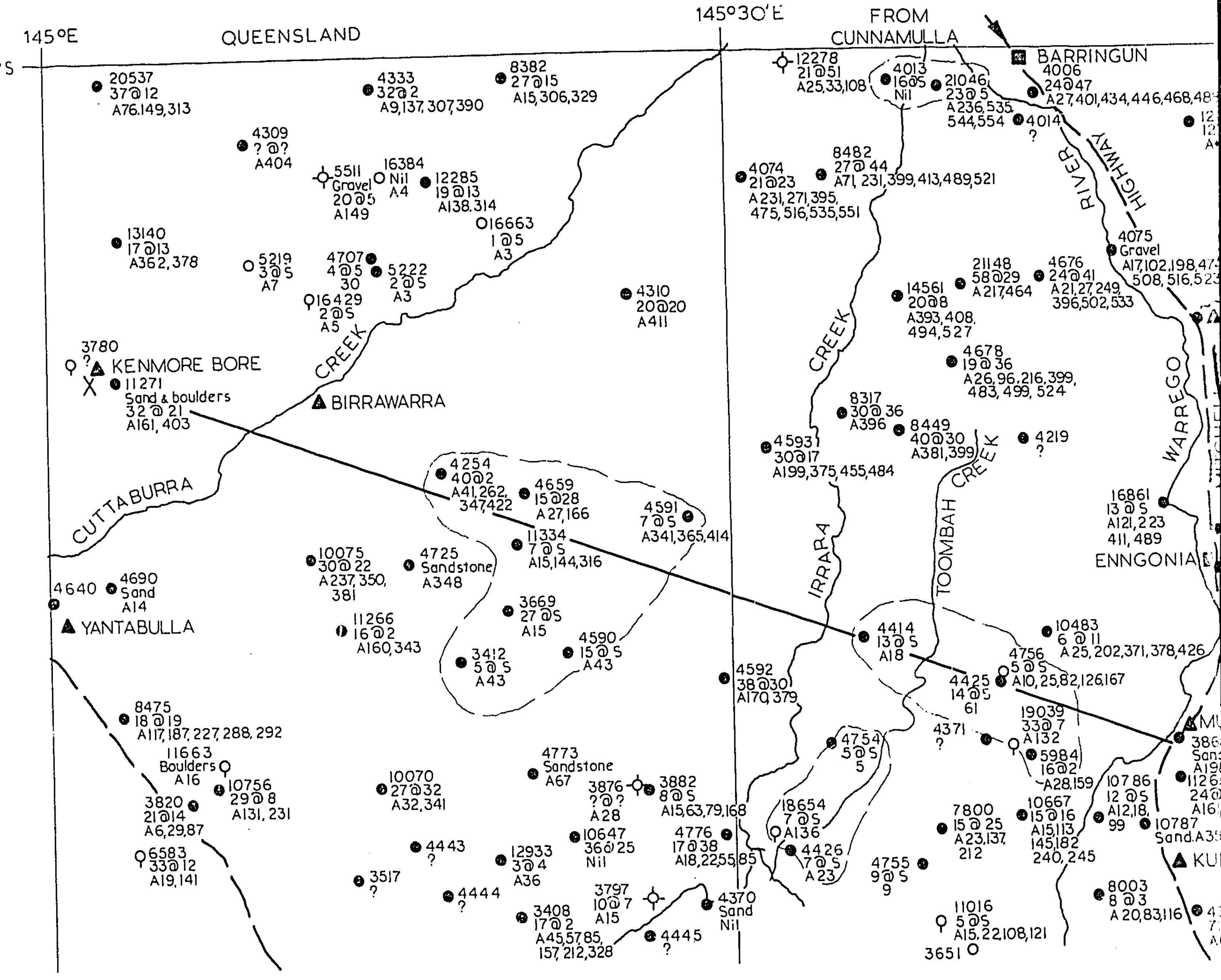
" " " "

y in some places)

—A—	Top of upper aquifer unit
SWL	Standing water level
10	Surface clay isopach
?	Information not recorded
·	Waterbore site
X-Y	Section locations
■	Township
15·31	Clay thickness · Aquifer depth

SECTION 2

igure Nº 7 -GREAT AUSTRALIAN BASIN, WARREGO RIVER SITE, WATER BORE LOCALITY MA



WARREGO RIVER SITE

Area 5775 km²
Number of bores 126
Density of bores 1 per 45 km²

X - Y Section location
⬭ Area of thick surface and near surface clays
? Information not recorded
A64,108 Aquifer depths from surface

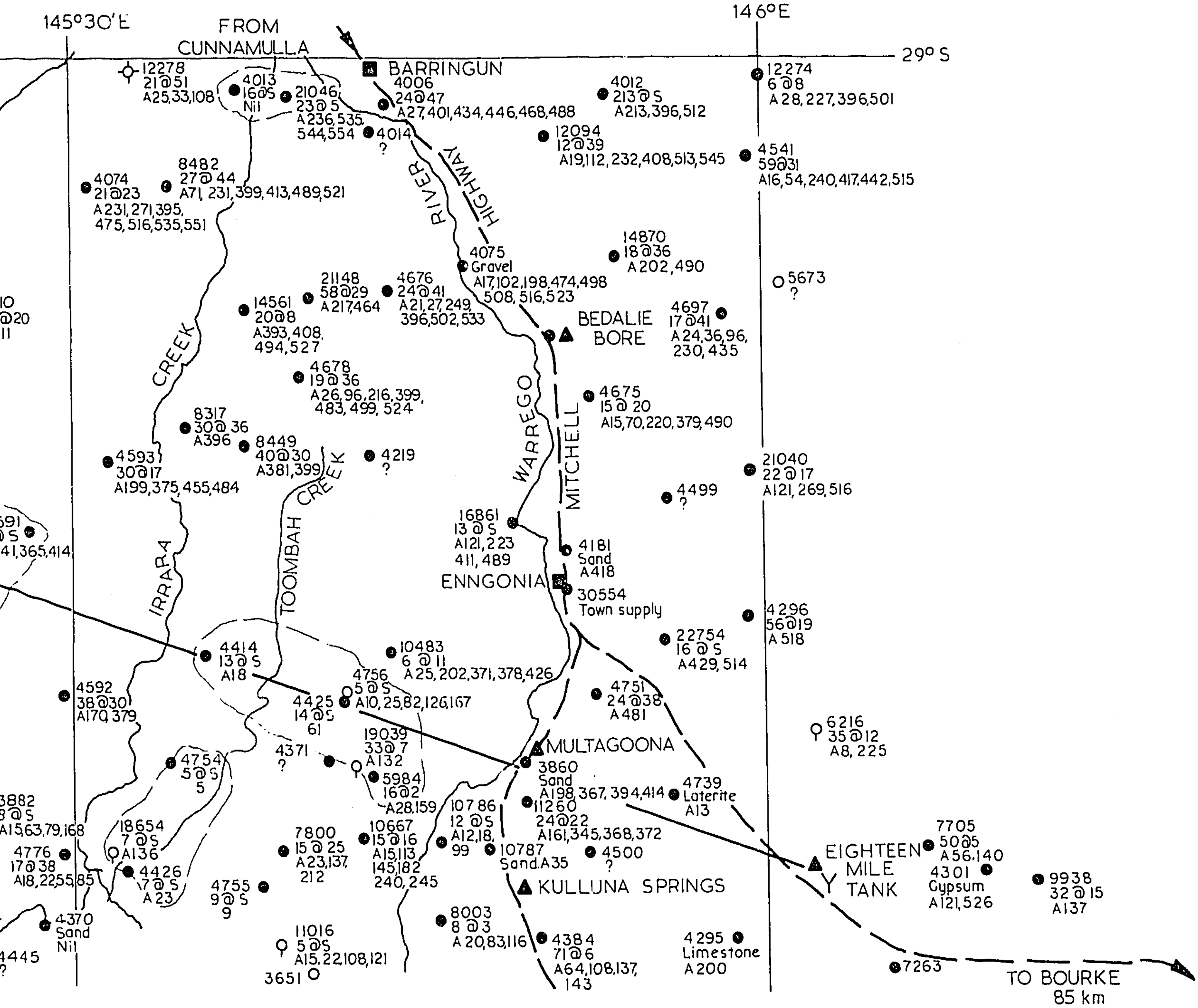
BORE TYPE LEGEND:

- ⚲ Bore
- ○ Well
- ● Irrigation bore
- ⌖ Abandoned bore
- ⚲ Domestic bore
- ⌖ Abandoned mill
- ● Artesian bore
- ■ Township
- ▲ Stock watering locality

0
0
● 4
Water

SECTION 1

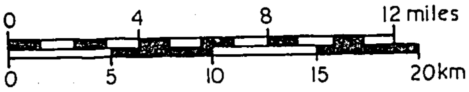
RIVER SITE, WATER BORE LOCALITY MAP



RE TYPE LEGEND:

♀	Bore
○	Well
●	Irrigation bore
-○-	Abandoned bore
♀	Domestic bore
-○-	Abandoned mill
●	Artesian bore
■	Township
▲	Stock watering locality

SCALE

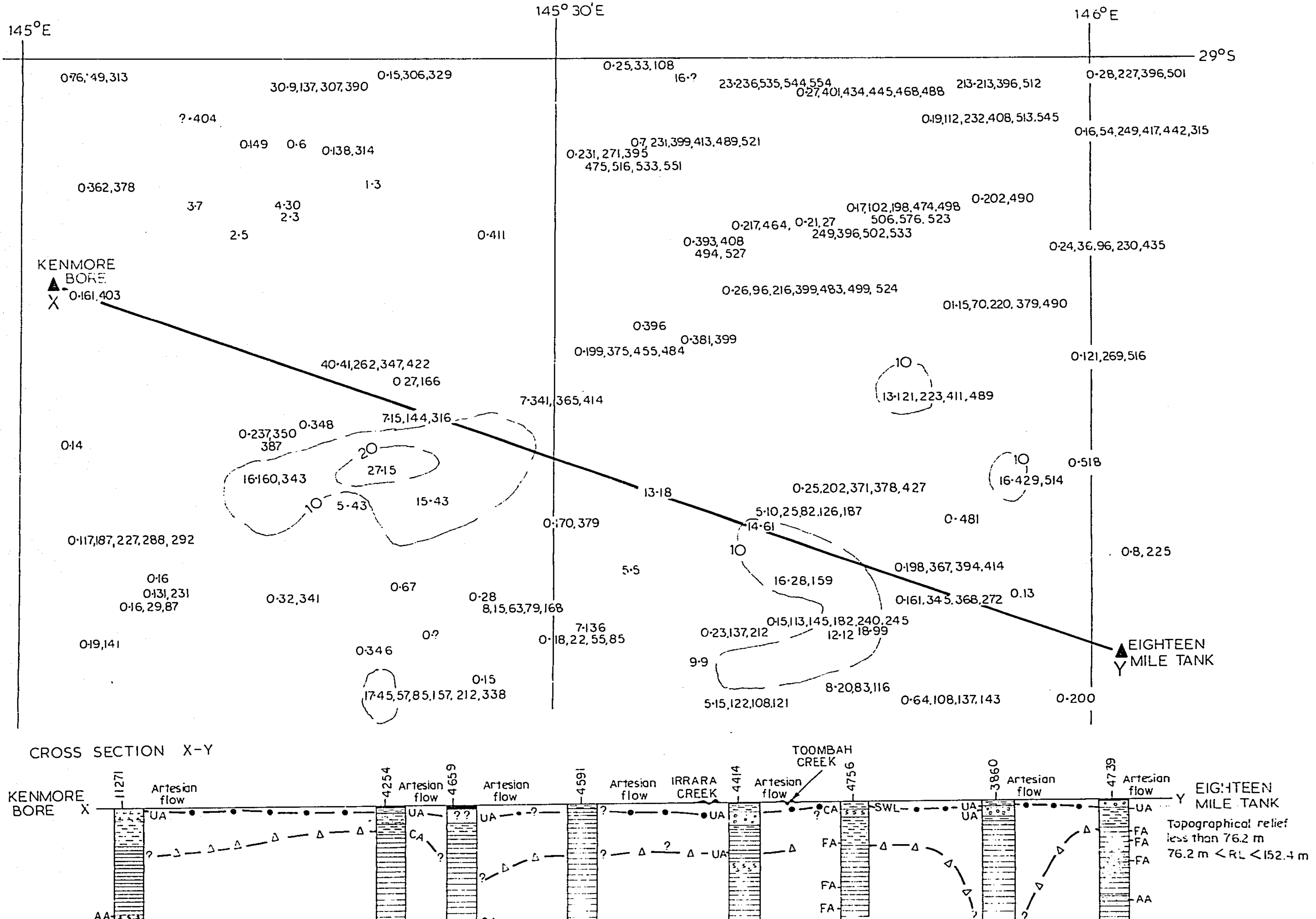


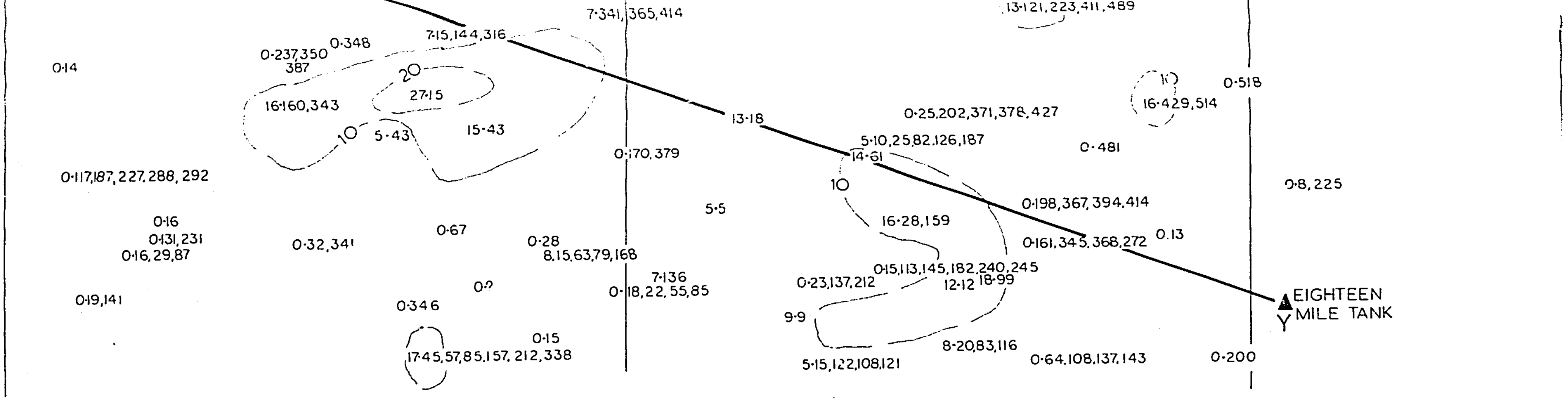
● 4384	71	@	6
Water bore	Metres Clay	at	Clay depth from surface

SECTION 2

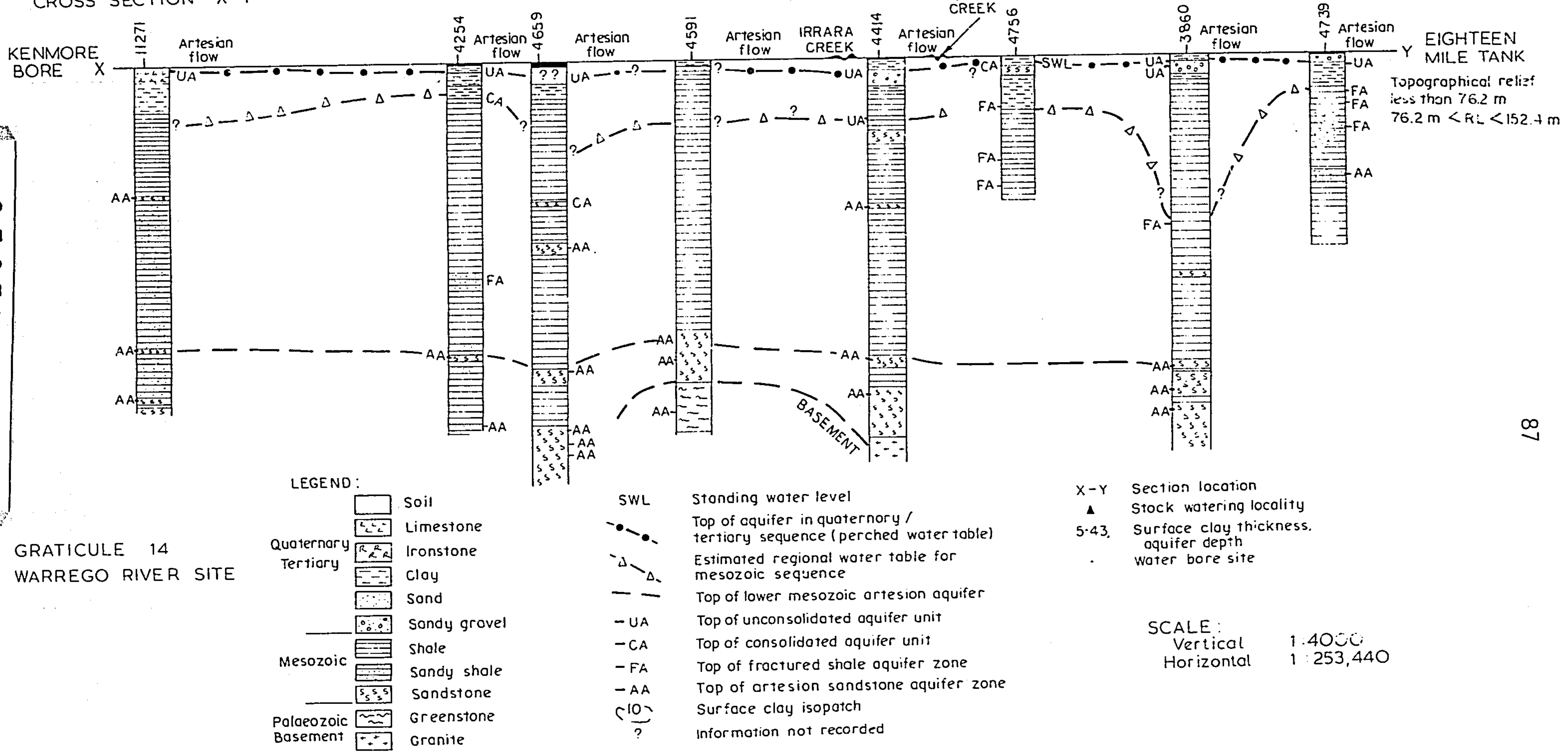
SECTION 1

Figure Nº 7a - GREAT AUSTRALIAN BASIN - WARREGO RIVER SITE, CLAY AQUIFER RELATIONSHIP





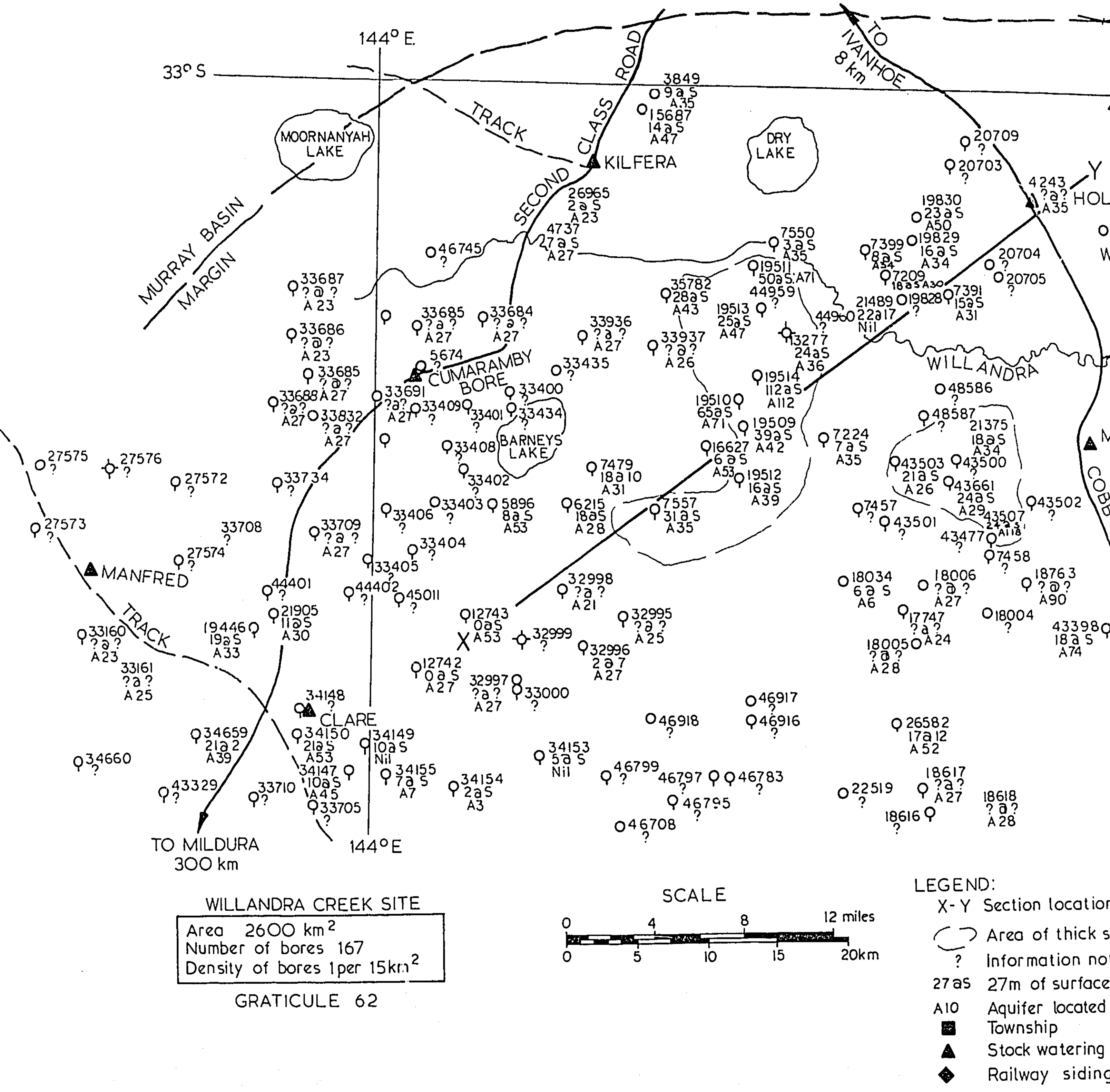
CROSS SECTION X–Y



GRATICULE 14
WARREGO RIVER SITE

SECTION 2

Figure Nº 8 - MURRAY BASIN, WILLANDRA CREEK SITE, WATER BORE LOCALITY MAP



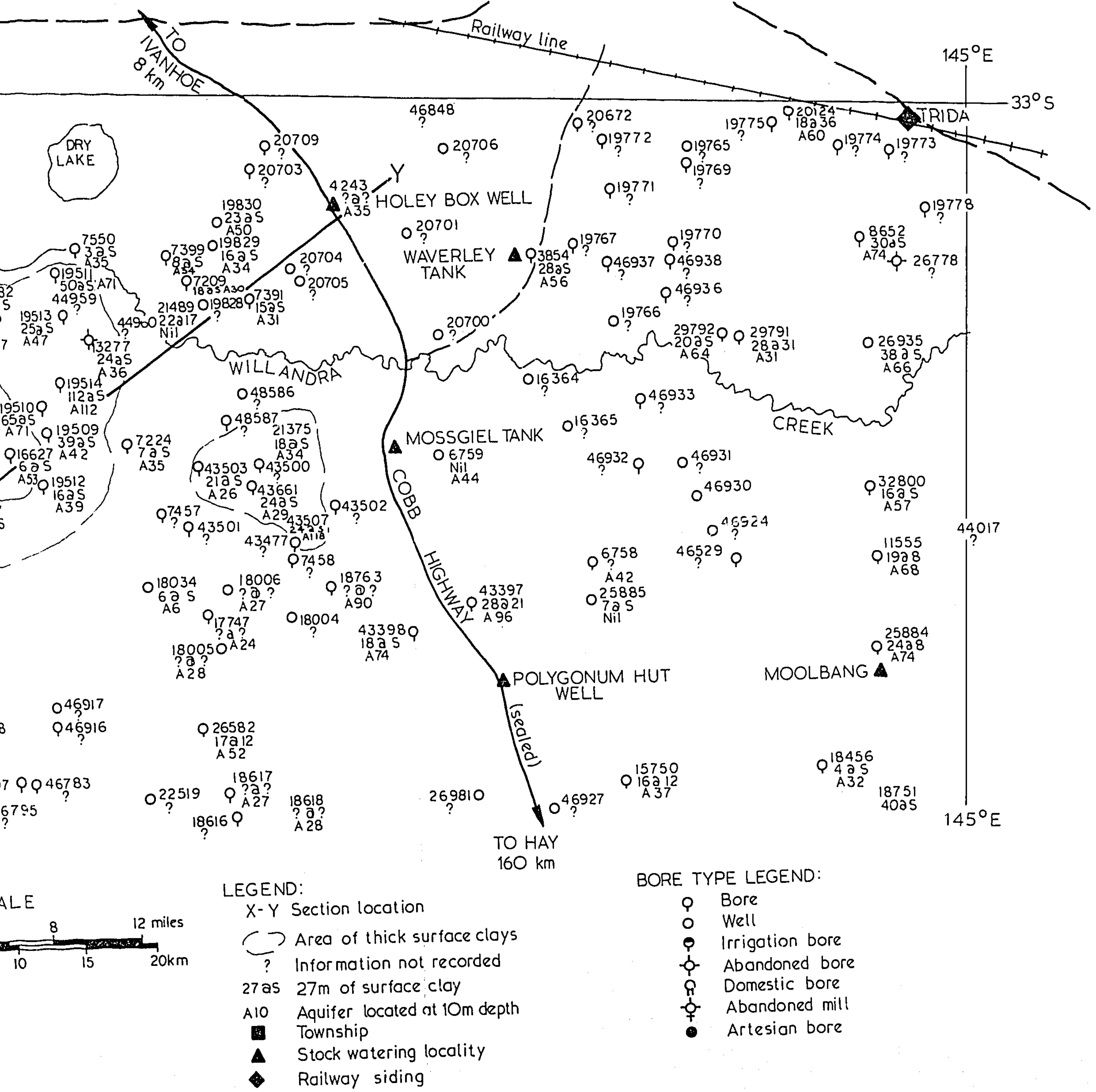
WILLANDRA CREEK SITE

Area 2600 km^2
Number of bores 167
Density of bores 1 per 15km^2

GRATICULE 62

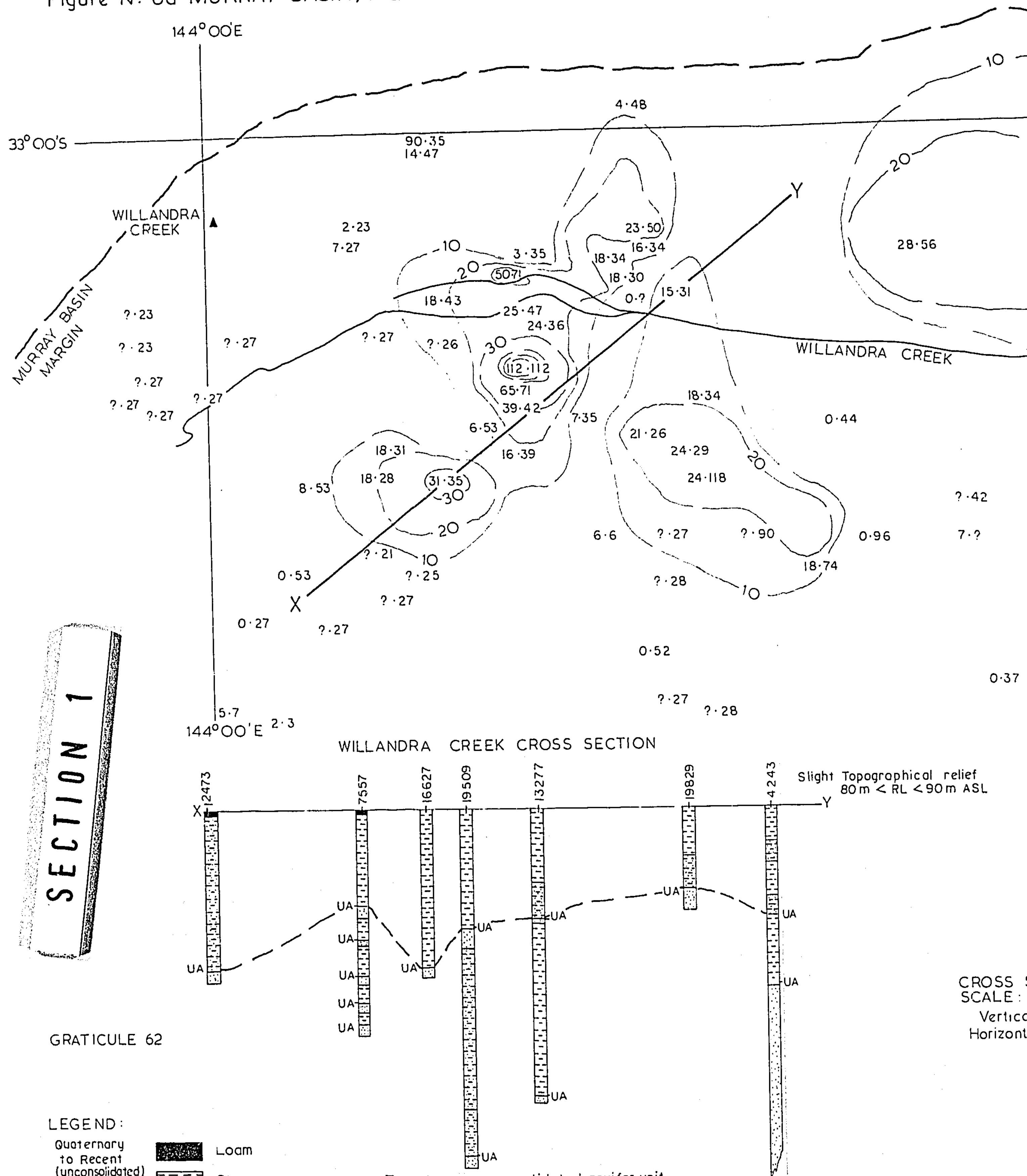
SECTION 1

E, WATER BORE LOCALITY MAP



SECTION 2

Figure Nº 8a MURRAY BASIN, WILLANDRA CREEK SITE, CLAY AQUIFER RELATIONSHIP



SECTION 1

GRATICULE 62

LEGEND:

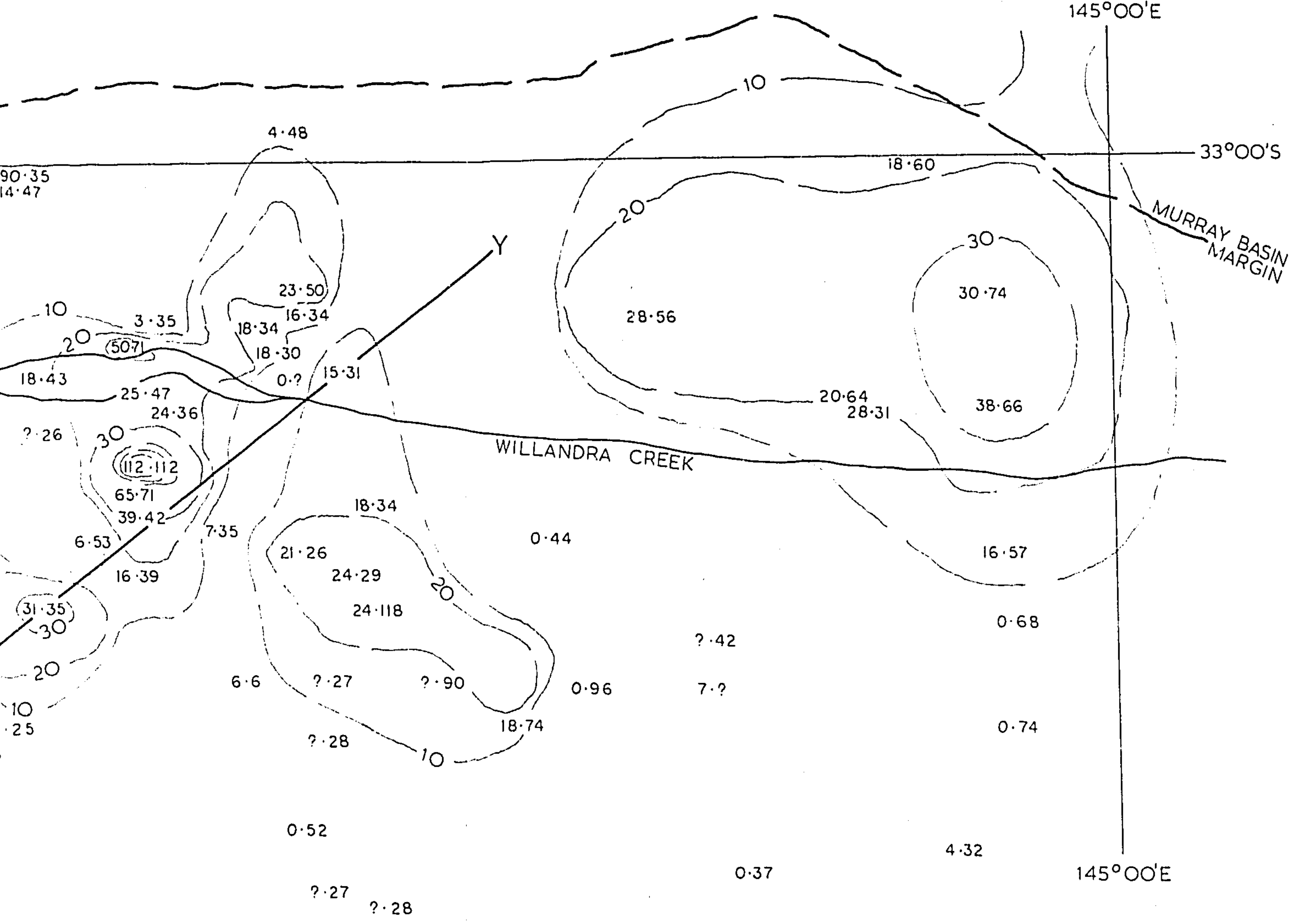
Quaternary to Recent (unconsolidated)

- ▩ Loam
- ▤ Clay
- ▤ Sandy clay
- ▨ Sand
- ⁘ Gravel

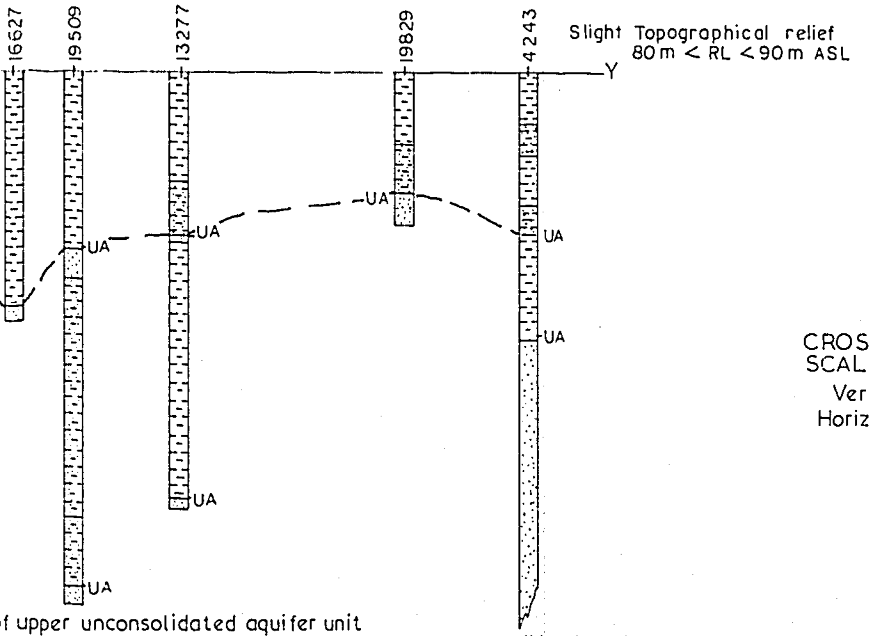
Bores indicate Murray Basin

- ~UA~ Top of upper unconsolidated aquifer unit
- ~10~ Surface clay isopach
- ? Information not recorded
- · Waterbore site
- X–Y Section locations
- ■ Township
- 15·31 Clay thickness aquifer depth

LANDRA CREEK SITE, CLAY AQUIFER RELATIONSHIP



RA CREEK CROSS SECTION

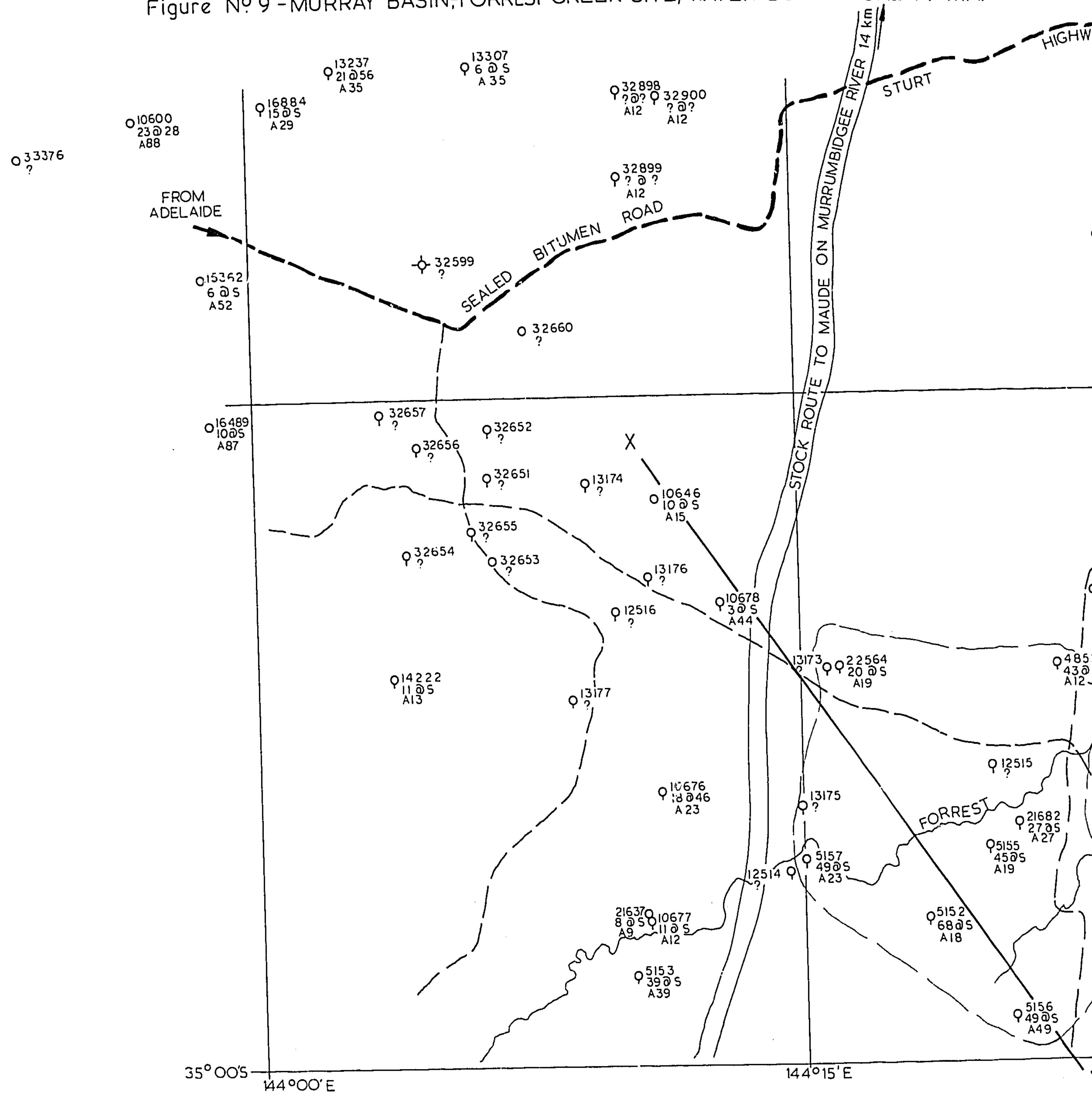


CROSS SECTION SCALE:
Vertical 1: 1000
Horizontal 1: 253,440

f upper unconsolidated aquifer unit
ce clay isopach
nation not recorded
rbore site
on locations
ship
thickness aquifer depth

SECTION 2

Figure No 9 - MURRAY BASIN-FORREST CREEK SITE, WATER BORE LOCALITY MAP



FORREST CREEK SITE

Area 2424 km²
Number of bores 78
Density of bores 1 per 31 km²

GRATICULE 69

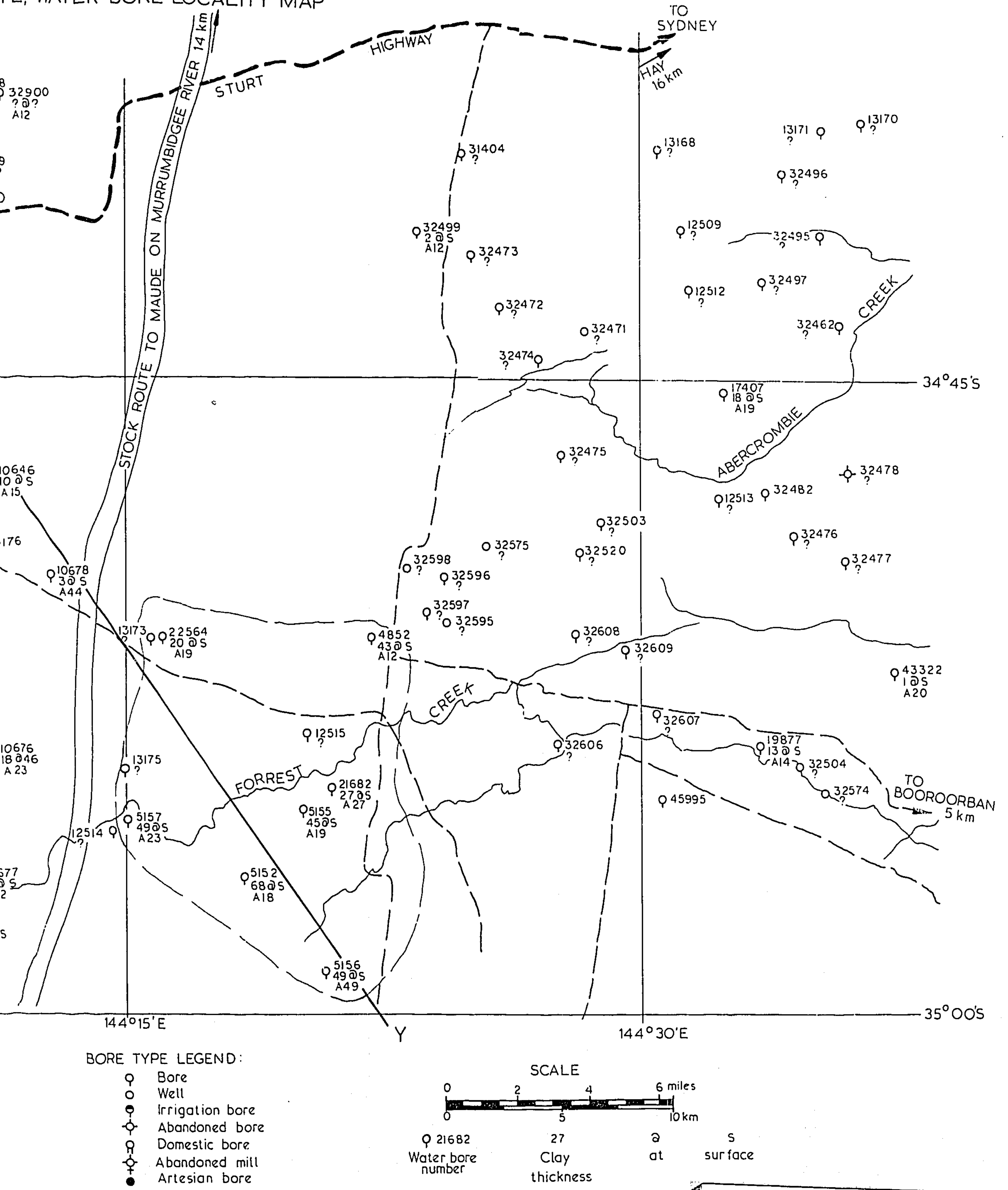
X-Y Section location
( ) Area of thick surface clays
? Information not recorded
Station tracks

BORE TYPE LEGEND:

Bore
Well
Irrigation bore
Abandoned bore
Domestic bore
Abandoned mill
Artesian bore

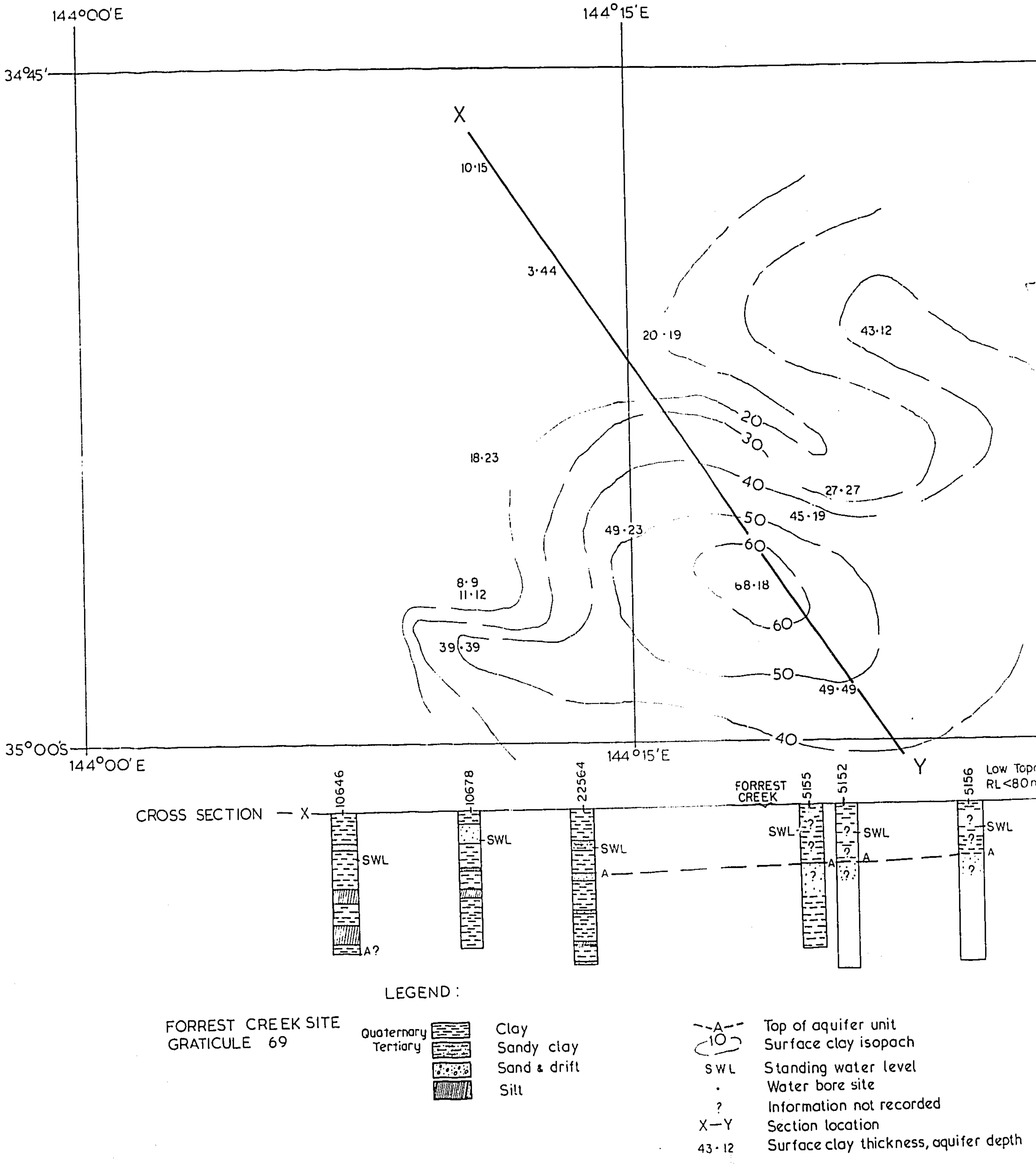
SECTION 1

TE, WATER BORE LOCALITY MAP



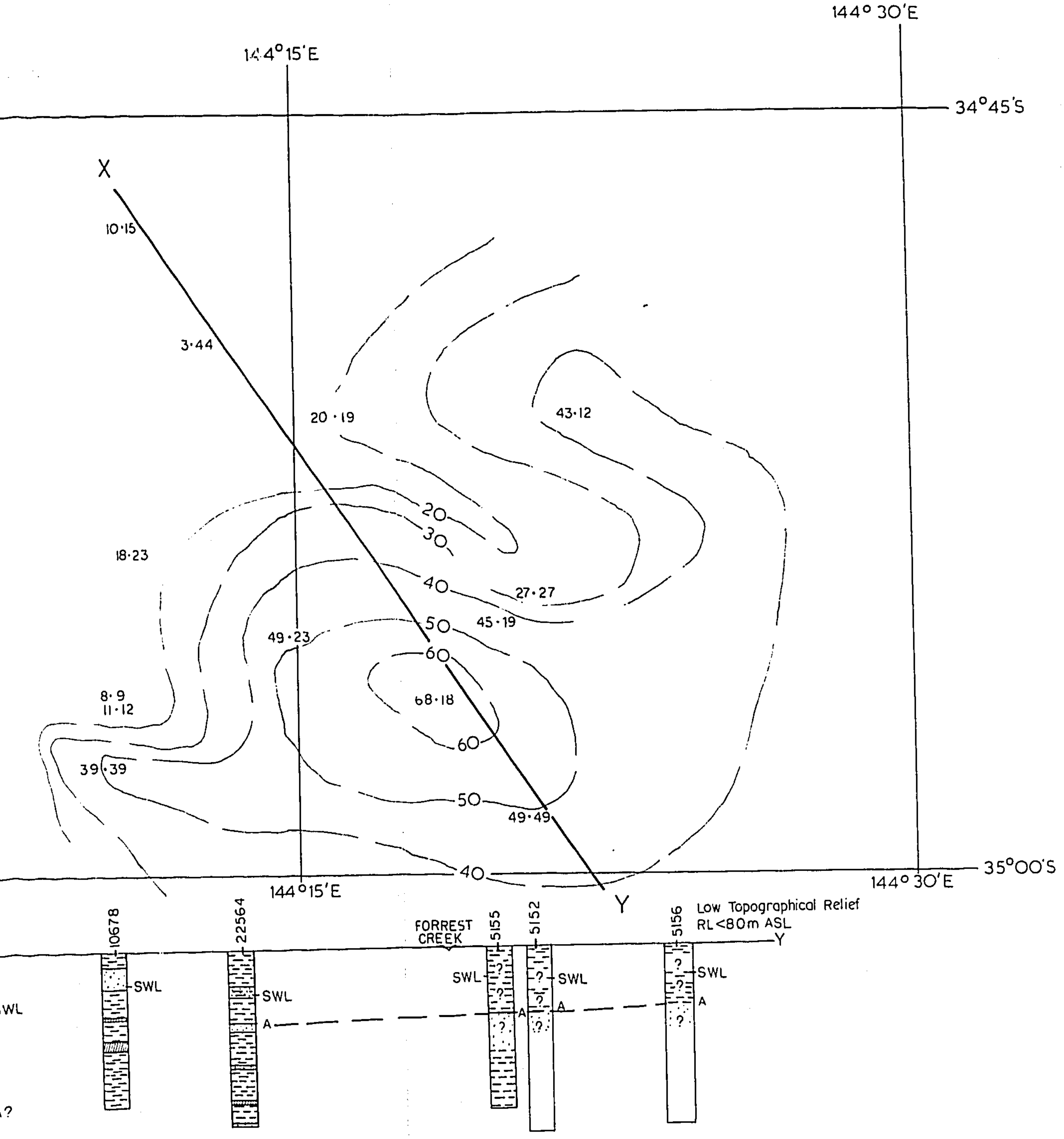
SECTION 2

Figure Nº 9a-MURRAY BASIN;-FORREST CREEK SITE, CLAY AQUIFER RELATIONSHIP



SECTION 1

CREEK SITE, CLAY AQUIFER RELATIONSHIP



LEGEND :

uaternary
Tertiary

▤	Clay
▤	Sandy clay
▨	Sand & drift
▥	Silt

--A--	Top of aquifer unit
10	Surface clay isopach
SWL	Standing water level
•	Water bore site
?	Information not recorded
X—Y	Section location
43 · 12	Surface clay thickness, aquifer depth

SCALE:
Vertical 1:1000
Horizontal 1:126,720

SECTION 2