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Title: **Synopsis of Hydrologic Data Collected by Waste Management for Characterization of Unsaturated Transport at Area G**

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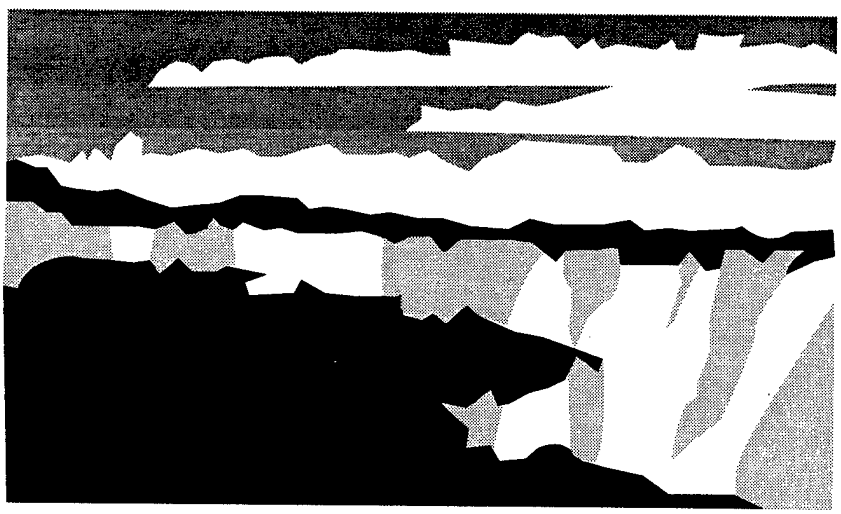

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Synopsis of Hydrologic Data Collected by Waste Management for Characterization of Unsaturated Transport at Area G

Erik Vold

Abstract

Data which have been collected by Los Alamos National Laboratory Waste Management for the hydrologic characterization of the subsurface at the low level radioactive waste disposal facility, Area G, are reported and discussed briefly. The data includes Unsaturated Flow Apparatus measurements of the unsaturated conductivity in samples from borehole G-5. Analysis compares these values to the predictions from van Genuchten estimates, and the implications for transport and data matching are discussed, especially at the location of the Vapor Phase Notch (VPN). There, evaporation drives a significant vapor flux and the liquid flux cannot be measured accurately by the UFA device. Data also include hydrologic characterization of samples from borehole G-5, Area G surface soils, Los Alamos (Cerros de Rio) basalts, Tsankawi and Cerro-Toledo layers, the Vapor Phase Notch (VPN), and additional new samples from the uppermost tuff layer at Area G. Hydraulic properties from these sample groups can be used to supplement the existing data base. The data in this report can be used to improve the accuracy and reduce the uncertainty in future computational modeling of the unsaturated transport at Area G. This report supports the maintenance plan for the Area G Performance Assessment.

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Contents:

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Introduction

The Los Alamos low level radioactive waste (LLRW) disposal facility at Area G is required by U.S. Department of Energy Orders to complete a technical evaluation of the site and its environment to understand potential future releases of radioactive waste material, its transport through the environment and the exposure risk to the public. The technical analysis is summarized in the current Performance Assessment Report [Hollis, et.al.1997]. The data base used for the hydrologic transport analyses was included in an Appendix to the Report and was compiled separately by Krier, et.al. [1995]. This compilation includes extensive site-specific and regional hydrologic data collected up to 1995, much of it taken from previous analyses [Rogers and Gallaher, 95] and [Rogers, 95].

The site Performance Assessment is a continuing project with new data collected on an on-going basis to refine the technical assessments and to reduce the uncertainty in the analyses. Since the 1995 compilation, new data has become available through Waste Management programs, from the site Environmental Restoration (ER) Project and from other sources. Specifically, the Waste Management program has initiated several studies relevant to subsurface transport at Area G to compliment the existing hydrology data base.

It is the purpose of this present report to summarize these hydrologic data from studies initiated by Waste Management, with an emphasis on the (van Genuchten) parameters used in unsaturated flow computations. In-situ moisture monitoring is also providing a valuable data base for analysis collected as part of an on-going program. The in-situ monitoring and analysis is conducted by Waste Management within boreholes completed in 1995 by the Environmental Restoration Project, with preliminary results discussed in a separate report [Vold, 1997A].

Hydrologic Data Studies

The hydrology data collected by Waste Management include several projects:

1, a suite of hydrologic parameters analyzed on core [DBSA, 1995] recovered at 10 ft intervals from vertical borehole G-5, located centrally in Area G (see Fig.1). Data included matric potential measurements by pressure plate, thermocouple psychrometer and by salt solution vapor equilibrium methods. These were used to derive moisture characteristic curves and van Genuchten parameters for modeling [Rogers, et.al.1995].

2, measurements of unsaturated hydraulic conductivity over a full range in moisture content by the UFA (unsaturated flow apparatus) method [Conca and Wright, 92]. These were measured on core samples co-located with the samples in G-5 [Conka and Mockler, 95] specifically for comparison between the unsaturated conductivity curves from the van Genuchten derived conductivity and from the UFA measured conductivity.

3, a suite of hydrologic parameters analyzed on core recovered from several sample groups [DBSA, 1996], selected to compliment the existing data [Krier, et.al.1995] at Area G. Data included moisture characteristics, derived moisture characteristic curves and van Genuchten parameters for modeling. The sample groups included vertical profiles through the Vapor Phase Notch (VPN) at locations including boreholes G-5, 1107 and 1121 at Area G (see Fig.1), basalts from beneath Mesita del Buey (Area G), Tsankawi and Cerro-Toledo samples evaluated separately and together, and surface soil samples from Area G (see locations in Fig.2).

Data from samples along vertical profiles through the Vapor Phase Notch (VPN) have been used to characterize van Genuchten properties for the VPN region. Each of these are described in this report. Also in support of Waste Management characterization studies at Area G, in-situ air permeability was measured throughout the vertical profile in borehole G-5 [SEA, 96]. The data collected in that study was discussed previously in relation to vapor flux determinations [Vold, 96B] and as summarized more recently in [Vold, 97B]. The data are repeated in this report for comparison to the VPN profile data discussed here.

Hydrologic characterization was also completed [DBSA, 96] on core samples selected from the horizontal holes drilled beneath pit 37 from pit 38 [Puglisi and Vold, 95]. The intent in these samples was to evaluate horizontal correlations in the hydrologic parameters for a comparison to vertical correlation lengths which can be inferred from the G-5 data [DBSA, 95] and other data sets. The sample integrity from the horizontal holes was poor, and the hydrologic analysis results are therefore poor quality. Analysis has been indefinately postponed, although the data may have some value in this regard.

Hydrologic Parameters in Core Samples from G-5

Core samples (6" sleeved segments) recovered during the drilling of borehole G-5 at 10' intervals were capped to preserve in-situ moisture content and sent to Danial B. Stephens and Associates for a suite of hydrologic analyses. There were 10 samples over the range of depths from 9' to 102', with the 92' sample coincidentally coinciding with the horizon of the VPN at this location. The location of borehole G-5 in Area G is shown in Fig.1, with several other boreholes and sample locations to be discussed later. A reference moisture profile in borehole G-5 is shown in Fig.3. The suite of analyses on G-5 samples included: initial (in-situ) moisture content, dry bulk density, calculated porosity, saturated hydraulic conductivity, specific surface area, air permeability over a range of moisture content, particle density, and moisture characteristics including pressure plate data, thermocouple psychrometer data in the drier region, and vapor equilibrium points at the dry end. The results were reported in [DBSA 95]. Co-located (adjacent) borehole sleeve samples were collected in order to measure hydraulic conductivity directly by the UFA method for comparisons at each location.

Subsequently, van Genuchten parameters [van Genuchten, 80] were calculated for each sample [Rogers, et.al., 95] except at the 92' sample which was reported to be cracked [DBSA 95]. However, the crack developed during air permeability testing, apparently after the moisture characteristic data was collected [Ankeny, 97]. Van Genuchten parameters for this sample were also subsequently calculated [Springer, 97].

Much of the G-5 data and some analysis of the implied moisture flux was presented previously [Rogers, et.al. 95] [Rogers, et.al. 96] and need not be repeated here. Previously unreported data is described below in two areas in order to increase the data base for Unit 2b propeties and to compare hydraulic properties at the VPN (92' in G5) from characteristic curves and from UFA measurements.

Hydraulic Conductivity by the UFA Method in Core Samples from G-5

Hydraulic conductivity was measured by the UFA method [Conca and Wright, 92] in 10 core samples (at ~ 10' intervals) from G-5 as reported in [Conka and Mockler, 95]. These samples were co-located with the samples sent to DBSA as described above for comparisons at approximately the same locations. The UFA unsaturated hydraulic conductivity results are shown in Fig. 4 for the 10 borehole core samples in G-5. Note that the data in Fig.4 at 92' is quite distinct with high moisture and low flow, characteristics more typical of a clay-like material than the volcanic tuff at other elevations.

The UFA data at all locations was combined with the in-situ moisture content by Conka and Mockler [95] to estimate a local recharge value assuming unit gradient conditions. The result at each depth is shown in Table I. In 3 out of 4 of the samples from the upper most elevations, the recharge is in reasonable agreement, in the range of ~ 1 - 10 cm/yr in this 'near-surface' region. These values agree with flux estimates using the Darcy flux analysis on the moisture profiles [Vold, 96A and Fig.14 in Vold, 1997B]. Below 50' depth, the UFA measurement suggests the recharge or flow rate is negligible, less than the UFA minimum measureable flow of $3 x 10^{-4}$cm/yr. Conka and Mockler's interpretation is that the moisture profile throughout this region must be determined by vapor phase flow since the liquid phase flow is negligible. This also agrees with the Darcy flux analyses throughout the depths 55' to 80' (see Fig.16 in [Vold,1997B]) which show the vapor flux is comparable to or exceeds the liquid flux at these depths in this borehole.

The UFA-measured hydraulic conductivity curves were compared to van Genuchten conductivity curves derived from moisture characteristics [DBSA, 95] in the co-located samples as discussed previously in two reports [Rogers, et.al. 95] and [Turin, et.al., 95]. These comparisons found the samples approximately evenly divided into three groups. In one group, the conductivity comparisons were relatively good. In a second group, comparisons were initially poor but could be improved to a relatively good agreement by normalizing the saturation and saturated conductivity points measured in each data set. The third group included sample comparisons which were poor even after this renormalization of data. The discrepencies were discussed primarily in the context of experimental differences and error.

The two methods are actually determining hydraulic conductivity under different conditions, and should not necessarily agree. The characteristic curves are determined from point measurements where the samples are dried out allowing evaporation to play a dominant role in the moisture balance of the sample. The UFA experiment measures only flow under specific 'head' conditions simulated by the centrifugal force, in such a way that does not allow any evaporation to enter in during the experimental determination. The UFA device directly measures the unsaturated flow but it is accurate only if evaporation does not play a significant role in the in-situ conditions. In our case, it is clear that vapor transport and evaporation are important at least below 50' (in G5), and therefore at these locations the UFA result cannot be accurate and the characteristic curve fit using the van Genuchten Maulem model is the best available estimate of the flow conditions where evaporation plays a significant role.

As noted previously, the data in Fig.4 at 92' is quite distinct with high moisture and low flow, characteristics typical of a clay-like material. This location is coincident with the Vapor Phase Notch in G5, and it is expected it may have unique properties. The DBSA data at this location was previously not analyzed, but it is re-examined here based on recent van Genuchten (vG) fits [Springer, 97] to the DBSA data. Fig.5 shows matric potential data (hm) from the core sample at 92' in G-5 (approximate location of the VPN), with van Genuchten characteristic curves fit to the pressure plate (PP) data alone and with the Thermocouple Psychrometer (TC) data. The fit to (PP&TC) data does not change appreciably if the vapor equilibrium (VE) data points are included.

It is expected that in the experimental conditions, the pressure plate points represent conditions with negligible evaporation while the 'low-end moisture points', seen in the thermocouple psychrometer data (TCP) and vapor equilibrium data (VE) on the curves, are acheived by evaporation drying of the samples. The pressure plate data is therefore taken under conditions more consistent with the UFA data.

It should be expected then that hydraulic conductivity calculated from a fit to the moisture characteristic points from the pressure plate data should be in better agreement with the UFA than with hydraulic conductivity from all the moisture characteristic data which includes 'evaporation-dried' data points. The unsaturated hydraulic conductivity curves estimated with the van Genuchten-Maulem model using the pressure plate data only and using all the moisture characteristic data is compared to the UFA measurement in Fig. 6. It is clear that the UFA and the pressure plate data fit are in good agreement and indicate the flow characteristics one would expect near this location *if* evaporation did *not* play a dominant role. Since the UFA data and the Darcy flux analyses [Vold, 96A, Vold, 1997B] consistently agree this is not true and that evaporation does play a significant role at these depths, the best estimate of the hydraulic conductivity at this location is from the van Genuchten-Mualem model, [van Genuchten, 80], [Mualem, 76] using the fit to the data including the 'evaporation-dried' sample determinations.

New Hydraulic Properties for Area G Computational Modeling

New hydraulic properties for Area G computational modeling are summarized in Table II. These values are recommended for subsequent unsaturated zone transport calculations related to the Area G Performance Assessment or related characterization studies. These values supplement and revise some of the previous values summarized in Krier, et.al [1995]. The new data include mean and standard deviations of the principle modeling parameters (van Genuchten parameters, etc.) for each of these sample groups: the Vapor Phase Notch (VPN), basalts from beneath Mesita del Buey (Area G), Tsankawi and Cerro-Toledo samples, surface soil samples from Area G, and a broader data base for Unit 2b. Variations (standard deviations) in the properties can be used to quantitatively compute the variations in flow under realistically varying conditions [Vold, 97C]. Data from each group is summarized and discussed in greater detail in the following, and the original data is included in a DBSA report [DBSA, 96].

Area G Surface Soil

Hydraulic properties measured on the 4 surface soil samples from Area G are shown in Table III, with the sample locations shown in Fig. 2. The samples were either on or off the top of an old disposal unit (DU) as indicated in the table. In this small sample there were no big differences on or off the DU, and all four samples showed similar characteristics. Generally, the results show this soil is clay-like and very different from the underlying tuff. The saturated conductivity is about two orders of magnitude less than the tuff and the unsaturated characteristics tend to increase this difference further at lower moisture contents.

This shows a very important point for modeling the near-surface behaviour at Area G, that the thickness of the surface soil overlying the tuff is critical to the hydraulic properties and therefore to the net infiltration into the mesa. Essentially, the near surface recharge rate may be controlled largely by the thickness of soil over the tuff. The immense difference (orders of magnitude) in infiltration by assuming tuff or by assuming soil at the surface was illustrated previously [Vold and Eklund, 96]. This difference in properties may also account in part for the wide variations observed in the distribution of moisture in near-surface soil samples [Vold and Eklund, 96].

The Table III also compares van Genuchten parameters, N and α, for different assumptions regarding the residual moisture content of the Area G surface soil samples. Even for the soil, where the residual content is significant (3-5%, volumetric content) if the residual content is evaluated as an independent parameter, there is not a large change in N or α compared to when the residual content is fixed at zero with some or all of the moisture characteristic data points.

Unit 2b Average Properties

The previous data base [Krier, et.al. 95] for hydraulic properties of Unit 2b (comprising the uppermost ~50' at Area G) included only 3 samples in Unit 2b as used in the unsaturated zone computations of the Area G Performance Assessment [Birdsell, et.al., 97]. Data from 5 of the samples in the upper 50' from borehole G-5 (all in unit 2b) have been used to supplement the previous data base. This revised 8 sample data base and comparison to the previous values using 3 samples are summarized in Table IV. Several parameter average values have changed. The standard deviations were very small previously, apparently the result of samples collected from a fairly homogeneous region, whereas now with the 8 sample data set, the standard deviations of the parameters in this unit are the largest for any of the stratigraphic units evaluated beneath Area G.

Tsankawi and Cerro-Toledo (T-CT)

Previously, the Tsankawi and the Cerro-Toledo layers were not clearly distinquished in most borehole logs, and the limited hydraulic properties were from 2 samples in a combined T-CT region. Recent borehole logging at Area G [Marin, 96] allowed borehole samples to be distinquished between the two layers and a limited number of samples (3 from CT and 2 from T) were sent to DBSA for hydrologic characterization. These data are summarized by sample and combined with the previous 2 samples to provide a 7 sample average of the T-CT layers. Averages for each group separately are provided if more detailed modeling is prefered to distinquish the two layers.

Both layers have small van Genuchten exponents, N, consistent with increased moisture content and small moisture flux. The value of N=1.31 for the Tsankawi layer is the smallest observed in any of the stratigraphic layers beneath Area G and suggests this layer is the greatest barrier to vertical recharge and thus also a likely layer to support lateral moisture movement from wetter zones (i.e., canyons or regions to the west of Area G). The other parameters exhibit a relatively small difference between the T and CT layers.

Basalts

Samples from the basalt layers beneath Mesita del Buey near Area L (0.25km west of Area G) were collected from the ER Project borehole 54-1015, which is drilled in Canada del Buey and angled 22° to the south beneath Mesita del Buey. These were analyzed at DBSA for the standard suite of hydrologic properties [DBSA,96] to provide site-specific data for the basalts at Los Alamos. The analyses were performed on relatively intact segments of the basalt and show these coherent sections of basalt have very low permeability and conductivity. However, the basalt is observed to be highly heterogeneous with many large pores, fractures, and spaces throughout the matrix, so that the properties of the intact matrix may not be relevant to the moisture flux through this zone. These findings are consistent with measurements on basalts at other locations, and also consistent with the assumptions previously made in modeling the unsaturated flow through this region [Birdsell, et.al,1997], that the flow is relatively rapid through the macropores, and not directly related to the intact basalt hydrologic parameters.

Vapor Phase Notch (VPN)

The VPN is a thin layer near the interface of a vitrified tuff unit (denoted 1a by Baltz or 1g by ER project nomenclature) and a devitrified tuff units (1b or 1v or 1vc). The horizon is coincident with canyon floors at many locations but not always. It is observed throughout the Pajarito plateau to be associated with a moisture spike with a peak near 10-30% depending upon location, and an average of about 17% for the boreholes at Area G. Darcy flux analyses, based on in-situ moisture profiles and stratigraphic averaged hydraulic properties, have shown a curious trend near the VPN with an apparent moisture source at that horizon and with moisture moving in liquid and vapor phases away from that plane at most boreholes at Area G [Vold,96A, 96B, Vold, 97B]. Darcy flux analyses, based on in-situ moisture and on the point-by-point hydraulic properties presented in this report, were discussed recently [Vold, 97] and tend to agree that an apparent moisture source to the vertical recharge rate exists at the VPN horizon. The magnitudes of local moisture flux are small (a few mm/yr) and comparable to the magnitude of uncertainty in the analysis, thus it is only the trend observed over many boreholes which suggests a real moisture source term. When flux is averaged over regions both above and below the VPN the net flux tends towards zero, consistent with a local source and flux in both directions.

One interpretation of the data is that the VPN has unique properties and the moisture spike is attributable to these property variations with a negligibly small flux through the region. However, a large variation in properties usually drives a variation in hydrologic flows and so there is probably a small moisture source at the VPN associated with lateral moisture movement, with transients, or other moisture sources, perhaps from the fracture network. Thus, it is likely that both interpretations of the data through the VPN profiles are contributing to the situation. The moisture spike is in part attributable to property variations and in part attributable to a local moisture source which is in turn probably related to the variations in the vertical profiles.

Average properties for the VPN (included in the summary Table II) were derived from data in vertical profiles through the Vapor Phase Notch (VPN) at 4 locations including boreholes G-5, 1107 and 1121 at Area G and one mesa edge near surface sample from Mortendad Canyon. In obtaining the VPN average properties, the VPN was assumed to be characterized by one data point closest to the VPN horizon from each of the profiles described in the following. Based on the sample spacing, a consistent vertical extent for the VPN is then about 5-10'. The 3 locations at Area G including boreholes G-5, 1107 and 1121 were identified in Fig.1, and the samples were taken from boreholes during drilling. Samples from Mortendad Canyon were collected at a location where the VPN is visibly apparent on the side of the mesa [D. Broxton, 1996, personal communication]. This allowed samples to be related to elevation with respect to the observed VPN. Samples were collected by chipping off tuff from the mesa edge and analysed so that the 'in-situ interior side' of the sample was represented. Data from each of these profiles are discussed in the following.

Figures 7 to 14 show the profiles of hydraulic parameters measured or calculated on core samples traversing the Vapor Phase Notch (VPN). Results from different profiles are combined in each figure by 'normalizing the depth of the VPN' to be at 100' in each profile. The actual depth of the VPN is estimated from borehole log data [Marin, 96] and from the location of the moisture spike in the borehole profiles [Vold, 97A]. It will be seen that the data indicates the estimated depth of the VPN is uncertain by a few feet, and probably in error by that much in the figures.

Figure 7 shows profiles verses depth of saturated hydraulic conductivity, Ksat, measured on core samples traversing the vapor phase notch (VPN). This includes values from the 4 profiles described above, and from a fifth profile measured by Conka on the second set of G-5 samples [Conka and Mockler, 95]. Two of the 5 profiles show an apparent trend towards a local minimum at the VPN, while the other 3 profiles show no apparent trend. Overall, the average of the values from the samples at 100' (our estimated VPN location) is significantly less than the average of the values from the surrounding tuff in the layers above or below the VPN horizon.

Figure 8 shows profiles verses depth of the van Genuchten parameter, α, (labelled vGa) as fit to characteristic data measured on core samples traversing the vapor phase notch (VPN). The spike at 99' in the 1107 sample is assumed to be an outlier and the value at 101' was used in evaluating the average VPN value. There is no apparent trend in the profiles.

Figure 9 shows profiles verses depth of the van Genuchten parameter, N, (labelled vGn) as fit to characteristic data measured on core samples traversing the vapor phase notch (VPN). Each profile shows a trend with a minimum value at one sample point near the 100' estimate of the VPN horizon. The minimum value in each profile was assumed to be at the VPN and used to obtain the VPN average. This would tend to be a minimum for the estimate in the VPN average. As a low estimate, this will tend to increase moisture and reduce recharge rate from the actual field conditions when used in computations. These profiles provide an estimate of the vertical extent of the VPN, seen in the figure to be about 5-10'.

Profiles of specific surface area measured on core samples traversing the vapor phase notch (VPN) verses depth, are seen in Fig. 10 from two boreholes. This parameter shows the clearest trend with depth, with a local maximum near the estimated depth of the VPN. This correlates well with the moisture spike seen in the profiles of each of these boreholes [Vold, 97A]. The peak width is about 7' consistent with the VPN width estimated above.

A problem for computational modeling is that the specific surface area is not directly used in determining the hydraulic flow properties in the van Genuchten-Mualem model, and so this profile is not directly relevant to computational modeling results of flow through the VPN. It is suggested that the empirical van Genuchten parameter, N, incorporates the physics associated with the specific surface area, and so the effects of the obvious profile in surface area are incorporated into the modeling effort through the more subtle profile variations observed in the van Genuchten parameter, N.

Profiles of saturation moisture content measured on core samples traversing the vapor phase notch (VPN), verses depth are seen in Fig. 11. There is no apparent trend near the VPN and the mean values are similar to that in the nearby tuff. Figure 12 shows profiles of bulk density verses depth measured on 4 sets of samples traversing the vapor phase notch (VPN). Two profiles (MC and 1107) show an apparent trend with a local minimum in bulk density near the VPN, while the other two profiles suggest no significant trend. This physical parameter also has no direct input to determining the van Genuchten model parameters but is presumably implicitly folded in to the parameter results.

Profiles in Fig. 13 of air permeability verses depth at the in-situ moisture content measured on core samples traversing the VPN in two boreholes (1107 and 1121) are inconclusive for trends. Profiles in Fig. 14 [discussed originally in Vold, 96B] over the whole borehole depth for borehole G-5 compares in-situ air permeability to core sample air permeability. The in-situ data was measured with a packer-isolation air injection system by W. Lowry, et.al., SEA, Inc [SEA, 95]. The core sample data is from Daniel B. Stephens and Associates [DBSA, 95].

The in-situ permeability values are larger at every location by a factor of 3-10 over the core sample values. This may reflect experimental technique differences but probably reflects a real difference in the in-situ values effectively integrating over a volume which includes fractures or other large macropores excluded from the core sample measurement. These issues were discussed in greater detail previously [Vold, 96C] in relation to a model for 'enhanced' vapor diffusion through the fractured matrix, based on analyses of local pressure fluctuations [Vold, 96D]. Each of the profiles in Fig.14 shows a large increase near the VPN, at ~92' (or 28m). This is consistent with the profiles for specific surface area seen in Fig. 10, and supports the view that the VPN is a horizon with unique properties. Large air permeability indicates the potential for significant vapor phase contributions to the moisture flux in this region, in agreement with the UFA data discussed previously and the Darcy flux analyses [Vold, 96A and Vold 97B]. Large permeabilities at this horizon could also indicate a tight coupling at this location to the fracture network which exists throughout the mesa subsurface. This could act as a moisture source to the matrix during moisture transients in the fractures and as a moisture sink during the drying phase between near-surface moisture transients. It remains to be demonstrated whether surface moisture transients can penetrate to this depth through the fractures.

Conclusions

Data which has been collected by Waste Management for the hydrologic characterization of the subsurface at Area G are reported and discussed briefly. This data can be used in future environmental transport modeling efforts concerning Area G and can be used in support of the maintenance plan for the Area G Performance Assessment.

The data includes measurements of the unsaturated conductivity for samples from borehole G-5 using the Unsaturated Flow Apparatus. Analysis compares these values to the predictions from van Genuchten parameter fits using characteristic moisture and saturated conductivity data. A detailed comparison at the VPN location has implications for transport that in this region, vapor flux is a dominant moisture flux mechanism and therefore the UFA cannot give a result which is directly relevant to the field conditions. The best estimate for flux at the very dry end is from the van Genuchten-Mualem model.

Data also include hydrologic characterization of samples from borehole G-5, Area G surface soils, Los Alamos specific (Cerros de Rio) basalts, Tsankawi and Cerro-Toledo layers, the Vapor Phase Notch (VPN), and additional new samples from the uppermost tuff layer at Area G. Area G surface soils have hydraulic conductivies which are about two orders of magnitude less than that for the tuff under typical moisture conditions, and therefore the cover thickness of this soil, which varies from none to a few feet at Area G locations, will critically determine the surface infiltration rate, which in turn serves as the driving boundary condition for the deeper recharge rate. The data reported here from the basalts, Tsankawi, and Cerro-

Toledo are among the first available for these units at Los Alamos. The new data from the uppermost tuff layer at Area G revises the previous data base [Krier, et.al., 95] in small but significant changes to the computational transport model parameters. Average values representing the Vapor Phase Notch are estimated for the first time from data taken on vertical profiles through the VPN horizon. These profiles show significant variations at the VPN primarily in air permeability, specific surface area, and to a lesser extent in the saturated conductivity. These variations in profiles at the VPN for several physical parameters are reflected in a significant profile variation in the computational model parameter, the van Genuchten exponent, N.

The averages and the variations in hydraulic properties from these sample groups can be used in the future to improve the accuracy and reduce the uncertainty in computational modeling of the unsaturated transport at Area G.

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Tables

Table I
UFA recharge estimates [Conka and Wonkler,1995] in borehole G-5.

depth -ft-	recharge -cm/yr-
9.5	15
21	<< $3x\ 10^{-4}$
32	0.19 - 1.5 *
42	0.22 - 1.2 *
52	<< $3x\ 10^{-4}$
60	<< $3x\ 10^{-4}$
70.5	<< $3x\ 10^{-4}$
82	<< $3x\ 10^{-4}$
92	<< $3x\ 10^{-4}$
102	~ $3x\ 10^{-4}$

* the range indicates the uncertainty in the in-situ moisture content

TABLE II

Hydrology Parameter Summary Table

Hydrology Modeling Parameter Summary

sample group		Ksat	α	N	θr	θs
			van Genuchten	fitting	parameters	
		-cm/s-	-1/cm-	ND*	(%)	(%)
Area G surface soils						
(on or off DU)	**mean**	4.68E-06	0.0107	1.3063	3.8750	41.1750
n = 4	st.dev	2.24E-06	0.0033	0.0144	0.9570	1.5196
Area G Tuff -upper layer						
Unit 2b (Baltz notation)						
n = 8 **	**mean**	3.59E-04	0.0050	2.1327	1.3625	41.3875
	st.dev	5.27E-04	0.0024	0.3313	1.2873	3.7065
Cerro-Toledo (CT)						
n = 3	**mean**	1.53E-04	0.0083	1.5823	1.0800	41.2994
	st.dev	1.13E-04	0.0019	0.0810	0.5500	1.3771
Tsankawi (T)						
n = 2	**mean**	9.93E-05	0.0237	1.4559	0.4650	47.4996
	st.dev	2.32E-05	3.54E-05	0.1250	0.1626	1.5150
Tsankawi-						
Cerro Toledo (T-CT)						
n = 7 ***	**mean**	3.41E-04	0.0147	1.5245	0.8243	44.7853
	st.dev	5.17E-04	0.0071	0.1009	0.6281	3.8281
Basalt						
n = 4	**mean**	2.07E-09	0.0294	1.3180	0.5339	9.9843
	st.dev	1.54E-09	0.0306	0.0907	0.1253	4.8501
Vapor Phase Notch- VPN						
n = 5 ****	**mean** ****	6.89E-05	0.0044	1.4270	0.4800	50.3000
	st.dev ****	8.86E-06	0.0025	0.0260	0.3000	4.1000

* - ND = non-dimensional van Genuchten exponent.
** - Unit 2b average of n=8 samples includes data from 3 samples reported in Krier, et.al.[1995].
*** - T-CT average of n=7 samples includes data from 2 samples reported in Krier, et.al.[1995].
**** - VPN statistics are approximated from profile data as described in the text.

TABLE III
Hydrology Parameters for Area G Surface Soil

Area G surface soil samples

		van Genuchten fits - all data - theta residual independent				measured Ksat
ID	location/DU	theta res -%-	theta sat -%-	alpha (cm-1)	N	Ksat -cm/s-
54-501	on DU	3.4	40	0.0082	1.3271	5.40E-06
54-502	off DU	3.9	42.9	0.0083	1.3042	5.40E-06
54-503	off DU - in SF	3	42	0.0152	1.2951	6.50E-06
54-504	on DU	5.2	39.8	0.0111	1.2986	1.40E-06
	mean	3.875	41.175	0.0107	1.30625	4.675E-06
	st.dev	0.95699181	1.51959424	0.00328735	0.01439641	2.2441E-06

		van Genuchten fits - all data - theta residual set to zero			van Genuchten fits - excluding RH data pt. - theta residual set to zero	
		theta res -%-	alpha (cm-1)	N	alpha (cm-1)	N
54-501	on DU	0	0.0082	1.2845	0.0091	1.3056
54-502	off DU	0	0.0078	1.2703	0.0099	1.2943
54-503	off DU - in SF	0	0.015	1.2642	0.0192	1.2839
54-504	on DU	0	0.0108	1.2438	0.0137	1.2831
	mean	0	0.01045	1.2657	0.012975	1.291725
	st.dev	0	0.0033121	0.01689635	0.00460968	0.01056358

TABLE IV
Hydrology Parameters for Unit 2b properties

unit 2b properties reviewed

Krier, et.al.		theta res -%-	theta sat -%-	alpha (cm-1)	N	Ksat -cm/s-
5 LLC 85-15	10' (Area L)	3.8	46.4	0.006	2.044	1.60E-03
8 LLC 85-14	29' (Area L)	0	44.1	0.006	1.89	4.20E-04
54-1006	41.5' (Area G)	0	44.9	0.0064	1.76	4.10E-04
	mean	1.26666667	45.1333333	0.00613333	1.898	0.00081
	st.dev	2.19393102	1.16761866	0.00023094	0.14216891	0.00068418
DBSA - G-5		van Genuchten fits from Rogers, et.al. (LA-UR-95-???)				
G-5		fit values	empirical data			
	21.5' (all pts)	0	43.2	0.00703	1.63357	
	21.5 (- 2 pts)	1.8	43.2	0.00818	2.9848	
	52.5 (all pts)	1.85	37.6	0.00204	2.9474	
	52.5 (- 1 pt)	0.39	37.6	0.00186	2.03611	
	9' (-1pt)	2.64	39.9	0.00759	1.74698	2.10E-04
	21.5 - ave	0.9	43.2	0.007605	2.309185	1.30E-04
	32.5 (all pts)	1.22	36.7	0.00285	2.6336	3.10E-05
	42.5 (all pts)	1.22	38.3	0.00186	2.18579	2.70E-05
	52.5 - ave	1.12	37.6	0.00195	2.491755	4.00E-05
G-5						
	5 loc.mean	1.42	39.14	0.004371	2.273462	0.0000876
	5 loc st.dev	0.69440622	2.55401644	0.00297071	0.34040308	8.05E-05
8 pt averages						
		1.3625	41.3875	0.00503188	2.13266375	0.0003585
		1.28727564	3.70653381	0.00242695	0.33128386	0.00052653

TABLE V

Hydrology Parameters for Tsankawi - Cerro Toledo (T-CT)

T-CT properties	Ksat -cm/s-	α (cm-1) Calculated Value	α 95% Confidence Limits Lower	α 95% Confidence Limits Upper	N (dimensionless) Calculated Value	N 95% Confidence Limits Lower	N 95% Confidence Limits Upper	θr (%)	θs (%)
Cerro Toledo									
T-CT-54-1123-91.5-92.0	2.77E-04	0.0105	0.0067	0.0143	1.4894	1.3848	1.5939	1.1	39.8
T-CT-54-1121-124.5-125.0	5.60E-05	0.0078	0.0052	0.0104	1.6195	1.4707	1.7682	1.6	42.6
T-CT-54-1121-134.5-135.0	1.25E-04	0.0067	0.0051	0.0084	1.6380	1.5246	1.7514	0.5	41.5
mean	**1.53E-04**	**8.33E-03**	**5.67E-03**	**1.10E-02**	**1.58E+00**	**1.46E+00**	**1.70E+00**	**1.08E+00**	**4.13E+01**
st.dev	0.00011312	0.00191649	0.00089629	0.00300056	0.0809918	0.07050775	0.09615004	0.55	1.37714413
n = 3									
Tsankawi									
T-CT-54-1123-89.0-89.5	8.30E-05	0.0238	-0.0001	0.0476	1.3675	1.1943	1.5408	0.4	46.4
T-CT-54-1121-121.0-121.5	1.16E-04	0.0237	0.0159	0.0315	1.5444	1.4254	1.6633	0.6	48.6
mean	**9.93E-05**	**2.37E-02**	**7.90E-03**	**3.96E-02**	**1.46E+00**	**1.31E+00**	**1.60E+00**	**4.65E-01**	**4.75E+01**
st.dev	2.3155E-05	3.5355E-05	0.01131371	0.01138442	0.12503769	0.16341238	0.08662058	0.16263456	1.51501143
n = 2									
T-CT together									
mean	**1.31E-04**	**1.45E-02**	**6.56E-03**	**2.24E-02**	**1.53E+00**	**1.40E+00**	**1.66E+00**	**8.34E-01**	**4.38E+01**
st.dev	8.5945E-05	0.00854401	0.0058222	0.01675897	0.10943073	0.12620651	0.09821913	0.52089346	3.61317285
n = 5									
Krier, et.al. data - T_CT									
CDBM1 -89'	2.30E-04	0.0131			1.428			0	44.3
CDBM1 - 94'	1.50E-03	0.0173			1.585			1.6	50.3
Krier, et.al. 2 pt. average	**8.65E-04**	**0.0152**			**1.506**			**0.8**	**47.3**
All 7 point averages									
mean	**3.41E-04**	**1.47E-02**			**1.52E+00**			**8.24E-01**	**4.48E+01**
st.dev	0.00051719	0.00708911			0.10094098			0.62808856	3.82810028

TABLE VI

Hydrology Parameters for Basalts beneath Area G *

Basalt Sample Number	Ksat -cm/s-	α (cm-1) Calculated Value	α 95% Confidence Limits Lower	α 95% Confidence Limits Upper	N (dimensionless) Calculated Value	N 95% Confidence Limits Lower	N 95% Confidence Limits Upper	θr (%)	θs (%)
54-1015-BAS-384.5-385.0	1.80E-09	0.0218	0.0121	0.0314	1.2941	1.2406	1.3475	0.7	16.2
54-1015-BAS-464.0-464.5	8.74E-11	0.0218	0.0121	0.0314	1.2941	1.2406	1.3475	0.5	4.5
54-1015-BAS-465.0-467.5	2.65E-09	0.0012	0.0003	0.0021	1.4478	1.2608	1.6348	0.5	8.7
54-1015-BAS-520.5-522.0	3.75E-09	0.0730	-0.0228	0.1688	1.2360	1.1402	1.3318	0.5	10.5
4 point averages									
mean	2.07E-09	0.0294	0.0004	0.0584	1.3180	1.2206	1.4154	0.5339	9.9843
st.dev	1.5433E-09	0.03062547	0.01645223	0.07486843	0.09074269	0.05440646	0.14645379	0.12534126	4.85008145

* - the borehole location is angled under Area L, ~1/2 km to the west of the active portion of Area G

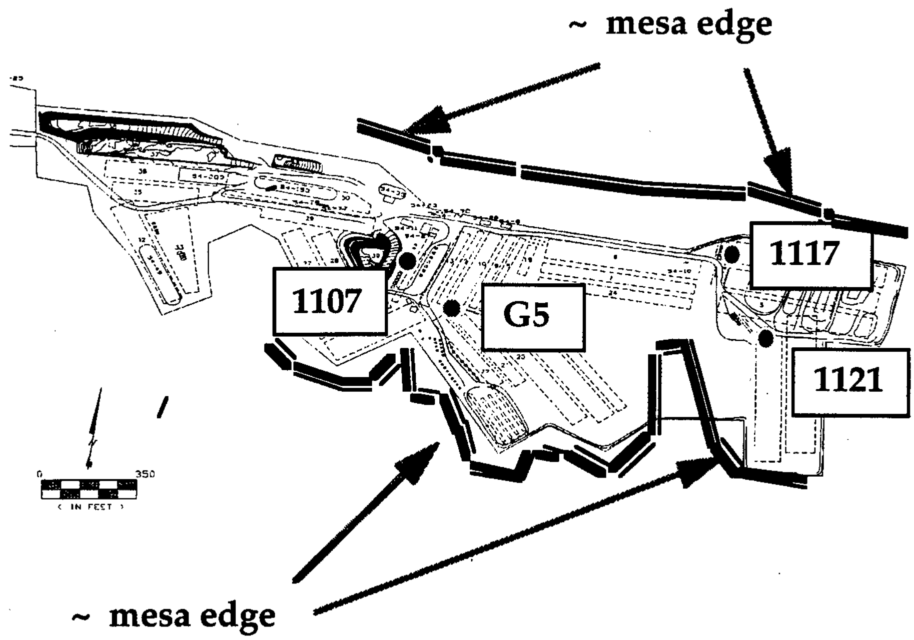

Fig.1 Area G facilities map showing locations of boreholes discussed in this report.

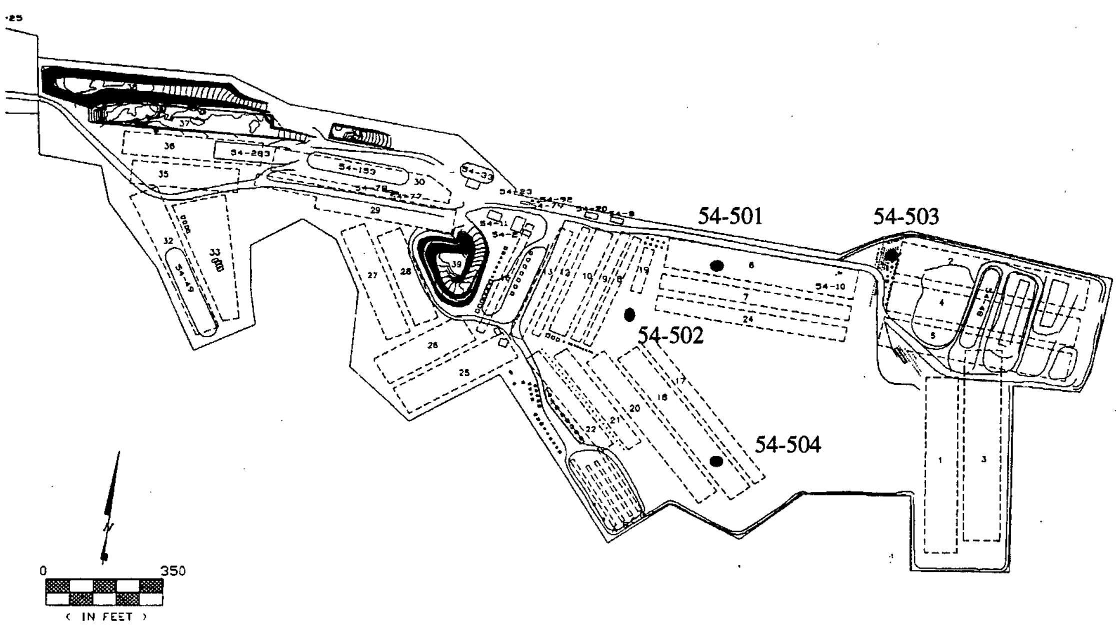

Fig.2 Area G facilities map showing locations of the four surface soil samples discussed in this report.

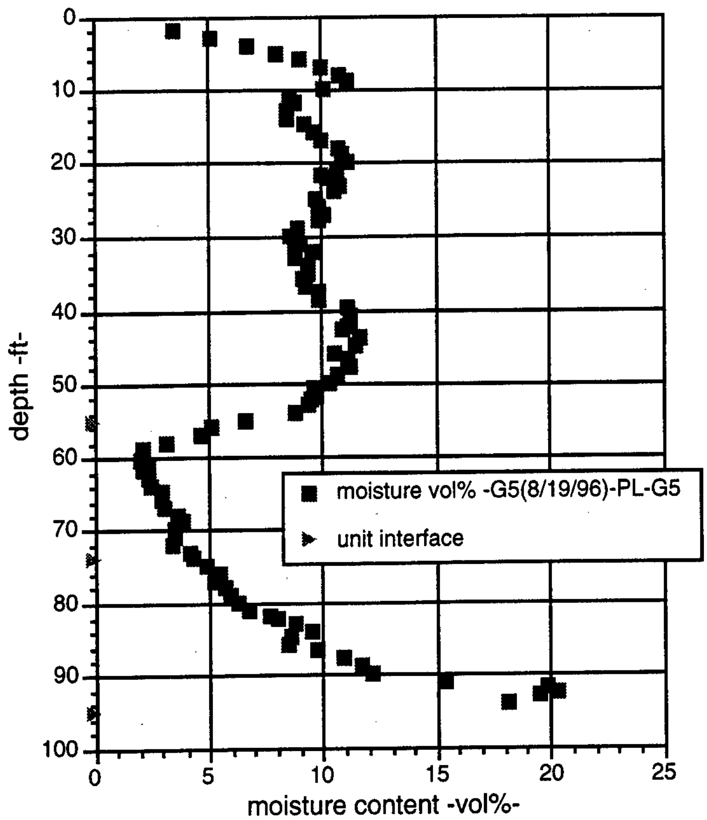

Fig. 3 Reference moisture profile in borehole G-5.

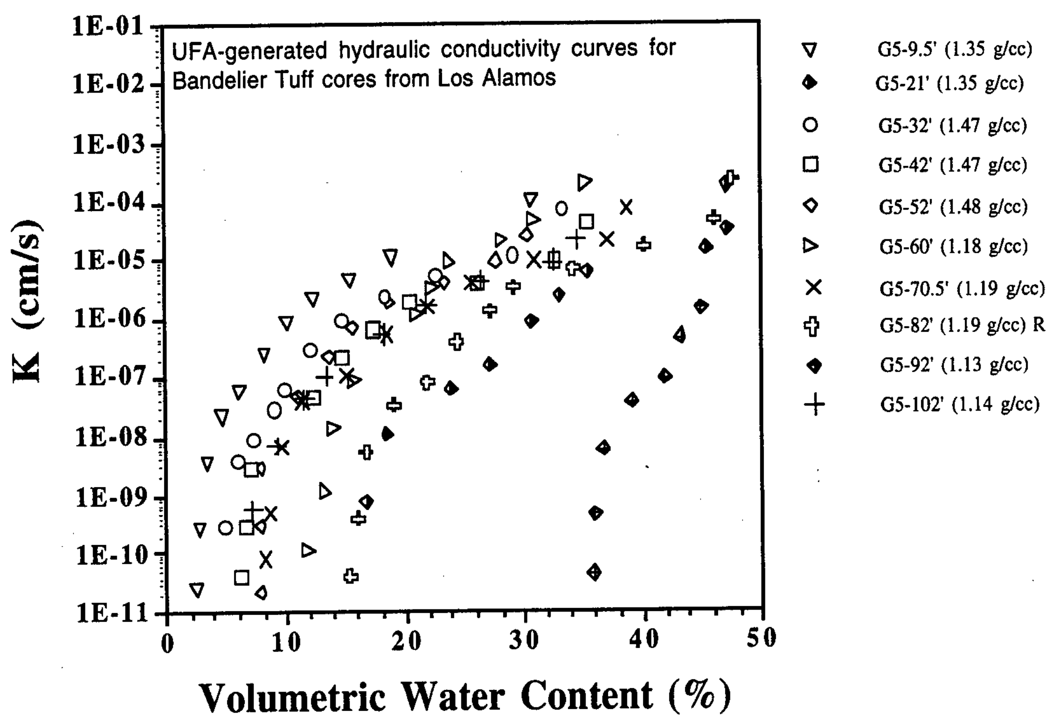

Fig. 4 Hydraulic conductivity data from the 10 borehole core samples in G-5 measured by UFA - Unsaturated Flow Apparatus [Conka and Wonkler, 1995].

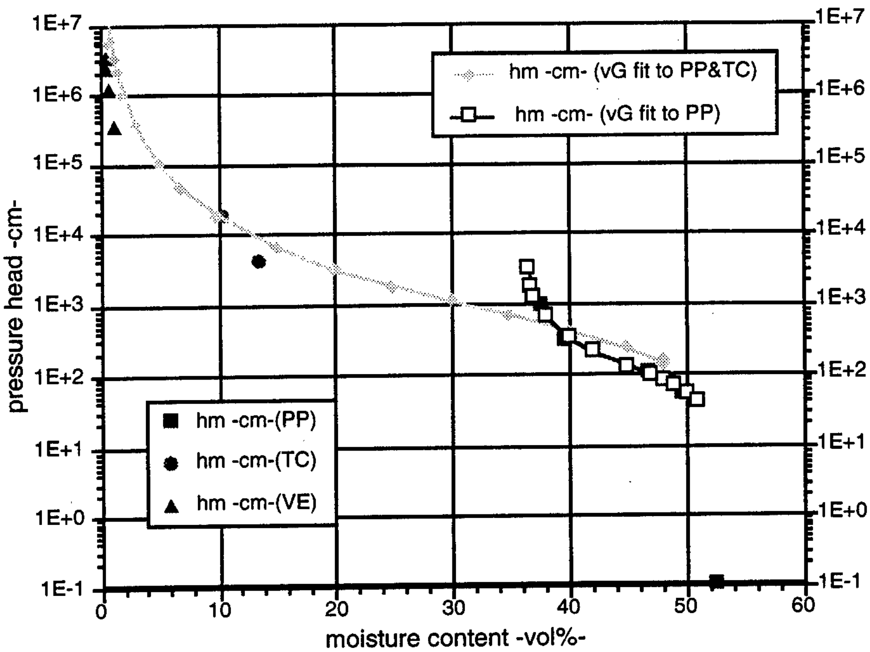

Fig. 5 Matric potential data (hm) from the core sample at 92' in G-5 (approximate location of the VPN), with van Genuchten characteristic curves fit to the pressure plate (PP) data alone and including the Thermocouple Psychrometer (TC) data.

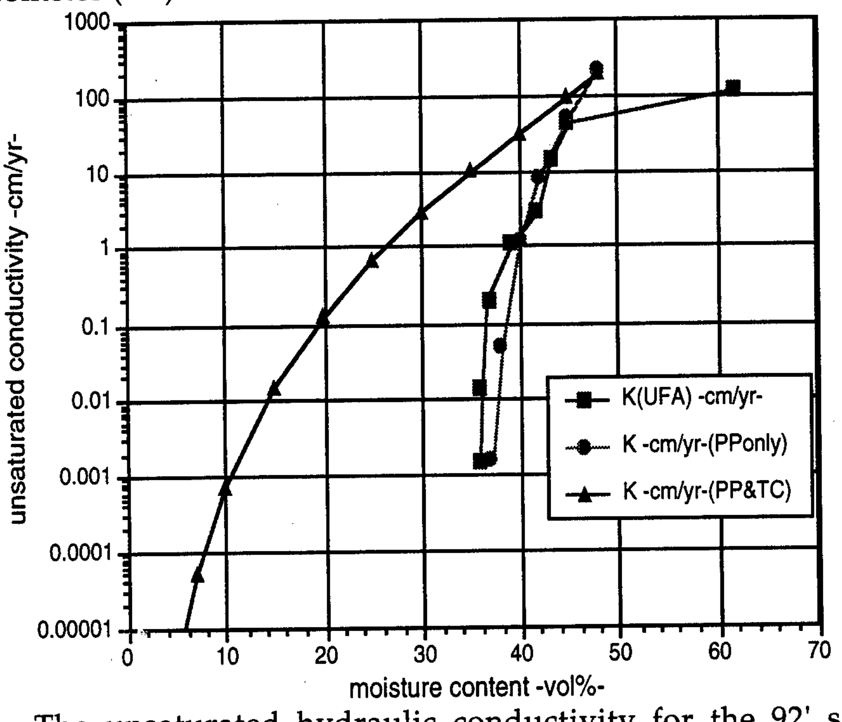

Fig. 6 The unsaturated hydraulic conductivity for the 92' sample in G-5 (approximate location of the VPN) as measureed by the UFA, labelled K(UFA), and for the two van Genuchten-Maulem model fits to the matric potential data as shown in Fig. 5, for the pressure plate (PP) only data and for the PP data with the thermocouple psychrometer (TC) data.

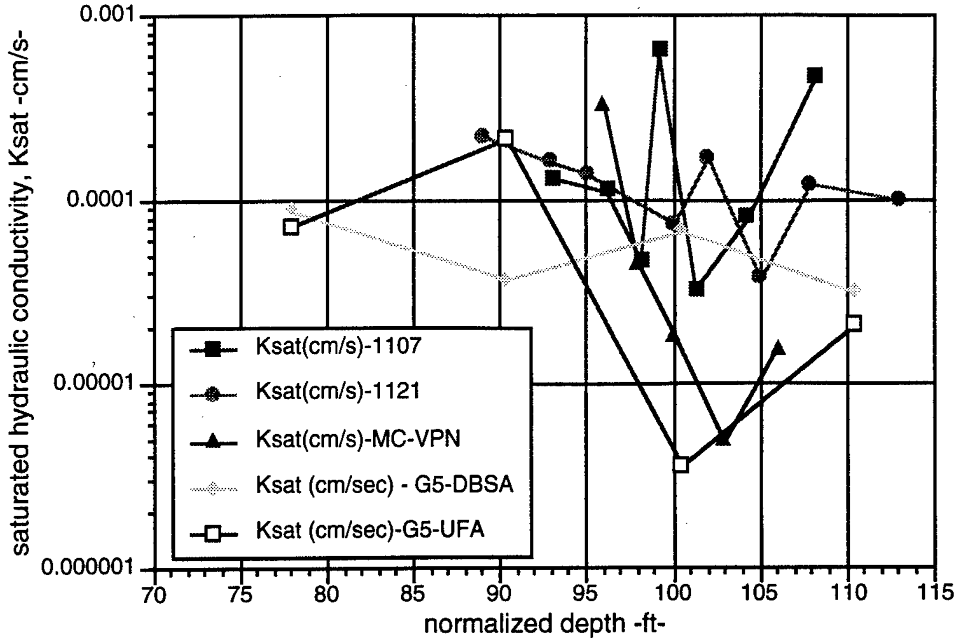

Fig. 7 Profiles verses depth of saturated hydraulic conductivity, Ksat, measured on core samples traversing the vapor phase notch (VPN), with the depth of the VPN normalized to be at approximately 100' in each of the boreholes.

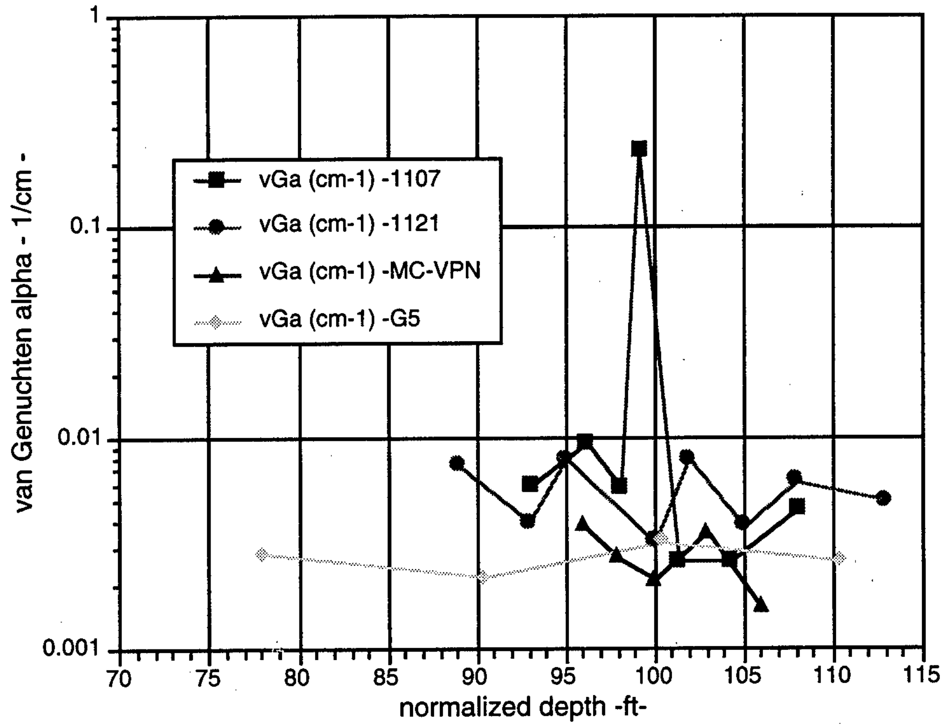

Fig. 8 Profiles verses depth of the van Genuchten parameter, α, (labelled vGa) as fit to characteristic data measured on core samples traversing the vapor phase notch (VPN). The depth of the VPN is normalized to be at approximately 100' in each of the boreholes.

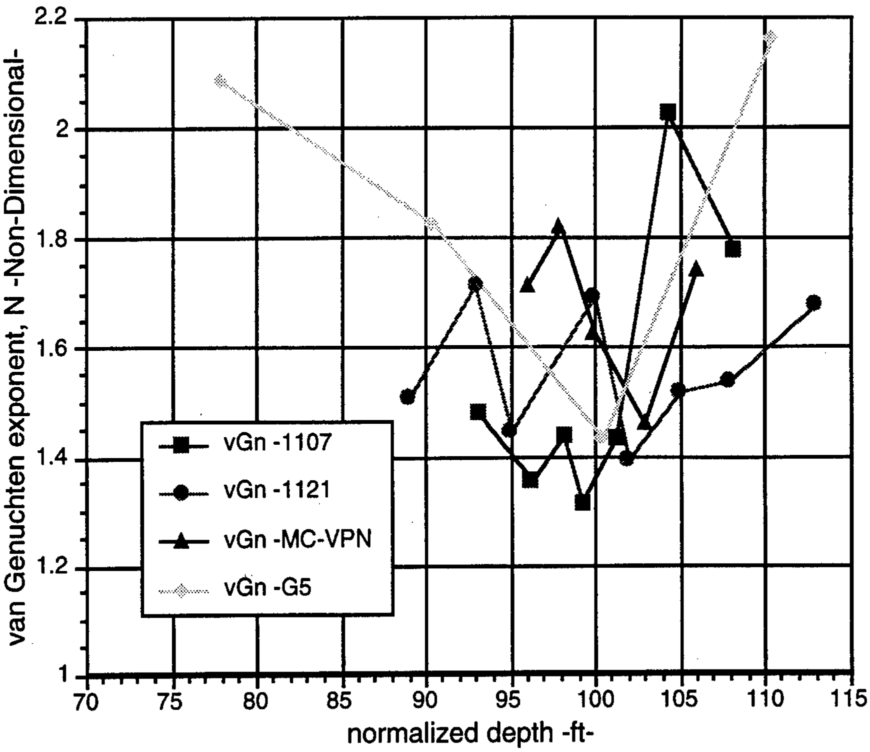

Fig. 9 Profiles verses depth of the van Genuchten parameter, N, (labelled vGn) as fit to characteristic data measured on core samples traversing the vapor phase notch (VPN). The depth of the VPN is normalized to be at approximately 100' in each of the boreholes.

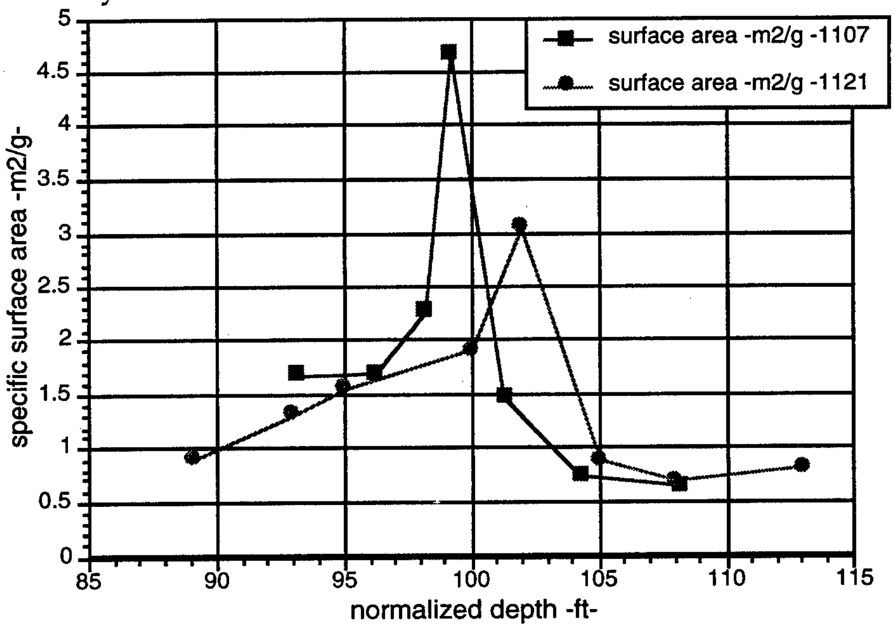

Fig. 10 Profiles verses depth of specific surface area measured on core samples traversing the vapor phase notch (VPN), with the depth of the VPN normalized to be at approximately 100' in each of the boreholes.

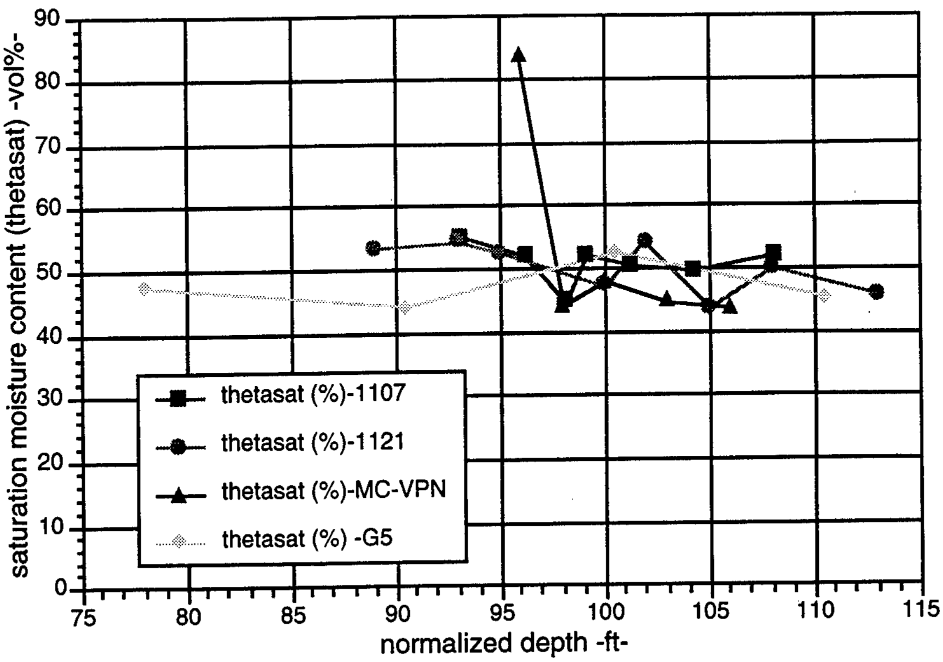

Fig. 11 Profiles verses depth of saturation moisture content measured on core samples traversing the vapor phase notch (VPN), with the depth of the VPN normalized to be at approximately 100' in each of the boreholes.

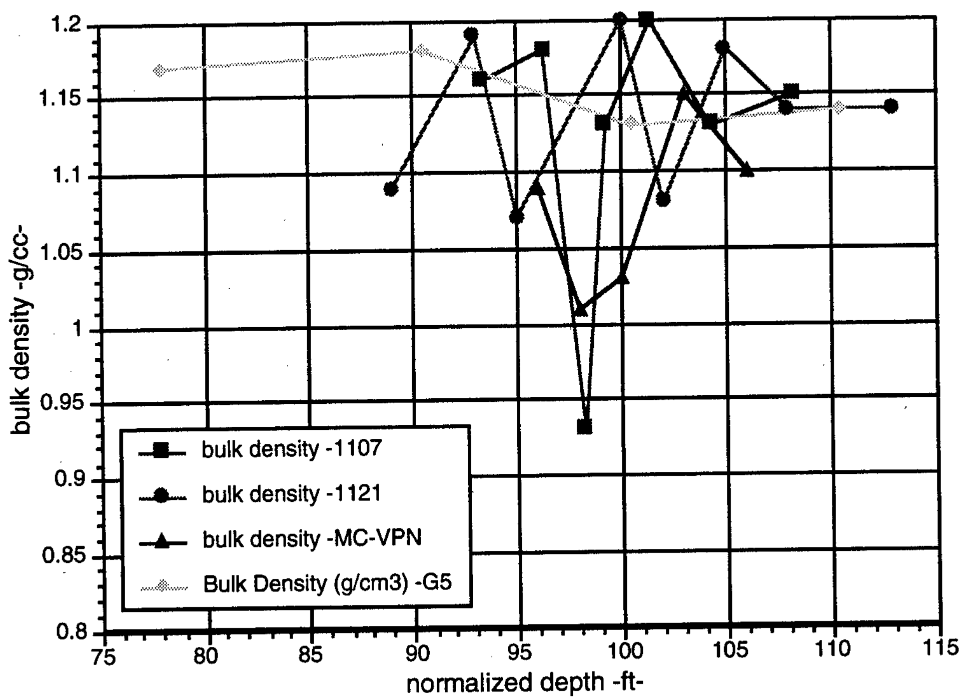

Fig. 12 Profiles verses depth of bulk density measured on core samples traversing the vapor phase notch (VPN), with the depth of the VPN normalized to be at approximately 100' in each of the boreholes.

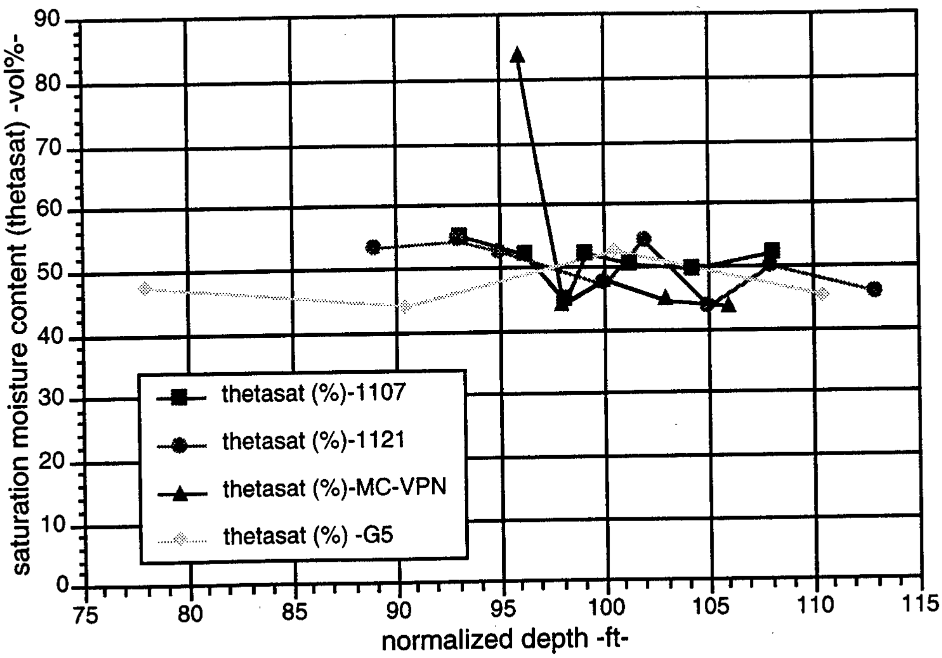

Fig. 11 Profiles verses depth of saturation moisture content measured on core samples traversing the vapor phase notch (VPN), with the depth of the VPN normalized to be at approximately 100' in each of the boreholes.

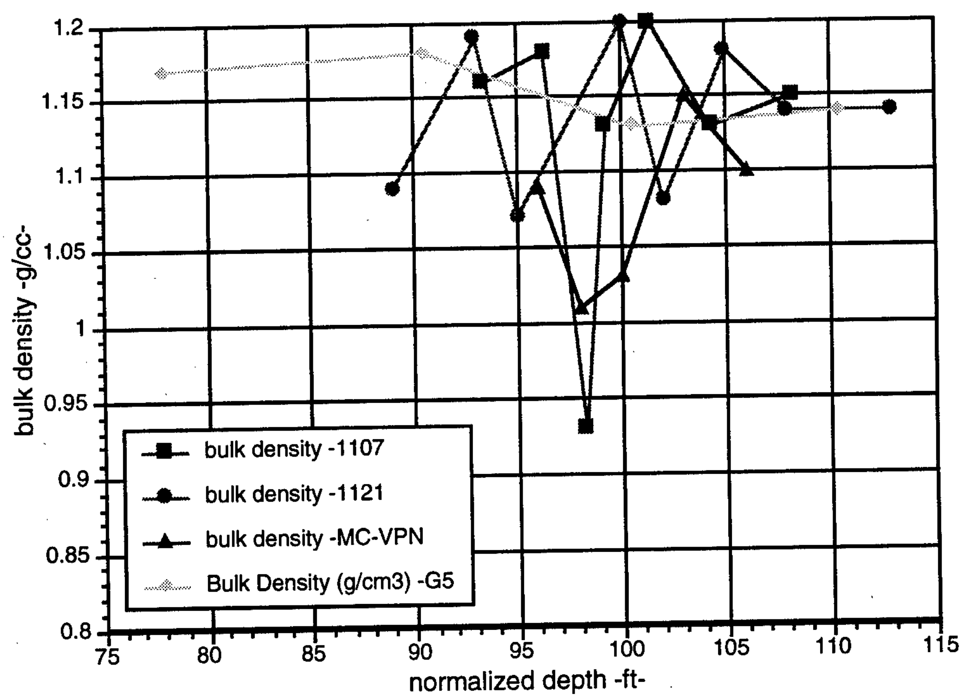

Fig. 12 Profiles verses depth of bulk density measured on core samples traversing the vapor phase notch (VPN), with the depth of the VPN normalized to be at approximately 100' in each of the boreholes.

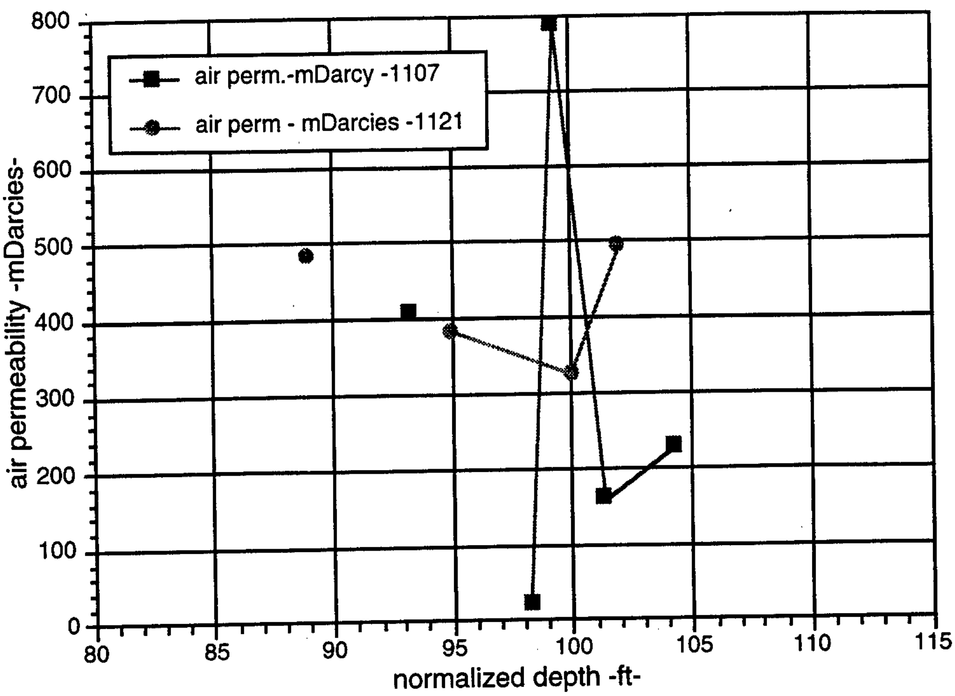

Fig. 13 Profiles verses depth of air permeability at the in-situ moisture content measured on core samples traversing the vapor phase notch (VPN. The depth of the VPN is normalized to be at approximately 100' in each of the boreholes.

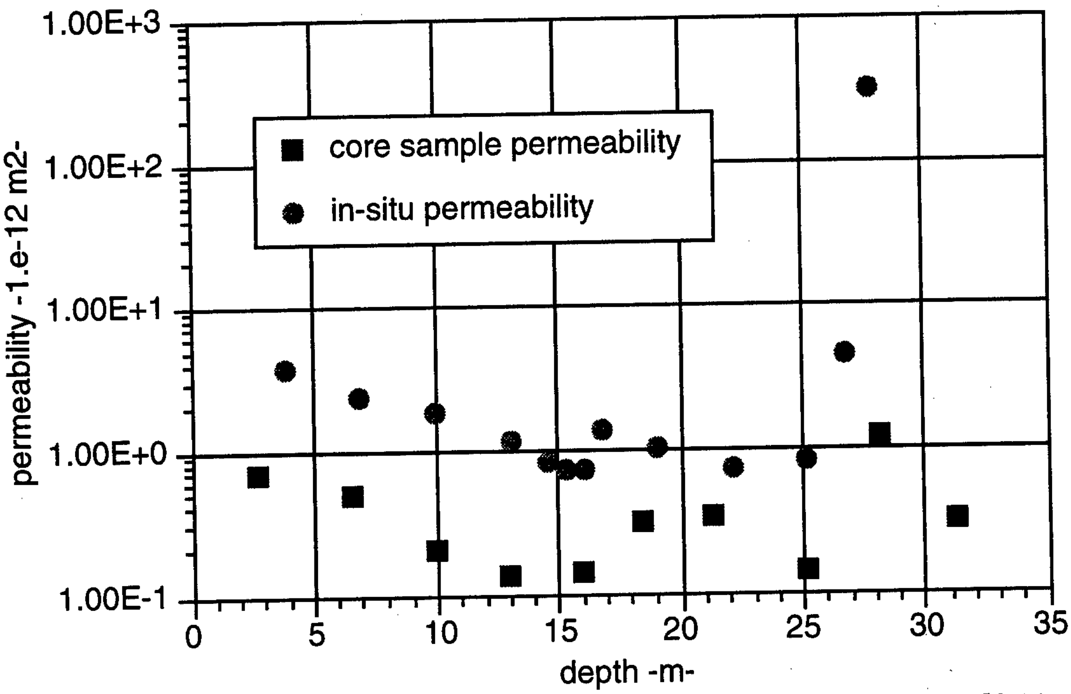

Fig. 14 Profiles verses depth of in-situ air permeability (data from [SEA, 96]) compared to core sample air permeability (data from [DBSA, 95]) for borehole G-5. Fig. from [Vold,96B]

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