NATIONAL WATER RESEARCH INSTITUTE

INSTITUT NATIONAL de RECHERCHE sur les EAUX

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by

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MANAGEMENT PERSPECTIVE

This report presents the results of a field study carried out in June to July 1989, by NWRI personnel, using boreholes at the USGS multi-well site in Niagara Falls, New York. The study was carried out in co-operation with the U.S. Geological Survey, Water Resources Branch in Ithaca, New York.

The identification and characterization of permeable fractures in sedimentary rock is essential to understanding groundwater flow and contaminant transport in bedrock. This study looks at constant-head injection tests as a method of characterizing open fractures. The use of short test intervals provides an effective means of identifying and characterizing fractures at a field scale. The study also contributes to the understanding of the controls on groundwater flow, and ultimately contaminant transport, in the bedrock of the Niagara Region.

PERSPECTIVES DE GESTION

Le présent rapport donne les résultats d'une étude sur le terrain, effectuée de juin à juillet 1989 par le personnel de l'INRE, à l'aide de trous de sonde sur un site de puits de l'USGS, à Niagara Falls (New York). L'étude a été conduite en collaboration avec la U.S. Geological Survey (Water Resources Branch) à Ithaca (New York).

La caractérisation des fractures perméables dans la roche sédimentaire est indispensable si on veut bien comprendre l'écoulement de l'eau souterraine et le transport des contaminants dans l'assise rocheuse. La présente étude évalue les essais d'injection à charge constante comme méthode permettant de caractériser les fractures ouvertes. L'utilisation de petits intervalles d'essai constitue un moyen efficace pour caractériser les fractures à l'échelle du terrain. L'étude permet également de mieux comprendre les caractéristiques relatives à l'écoulement de l'eau souterraine et, finalement, le transport des contaminants dans l'assise rocheuse de la région de Niagara.

ABSTRACT

Four boreholes which were drilled 25 to 50 m apart at a field site, in the Niagara Falls, New York region, were used to examine the nature of the fracture permeability in the Lockport dolostone. The Lockport Group is a sequence of dolostone formations of Upper Silurian age which make up the upper bedrock in the Niagara Falls region. The study was conducted to evaluate the use of standard packer separations in determining the permeability of a bulk rock mass which is pervaded by fractures at a frequency greater than the packer spacing. Permeability of the fractures in the boreholes was determined using the constant-head injection method. An initial set of tests was conducted using a 2 m test interval to determine the transmissivity along the length of each borehole (14 to 16 tests per borehole) and identify high permeability fractures. A second set of more detailed tests was conducted on selected fracture zones which had transmissivities greater than $1x10^{-7} m^2/s$ to identify and characterize the specific nature of permeable fractures. A 0.43-0.50 m test interval was used for these tests with up to 0.4 m overlap of adjacent test zones allowing identification of features to within 0.05 m in some cases. In zones where the predominance of the permeability is due to fractures, effective single fracture aperture was also calculated. The results of the constant-head injection tests were compared to fracture logs obtained from rock core examination.

The results show that while the bulk of the permeability in the

Lockport Dolostone is generally due to relatively few fractures, some high permeability zones contain no evidence of fractures. The vertical distribution of transmissivity as obtained from the boreholes ranges from $1x10^{-10}$ to $7x10^{-4}$ m^2/s. Transmissivities in zones with no observable fractures ranged from $1x10^{-10}$ to $3x10^{-5}$ m^2/s, suggesting a relatively heterogeneous rock matrix. The use of smaller test intervals allows the detailed characterization of the fracture-matrix system and provides valuable information not obtained with the larger test intervals. Therefore, in practical situations where average fracture spacing can be interpreted from core logs, at least some hydraulic testing should be conducted using a packer separation that is less than this mean value.

RÉSUMÉ

Quatre trous de sonde, forés à 25-50 m l'un de l'autre sur un site de puits de la région de Niagara Falls (New York), ont servi à examiner la nature de la perméabilité des fractures de la dolomie de Lockport. Le groupe de Lockport est constitué d'une série de formations de dolomie du Silurien supérieur, qui forme le l'assise rocheuse supérieure de la région de Niagara Falls. Le but de l'étude était d'évaluer l'utilisation de séparations normalisées au packer pour déterminer la perméabilité d'une masse rocheuse coupée par des fractures à une fréquence supérieure à celle de l'espacement par le packer. La perméabilité des fractures dans les trous de sonde a été mesurée grâce à la méthode d'injection à charge constante. On a effectué une série initiale d'essais en utilisant des intervalles de 2 m d'un essai à l'autre, de façon à déterminer la transmissivité le long de chaque trou de sonde (14 à 16 essais par trou de sonde) et à caractériser les fractures à forte perméabilité. Une seconde série d'essais plus détaillés a porté sur des zones de fractures choisies, présentant des transmissivités supérieures à 1×10^{-7} m^2/s, pour la caractérisation de la nature particulière des fractures perméables. Un intervalle de 0,43-0,50 m a été utilisé dans ces essais, avec parfois jusqu'à 0,4 m de chevauchement entre les zones d'essais contigus, ce qui a permis, dans certains cas, une précision de moins de 0,05 m. Dans les zones où la prédominance de la perméabilité est due aux fractures, on a également calculé l'ouverture réelle d'une fracture unique. Les résultats des essais d'injection à charge constante ont été comparés aux diagramme de fractures obtenus par étude du noyau rocheux.

Les résultats montrent que, même si le gros de la perméabilité dans la dolomie de Lockport est généralement due à un nombre relativement faible de fractures, certaines zones fortement perméables ne semblent en renfermer aucune. La distribution verticale de la transmissivité, obtenue à partir des trous de sonde, varie de 1×10^{-10} à 7×10^{-4} m^2/s. Dans les zones sans fractures observables, la transmissivité variait de 1×10^{-10} à 3×10^{-5} m^2/s, ce qui laisse supposer la présence d'une matrice rocheuse relativement hétérogène. L'utilisation d'intervalles plus petits pour les essais permet une caractérisation détaillée du système fracture-matrice et fournit de précieux renseignements, qu'il est impossible d'obtenir avec des intervalles plus grands. Par conséquent, dans les situations pratiques où l'espacement moyen des fractures peut être déterminé d'après les diagrammes de noyau, il faut faire au moins quelques essais hydrauliques, avec une séparation au packer inférieure à cette valeur moyenne.

INTRODUCTION

Fractures in rocks of low matrix permeability often provide the major conduits for groundwater flow. Thus fractures usually act as the pathway for the migration of toxic contaminants from disposal areas and industrial sites in overlying sediments. The heavily industrialized regions of southern Ontario and western New York State surrounding Lake Ontario are underlain by fractured sedimentary rocks such as dolostones, limestones, shales and sandstones. Sedimentary rocks are flat lying in this area and fracturing takes place along bedding plane partings (Novakowski and Lapcevic, 1988). These bedding plane partings can be very extensive and hydraulically connected over large areas. In rock having relatively few fractures, individual fractures play a large role in controlling the fate and transport of contaminants in groundwater at both local and regional scales. Thus, the identification and characterization of individual fractures in the subsurface is essential in understanding groundwater flow and predicting the fate of toxic contaminants in fractured sedimentary rock.

The most widely employed field method for determining the permeability of fractured rock is the constant-head injection test. This method is employed primarily because a very large range of transmissivity (eg.$1x10^{-4}$ m^2/s to $1x10^{-11}$ m^2/s) can be determined without equipment modification. In addition, due to the low storativity of fractured rocks, constant-head tests are usually of very short duration relative to other testing methods, especially for rock of low permeability.

Constant-head injection tests are conducted by introducing water at a constant flowrate into a test interval isolated by one or two packers and measuring the resulting change in hydraulic head in the test interval. The ratio of flow to hydraulic head change, when steady state conditions have been achieved, is proportional to the permeability of the rock mass isolated in the test interval. The values of permeability obtained by using constant-head injection tests is dependent on the size of the test interval. For example a large test interval (5-10 m) allows testing of large lengths of borehole in a rapid fashion and allows determination of the overall rock permeability but may not give any specific information about the fracture or matrix permeability. This is because rock aquifers often have large differences in permeability at the mesoscopic scale as a result of fracturing. Therefore, the permeability of a test interval having a single open fracture with a large transmissivity will be dominated by this fracture and hydraulic test results will give no information on smaller fractures, vertical connectivity of the fractures or matrix permeability. Thus, by reducing the length of the test interval, more information can be obtained on the location of discrete permeable fractures and matrix permeability.

The packer spacing required to effectively characterize a given portion of rock will be dependent on the fracture density. The smaller the fracture spacing the smaller the required test interval. For example, if fractures were spaced 0.5 m apart a test interval less than 0.5 m would yield results reflecting individual fractures and include zones with no fractures.

Constant-head injection tests, while easily conducted and analyzed, can be time consuming. For this reason it is essential that an effective hydraulic testing program be planned using all available geological and geophysical data on the boreholes studied.

Other fracture characterization studies have generally shown that even in rock with a high density of fractures usually only one or two fractures provide the bulk of the permeability (Magnussun and Durnan, 1984; Jones, 1985; Paillet 1985,and Paillet et al. 1985). Magnusson and Durnan (1984) found no relationship between fracture frequency and hydraulic conductivity in a study of fractures in a granitic rock mass. Zones containing a single isolated fracture exhibited a range of hydraulic conductivities from less than 10^{-9} m/s to greater than 10^{-7} m/s. In sedimentary rock, fracturing most frequently occurs along bedding plane partings. For example, in a detailed study of the contributions of fractures to groundwater flow in a sandstone aquifer, over 80% of the fractures mapped in borehole investigations were bedding plane partings (Francis et al.,1988).

The boreholes employed for this study intersect the Upper Silurian Lockport Group of dolstones and limestones which make up the bedrock directly underlying most of the Niagara Falls, NY area. In this region, the Lockport group is composed of four formations from base to top: Gasport, Goat Island, Eramosa, and Oak Orchard (Richard, 1975). The total thickness of the Lockport group averages about 52 m (D. Tepper, pers. comm.) Regional groundwater flow in the Lockport dolostone is within a network of horizontal bedding planes separations (Johnson, 1964). The horizontal fractures are well-connected in the upper 3-8 m of rock and are less connected at depth (Yager and Kappel, 1987). The geology and hydrogeology of the region is discussed in greater detail in Johnson (1964); Yager and Kappel (1987) and Novakowski and Lapcevic (1988).

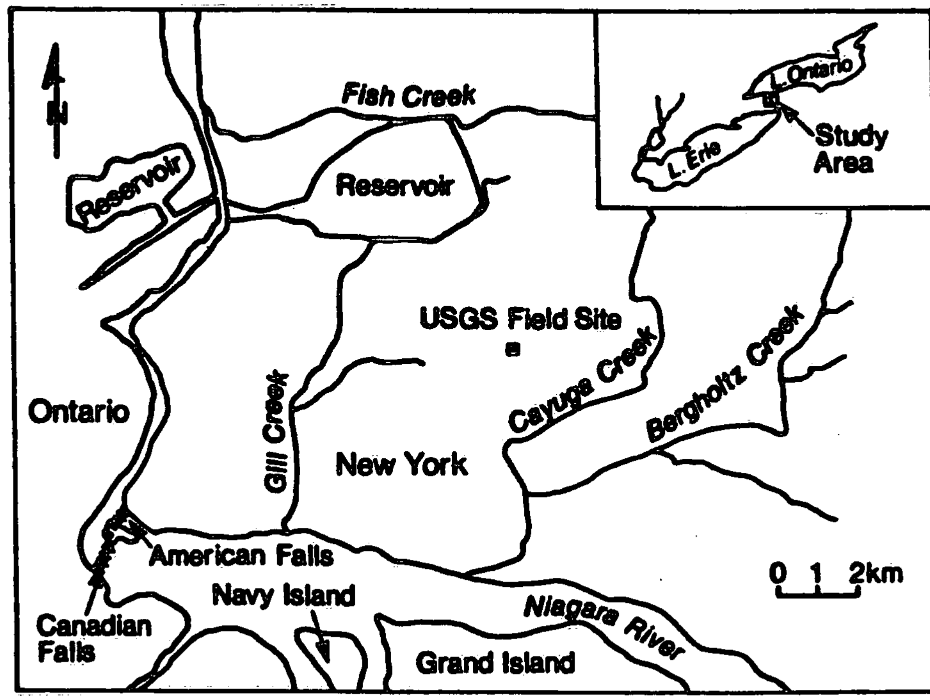
The purpose of this study is to characterize the transmissivity of the Lockport dolostone at a multiple well site using single-well hydraulic tests having short-packer-spacings to identify discrete hydraulically open fractures. The length of each borehole was tested using a 2 m test interval to provide reconnaissance level testing of the Lockport dolostone. To examine the use of short interval constant head injection tests to characterize hydraulically open fractures in the rock, selected permeable intervals were re-tested using a shorter test interval (0.43-0.50 m). As a means of assessing the utility of using the short packer spacing method, the results of both sets of tests are compared to fracture logs compiled directly from the rock core.

METHODS

Study Site:

The location of the U.S. Geological Survey's (USGS) multi-well research site is shown in Figure 1(a). A site plan showing the location of the boreholes used in this study is shown in Figure 1(b). Boreholes ANI2-ANI4 are vertical, 76 mm in diameter and were diamond drilled and cored using triple-tube wireline techniques. ANI5 is 152 mm in diameter and was drilled in a similar fashion. The 76 mm boreholes were designed as monitoring wells whereas the 152 mm borehole is intended to be used as a pumping well. The site was established by the USGS to study the hydrogeology of the Lockport dolostone in the Niagara Falls, New York region by conducting multiple-well hydraulic tests. It should be noted that the USGS refer to these boreholes as NI1 to NI5 but they are renamed ANI1 to ANI5 in this report to eliminate any possible confusion with Environment Canada boreholes in the region labelled NI1 to NI3. At the time this field study was carried out, ANI1 was completed with a permanent casing system and therefore could not be tested.

(a)



(b)

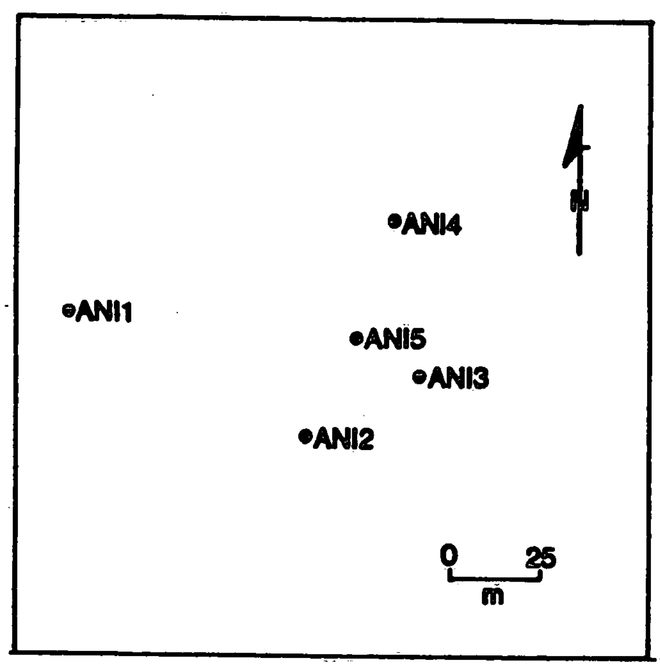


Figure 1: (a) Area map showing location of U.S. Geological Survey's multi-well field site (modified from Yager and Kappel, 1987).

(b) Plan view of field site showing boreholes used in this study.

<u>Constant-head injection tests:</u>

Constant-head injection tests were conducted in boreholes ANI2 to ANI5 by injecting water at a constant flowrate into an isolated test interval and measuring the resulting change in hydraulic head when steady-state conditions had been achieved. A schematic of the testing apparatus used to conduct the constant-head tests is shown in Figure 2. Each test interval was isolated using two pneumatic packers. The packers employed for this study consist of an expandable rubber gland with a reinforced kevlar cuff at each end covering a steel mandrel. When inflated in the borehole the packers have a seal length of 0.6 m each. Different lengths of the borehole can be tested by changing the separation distance between the two packers. In this study, two test interval lengths were used (2 m and 0.43 to 0.5 m). The 0.43-0.50 m tests are called short interval tests in this report. A different set of packers, configured in a similar manner, was used to characterize ANI5 due to the larger borehole diameter. To provide a constant injection flowrate for each test, a series of five tanks of different diameter was pressurized at the surface using a regulated source of compressed nitrogen. Flowrate was measured using sight tubes on the side of the tanks. Flowrates between 10^{-10} m^3/s and 10^{-3} m^3/s can be determined using this particular testing apparatus. A pressure transducer located above the packers, connected to the zone between the packers was used to measure the hydraulic head changes within the test interval.

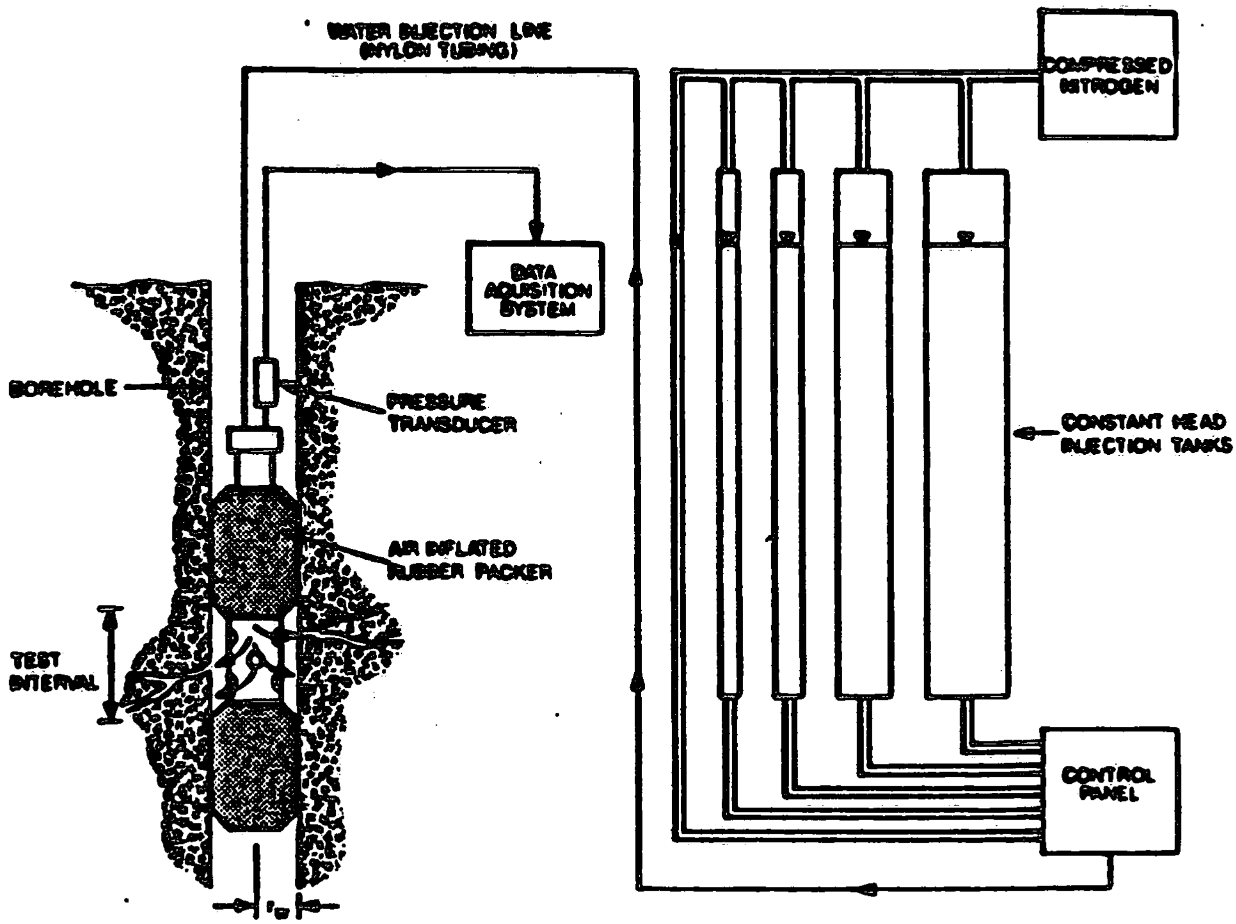


Figure 2: Schematic of constant-head injection testing set-up.

During the test procedure, imposed hydraulic heads ranged between 0.1 and 39 m above initial static conditions. Injection heads at the high end of the range were obtained during tests conducted in low-permeability zones where large head changes were required to obtain a measurable flowrate. At the low end of the range high flowrates in permeable sections produced only small changes in hydraulic head. Imposed hydraulic heads between 5 and 10 m above equilibrium were obtained for the majority of tests. Most intervals were tested successively two or three times using different injection flowrates. The field methodology employed for constant-head injection tests is discussed in more detail in Zeigler(1976), Doe and Remer (1980), and Doe et al. (1987).

Data analysis:

The results of constant-head injection tests are interpreted using the ratio of injection flowrate to the resulting hydraulic head difference over static conditions ($Q/\Delta H$). The Theim equation for steady state radial flow was used to obtain the equivalent transmissivity, T (m^2/s), for each given isolated interval. The expression used is given as follows:

$$T=\frac{Q}{\Delta H 2\pi}\cdot\ln\left(\frac{r_e}{r_w}\right) \qquad (1)$$

where Q is the steady state flowrate (m^3/s), ΔH is the difference in hydraulic head between static initial conditions and a steady flow condition (m), r_e is the radius of influence (m), and r_w is the radius of the well (m). The radius of influence was assumed to be 10 m in all tests (Bliss and Rushton, 1984). Although the radius of influence (r_e) is unknown in most field situations, large errors in estimation of r_e will result in only small errors in the calculation of T, because r_e appears as a logarithmic term in equation (1) (Zeigler, 1976; Doe et al., 1987).

An equivalent single fracture aperture, 2b (micrometres), can be determined from the test results by using the cubic law (Witherspoon et al., 1980). The fracture aperture is related to transmissivity according to:

$$2b=\left(T\cdot\frac{12\mu}{\rho g}\right)^{\frac{1}{3}}\cdot 1x10^{-6} \qquad (2)$$

where T is the transmissivity (m^2/s), ρ is the fluid density (kg/m^3), g is the gravitational acceleration (m/s^2) and μ is the kinematic viscosity (m^2/s).

Fracture Logging:

Logs showing formation contacts and the location of open fractures and probable open fractures were constructed by the U.S. Geological Survey for each borehole based on core examination alone. The fracture logs include open fractures, probable open fractures and broken core zones. A broken core zone may include one or more fractures which cannot be identified individually. The criteria used to distinguish open fractures from core breaks induced by drilling included closeness of fit of core pieces, weakness of core (ie. gypsum vein, shaley interval, fossiliferous zone or compositional change), evidence of weathering, presence of mineralization or staining, and the roughness of fracture surfaces (D. Tepper, pers. comm.).

RESULTS AND DISCUSSION

A total of 185 constant-head injection tests were completed in the four boreholes (ANI2 to ANI5). The results of all the tests are given in Appendix A. A total of 60 tests were conducted using a 2 m test interval with 14-16 tests in each borehole (Table 1). The remainder of the tests were carried out on selected higher transmissivity zones ($T > 1 \times 10^{-7}$ m^2/s) identified by the 2 m test interval tests. These tests were conducted using a 0.43 to 0.5 m test interval.

Table 1: Summary of two metre packer spacing tests.

Borehole	N^a	Range of T^b (m^2/s)	$\bar{T}^c$ (m^2/s)
ANI2	16	1.0×10^{-10}–1.6×10^{-4}	4.3×10^{-7}
ANI4	16	2.1×10^{-10}–7.5×10^{-4}	7.3×10^{-7}
ANI3	14	2.4×10^{-9}–3.5×10^{-4}	1.7×10^{-6}
ALL TESTS	46	1.0×10^{-10}–7.5×10^{-4}	1.2×10^{-6}

[a] Number of tests
[b] minimum and maximum values of transmissivity
[c] geometric mean transmissivity

The results of the tests conducted in ANI5 are questionable due to equipment problems which may have affected the measured flowrates into the test interval. Thus, calculated transmissivities in ANI5 less than $1x10^{-6}$ m^2/s may be overestimates. Short test intervals were not employed for any of the tests conducted in ANI5. Although, the results from this borehole are included in the report (Figure 6 and Appendix A), as they may be useful qualitatively, they are not discussed any further and are not used in any calculations or summary figures.

In boreholes ANI2 to ANI4 a range of transmissivities between $1x10^{-10}$ to $7.5x10^{-4}$ m^2/s was measured using the 2 m interval tests (Figures 3 to 5). A summary of the tests is shown in Table 1. The geometric mean of the transmissivity as determined from these tests, is $1.2x10^{-6}$ m^2/s. There is no trend in the magnitude of the transmissivity with depth.

The overall distribution of transmissivities at the site, obtained using the 2 m packer spacing tests only (excluding data from ANI5), is shown in Figure 7. The bulk of the transmissivity values (74%) are between $1x10^{-8}$ and $1x10^{-4}$ m^2/s. The distribution appears to be bi-modal and skewed. The range of transmissivities measured at this site is similar to ranges found at other boreholes in the same formations in the region (Novakowski and Lapcevic, 1988 and Lapcevic and Novakowski, 1989).

The results of the short interval tests are presented in a

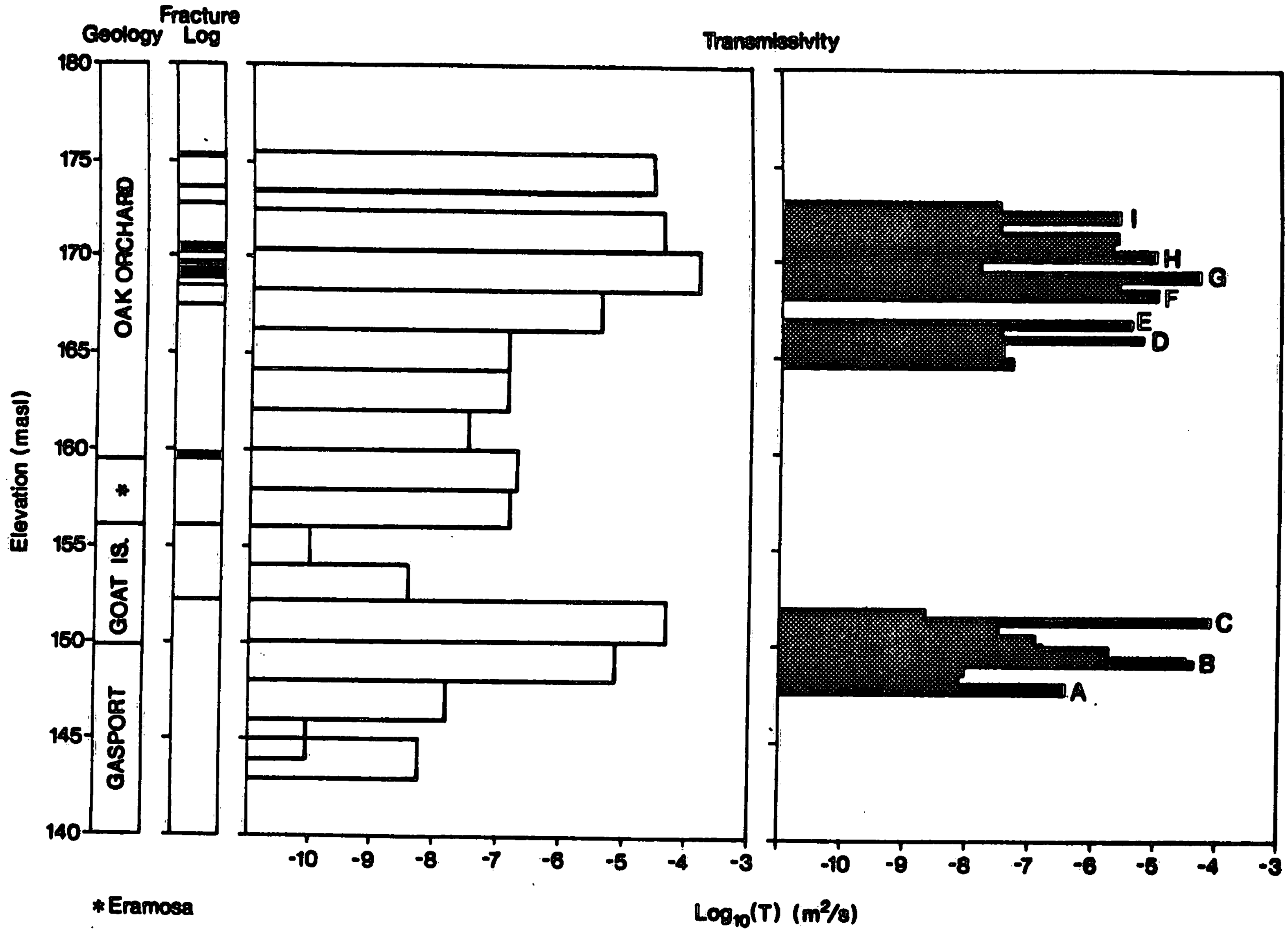


Figure 3: ANI2 transmissivity profile based on both sets of constant head injection tests and compared to fracture and lithology logs.

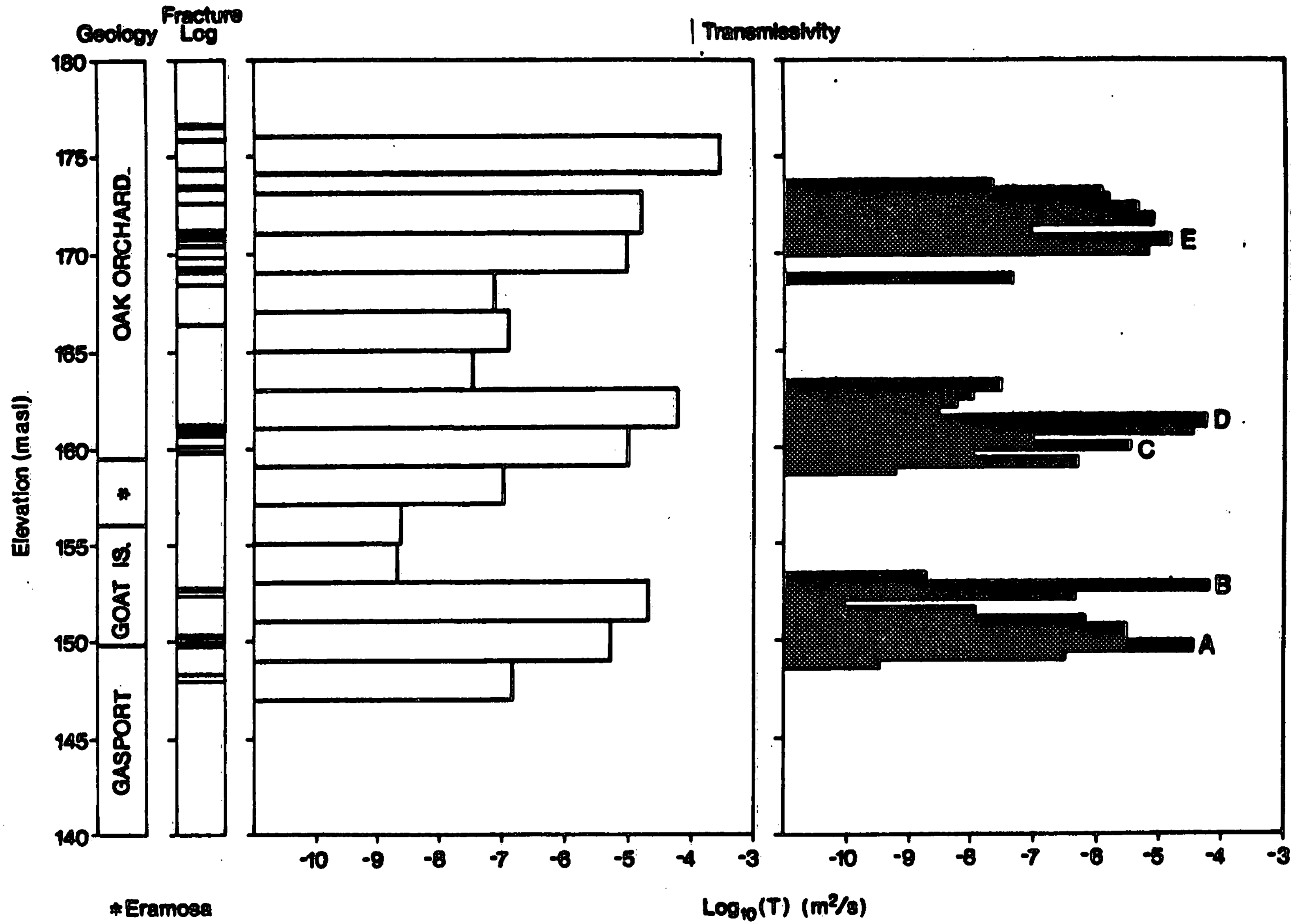


Figure 4: ANI3 transmissivity profile based on both sets of constant head injection tests and compared to fracture and lithology logs.

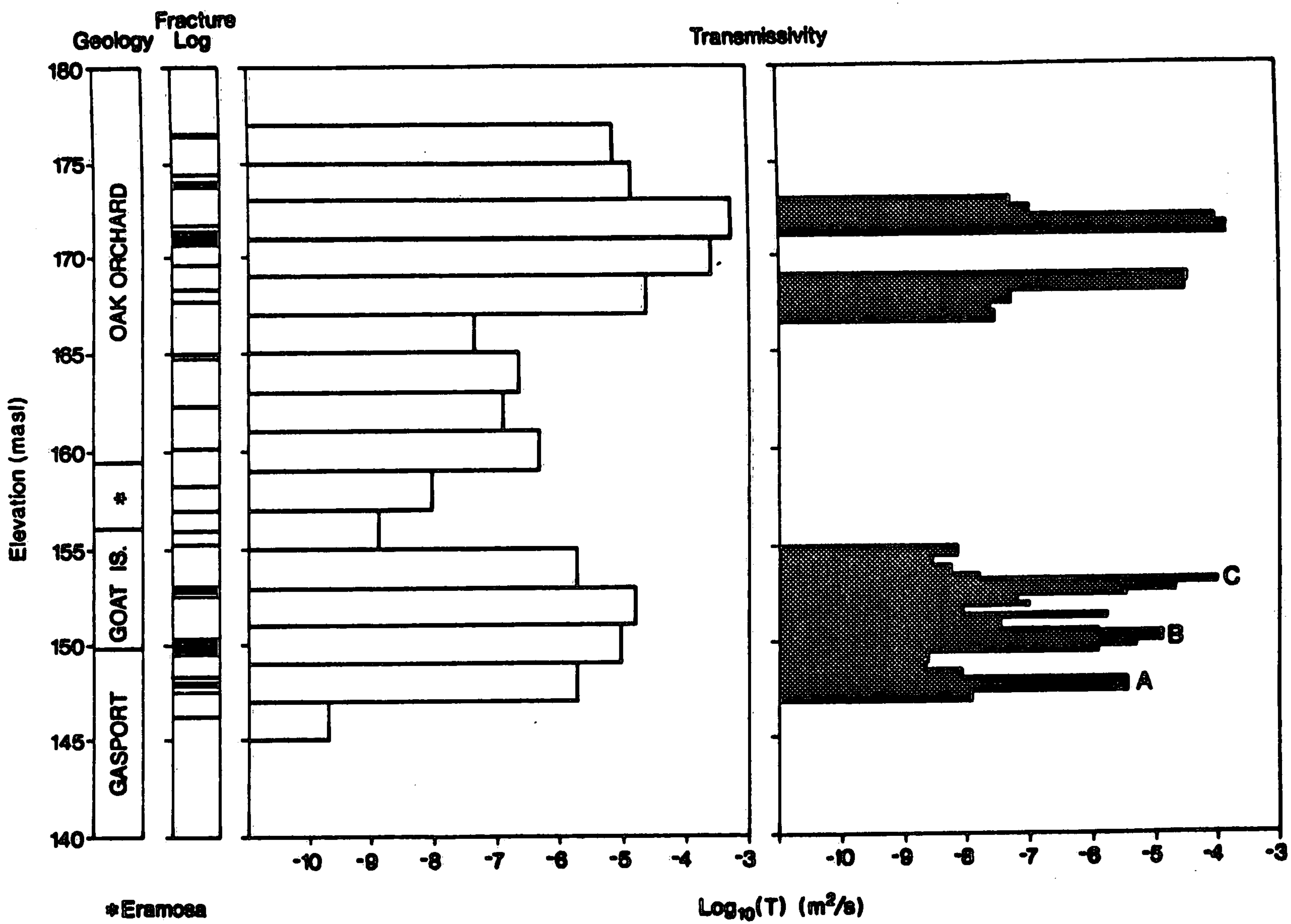


Figure 5: ANI4 transmissivity profile based on both sets of constant head injection tests and compared to fracture and lithology logs.

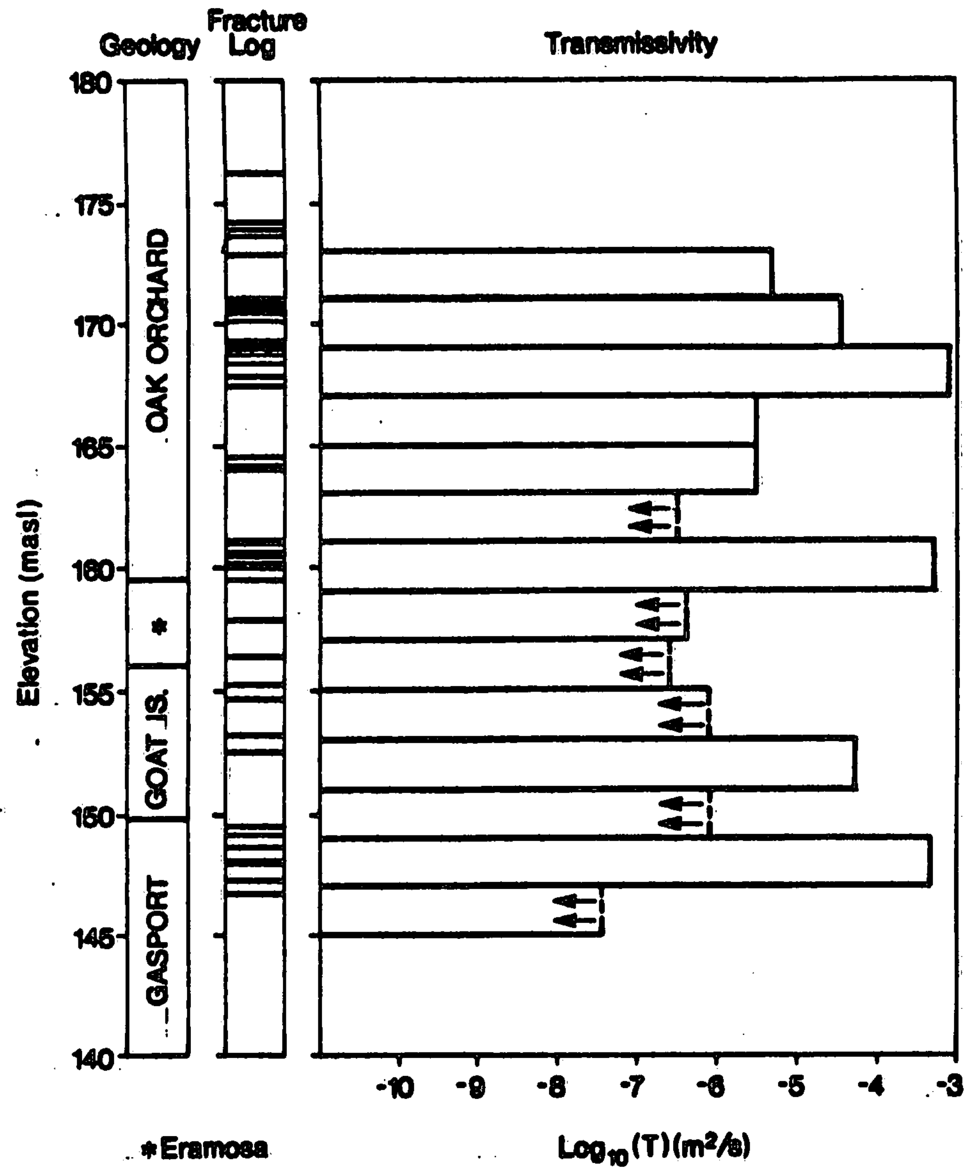


Figure 6: ANI5 transmissivity profile based on 2 m constant head injection tests and compared to fracture and lithology logs.

'consolidated' format in Figures 3 to 5 due to the overlapping of test intervals. This means that in zones which have been tested more than once because of overlapping test intervals, the lowest transmissivity calculated was taken to be representative of the zone. In ANI3 only 2 tests were conducted using overlapping test intervals. Larger scale plots of individual tests showing overlap, which were used to create the consolidated plots, are given in Appendix B. Overlapping of test intervals ensures that no portion of the borehole studied is omitted.

The detailed testing possible using a short test interval length allowed specific permeable fractures to be identified using the constant-head injection tests. These fractures are labelled on Figures 3-5 with letters A-H starting from the base of the borehole. A summary of the fractures is shown in Table 2. Fractures were labelled if they had transmissivities greater than $1x10^{-6}$ m^2/s and were distinctively more permeable than surrounding zones. These labels are for discussion in this report only. It should be noted that other higher permeability fractures probably exist in the boreholes especially closer to the bedrock/overburden interface. The fractures identified in this study are limited by the details of the hydraulic testing program. In other words, to identify all the permeable features in each borehole, every zone with $T>1x10^{-7}$ m^2/s would have to be tested in detail with the short test interval. This amount of testing was beyond the scope of this study. In ANI2, 3 fractures are identified at the base of the profile (A,B and C on Figure 3). At the top of the borehole 6 fractures are identified (D to I on Figure 3). In ANI3, 2 features are observed at the base of the borehole (A and B on Figure 4), two more are observed in the centre of the profile (C and D on Figure 4) and one at the top (F on Figure 4). Lastly, in ANI4 3 fractures (A to C on Figure 5) were identified. A few of fractures at the top of ANI4 are not labelled since the zone between them was not tested with the short packer tests and is observed to be permeable when tested with the 2 m tests.

Table 2: Summary of fractures identified by short interval tests

Borehole	Fracture	Elevation (masl)	T (m^2/s)	2b[a] (μm)
ANI2	A	149.60-149.20	3.2×10^{-5}	377
	B	151.33-151.30	6.1×10^{-5}	469
	C	166.60-166.40	4.3×10^{-6}	194
	D	167.53-167.13	3.0×10^{-6}	171
	E	169.03-168.53	7.3×10^{-6}	232
	F	170.03-169.53	3.5×10^{-5}	392
	G	171.03-170.53	6.7×10^{-6}	225
	H	173.03-172.53	1.7×10^{-6}	143
ANI3	A	149.71-149.27	4.0×10^{-5}	408
	B	152.79-152.35	7.3×10^{-5}	499
	C	160.15-159.71	3.7×10^{-6}	185
	D	161.47-160.59	5.1×10^{-5}	442
	E	171.33-170.83	1.7×10^{-5}	308
ANI4	A	147.83-147.23	4.4×10^{-6}	195
	B	149.83-150.33	1.6×10^{-5}	303
	C	152.83-153.03	9.9×10^{-5}	553

[a]equivalent single fracture aperture

The length of the zones containing the identified fractures ranges from 0.03 m to 0.88 m. Determination of this length depends on the length of the test interval, the amount of overlapping of adjacent intervals and the contrasts in transmissivity adjacent to the fracture. The permeable fractures are in most cases a single fracture but sometimes more than one fracture is observed in core. In ANI2 fractures A, B and C show no corresponding breaks in the core. Fractures A and B are in a reef zone which may explain the

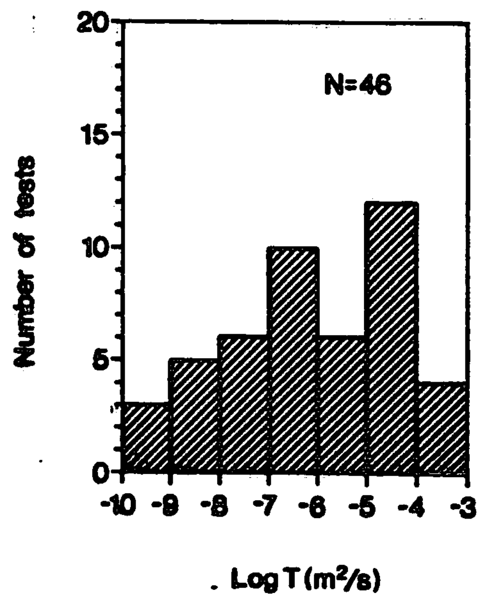


Figure 7: Distribution of measured transmissivities based on 2 m tests in ANI2 to ANI4.

increased permeability of these fractures relative to other zones. Fracture C is close to a vuggy zone identified in the core which may explain the higher transmissivity. Fractures D-H have 2-3 fractures each. Fracture F consists of two broken core zones, suggesting that broken core zones may be indicative of permeable fractures. In ANI3 fractures A-C each have 2-3 fractures. The uppermost fractures (D and E) each have 8 fractures and a broken core zone respectively. In ANI4 fracture A is associated with a single fracture while the other two have 2 fractures and a broken zone and a single broken zone respectively.

The continuity of the identified fractures is examined by comparing the detailed transmissivity profiles for the three boreholes (Figure 8). These profiles were constructed using both sets of tests. A possible correlation can be seen between fracture B in ANI2, A in ANI3 and B in ANI4. A second correlation may be between C in ANI2, B in ANI3 and C in ANI4. A third correlation may be between A in ANI2 and A in ANI4. It is interesting that fractures identified in ANI2 appear to be correlatable with the other boreholes even though no fractures were identified in the core to correlate with fractures A-C. No other fractures appear to be correlatable using the data presented. This does not imply that there are no other continuous fractures at the site but only that there is insufficient data to suggest other correlations.

Four zones in ANI3 and ANI4 were used to compare the results of the long and short packer tests quantitatively. To compare the two sets of tests, zones which were tested with both the long and short packer spacings were used. Only zones which were tested using short packer spacings with no overlapping of adjacent test intervals were used in the comparison. In ANI4 an 8 m zone was

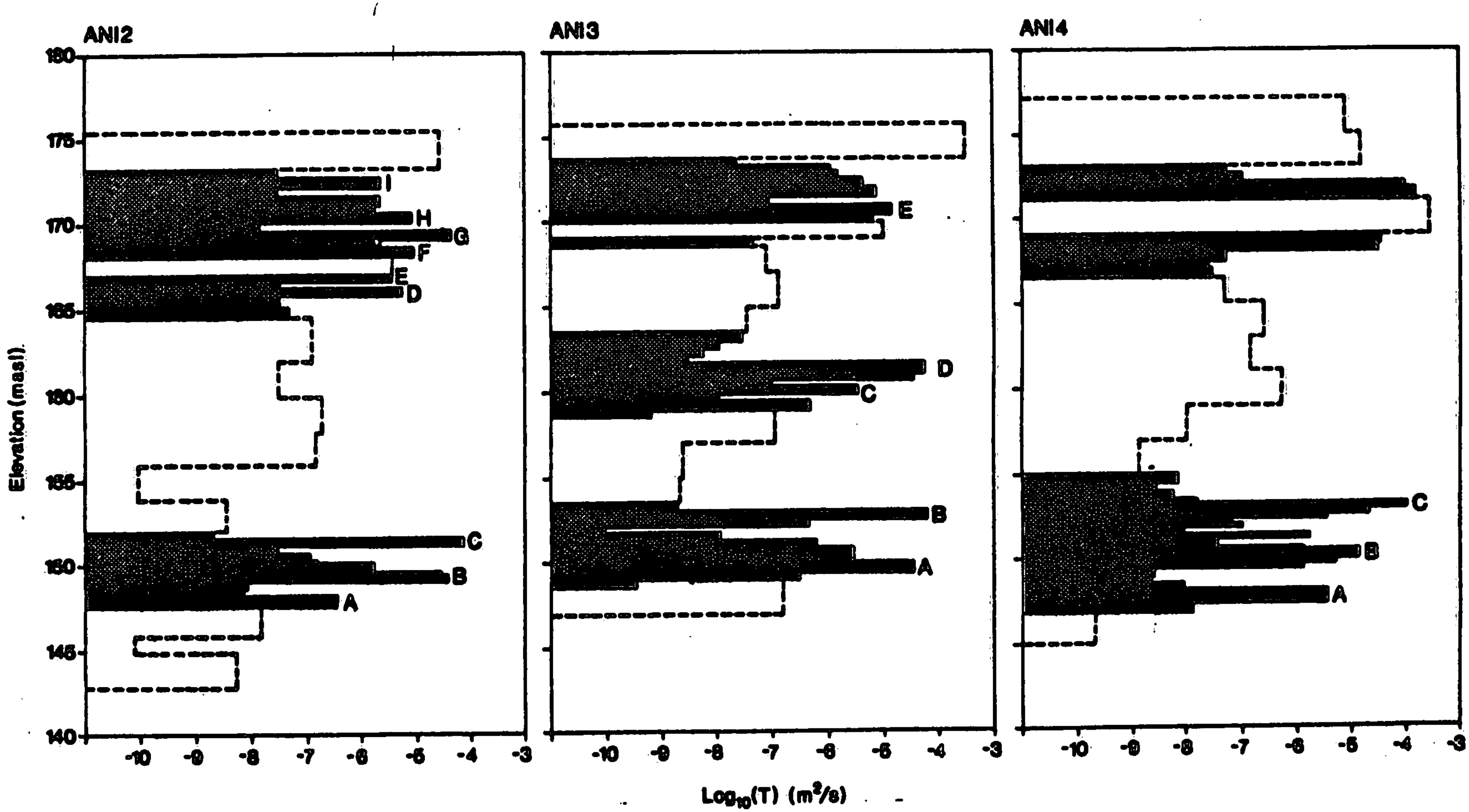


Figure 8: Comparison of ANI2, ANI3, and ANI4 transmissivity profiles (profiles are combinations of both long and short interval tests).

examined, in ANI3 two 4 m zones and one 2 m zone were examined. The total transmissivity for the zone was calculated by summing the transmissivities obtained from individual tests (Table 3). In all the comparisons, results from the short intervals gave a higher total transmissivity, by a factor of 4 or less, than the long packer tests.

Table 3: Comparison of short and long interval tests.

Comparison	Elevation (masl)	Bore-hole	N^a	T^a (m^2/s)	N^b	T^b (m^2/s)
1	154.83-146.83	ANI4	15	$1.6x10^{-4}$	4	$3.8x10^{-5}$
2	152.79-148.83	ANI3	9	$1.2x10^{-4}$	2	$3.4x10^{-5}$
3	162.79-158.83	ANI3	9	$1.1x10^{-4}$	2	$9.2x10^{-5}$
4	172.83-170.83	ANI3	4	$3.1x10^{-5}$	1	$2.0x10^{-5}$

[a]number of tests and total transmissivity using short interval.
[b]number of tests and total transmissivity using long interval.

To examine the matrix permeability at the site, tests conducted in boreholes ANI2-ANI4 tests carried out in zones with no identified fractures were used (Appendix B). Using 36 tests (both 2 m and 0.5 m intervals) a range of transmissivities between $3.2x10^{-5}$ to $1x10^{-10}$ was identified. To account for possible measurement errors in the core logging and hydraulic testing only tests which were greater than 0.5 m away from an identified fracture were used. The transmissivities at the high end of the range reflect the fractures identified in ANI2 which could not be correlated with observed core breaks. The bulk of the matrix transmissivity is probably in the range $1x10^{-8}$ m^2/s to $1x10^{-10}$ m^2/s. The wide range of transmissivities seen in zones with no corresponding breaks may be due to variations in lithology, microfractures or reef material.

CONCLUSIONS

The results of constant-head injection tests in four boreholes at the USGS multiple-well field site are presented in this report. Using a 2 m test interval a range of transmissivities between $1x10^{-10}$ and $7.5x10^{-4}$ m^2/s were measured. Detailed testing with a 0.43 - 0.50 m test interval identified permeable fractures in each borehole and yielded more specific information on the hydraulic nature of the rock not possible with the larger test intervals. Comparison of the hydraulic tests to fracture logs showed that the identified fractures for the most part correspond to one or more fractures or broken core zones. Matrix transmissivities range from $3.2x10^{-5}$ to $1x10^{-10}$ m^2/s, based on tests in zones with no observed breaks in the core. The single well testing program carried out at the site shows the heterogeneous nature of the Lockport formation and suggests that both fractures and matrix are contributing to the permeability of the rock. Lithological changes in the sequence including reef zones may also affect the observed transmissivity in the rock.

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APPENDIX A
RESULTS OF CONSTANT HEAD INJECTION TESTS

Constant Head Injection Test Results:

Borehole: ANI2
Datum (ground surface): 182.03 masl[a]

Test #	Elevation (masl)	(masl)	T (m^2/s)	K (m/s)	2b (microns)
16	175.20	173.20	$3.1x10^{-5}$	$1.5x10^{-5}$	374
15	172.20	170.20	$4.3x10^{-5}$	$2.1x10^{-5}$	418
14	170.20	168.20	$1.6x10^{-4}$	$8.2x10^{-5}$	654
13	168.20	166.20	$4.3x10^{-6}$	$2.2x10^{-6}$	194
26	166.20	164.20	$1.4x10^{-7}$	$7.0x10^{-8}$	62
25	164.20	162.20	$1.4x10^{-7}$	$7.2x10^{-8}$	63
24	162.20	160.20	$3.0x10^{-8}$	$1.5x10^{-8}$	37
23	160.20	158.20	$2.1x10^{-7}$	$1.1x10^{-7}$	71
22	158.20	156.20	$1.5x10^{-7}$	$7.7x10^{-8}$	64
21	156.20	154.20	$1.0x10^{-10}$	$5.0x10^{-11}$	6
20	154.20	152.20	$3.8x10^{-9}$	$1.9x10^{-9}$	19
8	152.20	150.20	$5.7x10^{-5}$	$2.8x10^{-5}$	458
7	150.20	148.20	$8.8x10^{-6}$	$4.4x10^{-6}$	247
19	148.20	146.20	$1.7x10^{-8}$	$8.6x10^{-9}$	31
18	146.20	144.20	$1.0x10^{-10}$	$5.0x10^{-11}$	6
17	145.20	143.20	$6.5x10^{-9}$	$3.2x10^{-9}$	22
67	173.53	173.03	$2.1x10^{-8}$	$4.2x10^{-8}$	33
66	173.03	172.53	$1.7x10^{-6}$	$3.4x10^{-6}$	143
65	172.53	172.03	$2.1x10^{-8}$	$4.1x10^{-8}$	33
64	172.03	171.53	$1.6x10^{-6}$	$3.2x10^{-6}$	139
63	171.53	171.03	$1.3x10^{-6}$	$2.7x10^{-6}$	131
62	171.03	170.53	$6.7x10^{-6}$	$1.3x10^{-5}$	225
61	170.53	170.03	$1.0x10^{-8}$	$2.0x10^{-8}$	26
60	170.03	169.53	$3.5x10^{-5}$	$7.1x10^{-5}$	392
59	169.53	169.03	$1.7x10^{-6}$	$3.3x10^{-6}$	141
58	169.03	168.53	$7.3x10^{-6}$	$1.5x10^{-5}$	232
57	167.53	167.03	$3.0x10^{-6}$	$5.9x10^{-6}$	171
56	167.13	166.63	$2.2x10^{-8}$	$4.4x10^{-8}$	34
55	167.03	166.53	$4.3x10^{-6}$	$8.6x10^{-6}$	194
50	166.53	166.03	$4.3x10^{-6}$	$8.6x10^{-6}$	194
54	166.43	165.93	$2.6x10^{-8}$	$5.1x10^{-8}$	35
53	166.33	165.83	$3.2x10^{-8}$	$6.3x10^{-8}$	38
52	166.23	165.73	$2.8x10^{-8}$	$5.6x10^{-8}$	36
51	166.13	165.63	$2.5x10^{-8}$	$4.9x10^{-8}$	35
49	166.03	165.53	$3.2x10^{-8}$	$6.4x10^{-8}$	38
48	165.53	165.03	$3.7x10^{-8}$	$7.4x10^{-8}$	40
43	152.20	151.70	$5.9x10^{-5}$	$1.2x10^{-4}$	466
47	152.03	151.53	$1.3x10^{-9}$	$2.7x10^{-9}$	13
46a	151.83	151.33	$1.4x10^{-8}$	$2.8x10^{-8}$	29
46	151.73	151.23	$4.5x10^{-5}$	$8.9x10^{-5}$	423
42	151.70	151.20	$3.2x10^{-6}$	$6.4x10^{-6}$	175
45	151.63	151.13	$6.1x10^{-5}$	$1.2x10^{-4}$	469
44	151.30	150.80	$6.8x10^{-7}$	$1.4x10^{-6}$	105
41	151.20	150.70	$2.0x10^{-8}$	$4.0x10^{-8}$	32
37	150.70	150.20	$8.5x10^{-8}$	$1.7x10^{-7}$	52
40	150.60	150.10	$1.1x10^{-7}$	$2.2x10^{-7}$	57
39	150.50	150.00	$1.3x10^{-6}$	$2.6x10^{-6}$	131

[a]masl-metres above sea level

Constant Head Injection Test Results:

Borehole: ANI2
Datum (ground surface): 182.03 masl[a]

Test #	Elevation (masl)	(masl)	T (m^2/s)	K (m/s)	2b (microns)
38	150.40	149.90	$1.4x10^{-6}$	$2.9x10^{-6}$	134
36	150.30	149.80	$1.4x10^{-6}$	$2.8x10^{-6}$	133
35	150.20	149.70	$1.2x10^{-6}$	$2.4x10^{-6}$	127
34	150.10	149.60	$1.3x10^{-6}$	$2.5x10^{-6}$	129
33	150.00	149.50	$2.2x10^{-5}$	$4.5x10^{-5}$	337
32	149.90	149.40	$3.2x10^{-5}$	$6.3x10^{-5}$	377
31	149.80	149.30	$2.8x10^{-5}$	$5.7x10^{-5}$	363
30	149.70	149.20	$3.0x10^{-5}$	$6.0x10^{-5}$	370
29	149.20	148.70	$5.8x10^{-9}$	$1.2x10^{-8}$	21
28	148.70	148.20	$4.9x10^{-9}$	$9.8x10^{-9}$	20
27	148.20	147.70	$2.6x10^{-7}$	$5.1x10^{-7}$	76

[a]masl-metres above sea level

Constant Head Injection Test Results:

Borehole: ANI3
Datum (ground surface): 182.48 masl[a]

Test #	Elevation (masl)	(masl)	T (m^2/s)	K (m/s)	2b (microns)
14	175.83	173.83	$3.5x10^{-4}$	$1.8x10^{-4}$	843
13	172.83	170.83	$2.0x10^{-5}$	$1.0x10^{-5}$	324
12	170.83	168.83	$1.2x10^{-5}$	$6.2x10^{-6}$	277
44	168.83	166.83	$8.8x10^{-8}$	$4.4x10^{-8}$	53
43	166.83	164.83	$1.5x10^{-7}$	$7.4x10^{-8}$	63
42	164.83	162.83	$4.0x10^{-8}$	$2.0x10^{-8}$	41
8	162.83	160.83	$7.9x10^{-5}$	$3.9x10^{-5}$	511
7	160.83	158.83	$1.3x10^{-5}$	$6.6x10^{-6}$	282
41	158.83	156.83	$1.3x10^{-7}$	$6.3x10^{-8}$	60
40	156.83	154.83	$2.8x10^{-9}$	$1.4x10^{-9}$	17
39	154.83	152.83	$2.4x10^{-9}$	$1.2x10^{-9}$	16
3	152.83	150.83	$2.7x10^{-5}$	$1.4x10^{-5}$	359
2	150.83	148.83	$7.1x10^{-6}$	$3.5x10^{-6}$	229
38	148.83	146.83	$1.8x10^{-7}$	$9.2x10^{-8}$	68
53	174.03	173.53	$2.4x10^{-8}$	$4.8x10^{-8}$	34
52	173.83	173.33	$1.3x10^{-6}$	$2.6x10^{-6}$	131
51	173.33	172.83	$1.7x10^{-6}$	$3.4x10^{-6}$	142
50	172.83	172.33	$5.1x10^{-6}$	$1.0x10^{-5}$	206
49	172.33	171.83	$9.0x10^{-6}$	$1.8x10^{-5}$	248
48	171.83	171.33	$9.8x10^{-8}$	$2.0x10^{-7}$	55
47	171.58	171.08	$1.1x10^{-5}$	$2.2x10^{-5}$	264
46	171.33	170.83	$1.7x10^{-5}$	$3.4x10^{-5}$	308
45	170.83	170.33	$7.8x10^{-6}$	$1.6x10^{-5}$	237
37	168.83	168.39	$4.4x10^{-8}$	$1.0x10^{-7}$	42
36	163.23	162.79	$2.8x10^{-8}$	$6.3x10^{-8}$	36
35	162.79	162.35	$1.1x10^{-8}$	$2.5x10^{-8}$	27
34	162.35	161.91	$6.0x10^{-9}$	$1.4x10^{-8}$	22
33	161.91	161.47	$3.0x10^{-9}$	$6.9x10^{-9}$	17
32	161.47	161.03	$6.3x10^{-5}$	$1.4x10^{-4}$	475
31	161.03	160.59	$4.0x10^{-5}$	$9.1x10^{-5}$	408
30	160.59	160.15	$1.0x10^{-7}$	$2.4x10^{-7}$	56
29	160.15	159.71	$3.7x10^{-6}$	$8.5x10^{-6}$	185
28	159.71	159.27	$1.1x10^{-8}$	$2.6x10^{-8}$	27
27	159.27	158.83	$5.4x10^{-7}$	$1.2x10^{-6}$	97
26	158.83	158.39	$5.8x10^{-10}$	$1.3x10^{-9}$	10
25	153.23	152.79	$1.8x10^{-9}$	$4.1x10^{-9}$	15
24	152.79	152.35	$7.3x10^{-5}$	$1.7x10^{-4}$	499
23	152.35	151.91	$4.7x10^{-7}$	$1.1x10^{-6}$	93
22	151.91	151.47	$8.7x10^{-11}$	$2.0x10^{-10}$	5
21	151.47	151.03	$1.2x10^{-8}$	$2.7x10^{-8}$	27
20	151.03	150.59	$7.0x10^{-7}$	$1.6x10^{-6}$	106
19	150.59	150.15	$3.3x10^{-6}$	$7.6x10^{-6}$	178
18	150.15	149.71	$3.1x10^{-6}$	$7.1x10^{-6}$	174
17	149.71	149.27	$4.0x10^{-5}$	$9.1x10^{-5}$	408
15	149.27	148.83	$3.4x10^{-7}$	$7.6x10^{-7}$	83
16	148.83	148.39	$3.4x10^{-10}$	$7.8x10^{-10}$	8

[a]masl-metres above sea level

Constant Head Injection Test Results:

Borehole: ANI4
Datum (ground surface): 182.76 masl[a]

Test #	Elevation (masl)	(masl)	T (m^2/s)	K (m/s)	2b (microns)
22	176.83	174.83	$9.5x10^{-6}$	$4.7x10^{-6}$	253
21	174.83	172.83	$1.9x10^{-5}$	$9.7x10^{-6}$	321
20	172.83	170.83	$7.5x10^{-4}$	$3.8x10^{-4}$	1084
19	170.83	168.83	$3.6x10^{-4}$	$1.8x10^{-4}$	851
18	168.83	166.83	$3.2x10^{-5}$	$1.6x10^{-5}$	380
63	166.83	164.83	$5.5x10^{-8}$	$2.7x10^{-8}$	45
62	164.83	162.83	$2.8x10^{-7}$	$1.4x10^{-7}$	78
61	162.83	160.83	$1.6x10^{-7}$	$8.1x10^{-8}$	65
60	160.83	158.83	$5.9x10^{-7}$	$2.9x10^{-7}$	100
59	158.83	156.83	$1.1x10^{-8}$	$5.6x10^{-9}$	27
58	156.83	154.83	$1.5x10^{-9}$	$7.6x10^{-10}$	14
8	154.83	152.83	$2.4x10^{-6}$	$1.2x10^{-6}$	161
12	152.83	150.83	$2.1x10^{-5}$	$1.0x10^{-5}$	329
11	150.83	148.83	$1.2x10^{-5}$	$6.0x10^{-6}$	272
10	148.83	146.83	$2.4x10^{-6}$	$1.2x10^{-6}$	160
57	146.83	144.83	$2.1x10^{-10}$	$1.0x10^{-10}$	7
114	172.83	172.33	$6.4x10^{-8}$	$1.3x10^{-7}$	48
113	172.33	171.83	$1.3x10^{-7}$	$2.5x10^{-7}$	60
112	171.83	171.33	$1.3x10^{-4}$	$2.6x10^{-4}$	603
111	171.33	170.83	$1.9x10^{-4}$	$3.7x10^{-4}$	681
110	168.83	168.33	$4.3x10^{-5}$	$8.5x10^{-5}$	417
109	168.33	167.83	$4.1x10^{-5}$	$8.2x10^{-5}$	411
108	167.83	167.33	$6.2x10^{-8}$	$1.2x10^{-7}$	47
107	167.33	166.83	$3.1x10^{-8}$	$6.2x10^{-8}$	38
106	166.83	166.33	$3.4x10^{-8}$	$6.9x10^{-8}$	39
105	154.83	154.33	$8.1x10^{-9}$	$1.6x10^{-8}$	24
104	154.33	153.83	$3.2x10^{-9}$	$6.4x10^{-9}$	18
93	153.83	153.33	$6.7x10^{-9}$	$1.3x10^{-8}$	22
103	153.53	153.03	$1.8x10^{-8}$	$3.7x10^{-8}$	32
102	153.43	152.93	$1.2x10^{-4}$	$2.3x10^{-4}$	584
92	153.33	152.83	$9.9x10^{-5}$	$2.0x10^{-4}$	553
101	153.23	152.73	$1.1x10^{-4}$	$2.3x10^{-4}$	576
100	153.13	152.63	$1.1x10^{-4}$	$2.3x10^{-4}$	576
99	153.03	152.53	$1.3x10^{-4}$	$2.7x10^{-4}$	608
98	152.93	152.43	$1.2x10^{-4}$	$2.3x10^{-4}$	581
91	152.83	152.33	$2.7x10^{-5}$	$5.4x10^{-5}$	358
94	152.73	152.23	$2.9x10^{-5}$	$5.9x10^{-5}$	368
95	152.63	152.13	$2.9x10^{-5}$	$5.8x10^{-5}$	366
96	152.53	152.03	$3.4x10^{-5}$	$6.7x10^{-5}$	385
97	152.43	151.93	$4.3x10^{-6}$	$8.7x10^{-6}$	195
90	152.33	151.83	$7.5x10^{-8}$	$1.5x10^{-7}$	50
79	151.83	151.33	$1.2x10^{-7}$	$2.4x10^{-7}$	59
89	151.73	151.23	$1.0x10^{-8}$	$2.1x10^{-8}$	26
88	151.63	151.13	$2.1x10^{-6}$	$4.3x10^{-6}$	154
87	151.53	151.03	$1.7x10^{-6}$	$3.5x10^{-6}$	144
78	151.33	150.83	$1.6x10^{-6}$	$3.2x10^{-6}$	140
86	151.03	150.53	$4.1x10^{-8}$	$8.2x10^{-8}$	41

[a]masl-metres above sea level

Constant Head Injection Test Results:

Borehole: ANI4
Datum (ground surface): 182.76 masl[a]

Test #	Elevation (masl)	(masl)	T (m^2/s)	K (m/s)	2b (microns)
85	150.93	150.43	$1.5x10^{-6}$	$3.0x10^{-6}$	136
77	150.83	150.33	$5.0x10^{-6}$	$9.9x10^{-6}$	203
76	150.33	149.83	$1.6x10^{-5}$	$3.3x10^{-5}$	303
84	150.23	149.73	$3.7x10^{-5}$	$7.5x10^{-5}$	399
83	150.13	149.63	$3.3x10^{-5}$	$6.6x10^{-5}$	382
82	150.03	149.53	$3.0x10^{-5}$	$6.1x10^{-5}$	372
75	149.83	149.33	$6.0x10^{-6}$	$1.2x10^{-5}$	216
80	149.53	149.03	$1.5x10^{-6}$	$2.9x10^{-6}$	136
81	149.43	148.93	$1.4x10^{-8}$	$2.9x10^{-8}$	29
74	149.33	148.83	$2.7x10^{-9}$	$5.4x10^{-9}$	17
68	148.83	148.33	$2.5x10^{-9}$	$5.0x10^{-9}$	16
73	148.43	147.93	$9.9x10^{-9}$	$2.0x10^{-8}$	26
67	148.33	147.83	$4.4x10^{-6}$	$8.9x10^{-6}$	196
72	148.23	147.73	$1.2x10^{-5}$	$2.4x10^{-5}$	273
71	148.13	147.63	$2.1x10^{-5}$	$4.2x10^{-5}$	329
70	148.03	147.53	$1.6x10^{-5}$	$3.1x10^{-5}$	298
69	147.93	147.43	$6.2x10^{-6}$	$1.2x10^{-5}$	219
66	147.83	147.33	$4.4x10^{-6}$	$8.7x10^{-6}$	195
65	147.33	146.83	$1.4x10^{-8}$	$2.7x10^{-8}$	28
64	146.83	146.33	$9.4x10^{-9}$	$1.9x10^{-8}$	25

[a]masl-metres above sea level

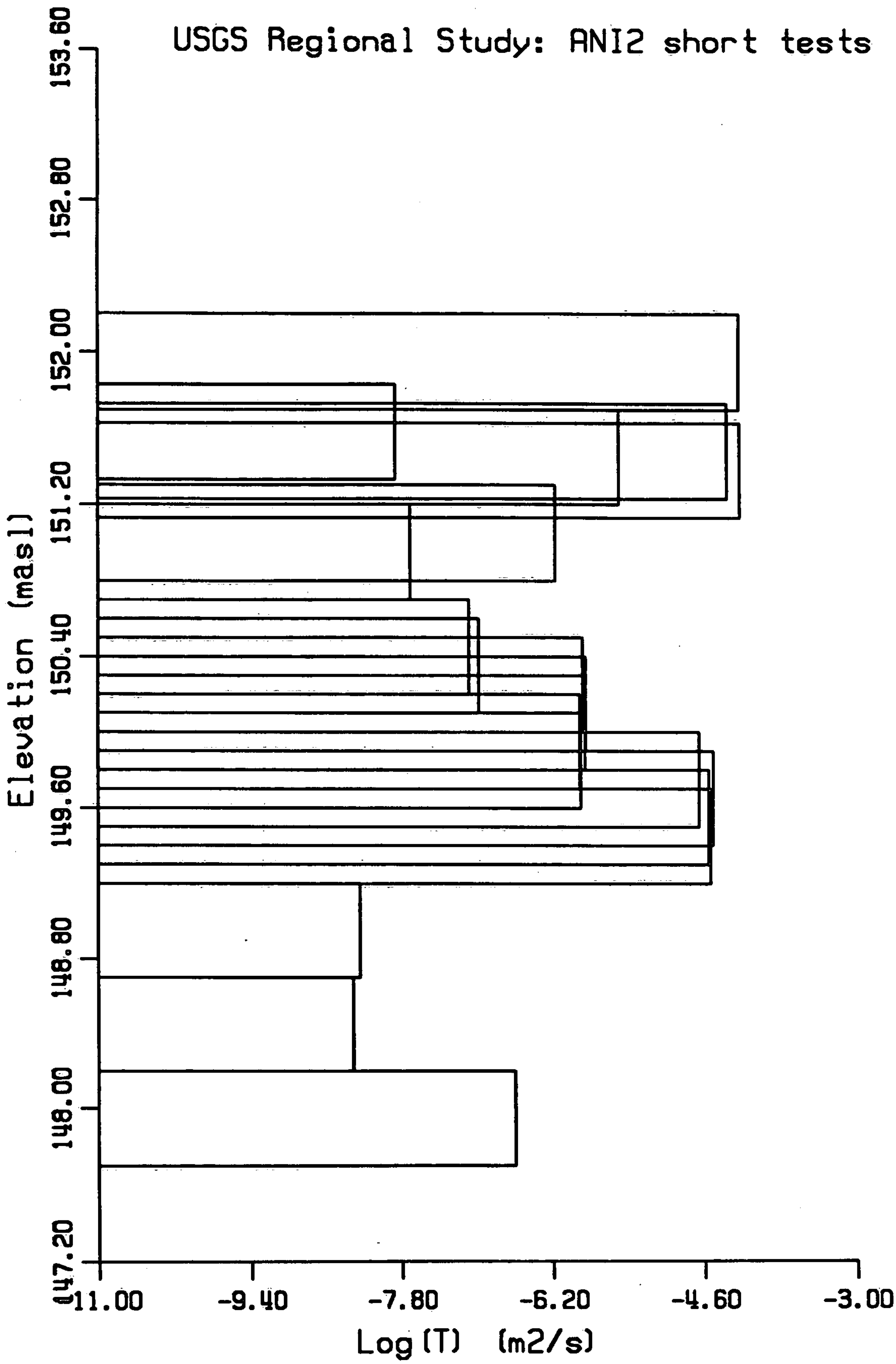
Constant Head Injection Test Results:

Borehole: AN15
Datum (ground surface): 182.48 masl[a]

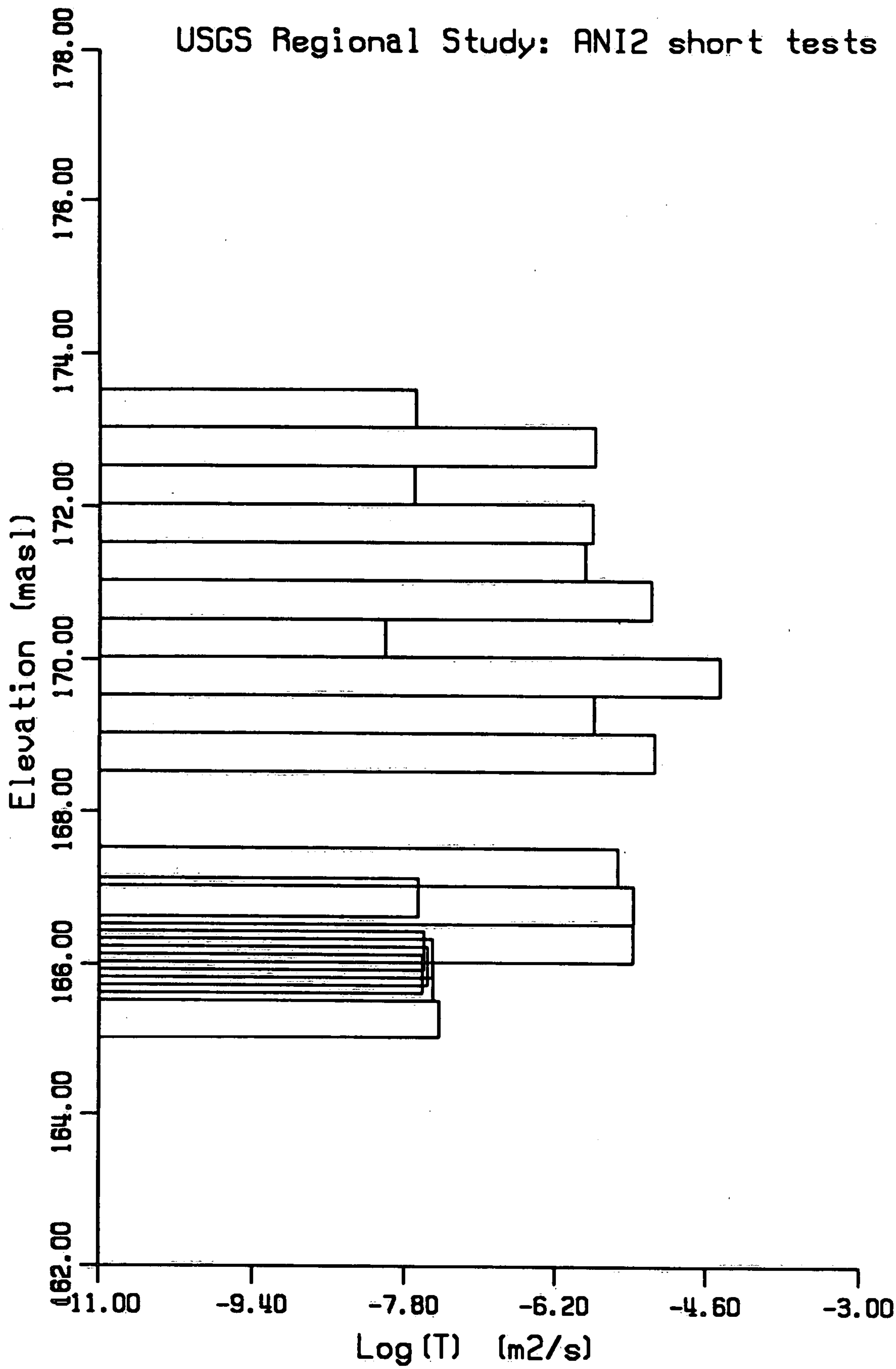
Test #	Elevation (masl)	(masl)	T (m^2/s)	K (m/s)	2b (microns)
1	147.05	144.98	$4.2x10^{-8}$	$2.0x10^{-8}$	41
2	149.12	147.05	$6.1x10^{-4}$	$3.0x10^{-4}$	1014
3	151.19	149.12	$1.0x10^{-6}$	$5.1x10^{-7}$	121
4	153.26	151.19	$6.9x10^{-5}$	$3.3x10^{-5}$	489
5	155.33	153.26	$9.4x10^{-7}$	$4.5x10^{-7}$	117
6	157.40	155.33	$3.0x10^{-7}$	$1.4x10^{-7}$	80
7	159.47	157.40	$4.9x10^{-7}$	$2.4x10^{-7}$	94
8	161.54	159.47	$6.9x10^{-4}$	$3.3x10^{-4}$	1053
9	163.61	161.54	$3.7x10^{-7}$	$1.8x10^{-7}$	86
10	165.68	163.61	$3.7x10^{-6}$	$1.8x10^{-6}$	185
11	167.75	165.68	$3.8x10^{-6}$	$1.8x10^{-6}$	186
12	169.82	167.75	$1.1x10^{-3}$	$5.1x10^{-4}$	1212
13	171.89	169.82	$4.5x10^{-5}$	$2.2x10^{-5}$	425
14	173.96	171.89	$5.9x10^{-6}$	$2.9x10^{-6}$	216

[a]masl-metres above sea level

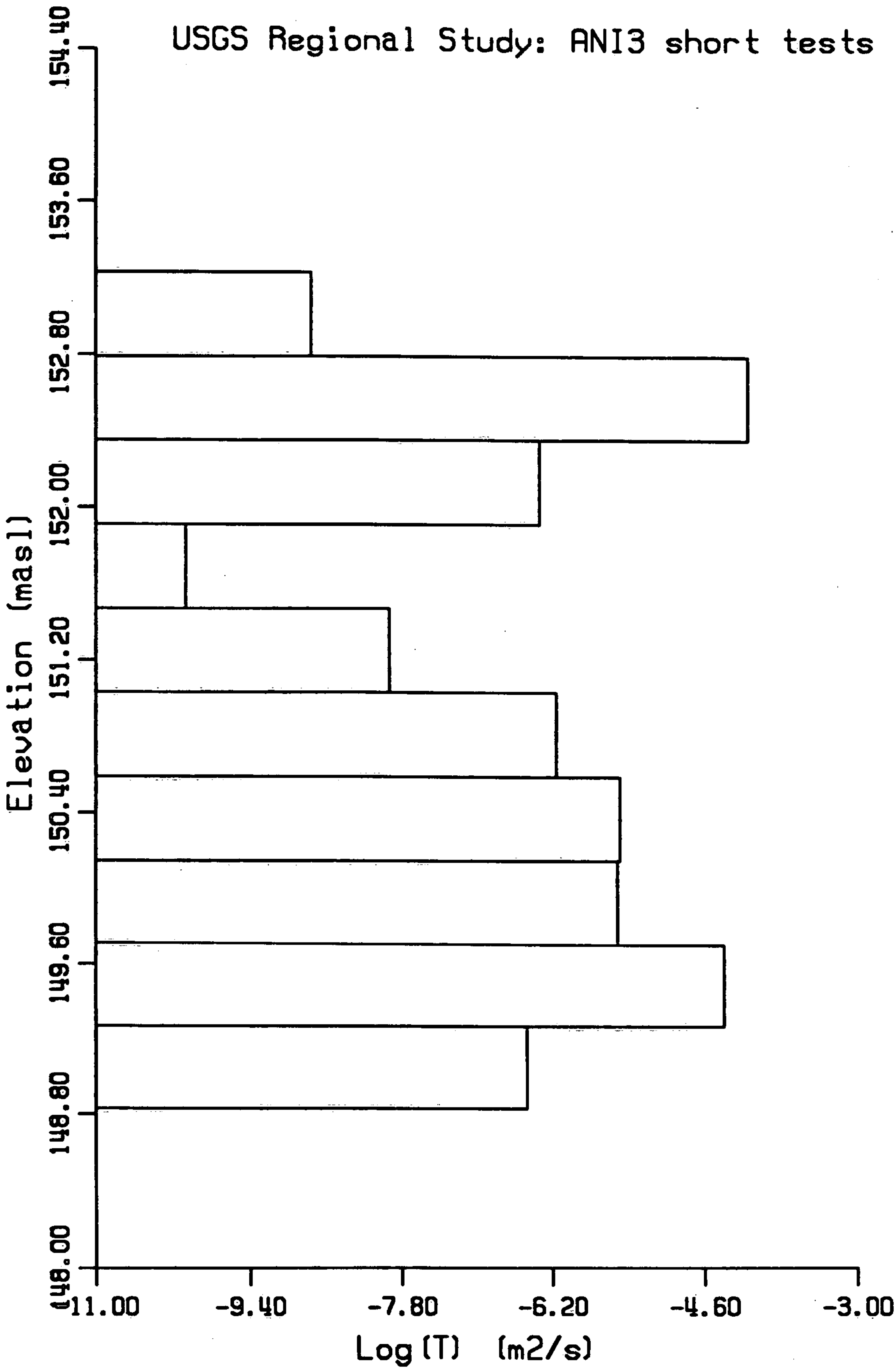
APPENDIX B
TRANSMISSIVITY PLOTS USED TO CREATE PROFILES



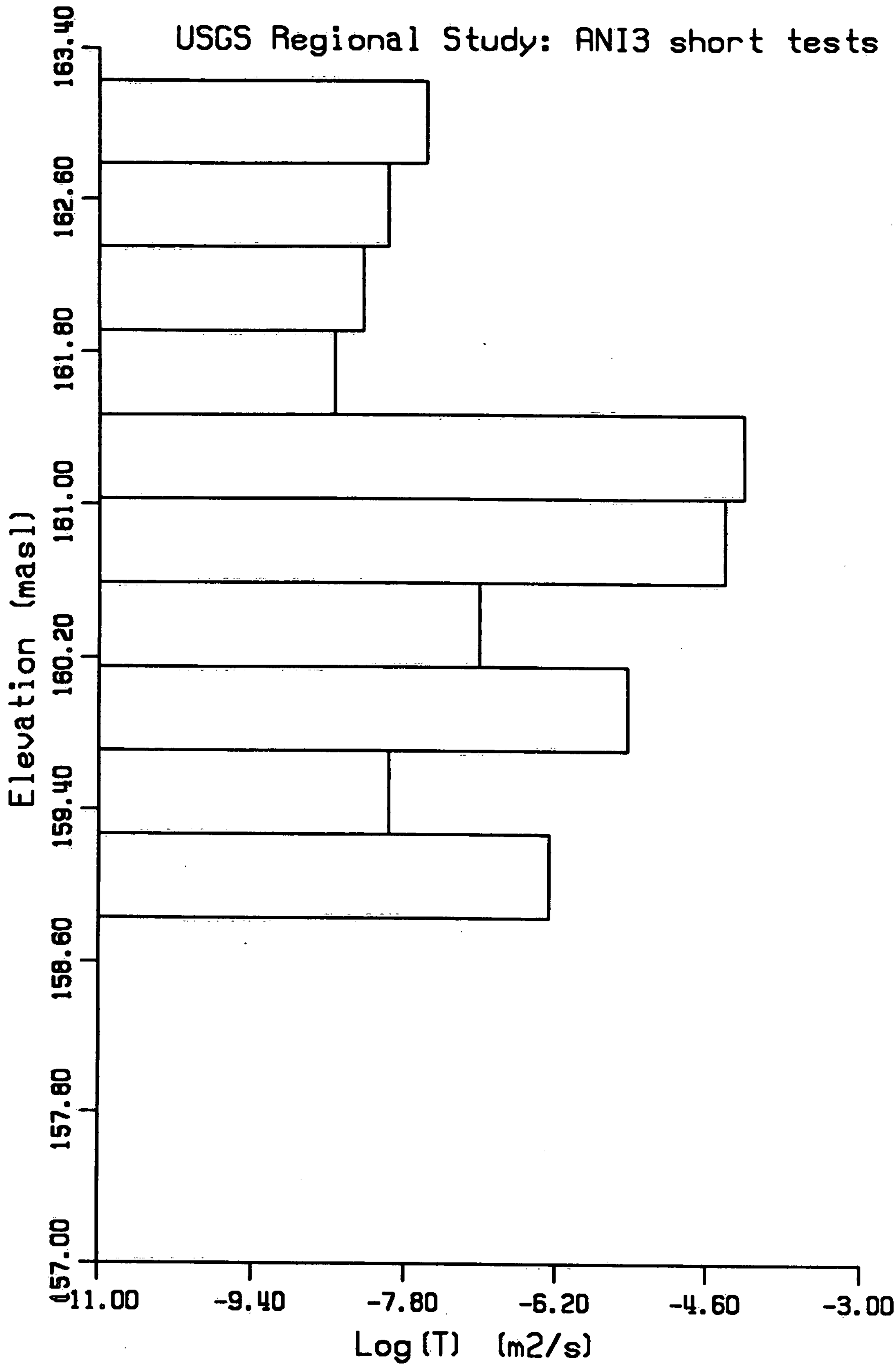
USGS Regional Study: ANI2 short tests
Elevation (masl)
153.60
152.80
152.00
151.20
150.40
149.60
148.80
148.00
147.20
-11.00
-9.40
-7.80
-6.20
-4.60
-3.00
Log(T) (m2/s)

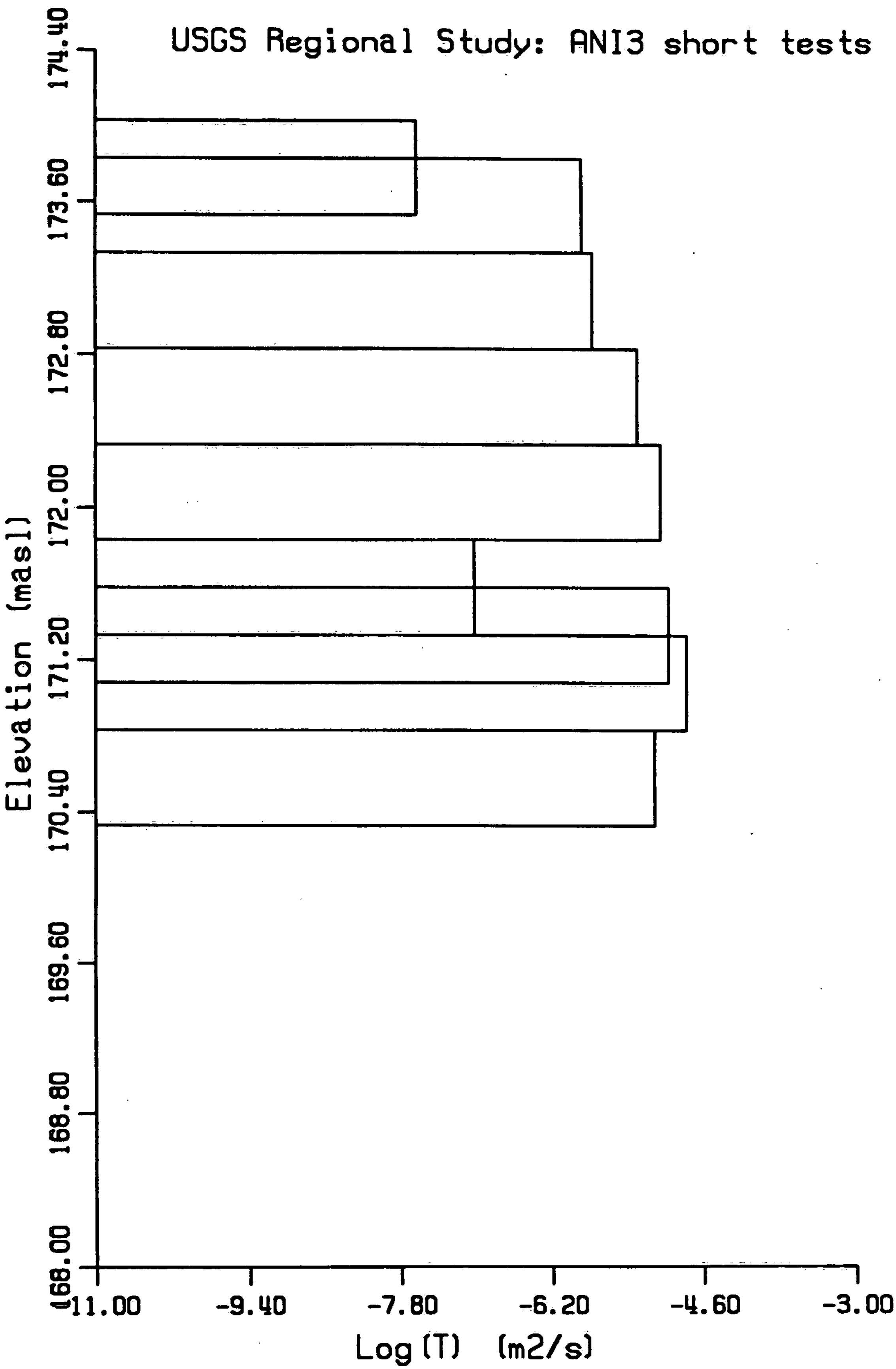


USGS Regional Study: ANI2 short tests
Elevation (masl)
178.00
176.00
174.00
172.00
170.00
168.00
166.00
164.00
162.00
-11.00
-9.40
-7.80
-6.20
-4.60
-3.00
Log(T) (m2/s)

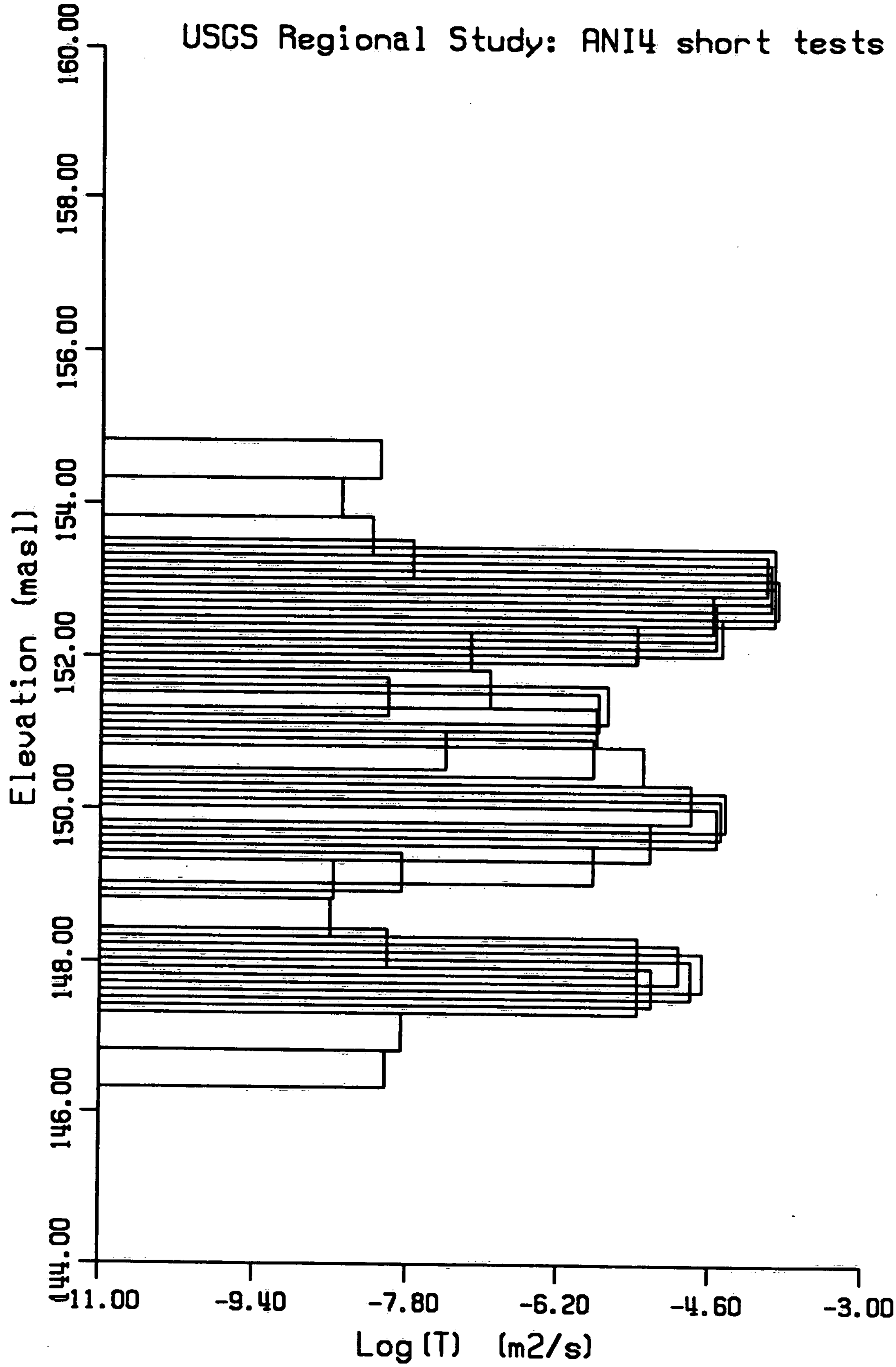


USGS Regional Study: ANI3 short tests
Elevation (masl)
154.40
153.60
152.80
152.00
151.20
150.40
149.60
148.80
148.00
-11.00
-9.40
-7.80
-6.20
-4.60
-3.00
Log(T) (m2/s)


USGS Regional Study: ANI3 short tests
Elevation (masl)
163.40
162.60
161.80
161.00
160.20
159.40
158.60
157.80
157.00
-11.00
-9.40
-7.80
-6.20
-4.60
-3.00
Log(T) (m2/s)



USGS Regional Study: ANI3 short tests
Elevation (masl)
174.40
173.60
172.80
172.00
171.20
170.40
169.60
168.80
168.00
-11.00
-9.40
-7.80
-6.20
-4.60
-3.00
Log(T) (m2/s)



USGS Regional Study: ANI4 short tests
Elevation (masl)
160.00
158.00
156.00
154.00
152.00
150.00
148.00
146.00
144.00
-11.00
-9.40
-7.80
-6.20
-4.60
-3.00
Log(T) (m2/s)

APPENDIX C
CONSTANT HEAD INJECTION TESTS USED TO EXAMINE MATRIX PERMEABILITIES

Test Results used to examine matrix permeability:

Borehole #	Test #	Elevation (masl)	(masl)	T (m^2/s)	K (m/s)
ANI2	26	166.20	164.20	$1.4x10^{-07}$	$7.0x10^{-08}$
	25	164.20	162.20	$1.4x10^{-07}$	$7.2x10^{-08}$
	7	150.20	148.20	$8.8x10^{-06}$	$4.4x10^{-06}$
	19	148.20	146.20	$1.7x10^{-08}$	$8.6x10^{-09}$
	18	146.20	144.20	$1.0x10^{-10}$	$5.0x10^{-11}$
	17	145.20	143.20	$6.5x10^{-09}$	$3.2x10^{-09}$
	64	172.03	171.53	$1.6x10^{-06}$	$3.2x10^{-06}$
	50	166.53	166.03	$4.3x10^{-06}$	$8.6x10^{-06}$
	54	166.43	165.93	$2.6x10^{-08}$	$5.1x10^{-08}$
	53	166.33	165.83	$3.2x10^{-08}$	$6.3x10^{-08}$
	52	166.23	165.73	$2.8x10^{-08}$	$5.6x10^{-08}$
	51	166.13	165.63	$2.5x10^{-08}$	$4.9x10^{-08}$
	49	166.03	165.53	$3.2x10^{-08}$	$6.4x10^{-08}$
	48	165.53	165.03	$3.7x10^{-08}$	$7.4x10^{-08}$
	35	150.20	149.70	$1.2x10^{-06}$	$2.4x10^{-06}$
	34	150.10	149.60	$1.3x10^{-06}$	$2.5x10^{-06}$
	33	150.00	149.50	$2.2x10^{-05}$	$4.5x10^{-05}$
	32	149.90	149.40	$3.2x10^{-05}$	$6.3x10^{-05}$
	31	149.80	149.30	$2.8x10^{-05}$	$5.7x10^{-05}$
	30	149.70	149.20	$3.0x10^{-05}$	$6.0x10^{-05}$
	29	149.20	148.70	$5.8x10^{-09}$	$1.2x10^{-08}$
	28	148.70	148.20	$4.9x10^{-09}$	$9.8x10^{-09}$
	27	148.20	147.70	$2.6x10^{-07}$	$5.1x10^{-07}$
ANI3	42	164.83	162.83	$4.0x10^{-08}$	$2.0x10^{-08}$
	41	158.83	156.83	$1.3x10^{-07}$	$6.3x10^{-08}$
	40	156.83	154.83	$2.8x10^{-09}$	$1.4x10^{-09}$
	35	162.79	162.35	$1.1x10^{-08}$	$2.5x10^{-08}$
	34	162.35	161.91	$6.0x10^{-09}$	$1.4x10^{-08}$
	27	159.27	158.83	$5.4x10^{-07}$	$1.2x10^{-06}$
	26	158.83	158.39	$5.8x10^{-10}$	$1.3x10^{-09}$
	21	151.47	151.03	$1.2x10^{-08}$	$2.7x10^{-08}$
	16	148.83	148.39	$3.4x10^{-10}$	$7.8x10^{-10}$
ANI4	79	151.83	151.33	$1.2x10^{-07}$	$2.4x10^{-07}$
	89	151.73	151.23	$1.0x10^{-08}$	$2.1x10^{-08}$
	106	166.83	166.33	$3.4x10^{-08}$	$6.9x10^{-08}$
	88	151.63	151.13	$2.1x10^{-06}$	$4.3x10^{-06}$
	104	154.33	153.83	$3.2x10^{-09}$	$6.4x10^{-09}$
	114	172.83	172.33	$6.4x10^{-08}$	$1.3x10^{-07}$
	87	151.53	151.03	$1.7x10^{-06}$	$3.5x10^{-06}$
	103	153.53	153.03	$1.8x10^{-08}$	$3.7x10^{-08}$

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