FORMATION EVALUATION METHODS IN COMPLEX CARBONATES AND CLASTIC LITHOLOGIES SHORT COURSE MANUAL

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Kansas Geological Survey
Open-file Report 96-39

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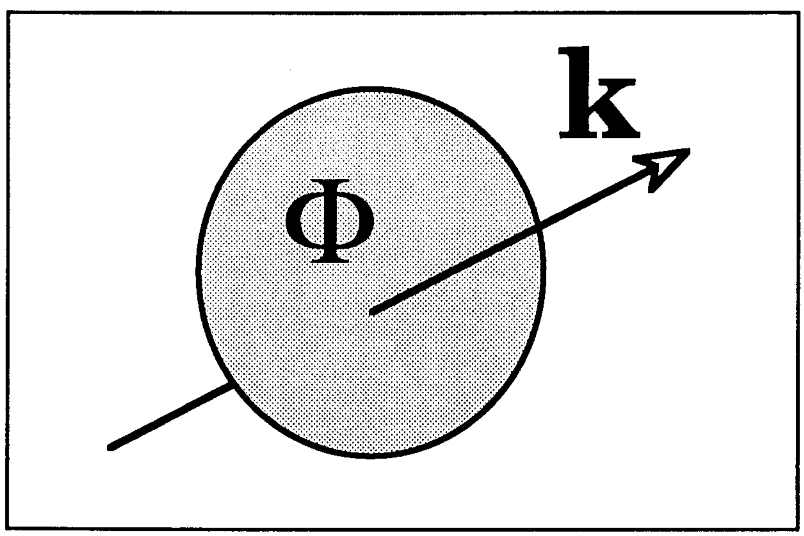
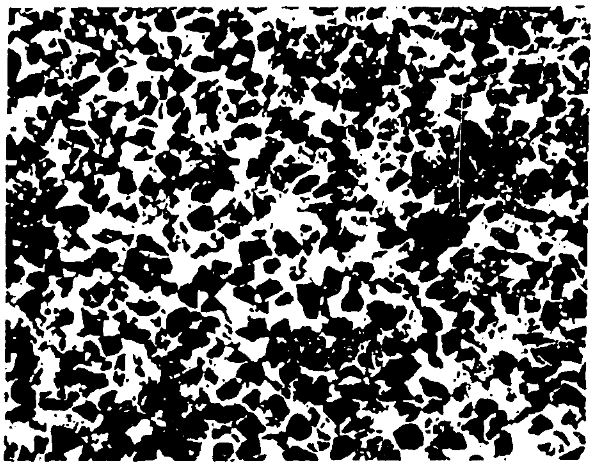
CONTENTS

POROSITY & PERMEABILITY IN SIMPLE AND COMPLEX LITHOLOGIES

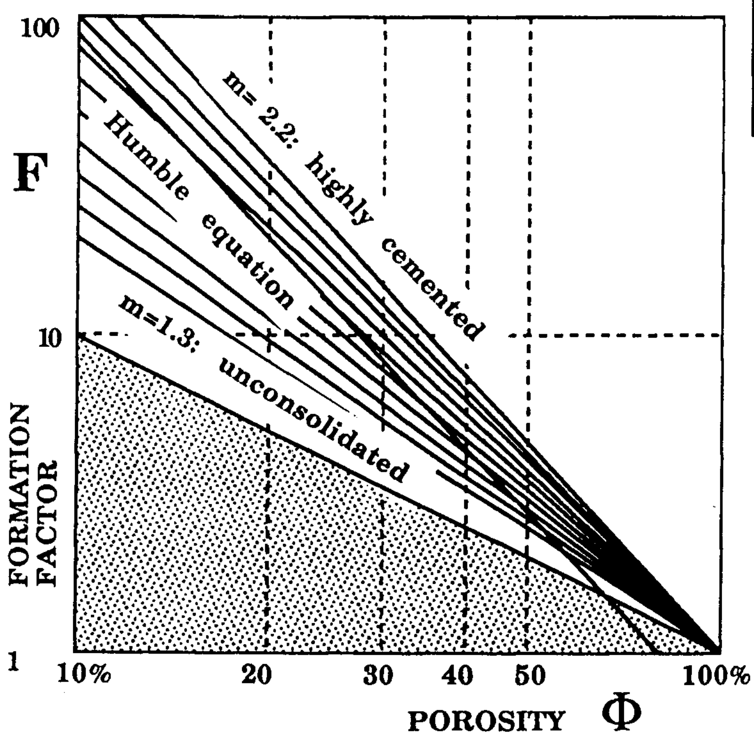


RESISTIVITY - POROSITY RELATIONS IN SANDSTONES



2-dimensional view of pore network, as seen in thin-section. Bartlesville Sandstone, Kansas

3-dimensional metallic pore cast from a consolidated sandstone (from Collins, 1961).



FLOW OF ELECTRICAL CURRENT THROUGH CLEAN SANDSTONES

Archie equation :

$$F = 1 / \Phi^{m}$$

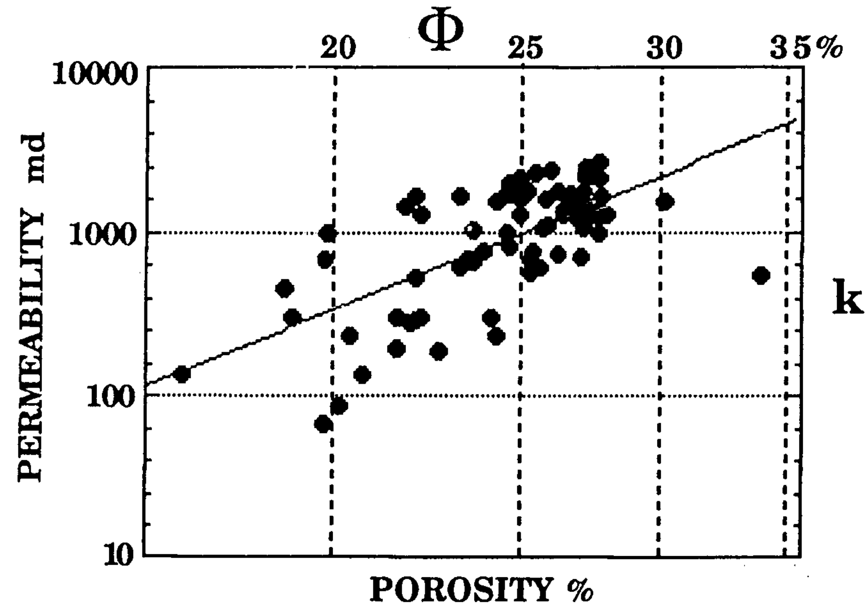
where :

$$F = R_{o} / R_{w}$$

Possible relationship between formation factor and permeability :

e.g. $k = \Phi D^{2} / (32T) \quad \alpha \quad D^{2}/F$

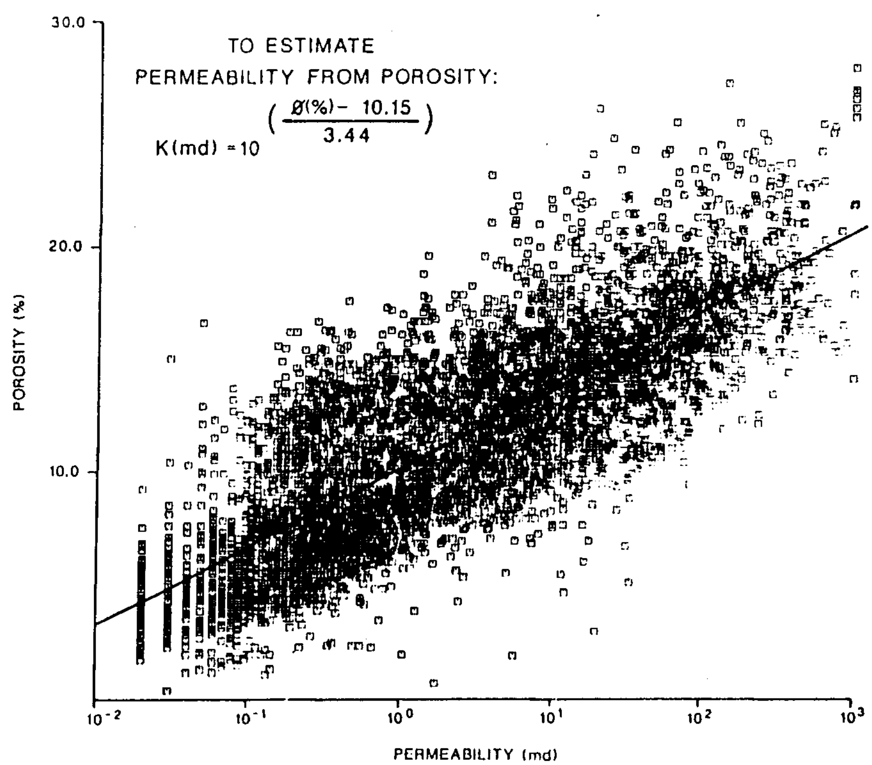
where T is tortuosity and D is a characteristic length (Kimminau and Schwartz, 1987)



Simple relationship :

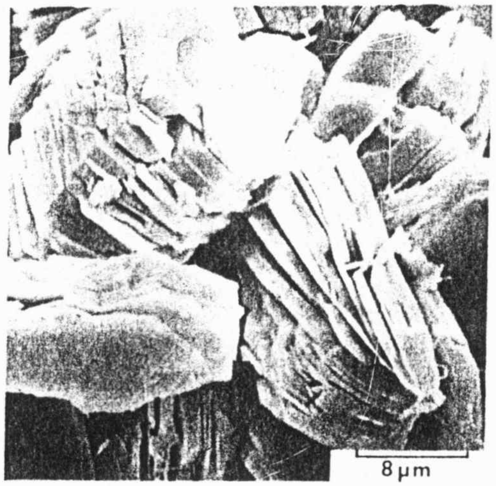
$$k = a\Phi^{b} \quad \therefore \quad \log k = \log a + b \log \Phi$$

Dakota Formation, Kansas (core data from Preston, 1959)

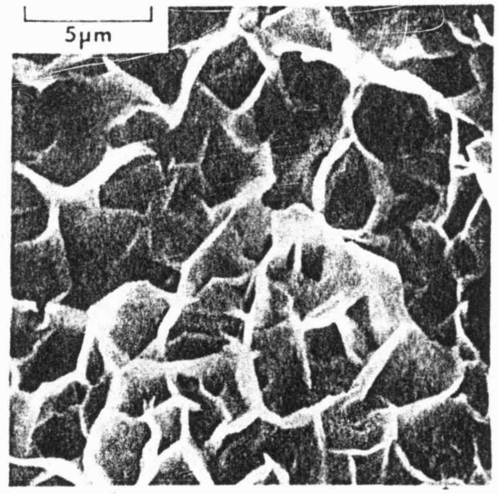


Porosity - permeability relationship for 5419 core samples of Norphlet sandstone (Upper Jurassic), Alabama. from Dixon et al (1989)

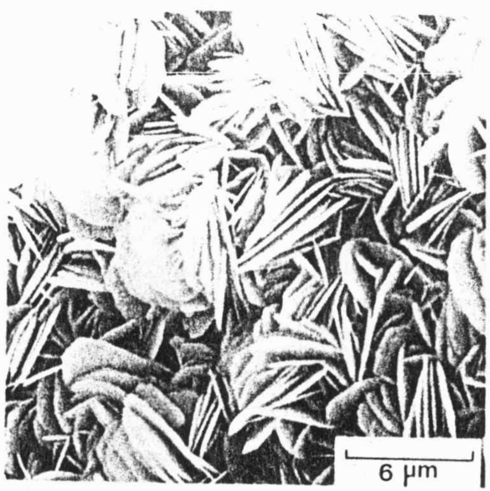
LITTLE SHOP OF HORRORS : CLAY MINERALS & THEIR ROLE IN FORMATION DAMAGE



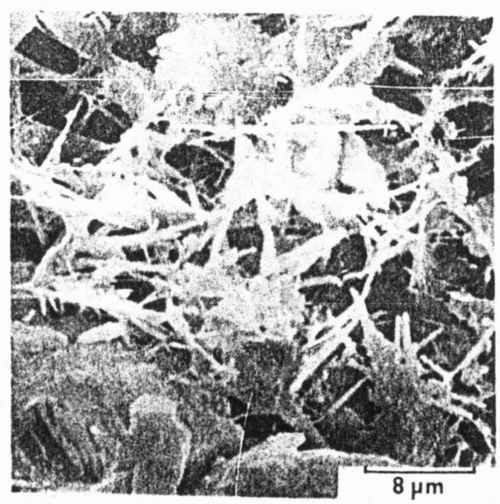
KAOLINITE
patchy discrete particles
Migration of fines which can block pore throats



SMECTITE
pore - lining / bridging
Highly sensitive to fresh water, resulting in clay swelling and microporosity



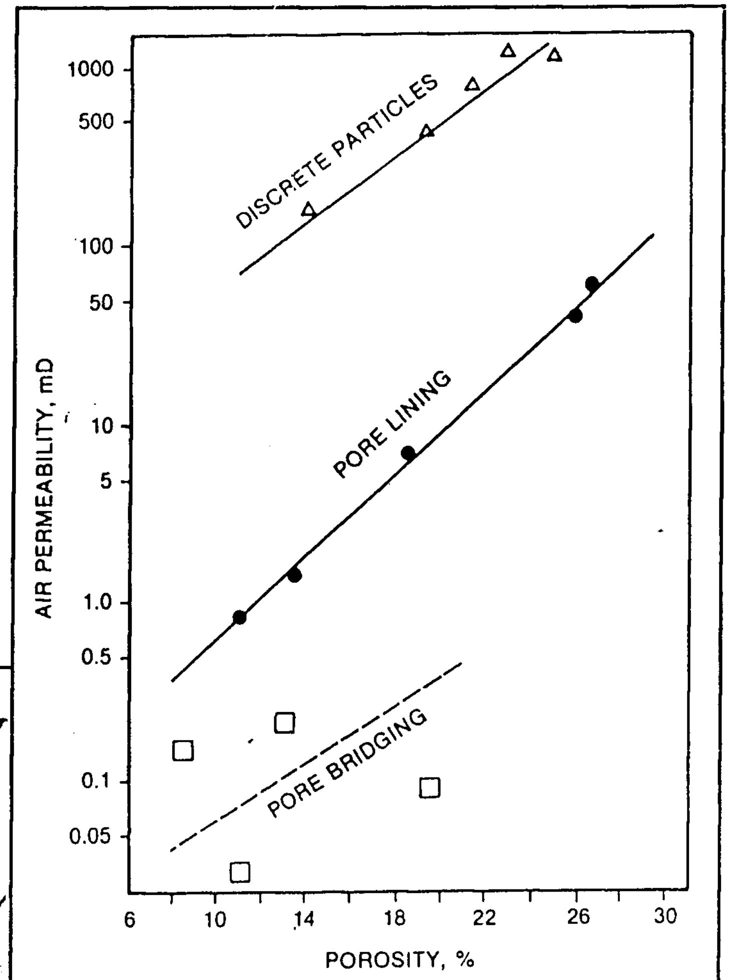
CHLORITE
pore -lining / bridging
Very acid - sensitive, with production of iron hydroxide precipitate to fill pore throats



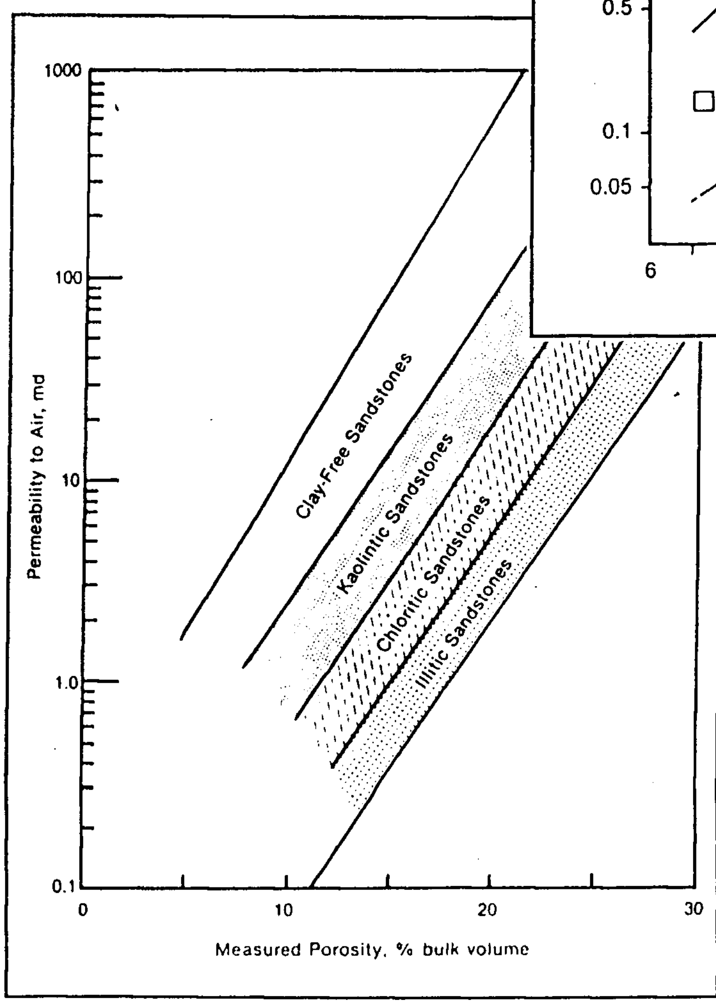
ILLITE
Pore - lining / bridging
Microporosity formation, some migration of fines

SEM photos by Syed Ali in Bigelow (1985)

INFLUENCE OF CLAY MINERALS / CLAY MORPHOLOGIES ON POROSITY - PERMEABILITY RELATIONSHIPS IN SANDSTONES

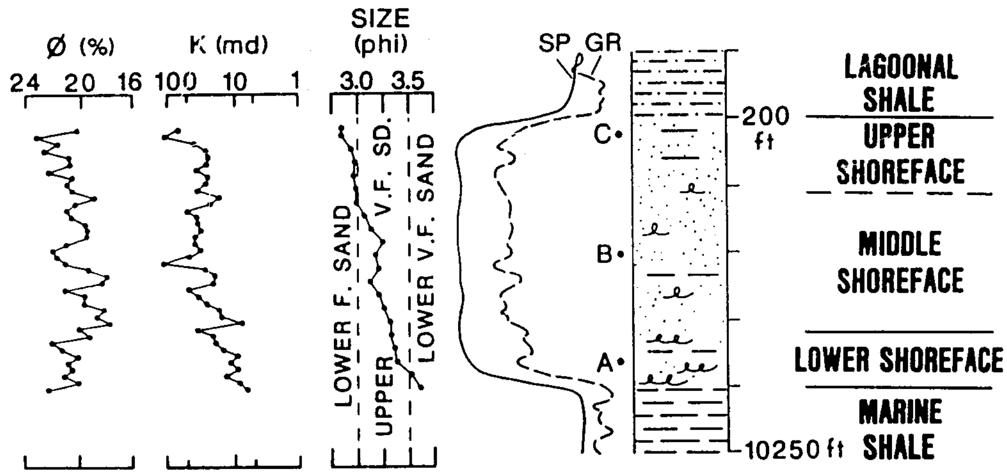


(Neashan, 1977)

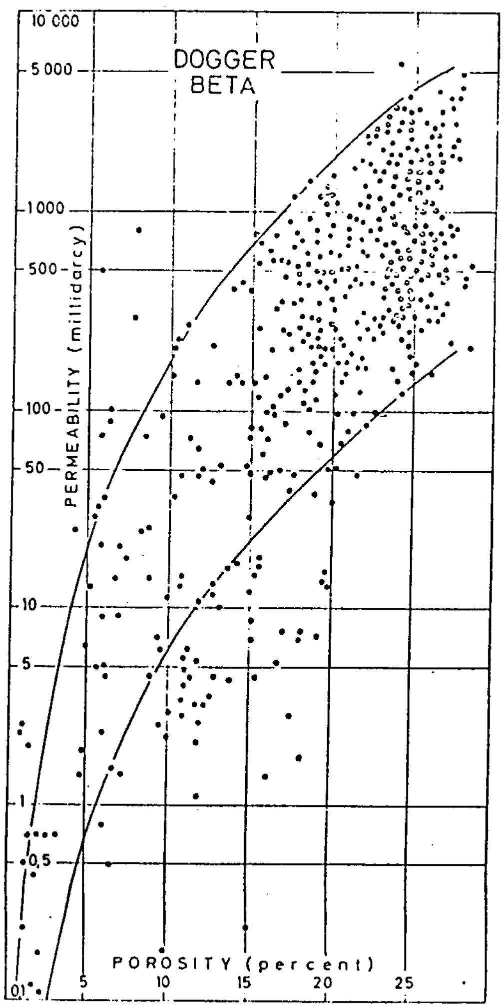


(Wilson, 1982)

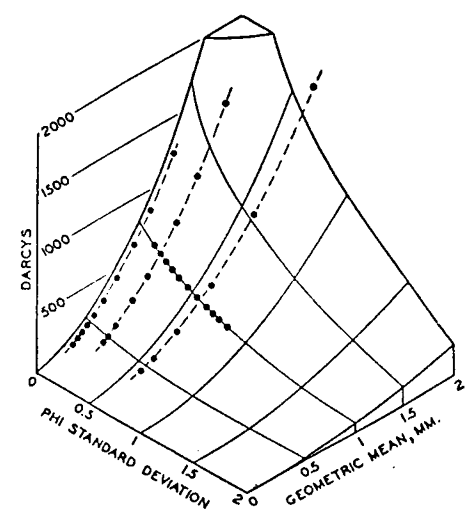
INFLUENCE OF CLASTIC GRAIN SIZE ON PERMEABILITY IN SANDSTONE RESERVOIRS



Porosity, permeability and grain-size variation in a Lower Eocene bar sandstone, Louisiana (Self et al, 1986)



Kozeny-Carman specific -surface contours as indicators of grain size on $\Phi - k$ plot (from Fuchtbauer, 1967)



Grain size and sorting control of permeability in sands (from Krumbein and Monk, 1942)

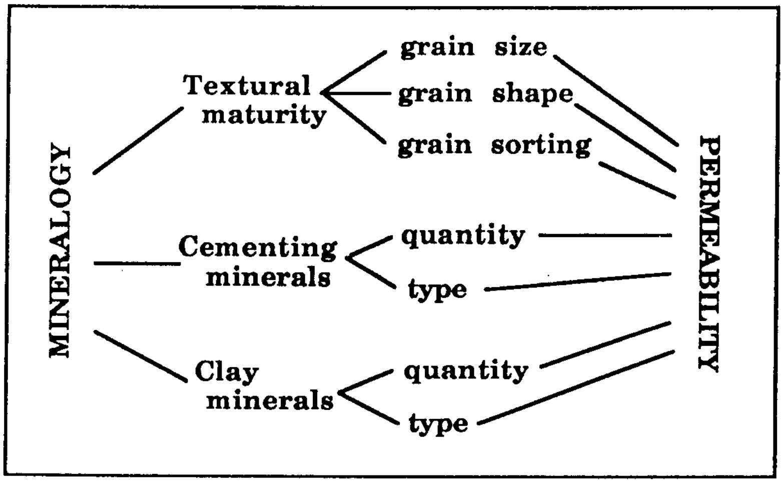
Kozeny - Carman equation :

$$k = \frac{A\Phi^3}{(1-\Phi)^2 S^2}$$

where A is a constant and S is the specific surface area i.e. ratio of surface area to volume of framework solid
For a sphere, S = 6/d
where d is the sphere diameter

HERRON MODEL FOR PERMEABILITY ESTIMATION IN CLASTICS BASED ON POROSITY AND MINERALOGY

Kozeny - Carman equation : $K = \frac{A\Phi^3}{(1-\Phi)^2 S^2}$



Herron equation : $K = \frac{a_f \Phi^3}{(1-\Phi)^2} \exp(\sum B_i M_i)$

Rewritten :

$$\log K = A_f + 3\log\Phi - 2\log(1-\Phi) + \sum B_i M_i$$

where A_f is the textural maturity term, M_i is the abundance of the ith mineral and B_i is a constant

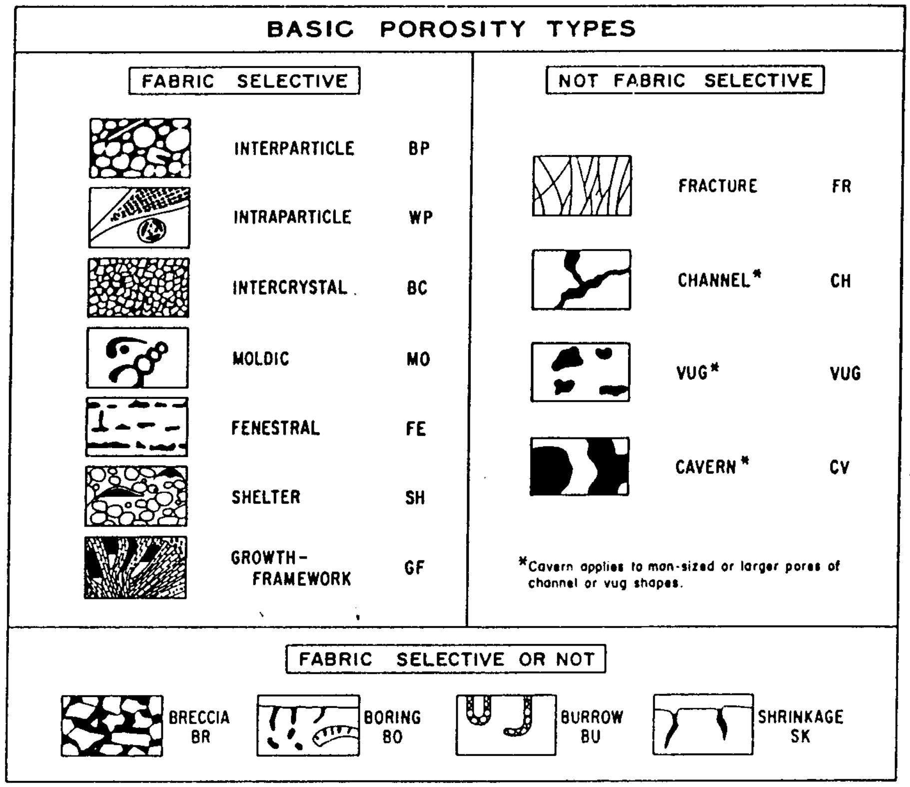
Based on data from Venezuela, California and Oklahoma :

$$A_f = 4.9 + 2\,\text{Feldspar}_{max}$$

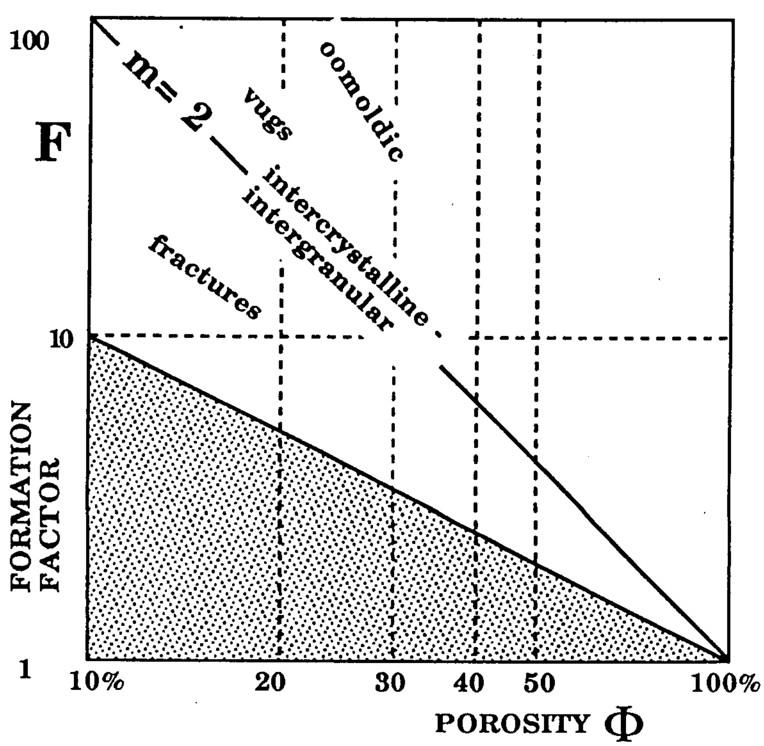
B_i values :

CLAYS		CEMENTS		FRAMEWORK MINERALS	
Kaolinite	-4.5	Calcite	-2.5	Quartz	0.1
Illite	-5.5			Feldspars	1.0
Smectite	-7.5				

Reference : Herron (1987)



from Choquette and Pray, 1970



FLOW OF ELECTRICAL CURRENT THROUGH CARBONATES

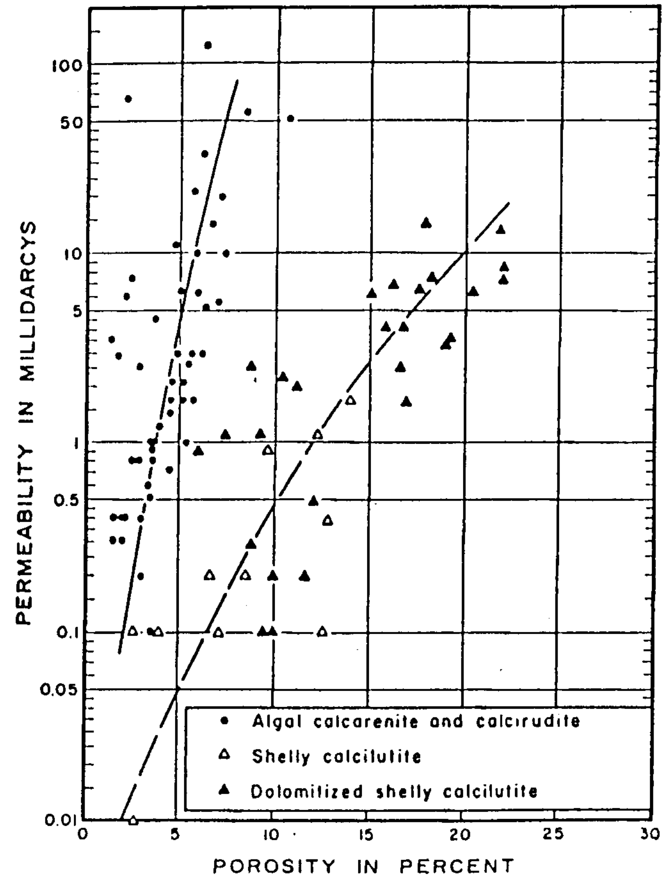
Archie equation :

$$F = 1 / \Phi^{m}$$

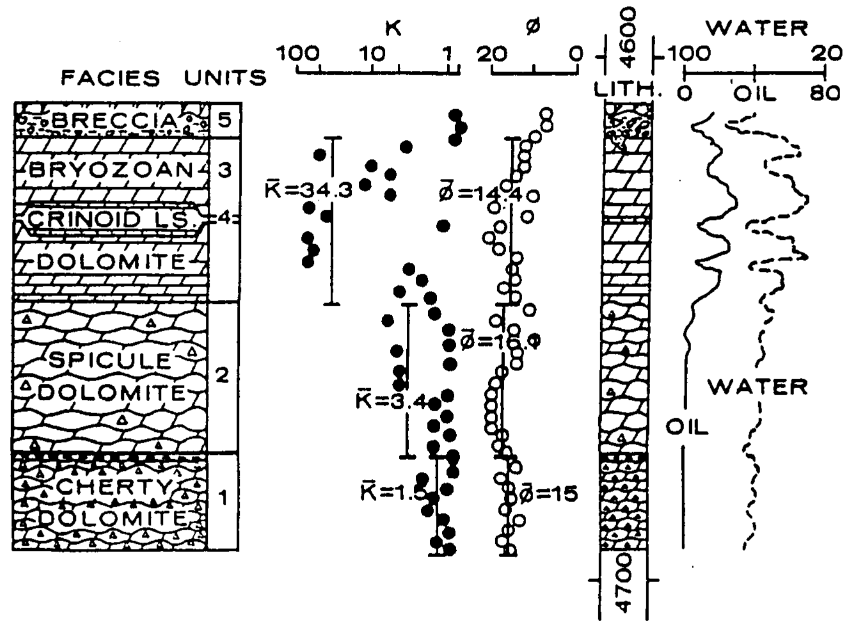
where :

$$F = R_o / R_w$$

CONTROL OF POROSITY - PERMEABILITY PATTERNS IN CARBONATES BY SEDIMENTARY FACIES AND DIAGENESIS



after Choquette and Traut, 1963



from Ebanks, Euwer and Nodine - Zeller, 1977

CASE STUDIES

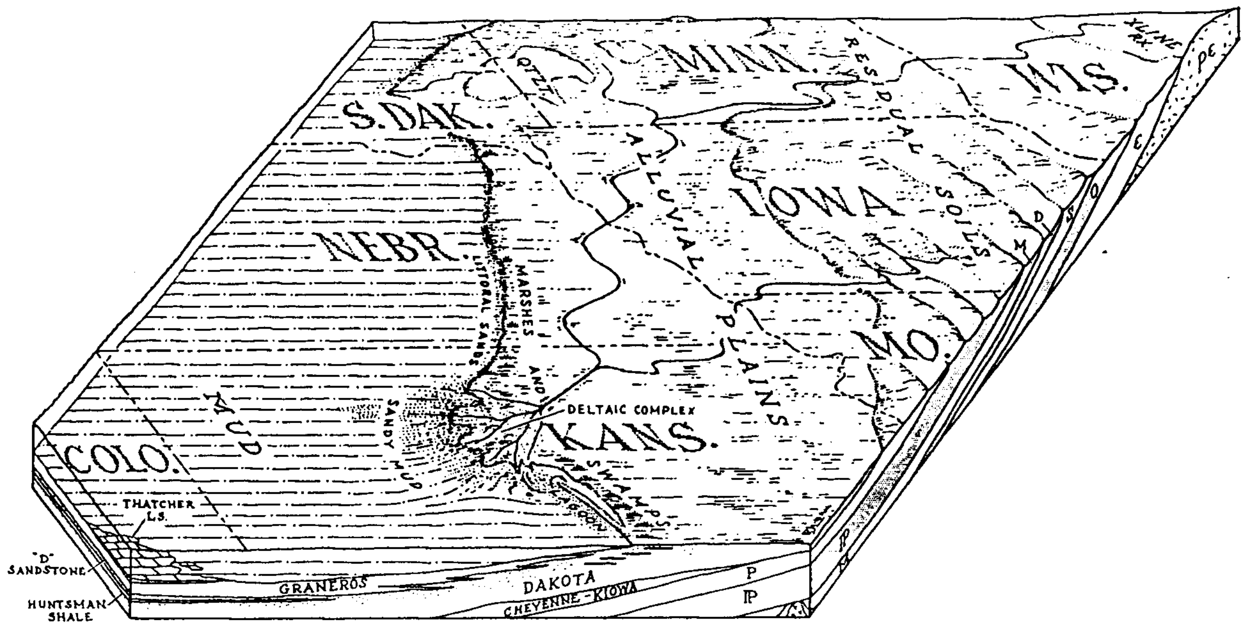
* CLASTIC CASE STUDY LOGS
Graneros Shale, Dakota Formation,
Kiowa Formation, Cheyenne Sandstone
(Lower Cretaceous) ; Cedar Hills Sandstone
(Lower Permian)
KGS Braun #1 NENENE 30-12S-18W
Ellis County, Kansas

* CARBONATE CASE STUDY LOGS
Chase Group (Lower Permian)
Mobil Brown #1-2 CNW 11-35S-37W
Stevens County, Kansas

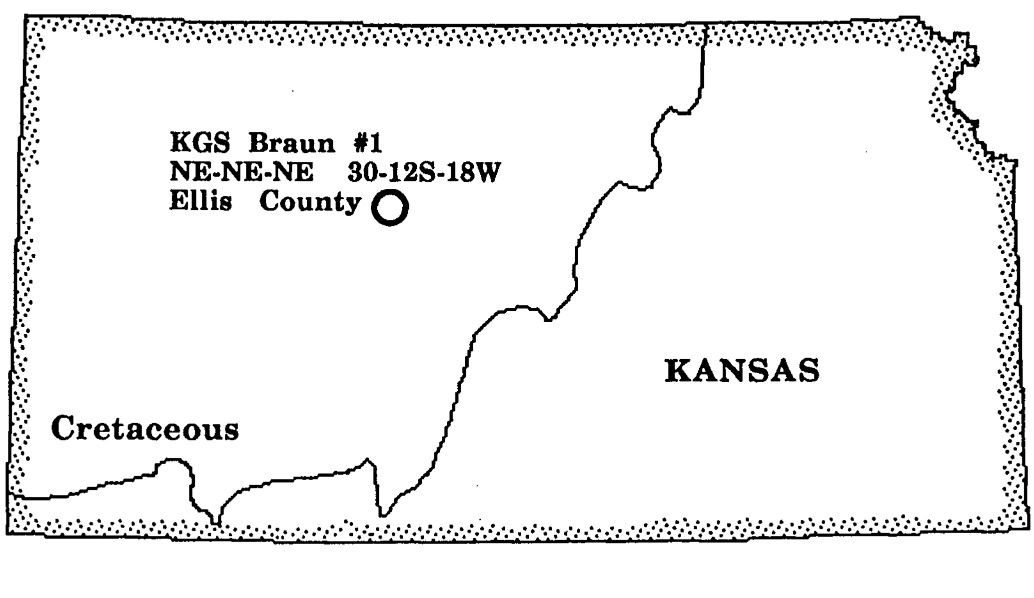
DAKOTA

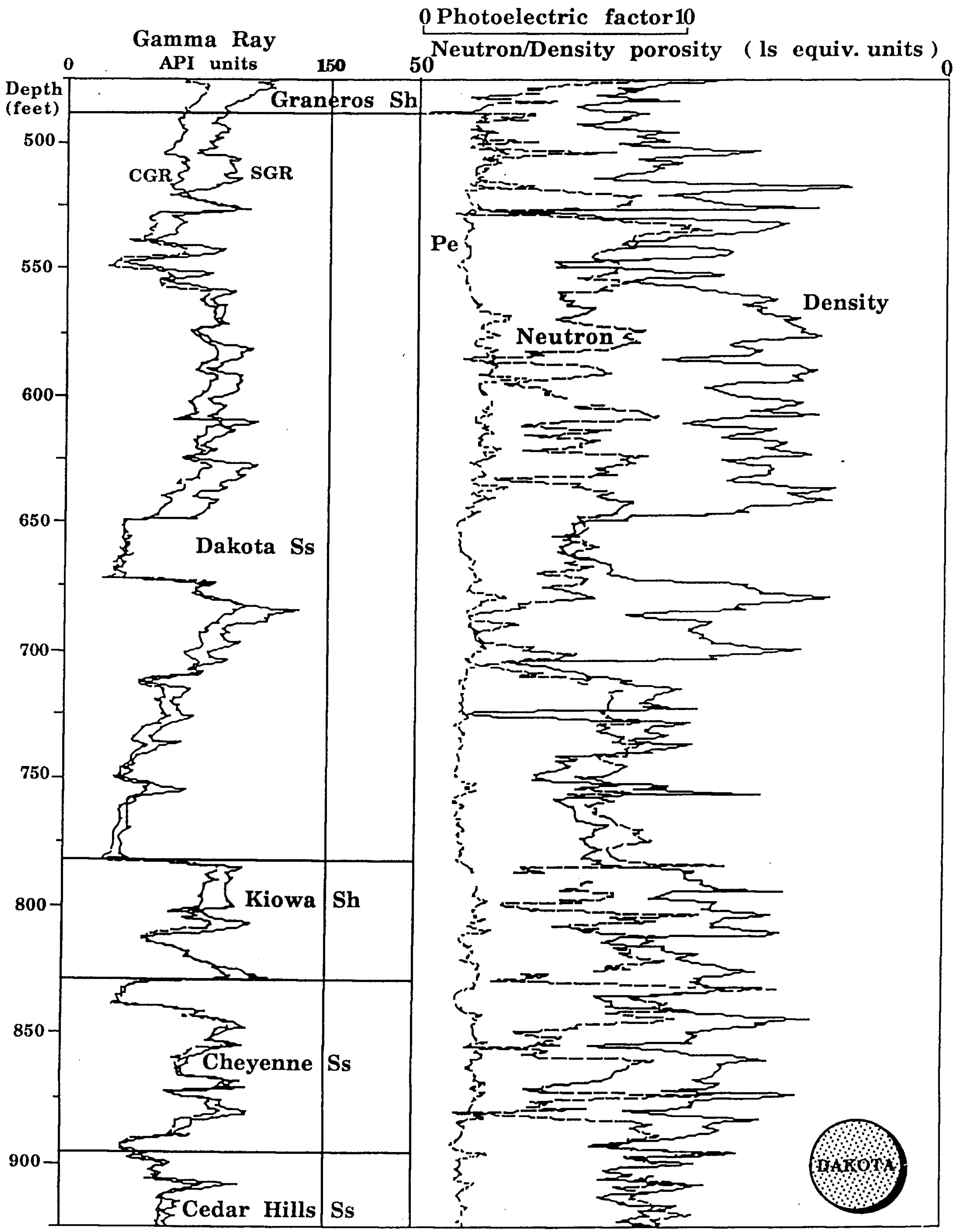
CLASTIC CASE STUDY

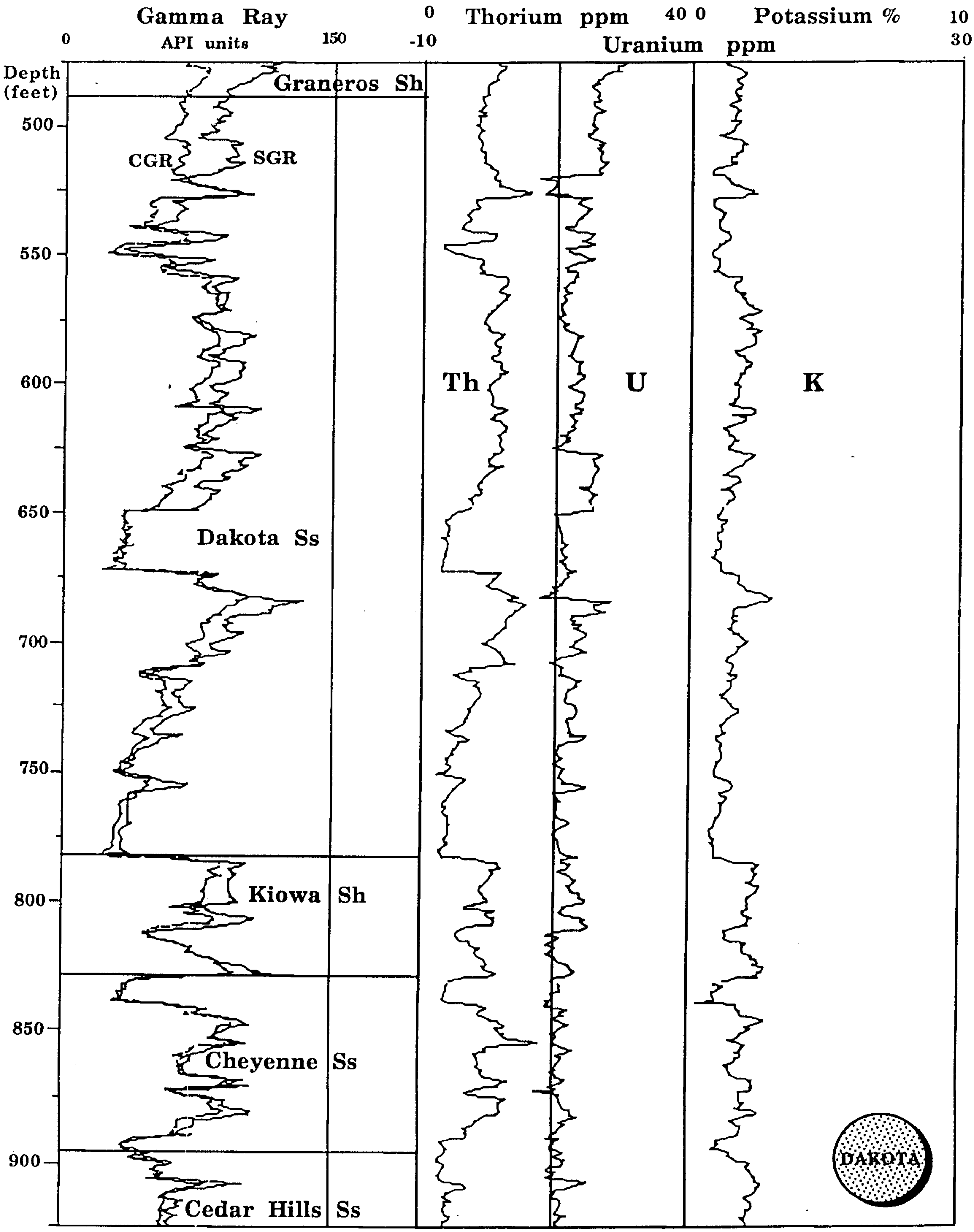
Lower Cretaceous - Lower Permian sandstones and shales



(from Hattin, 1967)



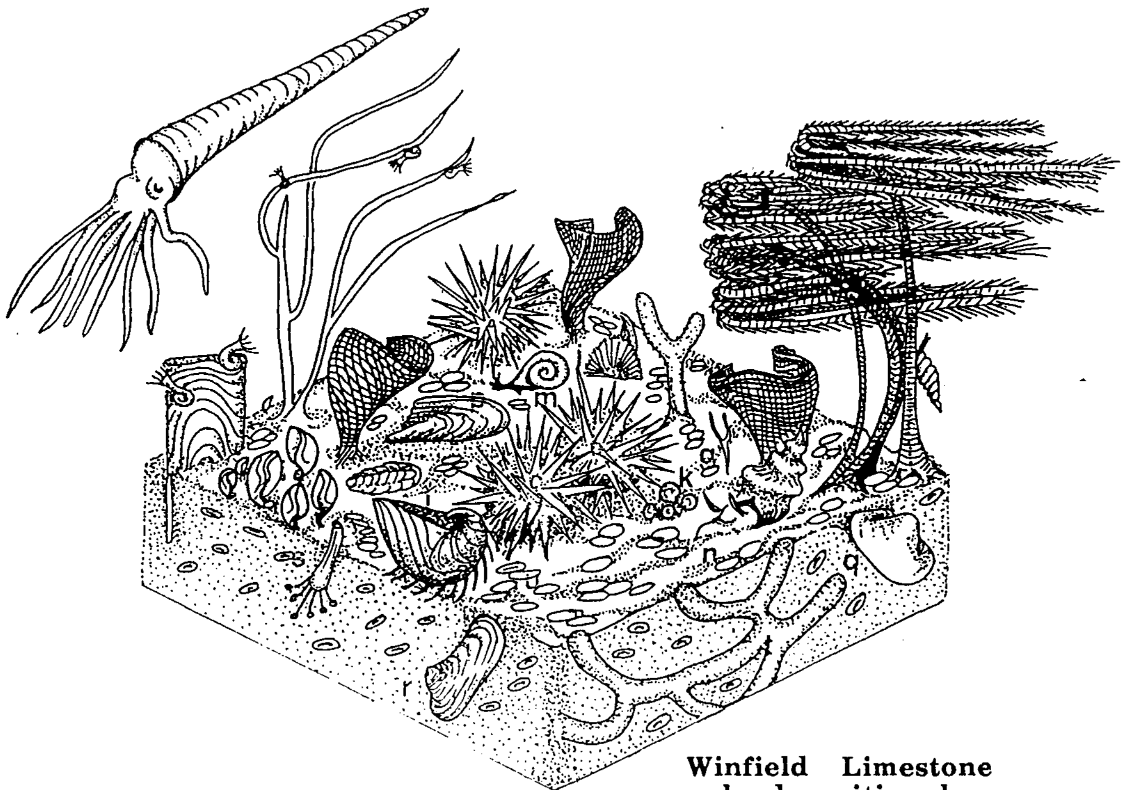

0 Photoelectric factor 10
Gamma Ray
API units
0
150
50
Neutron/Density porosity (ls equiv. units)
0
Depth (feet)
500
550
600
650
700
750
800
850
900
Graneros Sh
CGR
SGR
Pe
Density
Neutron
Dakota Ss
Kiowa Sh
Cheyenne Ss
Cedar Hills Ss
DAKOTA


Gamma Ray
API units
0
150
Thorium ppm
0
40
-10
Uranium ppm
30
Potassium %
0
10
Depth (feet)
500
550
600
650
700
750
800
850
900
Graneros Sh
CGR
SGR
Dakota Ss
Kiowa Sh
Cheyenne Ss
Cedar Hills Ss
Th
U
K
DAKOTA

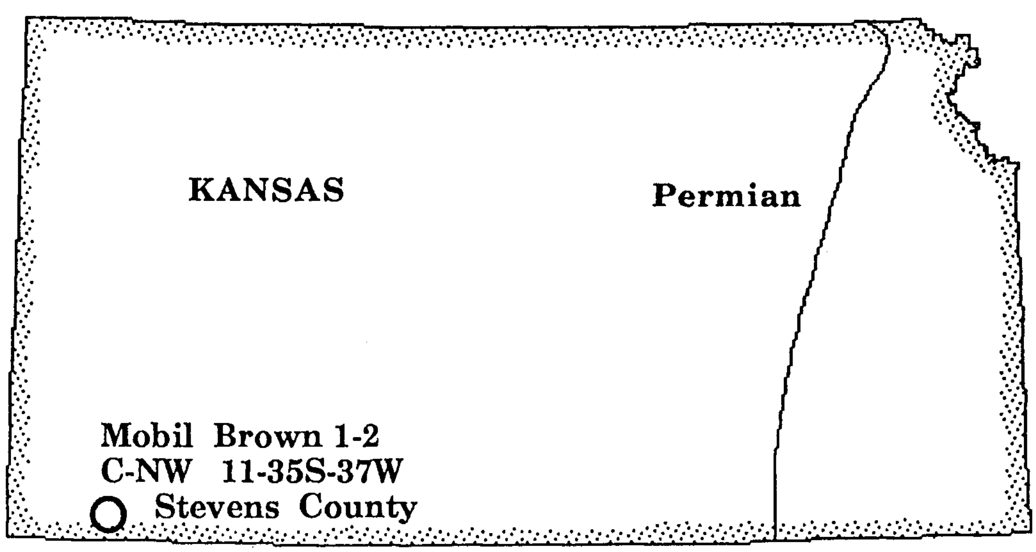
CHASE

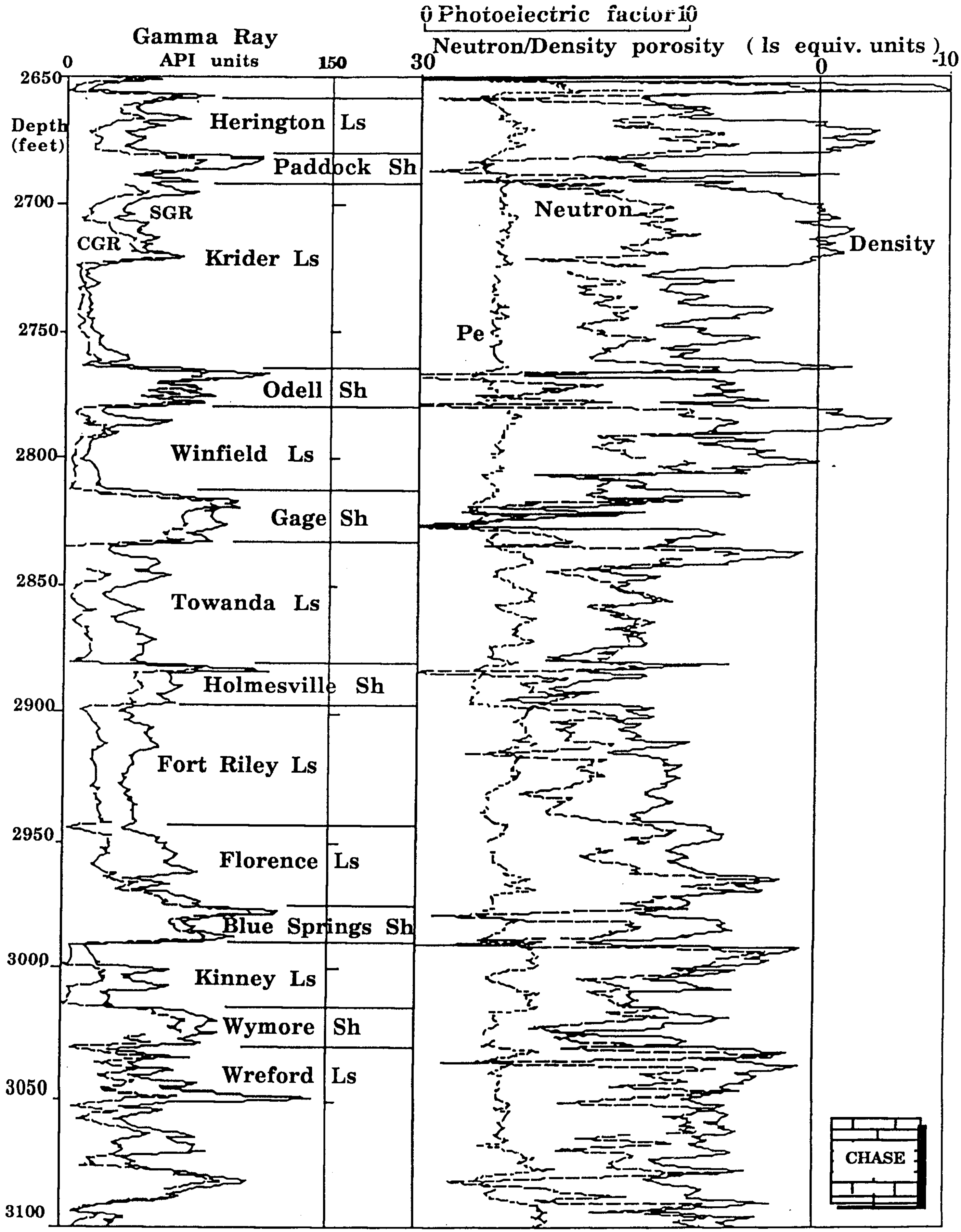
CARBONATE CASE STUDY

Lower Permian dolomites, cherty limestones, anhydrite and shales

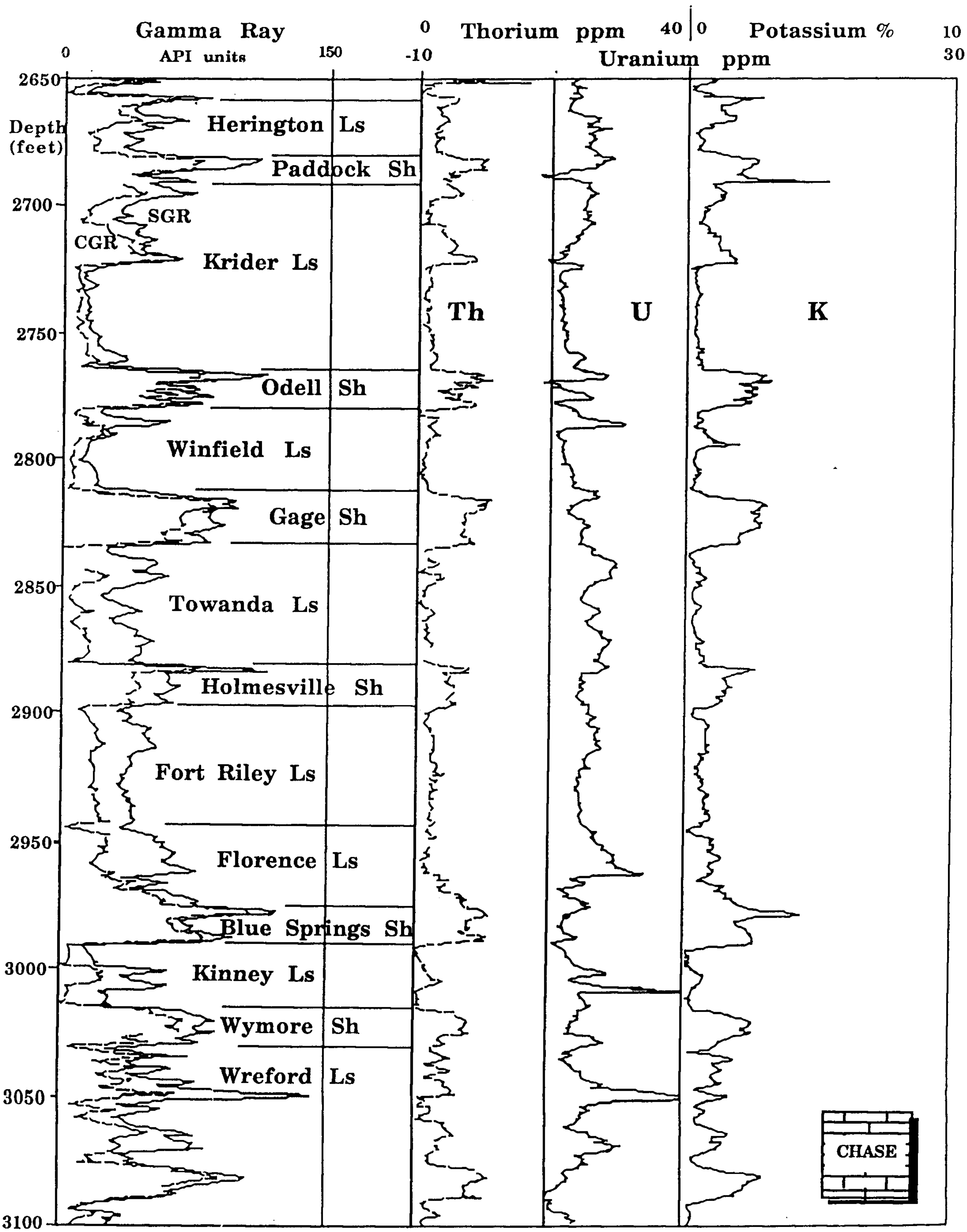


Winfield Limestone paleodepositional community (from Toomey & Mitchell, 1986)

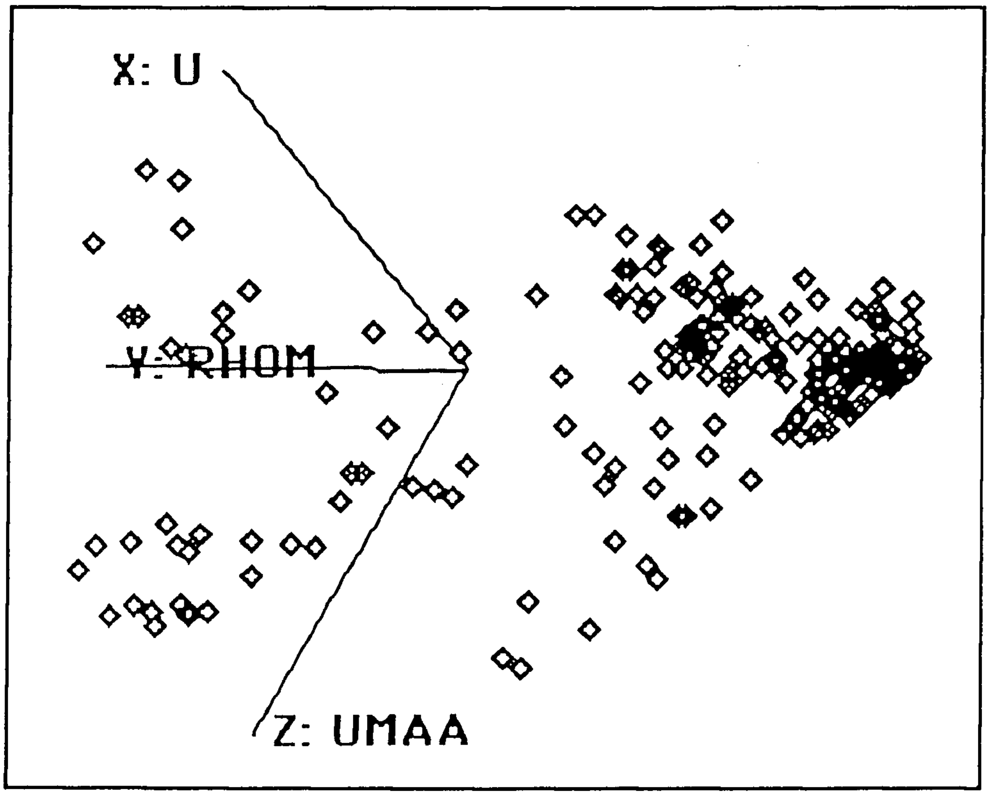




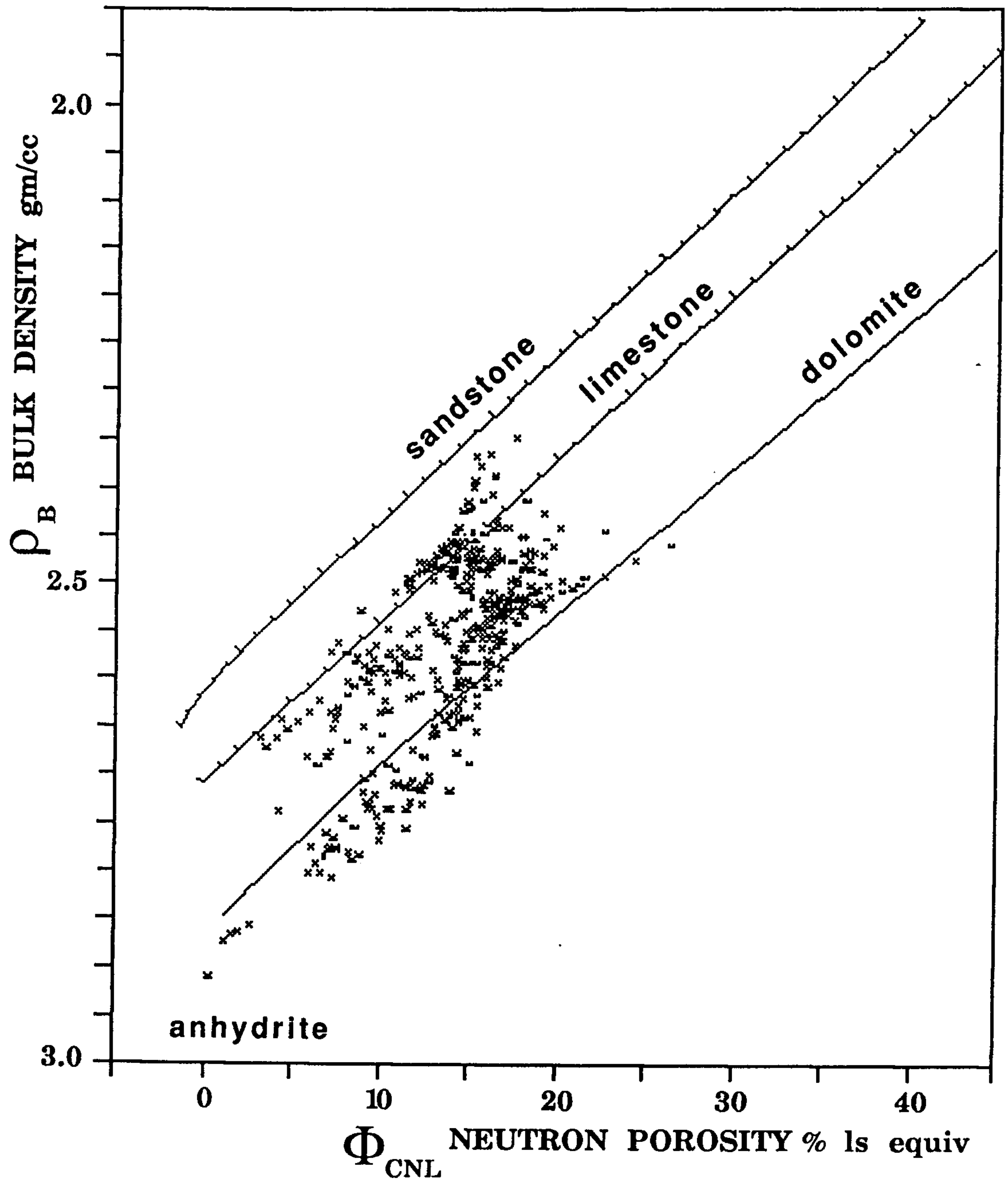
0 Photoelectric factor 10
Gamma Ray
API units
0
150
30
Neutron/Density porosity (ls equiv. units)
0
-10
Depth (feet)
2650
2700
2750
2800
2850
2900
2950
3000
3050
3100
Herington Ls
Paddock Sh
Krider Ls
SGR
CGR
Neutron
Density
Pe
Odell Sh
Winfield Ls
Gage Sh
Towanda Ls
Holmesville Sh
Fort Riley Ls
Florence Ls
Blue Springs Sh
Kinney Ls
Wymore Sh
Wreford Ls
CHASE


Gamma Ray
0
API units
150
0
Thorium ppm
40
-10
Uranium ppm
0
Potassium %
10
30
Depth (feet)
2650
2700
2750
2800
2850
2900
2950
3000
3050
3100
Herington Ls
Paddock Sh
SGR
CGR
Krider Ls
Th
U
K
Odell Sh
Winfield Ls
Gage Sh
Towanda Ls
Holmesville Sh
Fort Riley Ls
Florence Ls
Blue Springs Sh
Kinney Ls
Wymore Sh
Wreford Ls
CHASE

PATTERN RECOGNITION TECHNIQUES

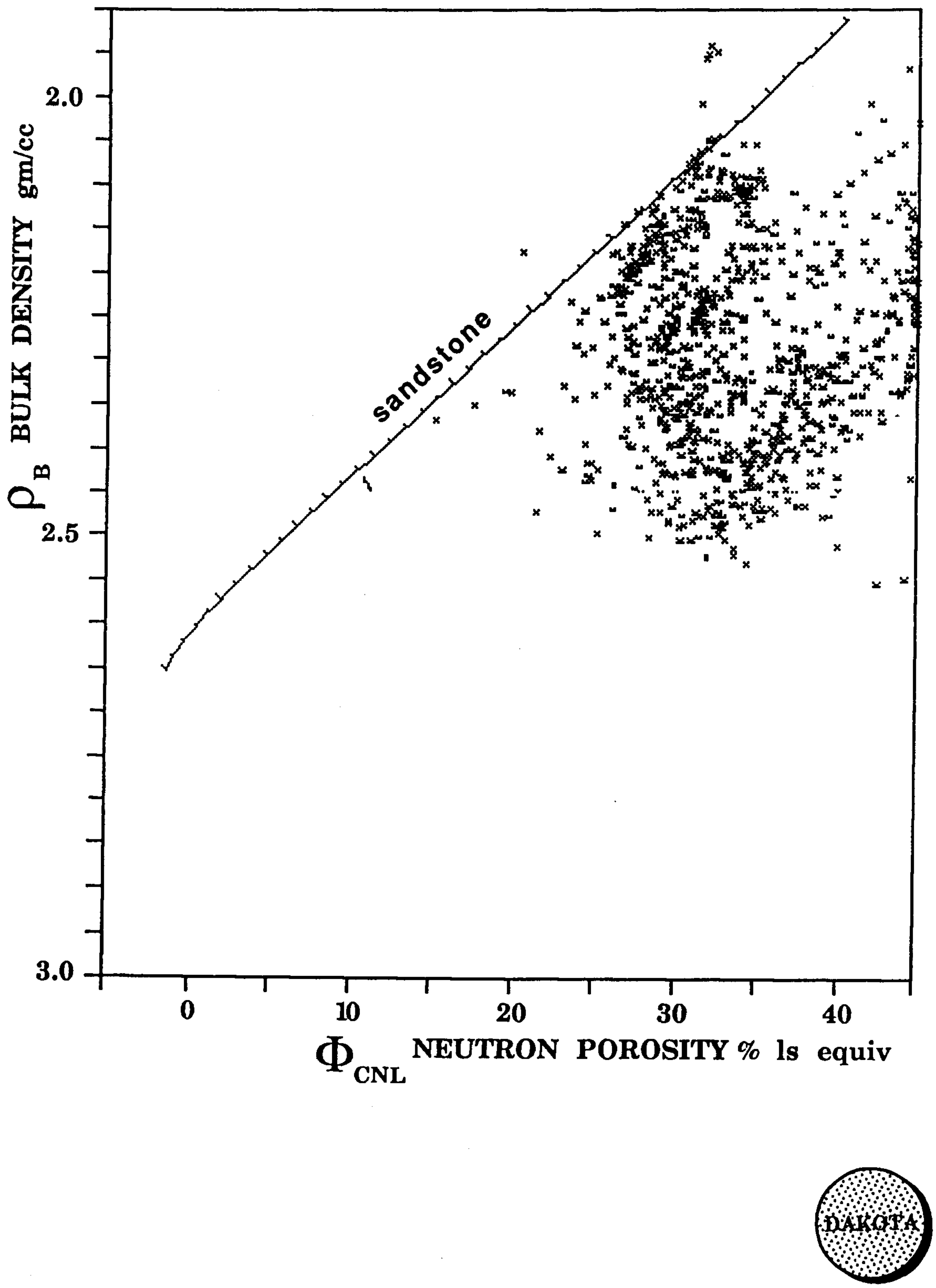


COMPLEX CARBONATE NEUTRON - DENSITY CROSSPLOT
Zones with gamma ray values < 20 API units
Mineral types : calcite, dolomite, chert, anhydrite

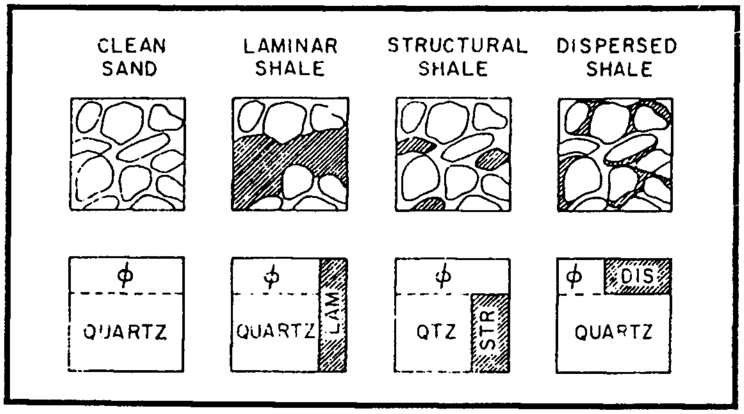


CHASE

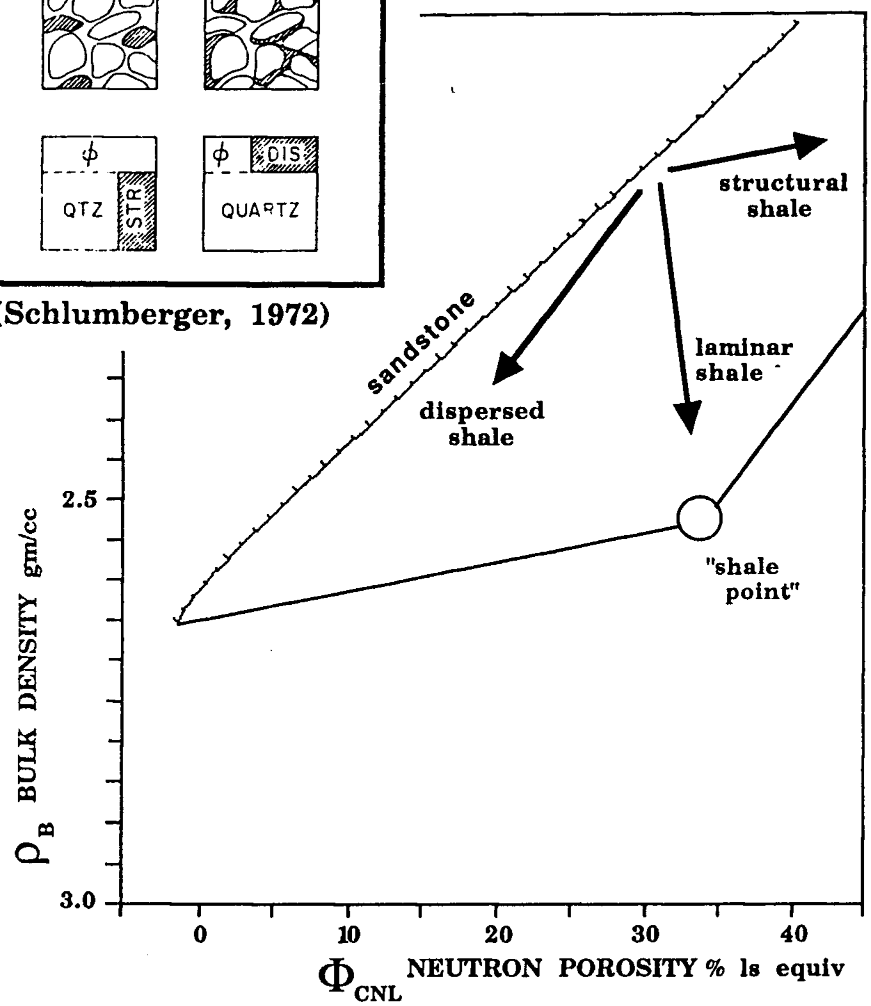
SANDSTONE - SHALE NEUTRON - DENSITY CROSSPLOT

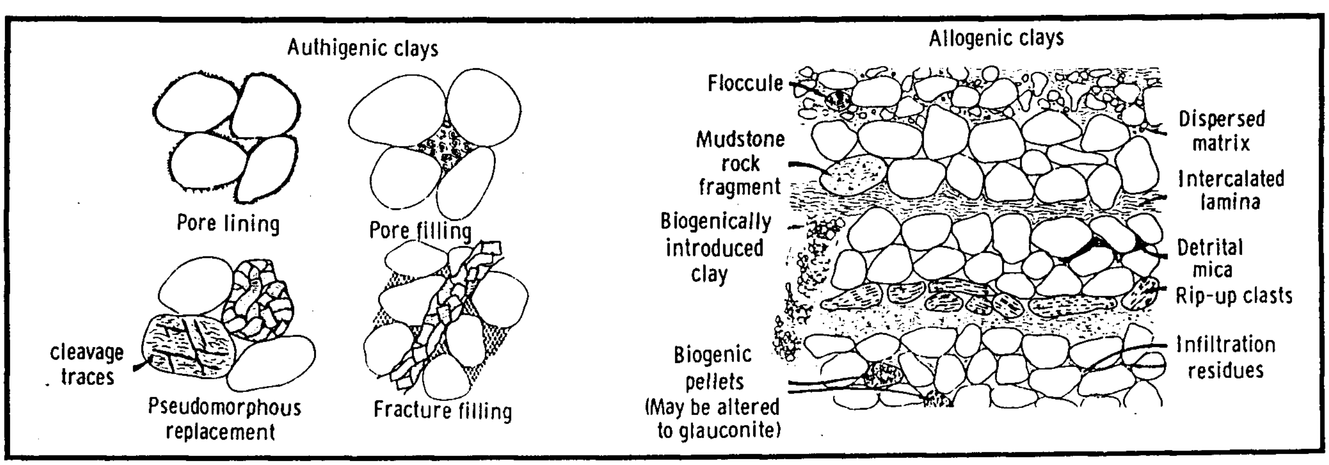


CLASSIC LOG ANALYSIS MODEL OF SHALE AND CLAY DISTRIBUTION IN SHALY SANDSTONES



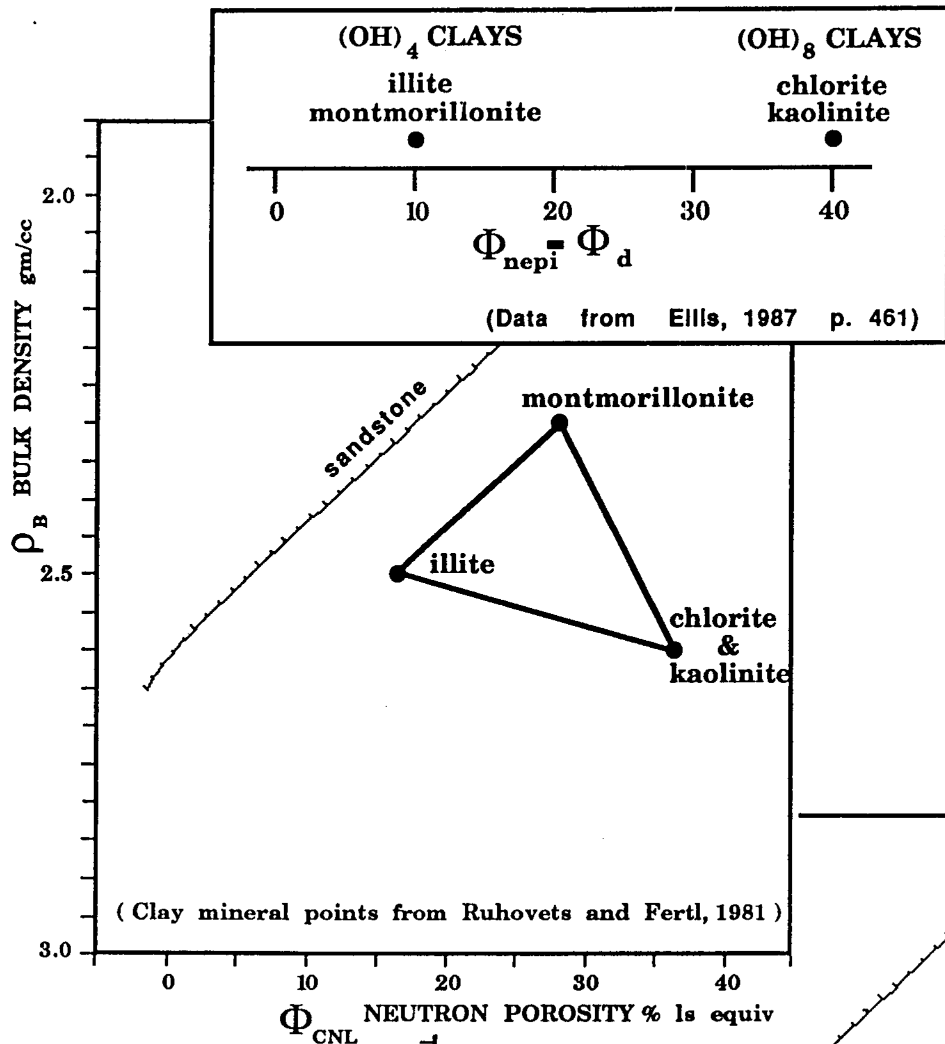
MORPHOLOGY (Schlumberger, 1972)

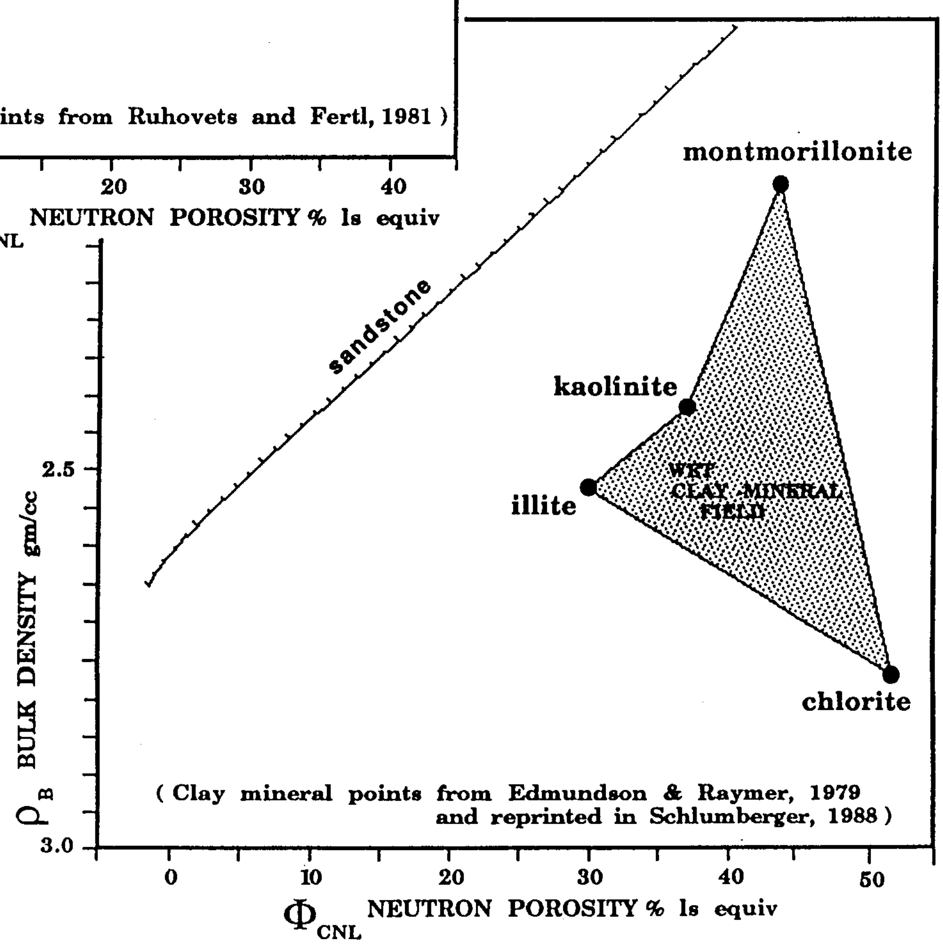




GENESIS (Wilson and Pittman, 1977)

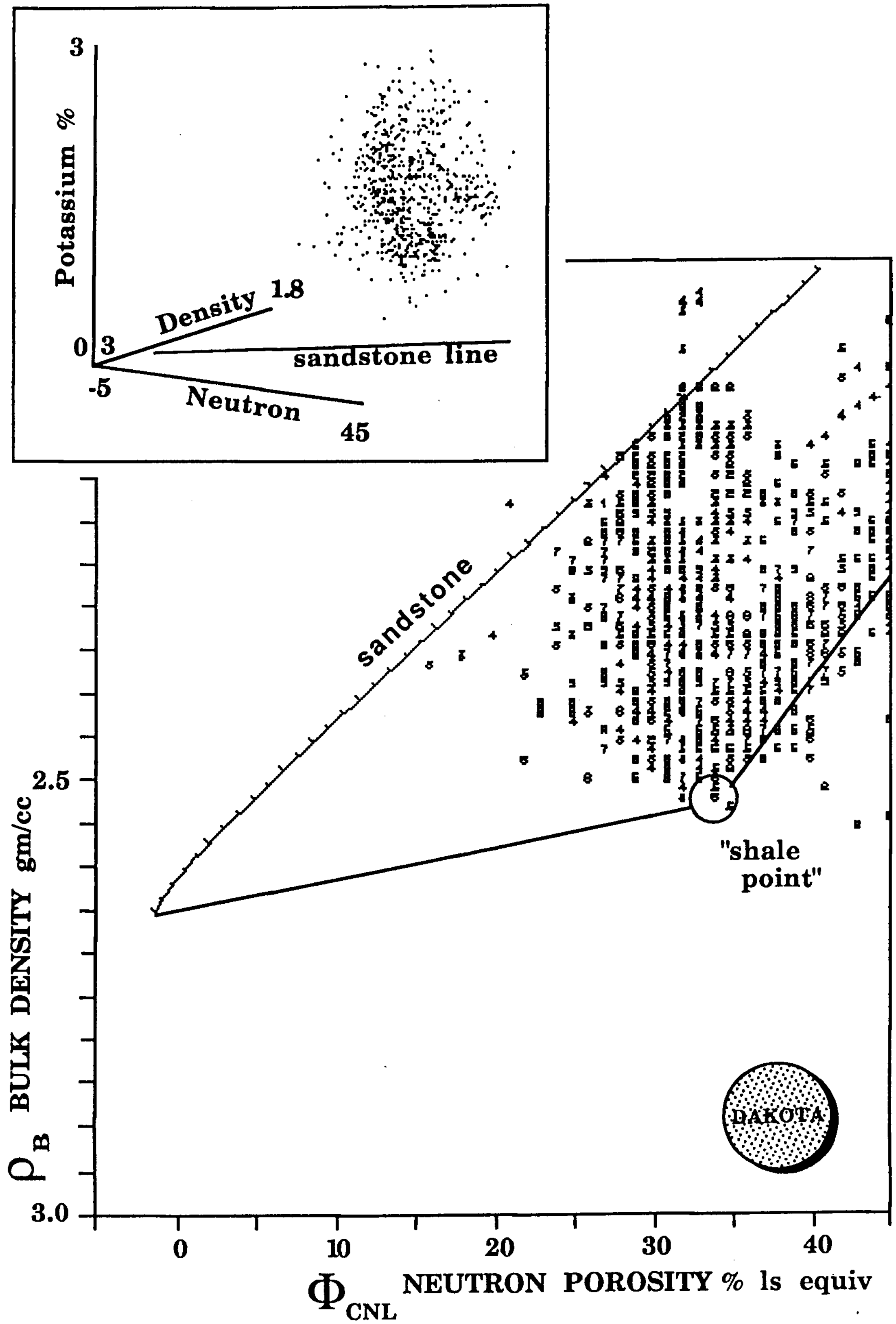
MODERN SHALY SANDSTONE MODELS BASED ON CLAY MINERAL COMPOSITIONS

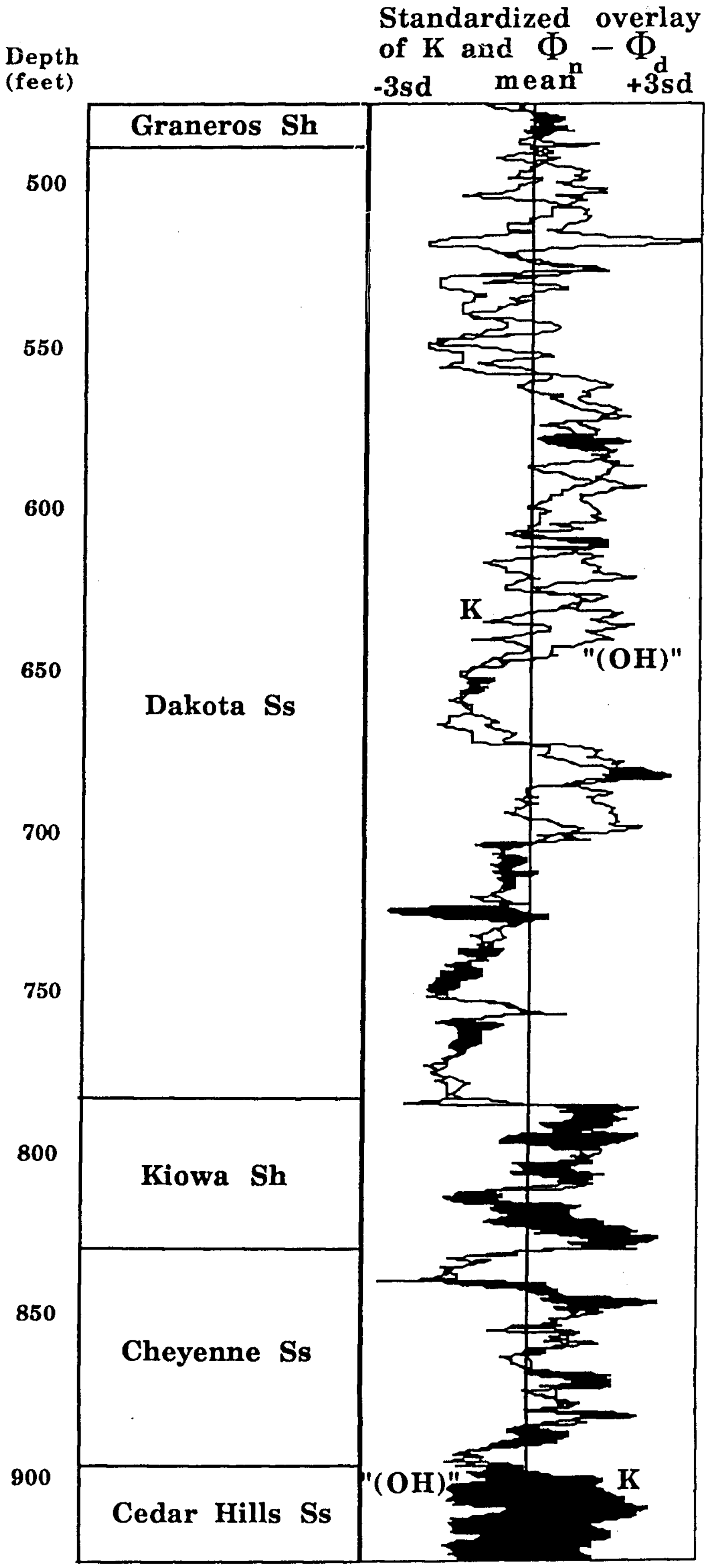




SANDSTONE - SHALE NEUTRON - DENSITY Z- PLOT

Z - variable = Potassium %
Integer range 0 - 9 for 0 - 3% K

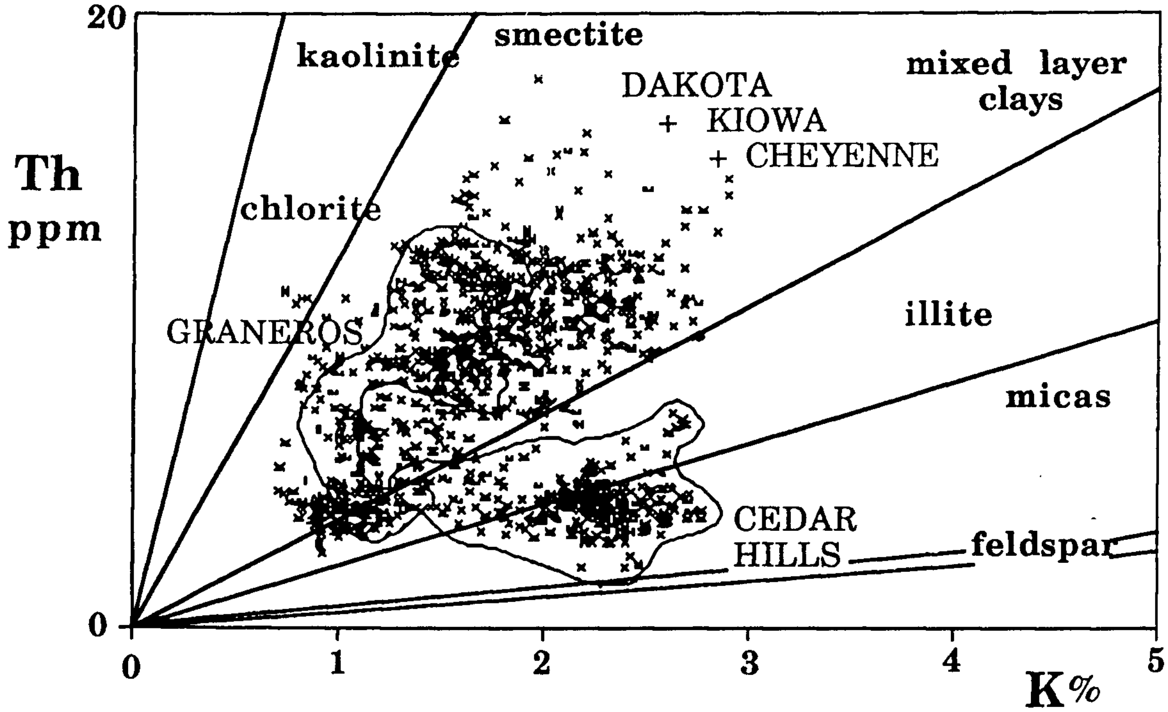




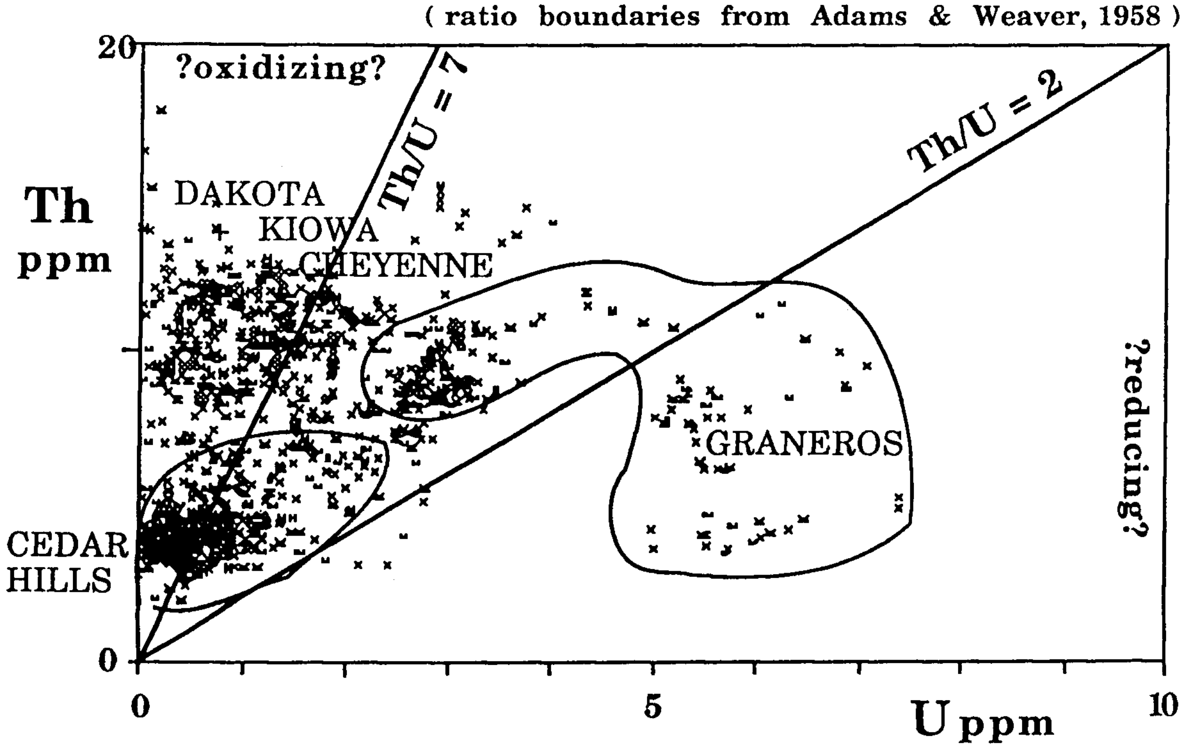
Depth (feet)
Standardized overlay of K and Φn − Φd
-3sd
mean
+3sd
Graneros Sh
500
550
600
650
700
750
800
850
900
Dakota Ss
Kiowa Sh
Cheyenne Ss
Cedar Hills Ss
K
"(OH)"
"(OH)"
K

DAKOTA

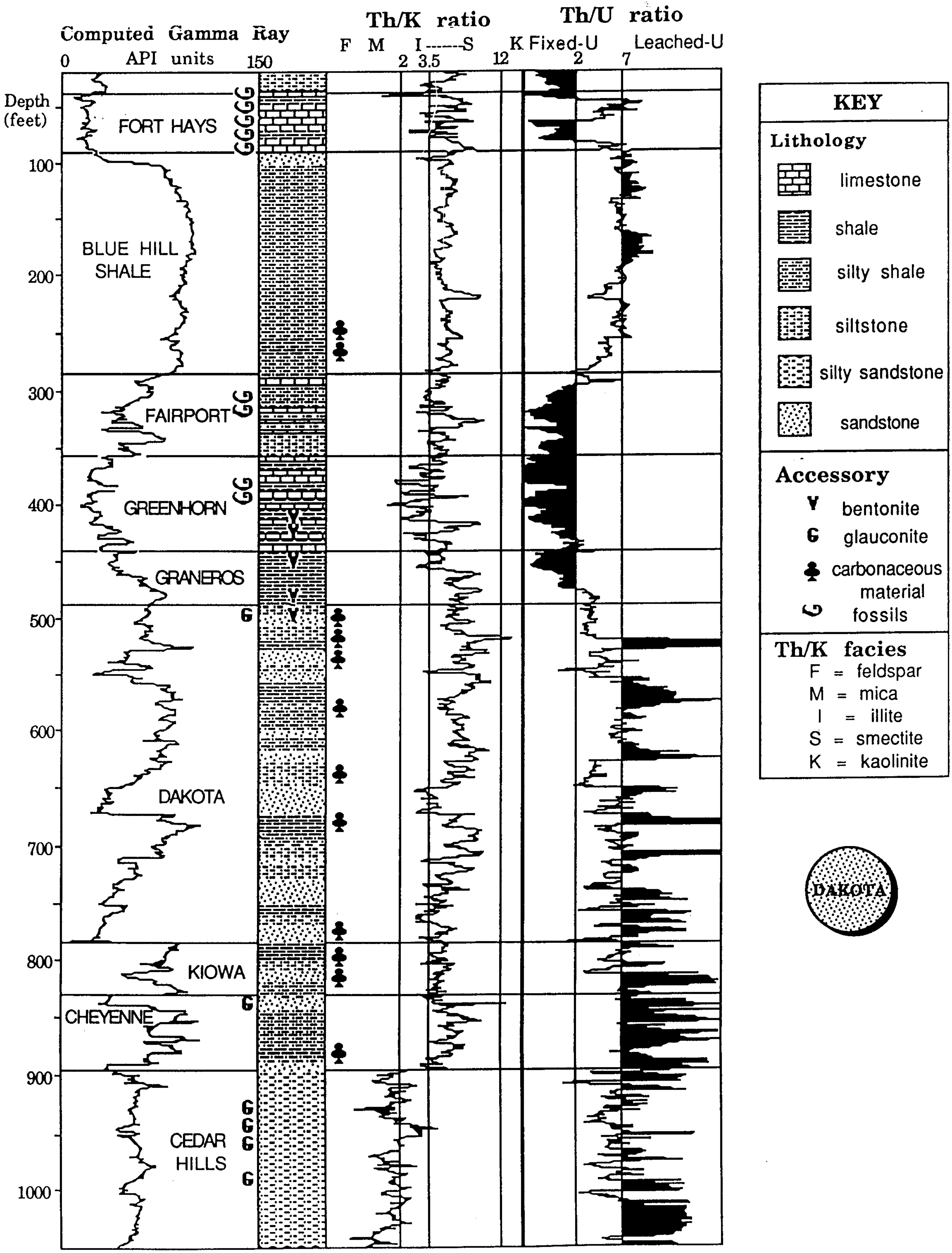
SANDSTONE - SHALE SPECTRAL GAMMA-RAY CROSSPLOTS



(ratio boundaries from Adams & Weaver, 1958)

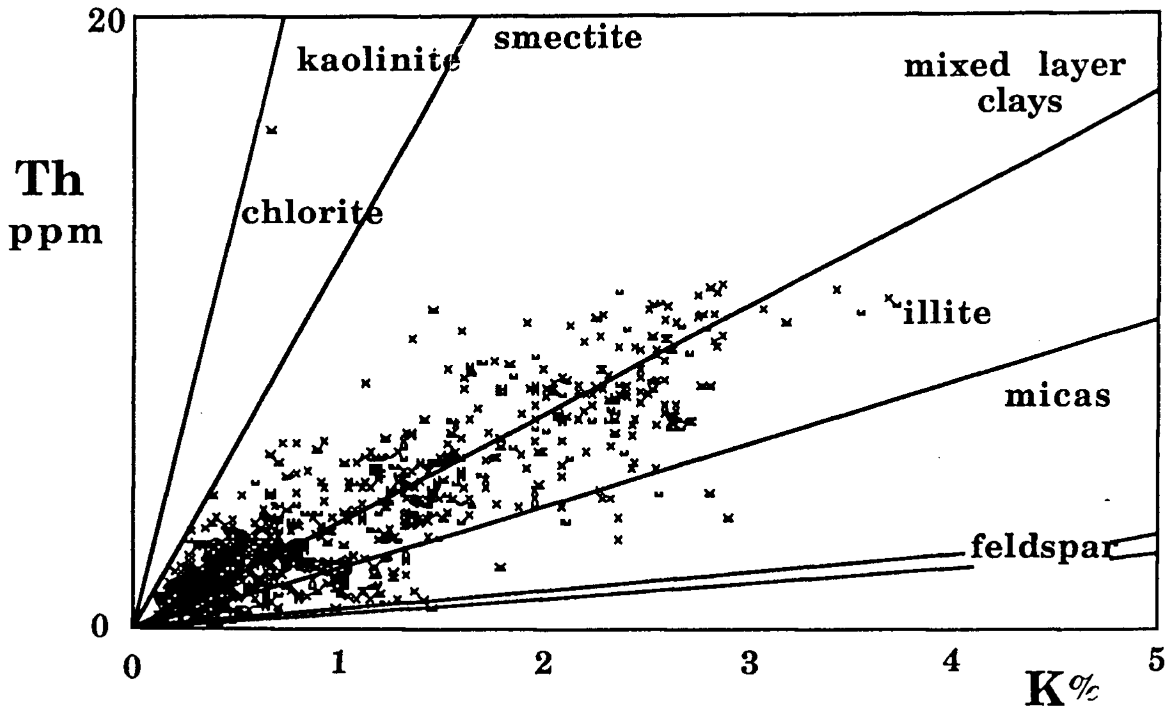


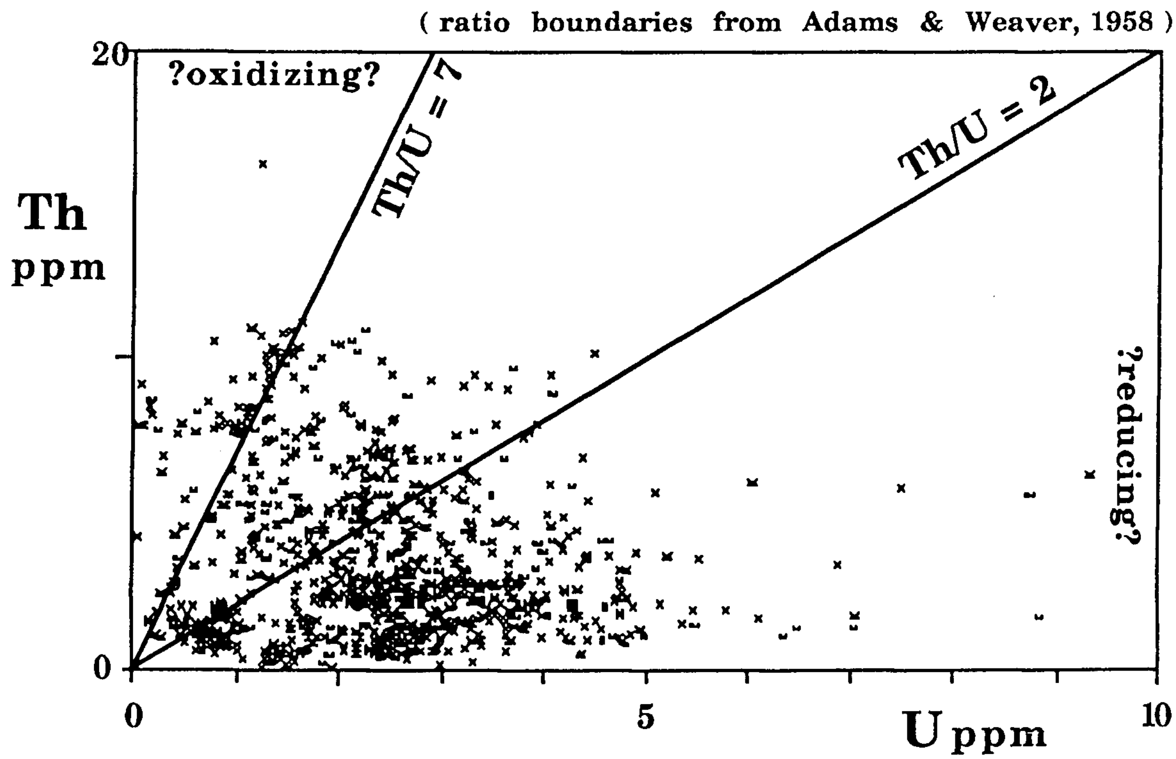
DAKOTA



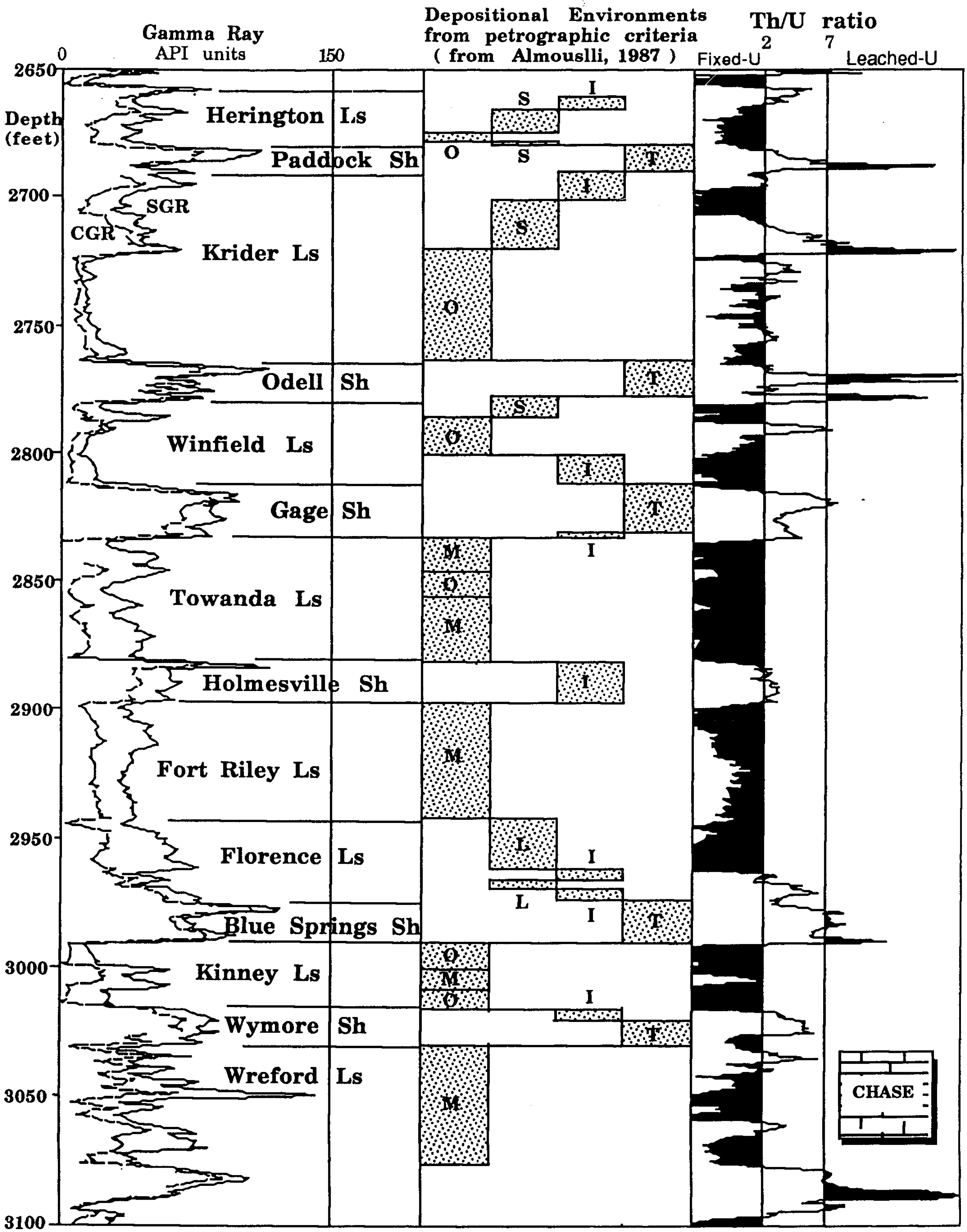
Computed Gamma Ray
API units
0
150
Th/K ratio
F M
I ------- S
2 3.5
12
K
Th/U ratio
Fixed-U
Leached-U
2
7
Depth
(feet)
100
200
300
400
500
600
700
800
900
1000
FORT HAYS
BLUE HILL
SHALE
FAIRPORT
GREENHORN
GRANEROS
DAKOTA
KIOWA
CHEYENNE
CEDAR
HILLS
KEY
Lithology
limestone
shale
silty shale
siltstone
silty sandstone
sandstone
Accessory
bentonite
glauconite
carbonaceous
material
fossils
Th/K facies
F = feldspar
M = mica
I = illite
S = smectite
K = kaolinite
DAKOTA

COMPLEX CARBONATE SPECTRAL GAMMA-RAY CROSSPLOTS





CHASE



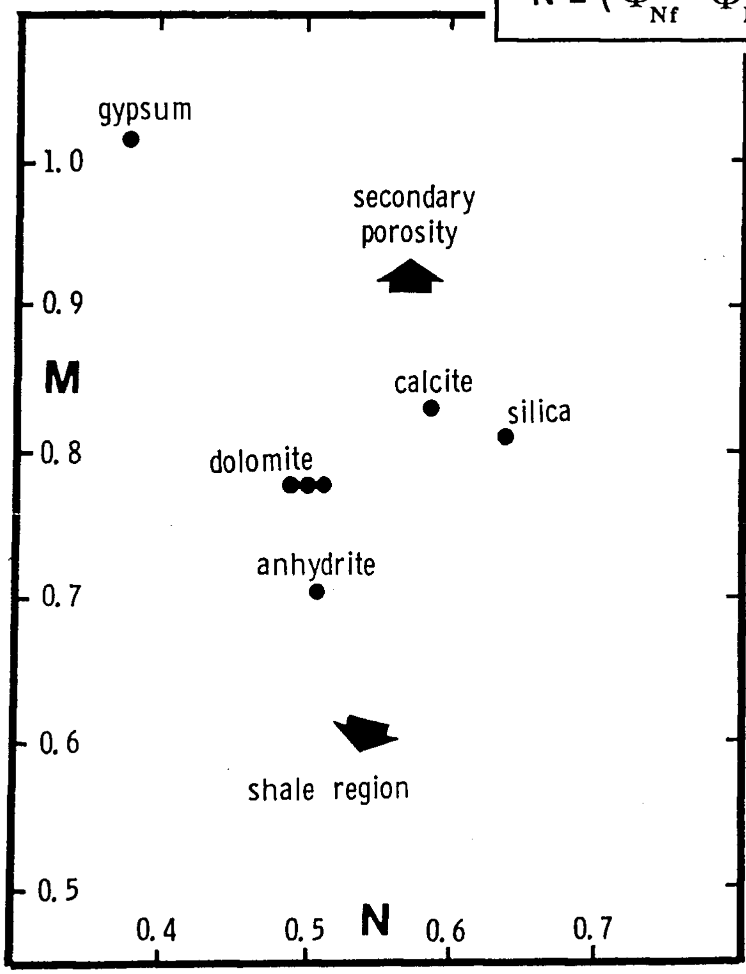
M = marine; O = off-bank; S = subtidal; L = lagoonal; I = intertidal; T = supratidal

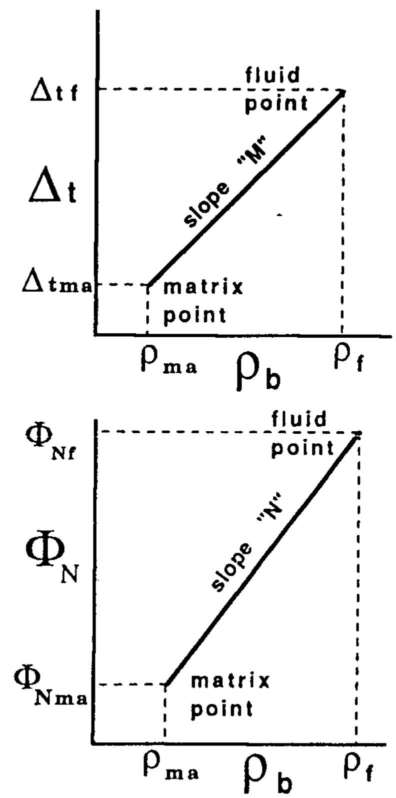
THE M - N PLOT :

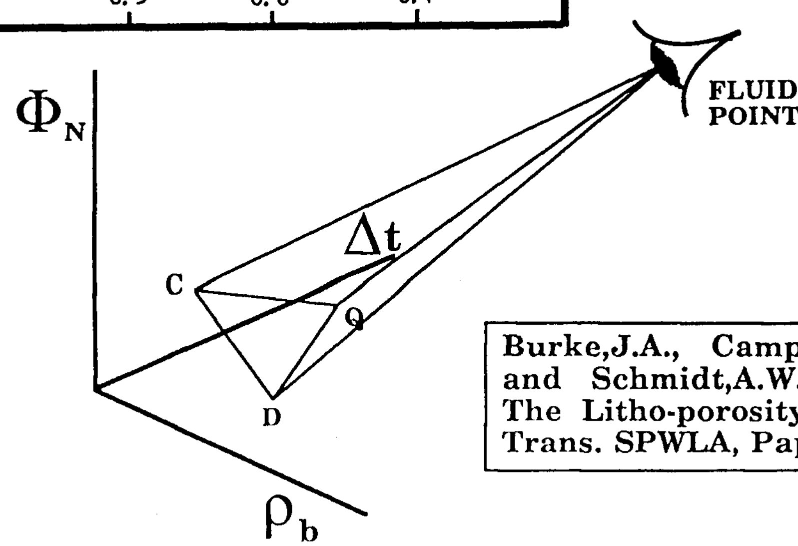
A PROJECTION IN THREE POROSITY LOG SPACE AS SLOPES ONTO A 2-DIMENSIONAL PLOT

$$M = (\Delta t_f - \Delta t)/(\rho_b - \rho_f) \quad * 0.01$$

$$N = (\Phi_{Nf} - \Phi_N)/(\rho_b - \rho_f)$$



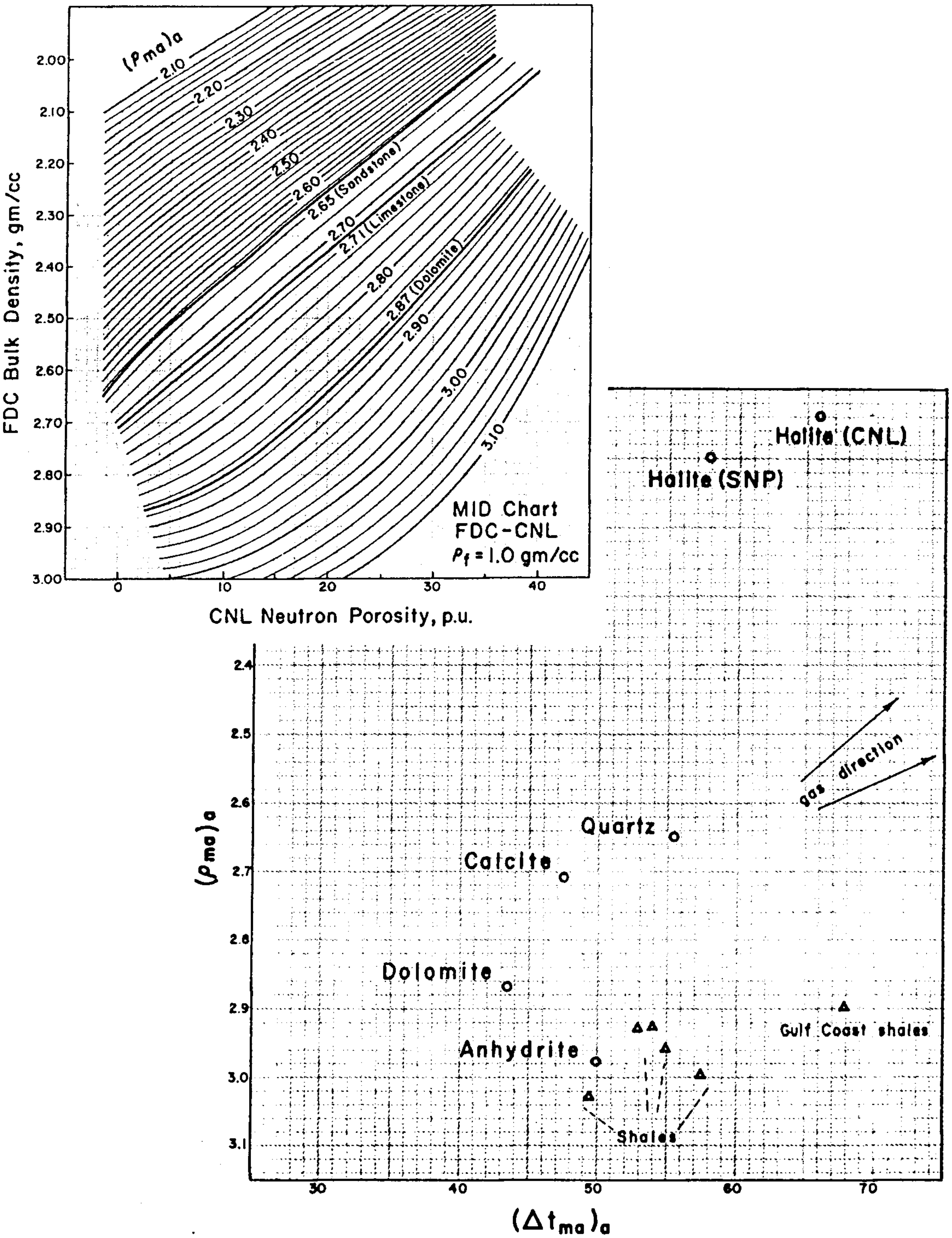




Burke,J.A., Campbell,R.L.,Jr, and Schmidt,A.W., 1969,
The Litho-porosity Cross Plot:
Trans. SPWLA, Paper Y, 29 pp.

THE MID PLOT :

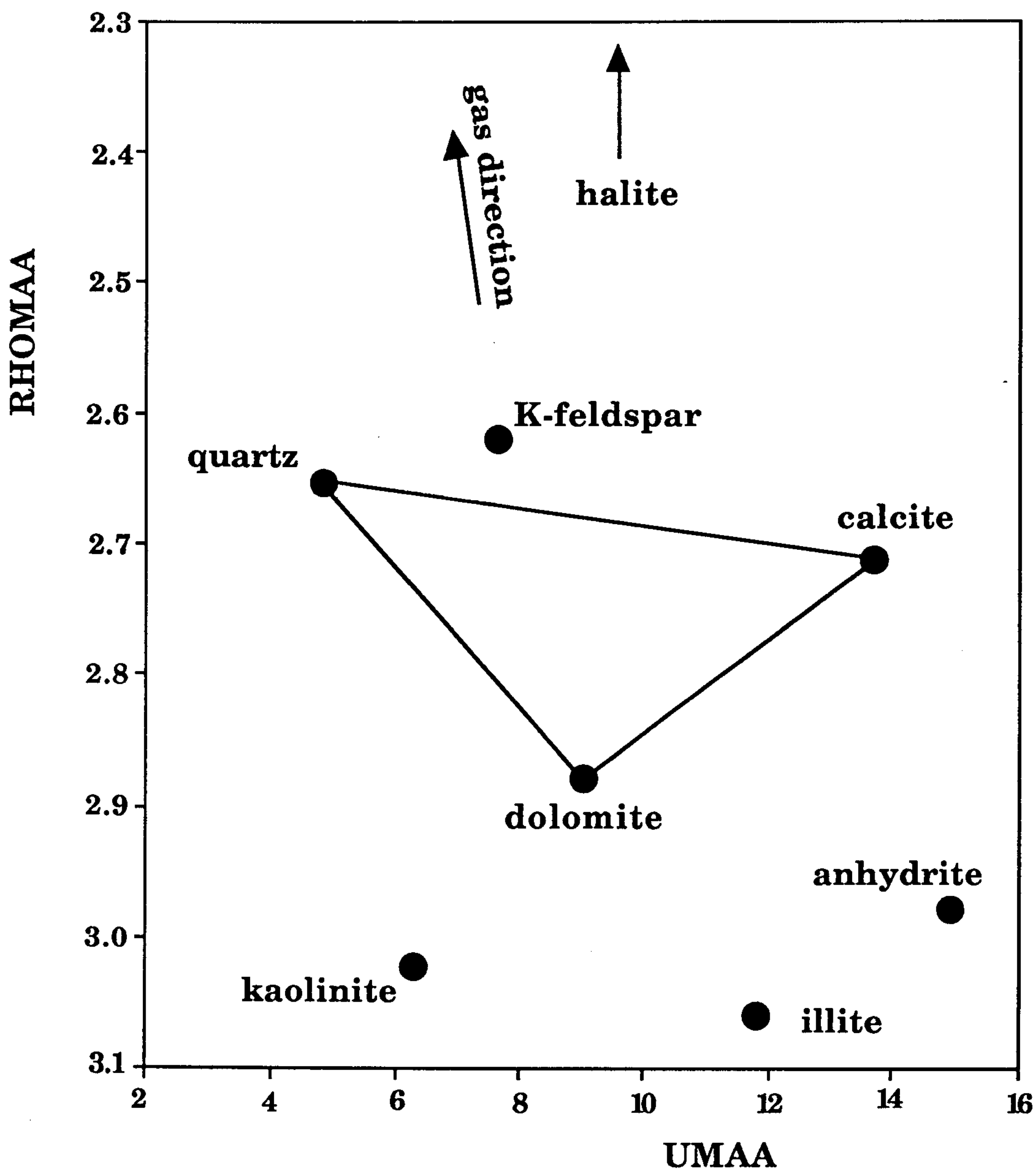
A NON-LINEAR PROJECTION IN THREE POROSITY LOG SPACE AS INTERCEPTS ON A 2-DIMENSIONAL PLOT



Clavier, C., and Rust, D.H., 1976, MID plot: A new lithology technique : The Log Analyst, v. XVII, no.6, p. 16 -24.

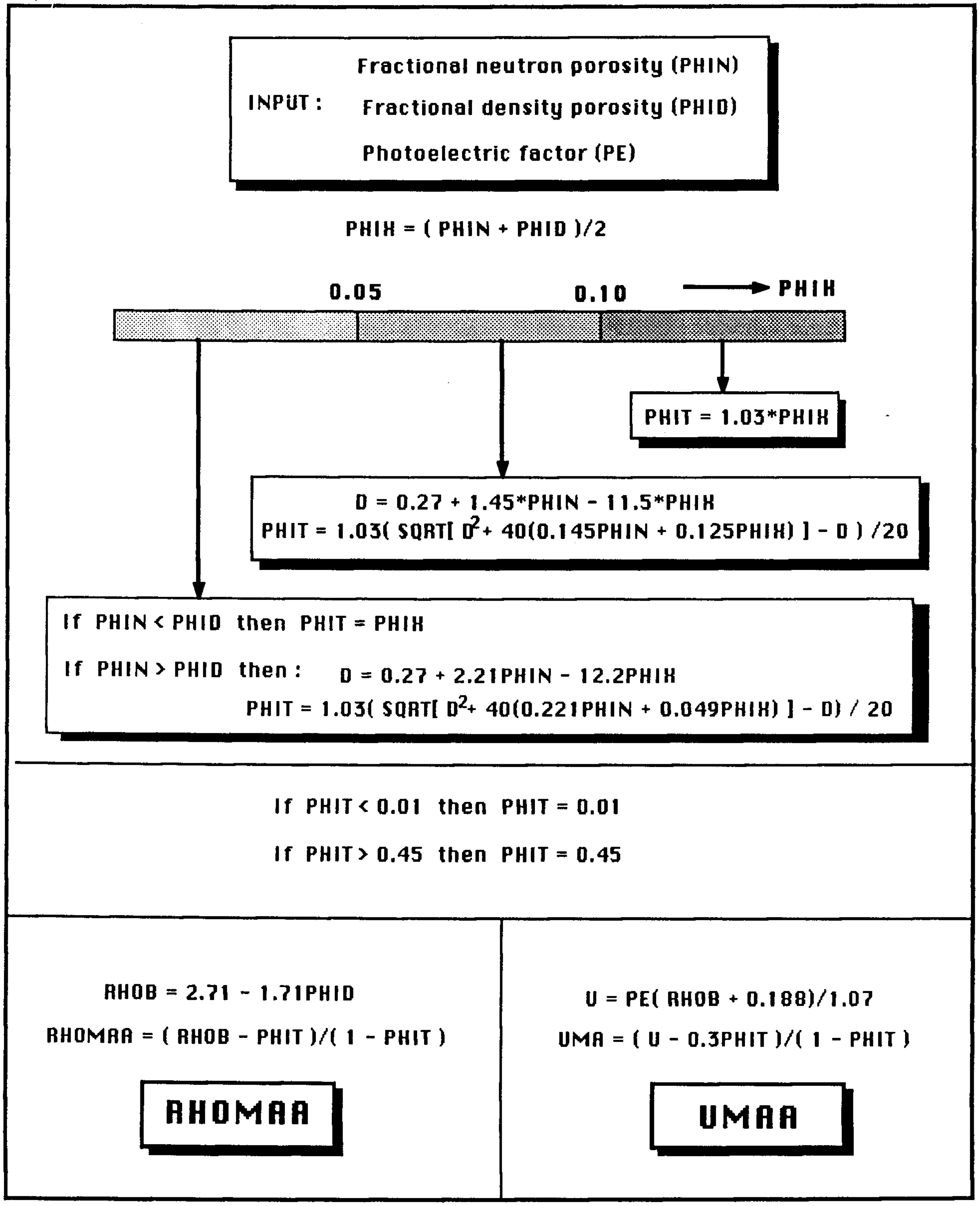
THE RHOMAA - UMAA PLOT :

A LITHODENSITY - NEUTRON SPECIES OF MID PLOT



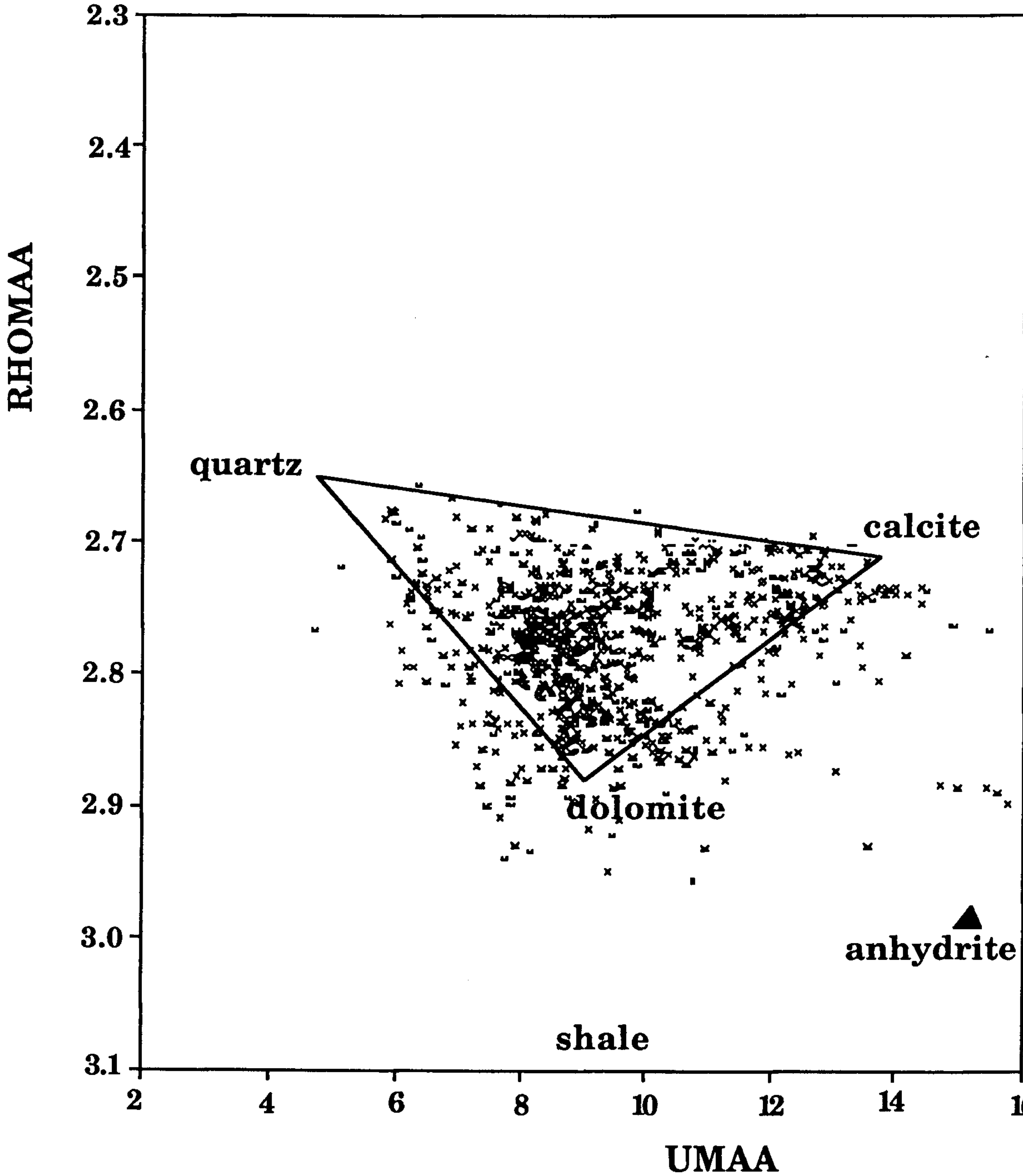
Gardner, J.S. and Dumanoir, J.L., 1980, Lithodensity Log Interpretation : Trans. SPWLA, Paper N, 23 pp.

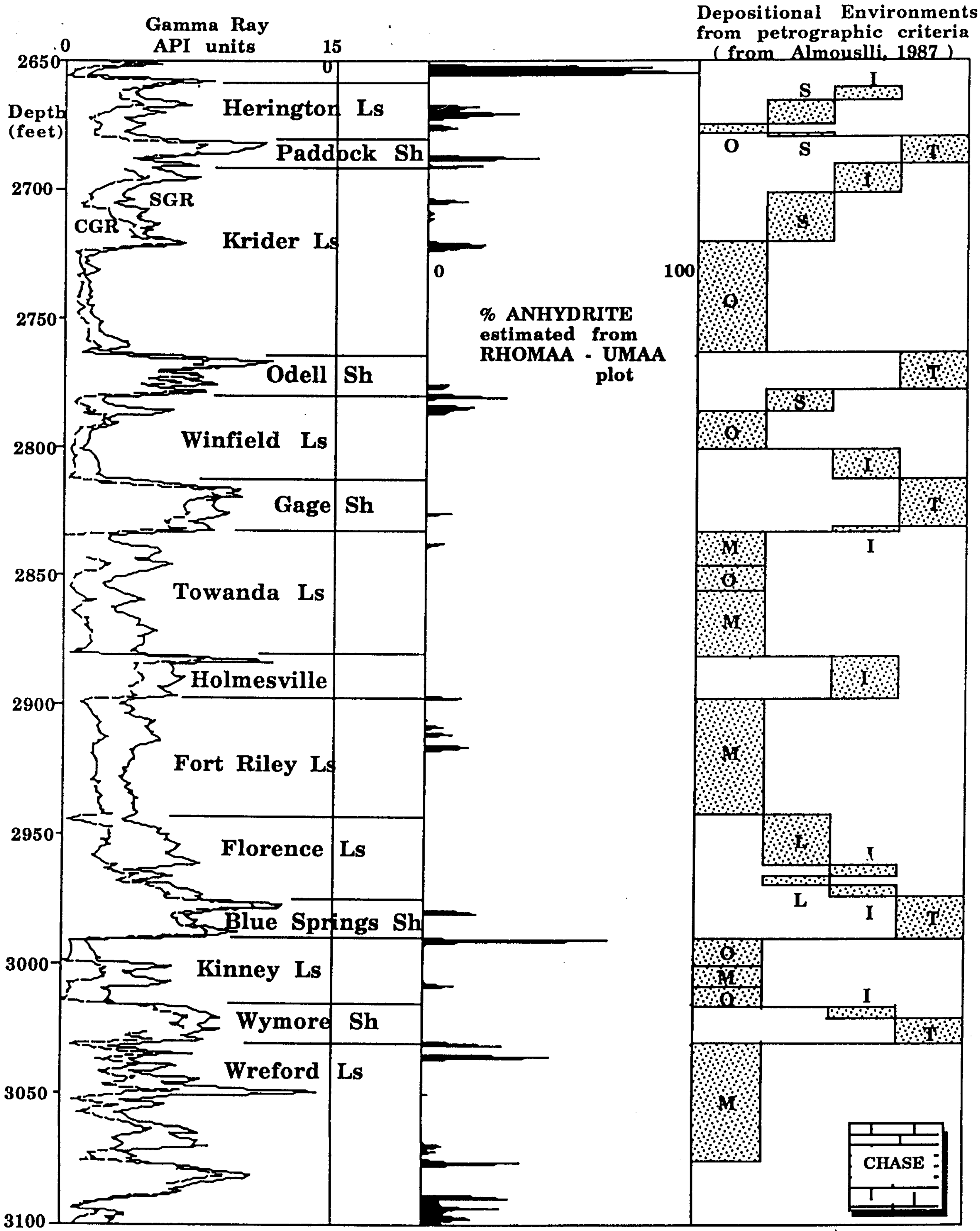
CALCULATION OF RHOMAA AND UMAA



Algorithm from BASIC program published by :
Elphick, R.Y., 1987, Nuclear log interpretation in hard rock formations : Geobyte, v. 2, no. 3, p. 44 - 47.

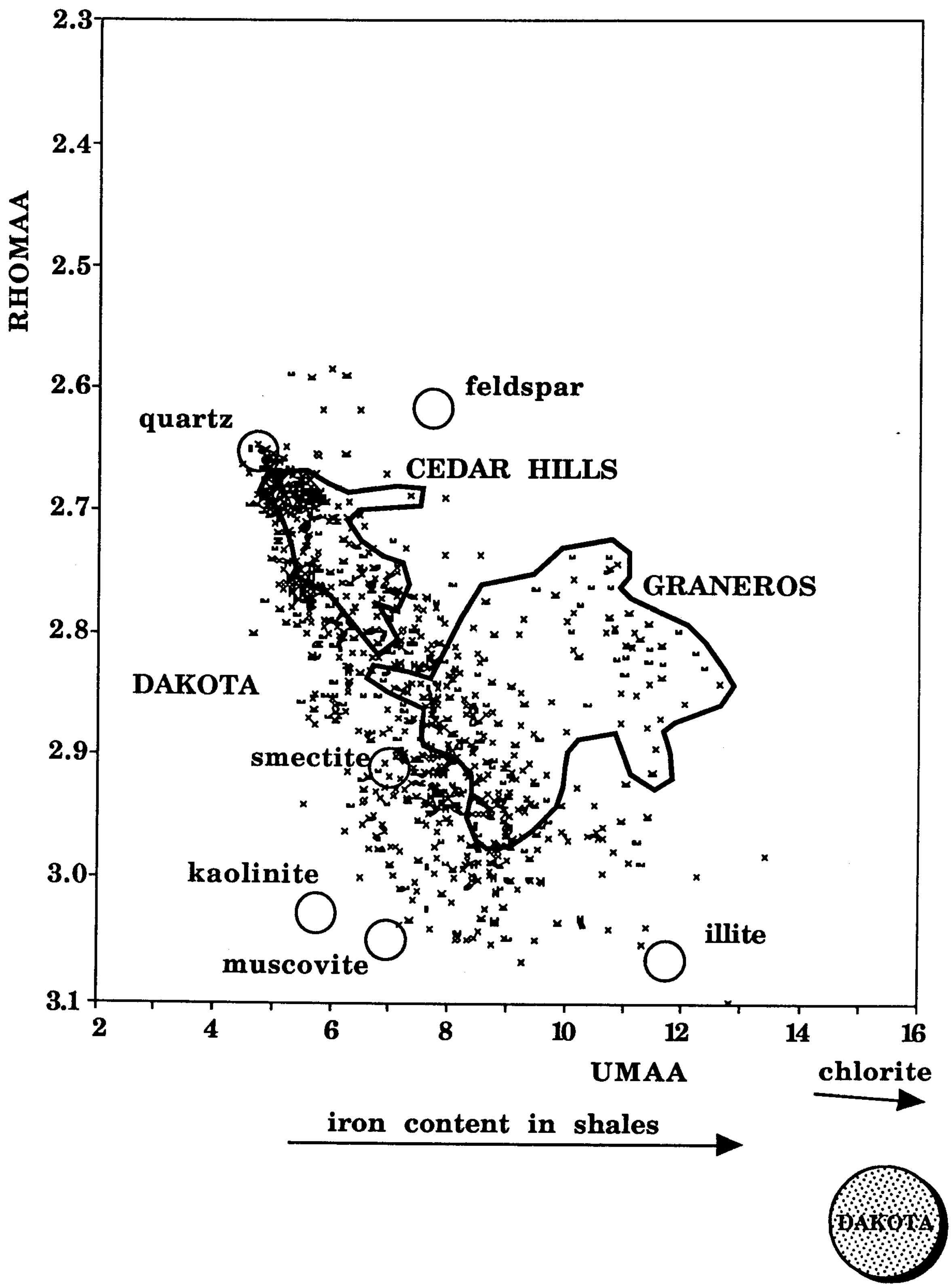
COMPLEX CARBONATE RHOMAA - UMAA PLOT

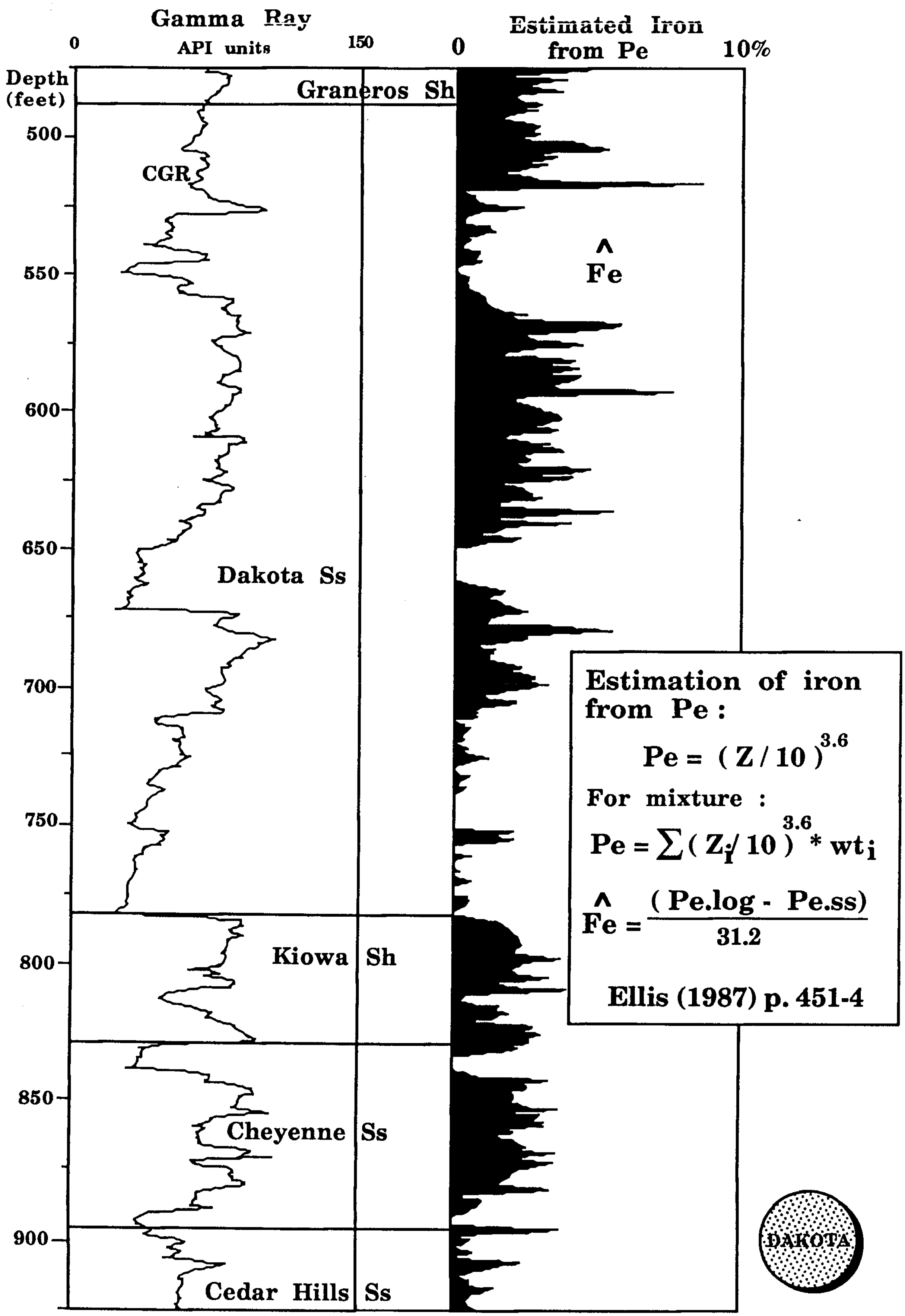




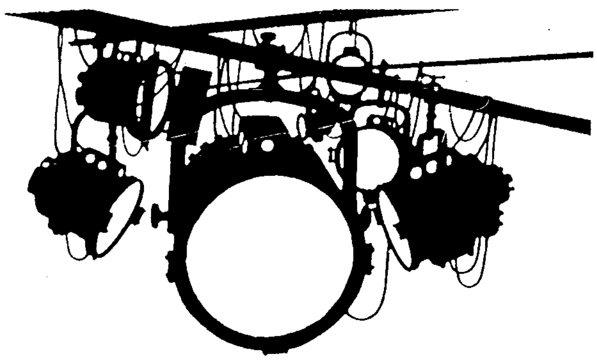
M = marine; O = off-bank; S = subtidal; L = lagoonal; I = intertidal; T = supratidal

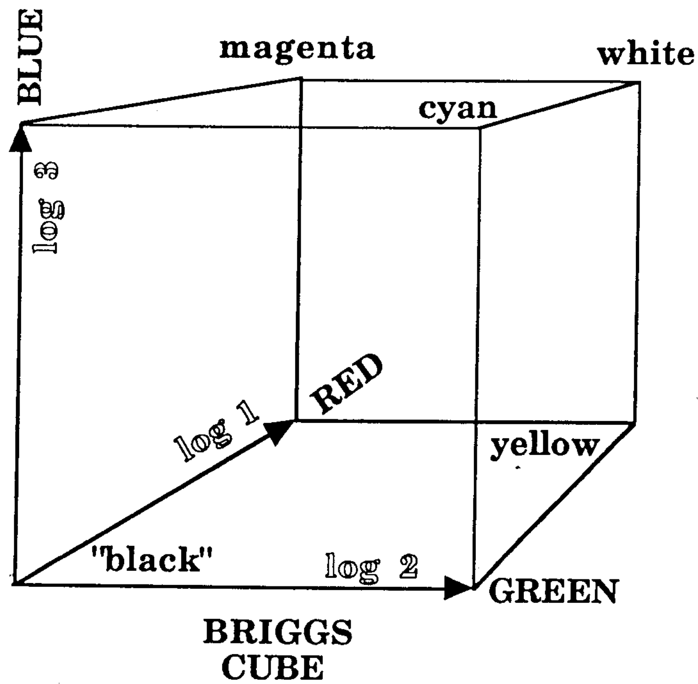
SANDSTONE - SHALE RHOMAA - UMAA PLOT

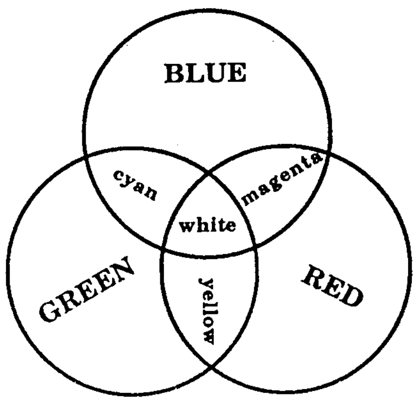


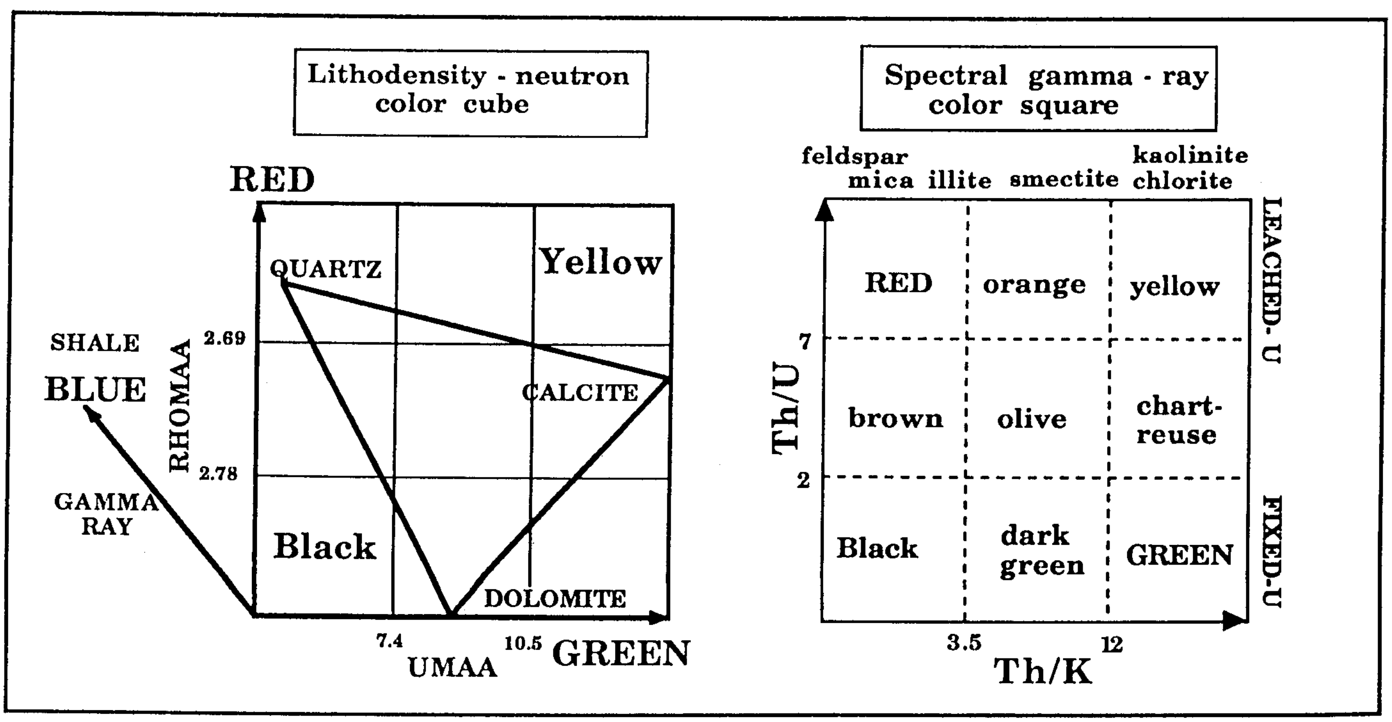

Gamma Ray
0
API units
150
Estimated Iron
0
from Pe
10%
Depth
(feet)
500
550
600
650
700
750
800
850
900
CGR
Graneros Sh
Dakota Ss
Kiowa Sh
Cheyenne Ss
Cedar Hills Ss
^
Fe
Estimation of iron from Pe :
Pe = (Z / 10)^3.6
For mixture :
Pe = ∑(Zi/ 10)^3.6 * wti
^
Fe = (Pe.log - Pe.ss) / 31.2
Ellis (1987) p. 451-4
DAKOTA

COLOR AS INFORMATION: 3-D LOG CROSSPLOTS AND STRIPLOGS USING THE BRIGGS COLOR CUBE



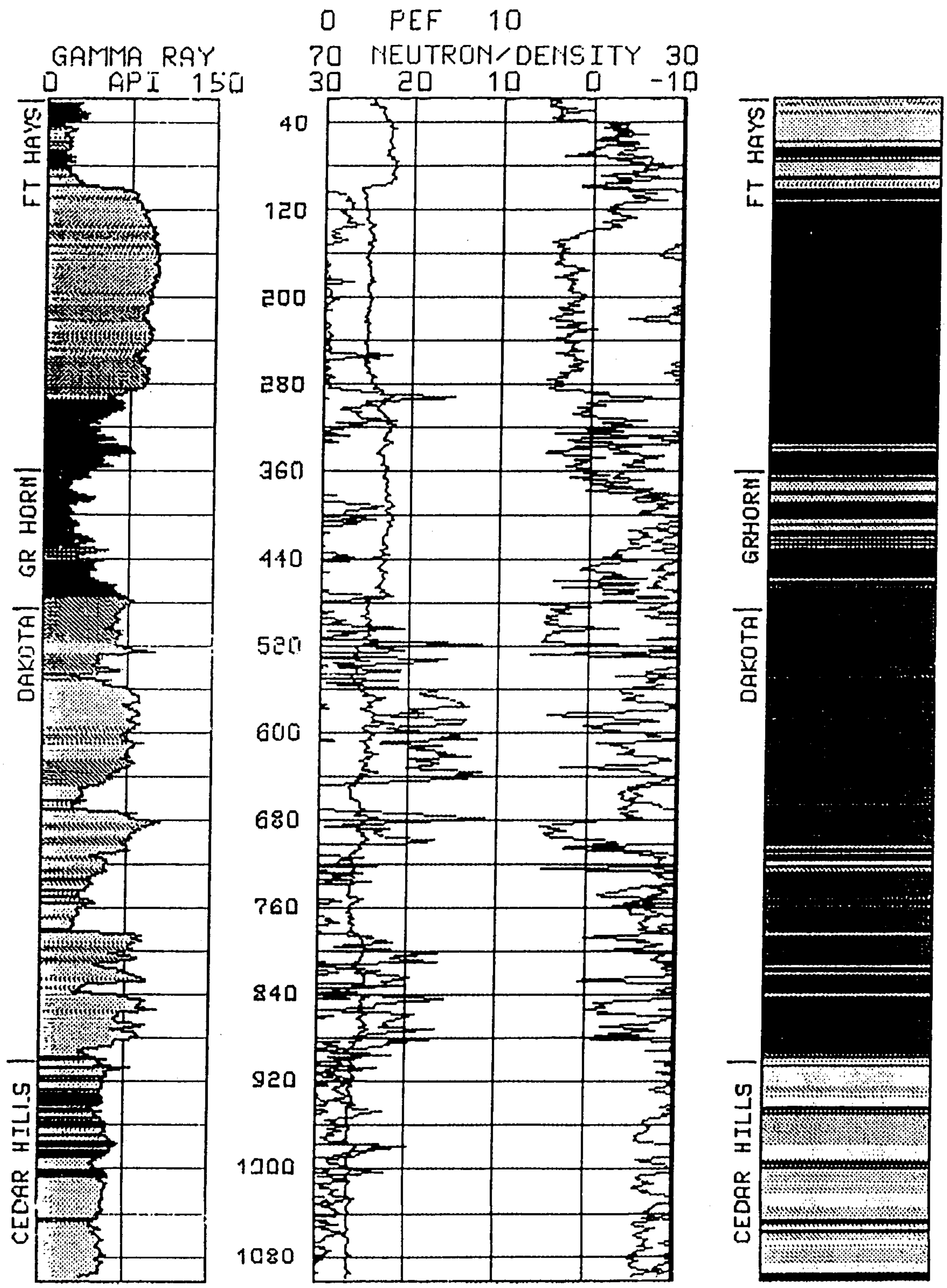






References: Briggs (1985); Collins and Doveton (1989)

KGS BRAUN #1 30-12S-18W ELLIS CO.
INITIAL DEPTH - 20.0 FINAL DEPTH - 1100.0
DATA INTERVAL = 2.0



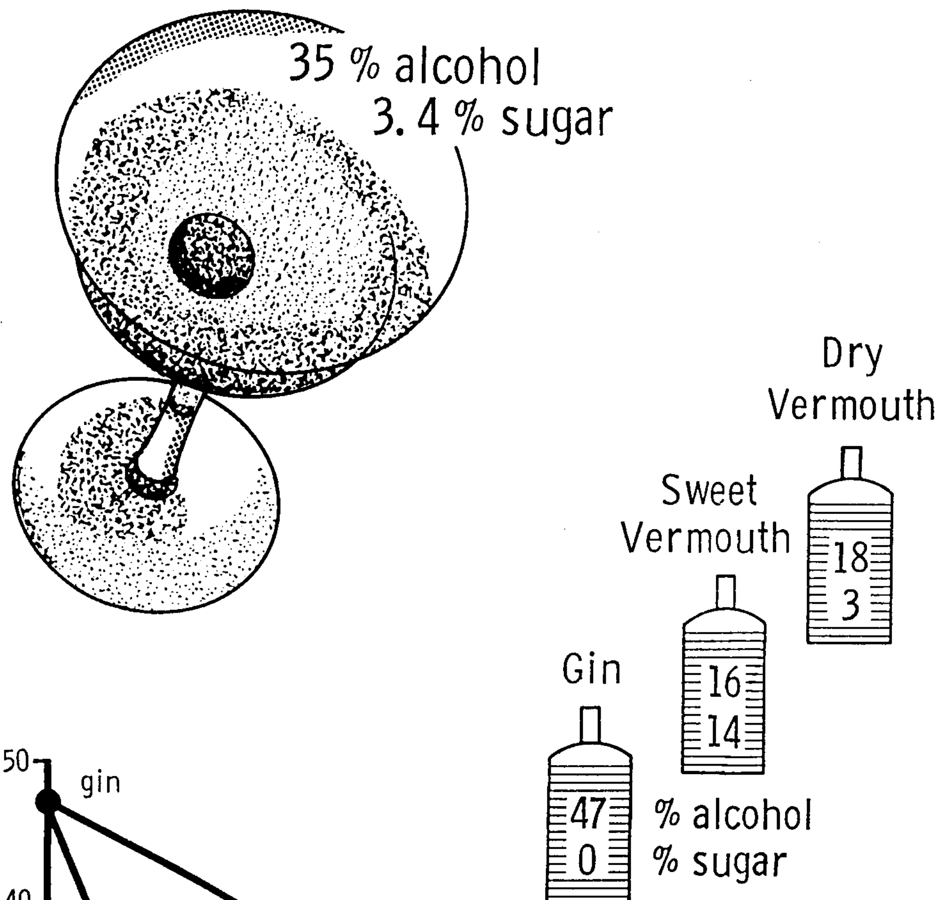
DAKOTA

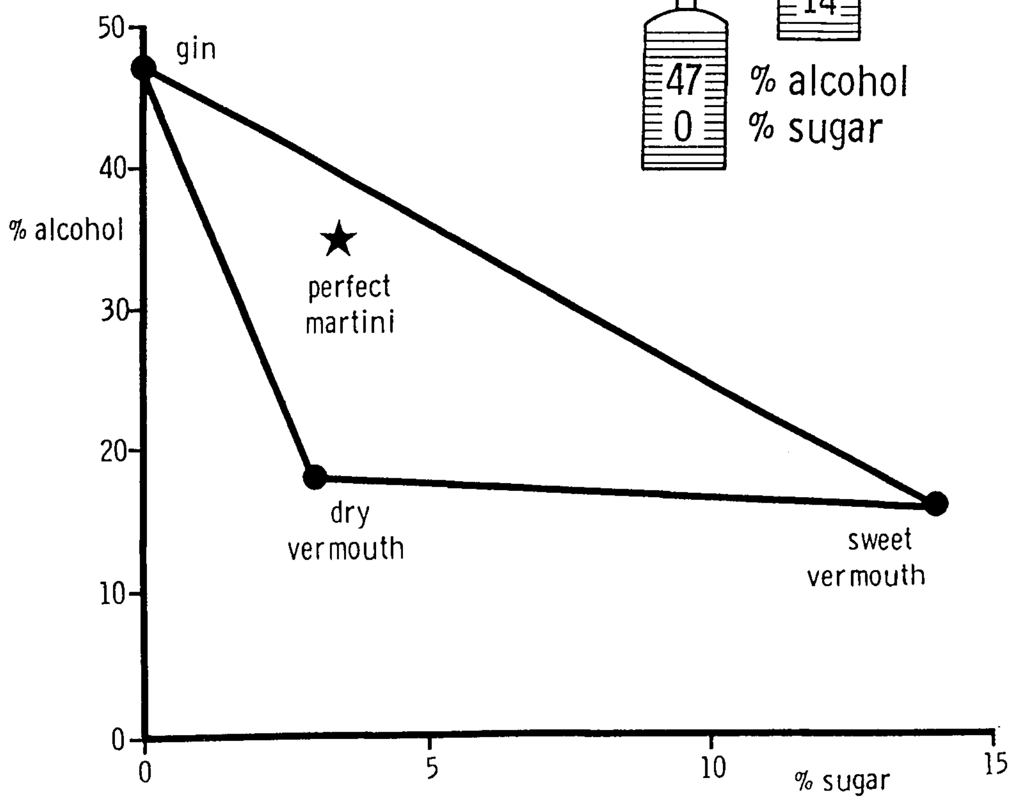
TOP-DOWN METHODS :

Matrix algebra solutions of normative petrography

$$CV = L$$

THE PERFECT MARTINI





MATRIX ALGEBRA SOLUTION OF PERFECT MARTINI PROBLEM

G = GIN D = DRY VERMOUTH S = SWEET VERMOUTH

SIMULTANEOUS EQUATIONS

Alcohol:	47G	+	18D	+	16S	=	35
Sugar:	0G	+	3D	+	14S	=	3.4
Unity:	G	+	D	+	S	=	1

MATRIX ALGEBRA FORMAT

$$\begin{bmatrix} 47 & 18 & 16 \\ 0 & 3 & 14 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} G \\ D \\ S \end{bmatrix} = \begin{bmatrix} 35 \\ 3.4 \\ 1 \end{bmatrix}$$

$$C * V = L$$

MATRIX SOLUTION

$$V = C^{-1} * L$$

$$V = \begin{bmatrix} G \\ D \\ S \end{bmatrix} = \begin{bmatrix} 0.60 \\ 0.20 \\ 0.20 \end{bmatrix}$$

kiwi

Program to compute proportions of N components from (N-1) logs, using matrix algebra solution of simultaneous equation set

INPUT:

Well name, section, number of logs, names of logs and components, log responses of components, zone depths and log readings

OPERATION:

- Written in MICROSOFT BASIC (FORTRAN version in Doveton, 1986)
- Runs on IBM PC or compatible
- Interactive data entry version
- Will solve for up to 6 components, but can be expanded

```
100 REM*****************************************************************
110 REM K I W I :
120 REM  COMPUTATION OF MINERAL AND FLUID COMPONENT PROPORTIONS
121 REM  BASED ON LOG RESPONSES.
122 REM
123 REM  MICROSOFT BASIC; IBM IMPLEMENTATION.
124 REM
125 REM  JOHN H. DOVETON; KANSAS GEOLOGICAL SURVEY; 1981
126 REM  (BASIC ADAPTATION: RICHARD BROWNRIGG; K.G.S.; 1985)
127 REM
128 REM *****************************************************************
130 OPTION BASE 1
140 DIM L$(5),C$(6)
150 DIM V(6,6),V2(6,6)
160 DIM D3(200),R1(6),R2(6),R4(200,6)
161 OPEN "O",#1,"KIWIWORK.TMP"
170 PRINT "*** K I W I PROGRAM ***"
180 PRINT "NAME OF WELL ";
190 LINE INPUT "? ";N$
200 PRINT "NAME OF SECTION ";
210 LINE INPUT "? ";S$
211 GOSUB 2000
220 PRINT
230 PRINT "NUMBER OF LOGS ";
240 INPUT N
250 IF N>5 THEN PRINT "***NO MORE THAN 5 CAN BE ACCEPTED!":LET N=5
260 FOR I=1 TO N
270  PRINT "NAME OF LOG ";I;
280  INPUT L$(I)
290 NEXT I
291 GOSUB 2080
300 LET M=N+1
310 PRINT
320 FOR I=1 TO M
330  PRINT "NAME OF COMPONENT ";I;
340  INPUT C$(I)
350 NEXT I
351 GOSUB 2190
360 PRINT
370 FOR I=1 TO N
380  FOR J=1 TO M
390   PRINT L$(I);" VALUE FOR ";C$(J);
400   INPUT V(I,J)
410  NEXT J
420  PRINT
430 NEXT I
440 FOR J=1 TO M
450  LET V(M,J)=1
460 NEXT J
461 GOSUB 2280
480 REM ****************************
490 REM INVERT MATRIX OF LOG COEFFICIENTS:
500 REM   V = MATRIX OF VALUES;  V2 = INVERTED MATRIX
510 REM   D = DETERMINATE       D2 = DIVISOR
520 REM   R = RATIO
530 REM ****************************
540 FOR I=1 TO M
550  LET V2(I,I)=1
560 NEXT I
570 LET D=1
580 FOR I=1 TO M
590  LET D2=V(I,I)
600  LET D=D*D2
610  FOR J=1 TO M
620   LET V(I,J)=V(I,J)/D2
630   LET V2(I,J)=V2(I,J)/D2
640  NEXT J
650  FOR J=1 TO M
660   IF (I-J)=0 THEN GOTO 720
670   LET R=V(J,I)
680   FOR K=1 TO M
690    LET V(J,K)=V(J,K)-R*V(I,K)
700    LET V2(J,K)=V2(J,K)-R*V2(I,K)
710   NEXT K
720  NEXT J
730 NEXT I
740 REM ****************************
750 REM NOW READ AND PROCESS LOG RESPONSES:
780 REM  D3(..) = DEPTHS           R1(..) = TMP.VR.,CALC. OF PROP.
790 REM  R2(..) = INPUT LOG VALUES  R3 = TMP.VR.
800 REM  R4(..) = COMPONENT'S PROPORTIONS, INDEXED BY DEPTH
801 REM ****************************
830 LET Z=0
840 LET R2(M)=1
850 PRINT
860 PRINT "ENTER LOG READINGS FOR EACH ZONE, AS:"
870 PRINT
880 PRINT "DEPTH";
881 GOSUB 2470
890 FOR I=1 TO N
900  PRINT ",";L$(I);
910 NEXT I
920 PRINT
930 PRINT
940 PRINT "...ONE ZONE PER LINE.  ENTER -1 FOR DEPTH TO QUIT."
950 FOR L=1 TO 200
960 LINE INPUT "? ";A$
970 LET A=0
980 GOSUB 1270
981 IF X<=0 GOTO 9000
```

```
990 LET D3(L)=X
1000 FOR I=1 TO N
1010  GOSUB 1270
1020  LET R2(I)=X
1030 NEXT I
1070  LET Z=Z+1
1080  FOR I=1 TO M
1090   LET R1(I) = 0
1100   FOR J=1 TO M
1110    LET R1(I)=R1(I)+V2(I,J)*R2(J)
1120   NEXT J
1130  NEXT I
1131  GOSUB 2610
1140  LET R3=0
1150  FOR I=1 TO M
1160   IF R1(I)<0 THEN LET R1(I)=0
1170   LET R3=R3+R1(I)
1180  NEXT I
1190  FOR I=1 TO M
1200   LET R1(I)=100*R1(I)/R3
1210   LET R4(L,I)=R1(I)
1220  NEXT I
1230 NEXT L
1260 REM ************************************************************
1270 REM S U B R O U T I N E: ISOLATES THE NEXT NUMERIC STRING IN A$
1280 LET A=A+1
1290 IF A>LEN(A$) GOTO 1420
1300 LET X=ASC(MID$(A$,A,1))
1310 IF X<45 GOTO 1280
1320 IF X>57 GOTO 1280
1330 LET B=A
1340 LET A=A+1
1350 IF A>LEN(A$) GOTO 1400
1360 LET X=ASC(MID$(A$,A,1))
1370 IF X<45 GOTO 1400
1380 IF X>57 GOTO 1400
1390 GOTO 1340
1400 LET X=VAL(MID$(A$,B,(A-B)))
1410 RETURN
1420 LET X=0
1430 RETURN
1999 REM ************************************************************
2000 REM SUBROUTINE: PRINT HEADER, AND WELL NAME:
2001 PRINT #1,
2010 PRINT #1," * * * K I W I   P R O G R A M * * *"
2020 PRINT #1,
2030 PRINT #1,
2040 PRINT #1,
2050 PRINT #1," WELL NAME: ";N$
2060 PRINT #1,"   SECTION: ";S$
2070 RETURN
2079 REM ************************************************************
2080 REM SUBROUTINE: PRINT LOG KEY...
2090 PRINT #1,
2100 PRINT #1,
2110 PRINT #1,
2120 PRINT #1," KEY TO LOGS:"
2140 FOR I=1 TO N
2150   PRINT #1,USING "   LOG #=\            \";I;L$(I)
2170 NEXT I
2180 RETURN
2189 REM ************************************************************
2190 REM SUBROUTINE: PRINT THE KEY TO THE COMPONENTS...
2200 PRINT #1,
2210 PRINT #1,
2220 PRINT #1," KEY TO COMPONENTS:"
2230 FOR I=1 TO M
2240   LET A$=CHR$(64+I)
2250   PRINT #1,"   COMPONENT ";A$;"=";C$(I)
2260 NEXT I
2270 RETURN
2279 REM ************************************************************
2280 REM SUBROUTINE: PRINT THE LOG COEFFICIENTS...
2290 PRINT #1,
2300 PRINT #1,
2310 PRINT #1,
2320 PRINT #1," LOG COEFFICIENTS:"
2330 PRINT #1,"        ";
2340 FOR I=1 TO M
2350   LET A$=CHR$(64+I)
2360   PRINT #1,"        ";A$;
2370 NEXT I
2380 PRINT #1,
2390 FOR I=1 TO N
2400   PRINT #1,USING "   LOG # ";I;
2410   FOR J=1 TO M
2420     PRINT #1,USING "#######.##";V(I,J);
2430   NEXT J
2440   PRINT #1,
2450 NEXT I
2460 RETURN
2469 REM ************************************************************
2470 REM SUBROUTINE:  PRINT HEADING FOR RESPONSES AND PROPORTIONS OUTPUT...
2480 PRINT #1,
2490 PRINT #1,
2500 PRINT #1,
2510 PRINT #1," LOG RESPONSES AND COMPONENT PROPORTIONS:"
2511 PRINT #1,"  DEPTH";
2520 FOR I=1 TO N
2530   PRINT #1,USING "   # ";I;
2540 NEXT I
2550 PRINT #1,"   ";
2560 FOR I=1 TO M
2570   PRINT #1,"    ";CHR$(64+I);"  ";
2580 NEXT I
2590 PRINT #1,
2600 RETURN
2609 REM ************************************************************
2610 REM SUBROUTINE: PRINT USER'S LOG RESPONSES AND THEIR PROPORTIONS...
2620 PRINT #1,USING "########";D3(L);
2630 FOR A=1 TO N
2640   PRINT #1,USING "####.##";R2(A);
2650 NEXT A
2660 PRINT #1,"   ";
2670 FOR A=1 TO M
2680   PRINT #1,USING "####.##";R1(A);
2690 NEXT A
2700 PRINT #1,
2710 RETURN
9000 REM ************************************************************
9010 REM FINALLY,  GENERATE THE GRAPHIC...
9020 REM
9030 PRINT
9040 PRINT " SCALE PLOT FOR 133 CHARACTERS/LINE OUTPUT (Y/N)";
9050 INPUT Y$
9060 IF Y$="Y" GOTO 9120
9070 PRINT " ...PLOT WILL BE SCALED FOR 80 COLUMN OUTPUT."
9080 W=2
9091 LET P1$="*...10...20...30...40...50...60...70...80...90..100* %"
9100 LET P2$="*"+STRING$(50," ")+"*"
9110 GOTO 9150
9120 W=1
9131 LET P1$="*....+...10....+...20....+...30....+...40....+...50....+
     ...60....+...70....+...80....+...90....+..100* %"
9140 LET P2$="*"+STRING$(100," ")+"*"
9150 PRINT #1,
9160 PRINT #1,
9170 PRINT #1,
9180 PRINT #1," GRAPHIC COMPONENT LOG:"
9190 PRINT #1,
9200 PRINT #1," DEPTH";P1$
9210 LET D4=D3(1)
9220 FOR L=1 TO Z
9230   PRINT #1,USING "######";D4;
9240   IF D3(L)<=D4 GOTO 9280
9250   PRINT #1,P2$
9260   LET D4=D4+1
9270   GOTO 9230
9280   LET P3$=P2$
9290   MID$(P3$,LEN(P3$)-1,1)=CHR$(64+M)
9300   LET K=1
9310   FOR J=1 TO N
9320     IF R4(L,J)<0 GOTO 9360
9330     LET I=K+(R4(L,J)\W)
9340     MID$(P3$,I,1)=CHR$(64+J)
9350     LET K=I
9360   NEXT J
9370   PRINT #1,P3$
9371   LET D4=D4+1
9380 NEXT L
9390 PRINT #1," DEPTH";P1$
9400 PRINT #1,"      SCALE = ";W;" UNITS/SPACE."
9401 PRINT #1,
9410 PRINT #1,
9420 CLOSE #1
9421 PRINT:PRINT " ROUTE OUTPUT TO PRINTER (Y/N)";
9422 INPUT Y$
9423 IF Y$<>"Y" THEN PRINT:PRINT " AT DOS-LEVEL, ENTER 'TYPE
     KIWIWORK.TMP' TO VIEW THE OUTPUT":GOTO 9500
9430 OPEN "I",#1,"KIWIWORK.TMP"
9440 IF EOF(1) GOTO 9480
9450 LINE INPUT #1,A$
9460 LPRINT A$
9470 GOTO 9440
9480 CLOSE
9490 KILL "KIWIWORK.TMP"
9500 END
```

EXAMPLE OF KIWI PROGRAM RUN IN VIOLA LIMESTONE SECTION OF CHERTY DOLOMITES AND LIMESTONES

KIWI PROGRAM

****

CITIES SERVICE BECK A-1 SW-SE-SE 14-5S-12E
LOWER VIOLA (MIDDLE ORDOVICIAN)

****

KEY TO LOGS
LOG 1 = NEUTRON
LOG 2 = DENSITY
LOG 3 = SONIC

KEY TO COMPONENTS
COMPONENT A=DOLOMITE
COMPONENT B=CHERT
COMPONENT C=CALCITE
COMPONENT D=POROSITY

****

LOG COEFFICIENTS	A	B	C	D
LOG 1	5.00	-5.00	.00	100.00
LOG 2	2.87	2.65	2.71	1.00
LOG 3	43.50	55.10	47.50	189.00

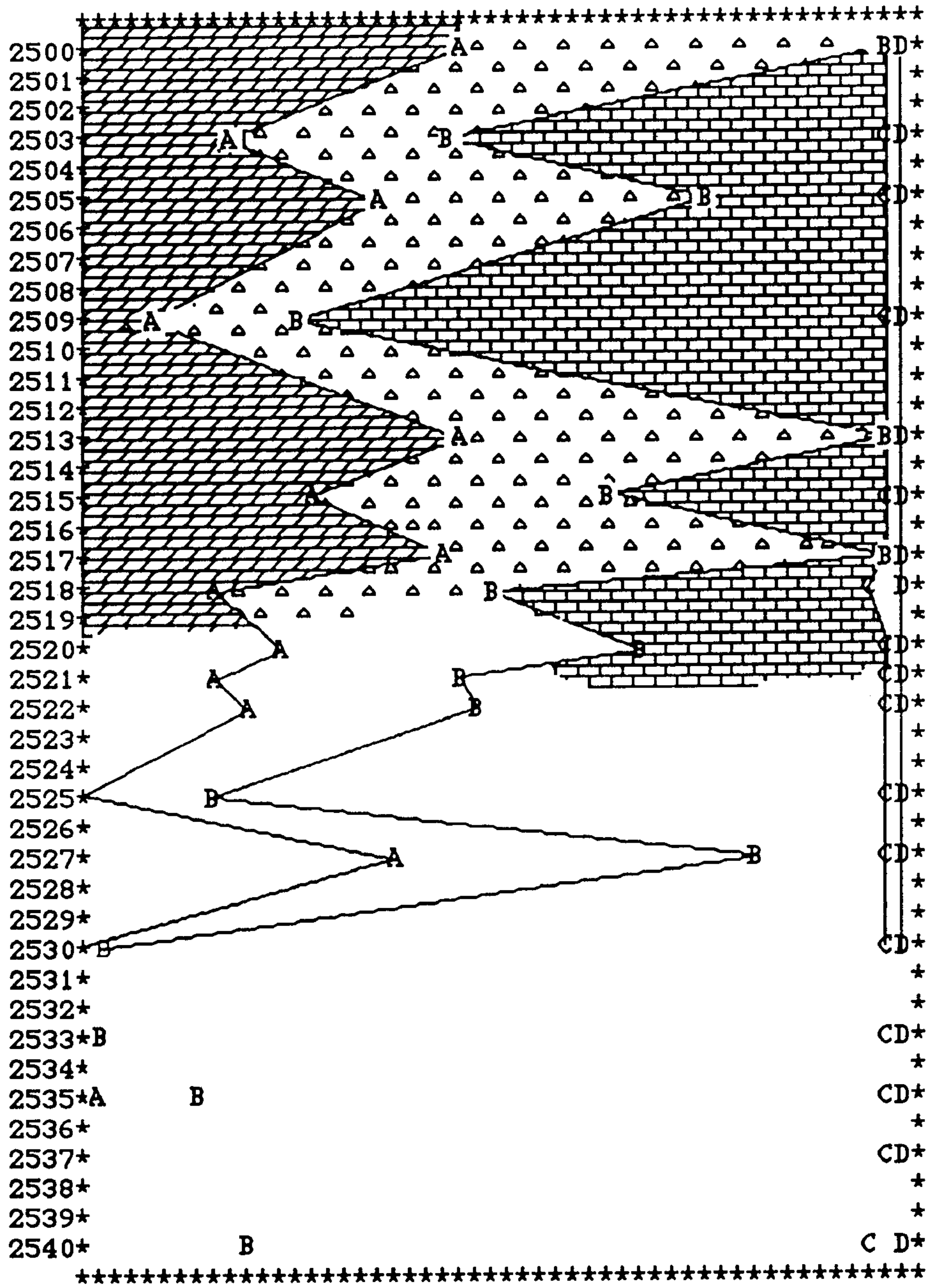
****

LOG RESPONSES AND COMPONENT PROPORTIONS

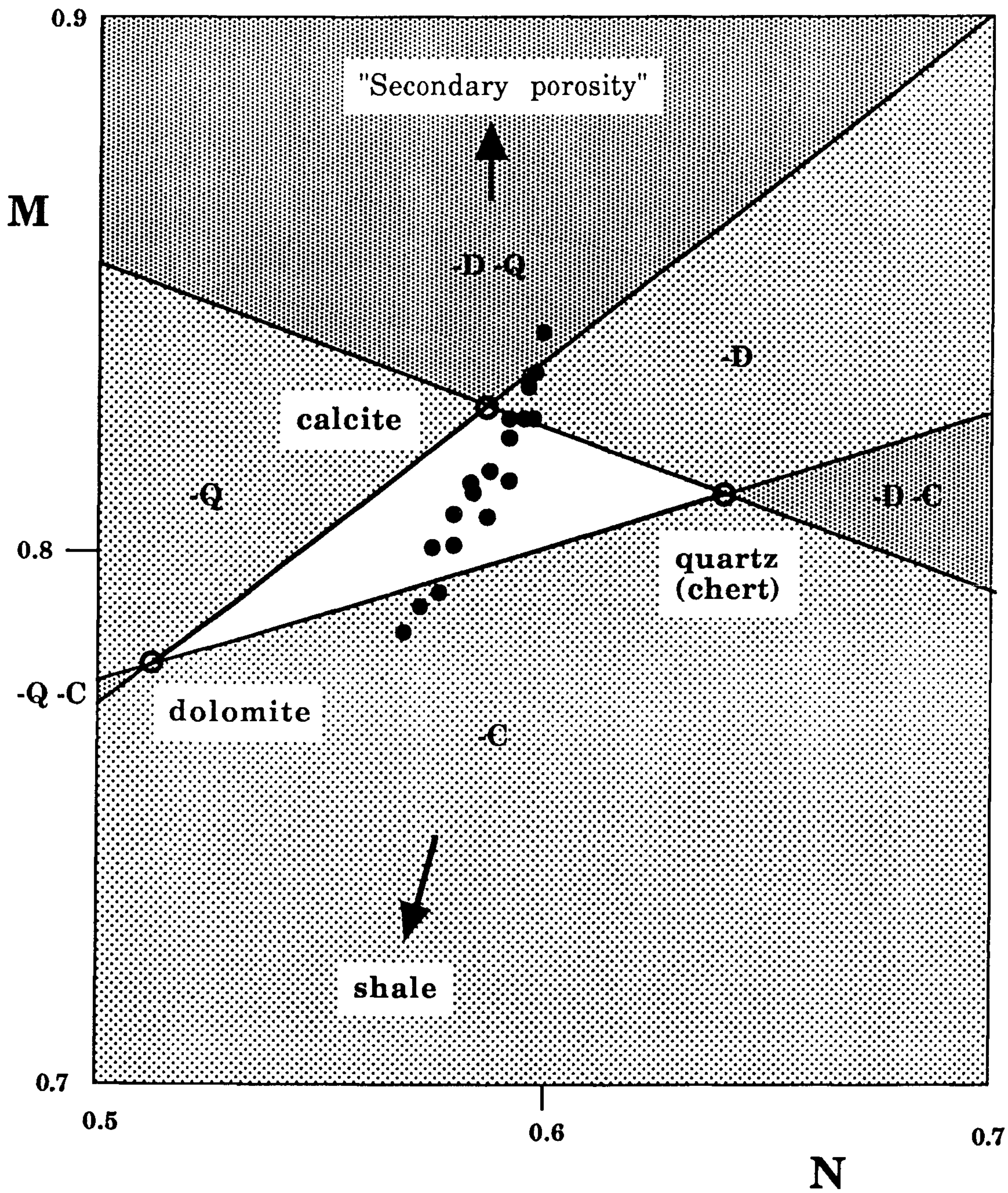
DEPTH	1	2	3	A	B	C	D
2500	2.40	2.72	53.80	.59	.64	-.26	.03
2503	2.00	2.68	52.30	.17	.27	.53	.02
2505	1.70	2.71	51.90	.36	.41	.21	.02
2509	1.80	2.67	51.90	.07	.18	.73	.02
2513	1.80	2.72	52.90	.51	.58	-.11	.02
2515	2.00	2.69	52.60	.27	.36	.35	.02
2517	1.70	2.71	53.40	.47	.59	-.09	.02
2518	1.50	2.67	53.10	.15	.35	.48	.03
2520	.90	2.69	52.50	.24	.43	.31	.02
2521	1.00	2.69	51.40	.16	.29	.53	.02
2522	1.20	2.70	50.90	.20	.27	.51	.02
2525	1.00	2.67	51.20	.00	.15	.83	.02
2527	.90	2.72	51.30	.37	.45	.16	.01
2530	1.20	2.66	50.80	-.10	.03	1.05	.02
2533	.90	2.67	50.00	-.09	.01	1.06	.01
2535	.80	2.68	50.40	.01	.13	.85	.01
2537	1.20	2.65	50.10	-.23	-.11	1.32	.02
2540	1.70	2.65	52.90	-.01	.20	.78	.03

****

GRAPHIC COMPONENT LOG



EXPLANATION OF "NEGATIVE COMPONENTS" IN CONTEXT OF KIWI OUTPUT EXAMPLE



MATRIX ALGEBRA SOLUTIONS OF COMPONENT PROPORTIONS (V) FROM LOG READINGS (L), BASED ON COMPONENT LOG RESPONSES (C), FOR ALL SYSTEMS OF DETERMINACY

$$CV = L$$

Reference :
Doveton (1986)
p. 170 - 177

UNDERDETERMINED

maximum variance

$$V = C^T(CC^T)^{-1} L$$

DETERMINED

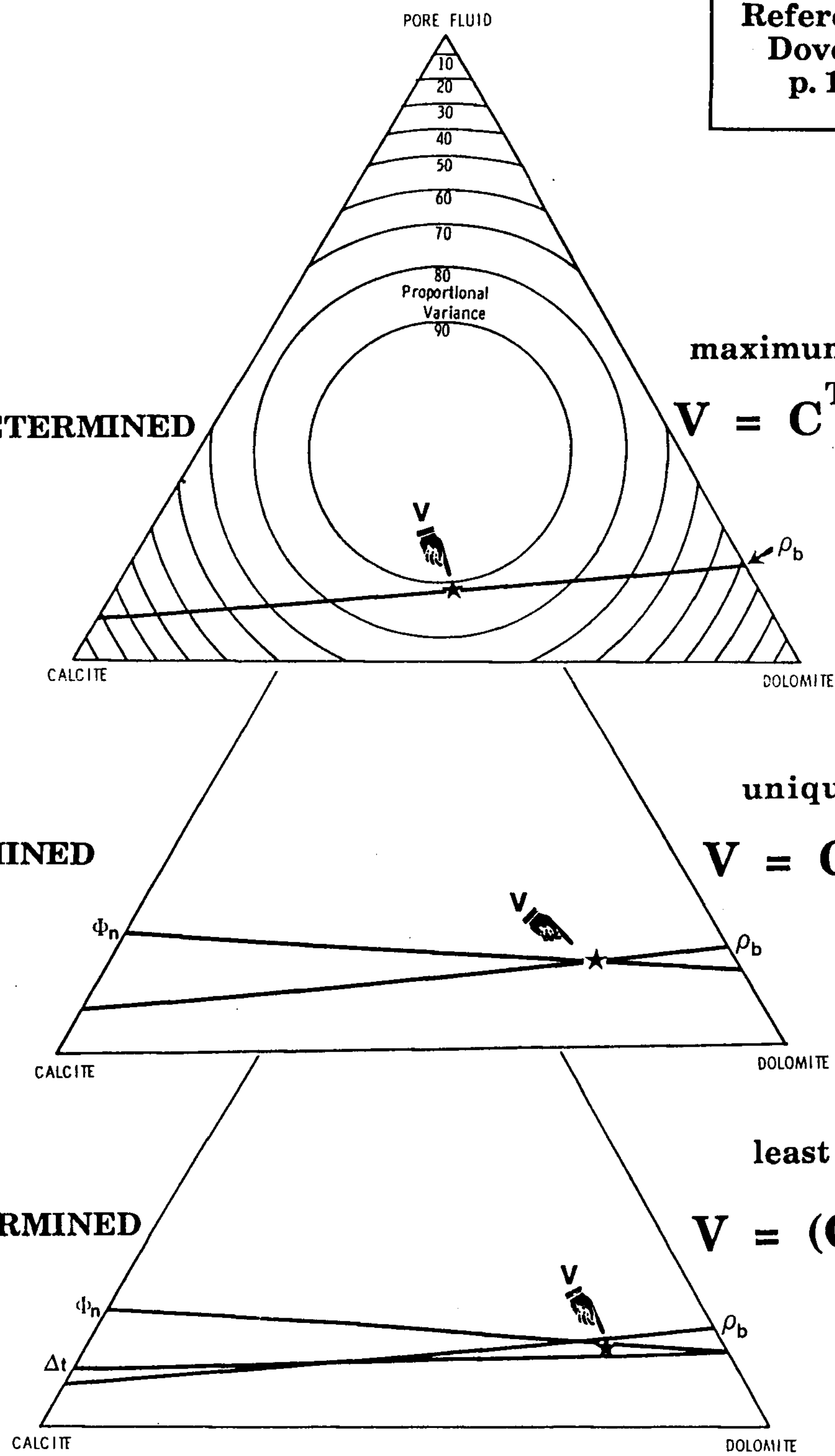
unique

$$V = C^{-1}L$$

OVERDETERMINED

least - squares

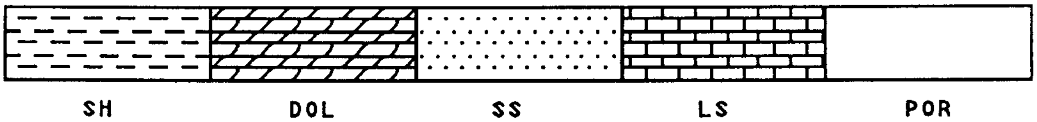
$$V = (C^TC)^{-1} C^TL$$



EXAMPLE OF A MATRIX ALGEBRA SOLUTION OF COMPONENTS IN A COMPLEX CARBONATE

WELL NAME:	CHASE				
LOCATION:				DATE:	
DEPTH:	2650.00 TO	3100.00 BY		.50 FEET	
LOGS:	UTOT	CGR	DENS		CNL%
COMPONENTS:	SH	DOL	SS	LS	POR

KEY

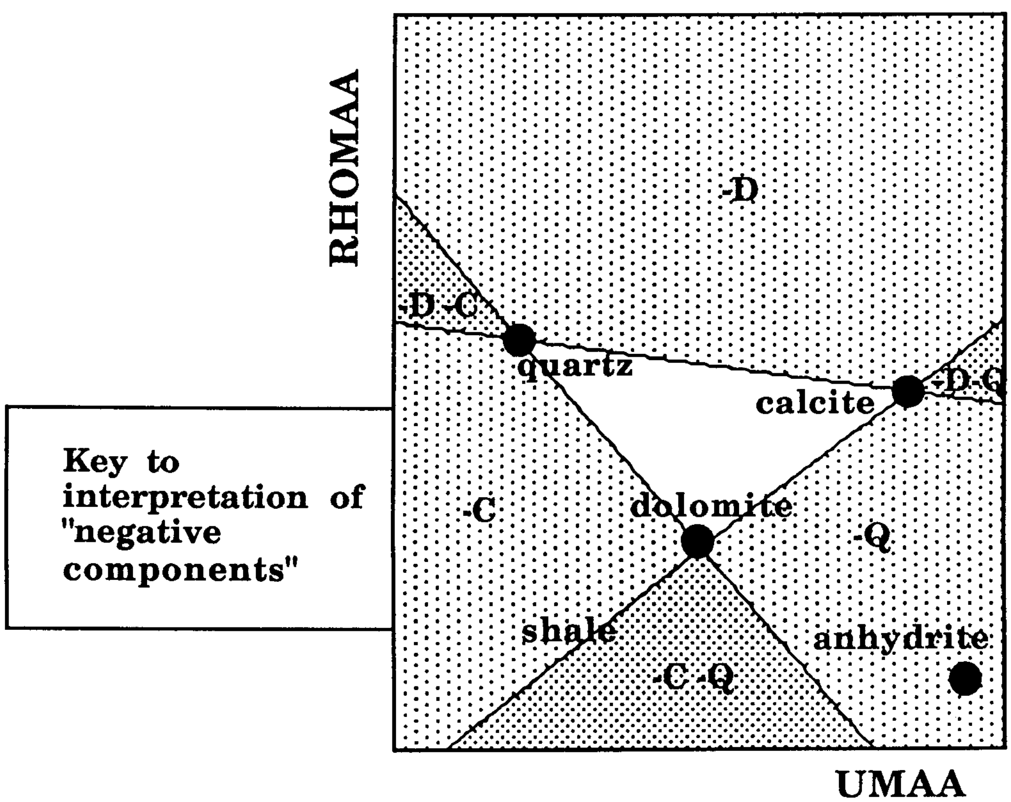


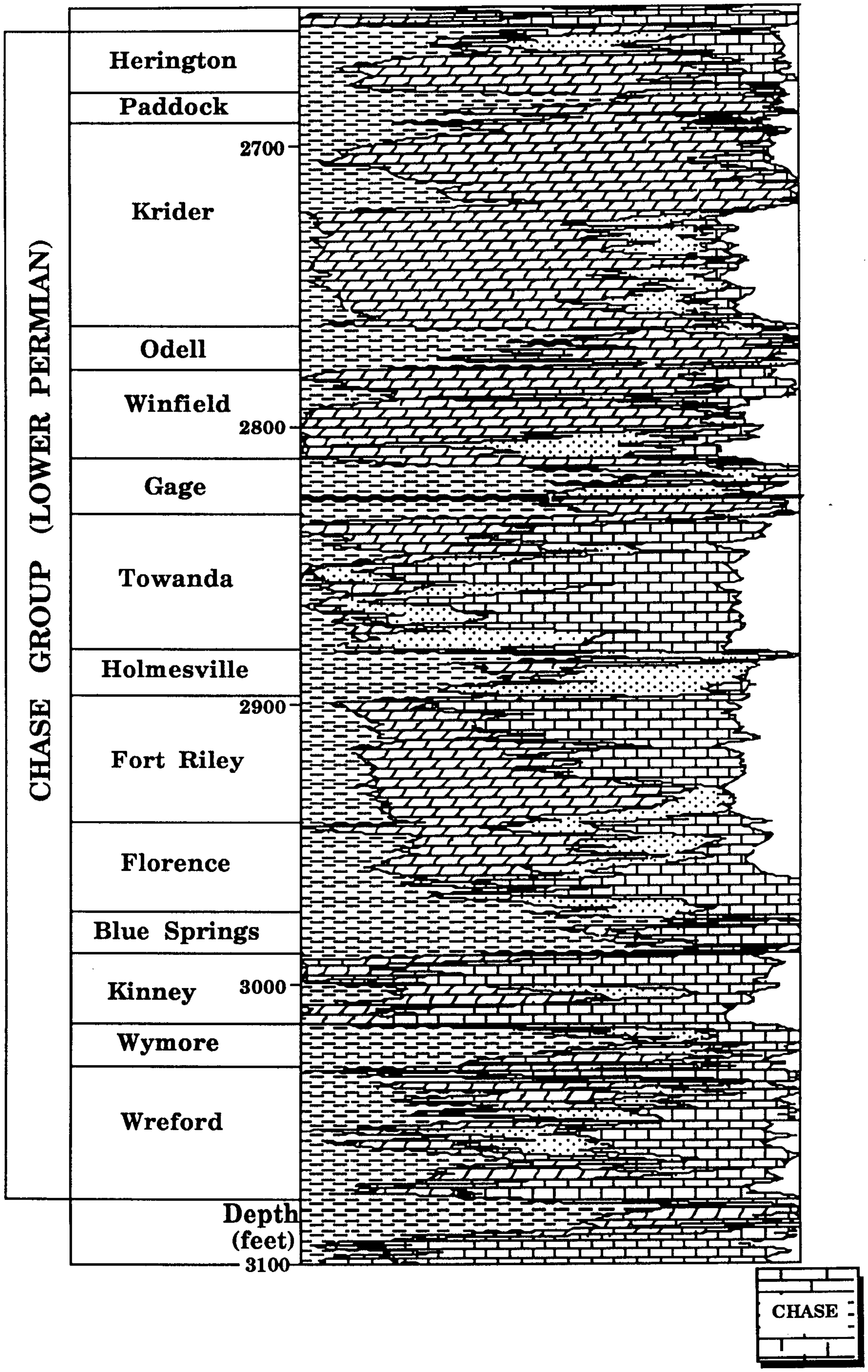
INPUT COEFFICIENTS:

	SH	DOL	SS	LS	POR
UTOT	6.20	9.00	4.78	13.80	.50
CGR	100.00	5.00	5.00	5.00	5.00
DENS	2.40	2.87	2.65	2.71	1.00
CNL%	28.00	3.00	-4.00	.00	100.00

EQUATIONS EQUAL UNKNOWNS N+1=M

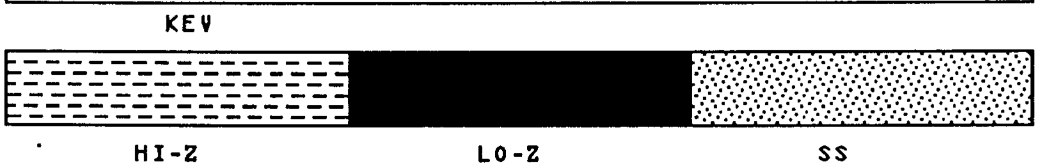
SOLUTION CALCULATED BY MATRIX INVERSION ....



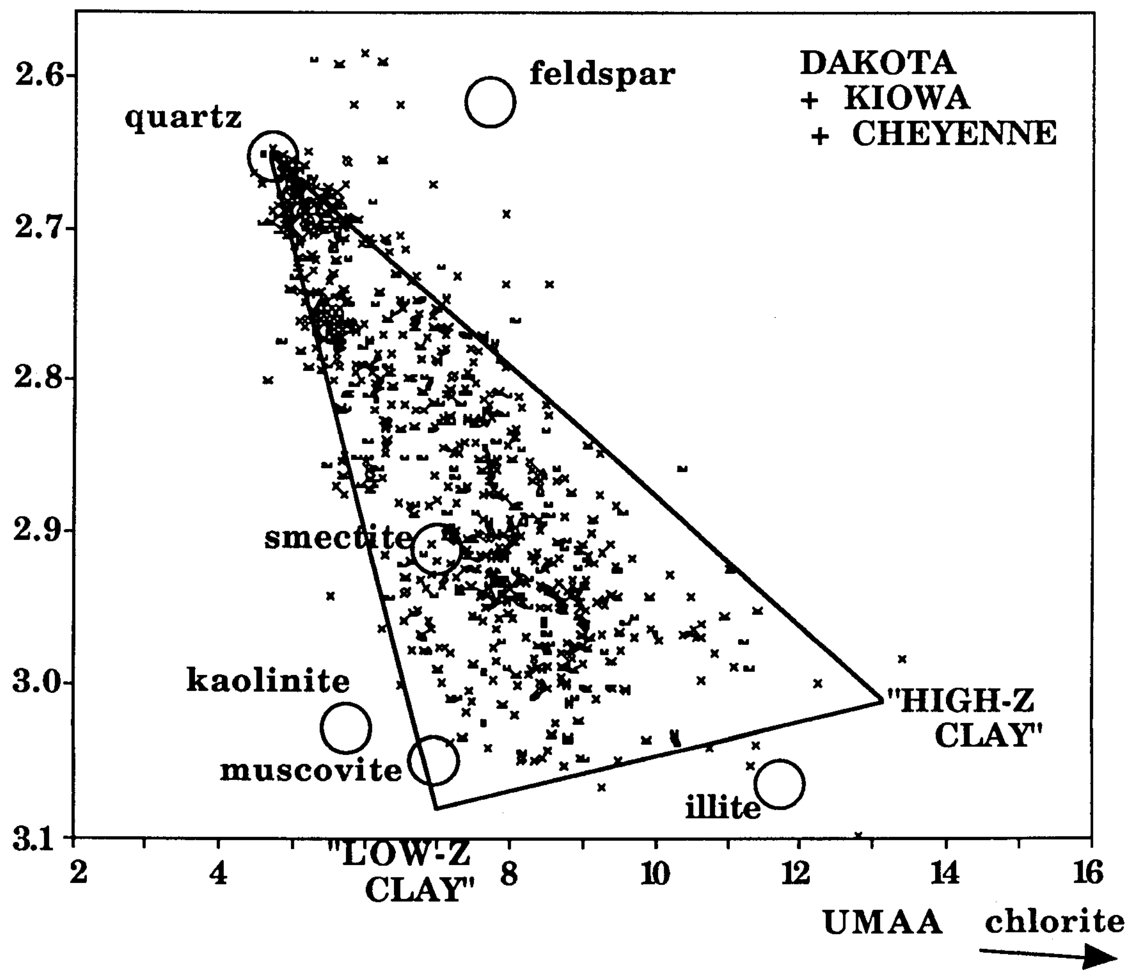

CHASE GROUP (LOWER PERMIAN)
Herington
Paddock
2700
Krider
Odell
Winfield
2800
Gage
Towanda
Holmesville
2900
Fort Riley
Florence
Blue Springs
Kinney
3000
Wymore
Wreford
Depth
(feet)
3100
CHASE

EXAMPLE OF A MATRIX ALGEBRA SOLUTION OF COMPONENTS IN A SANDSTONE - SHALE SEQUENCE

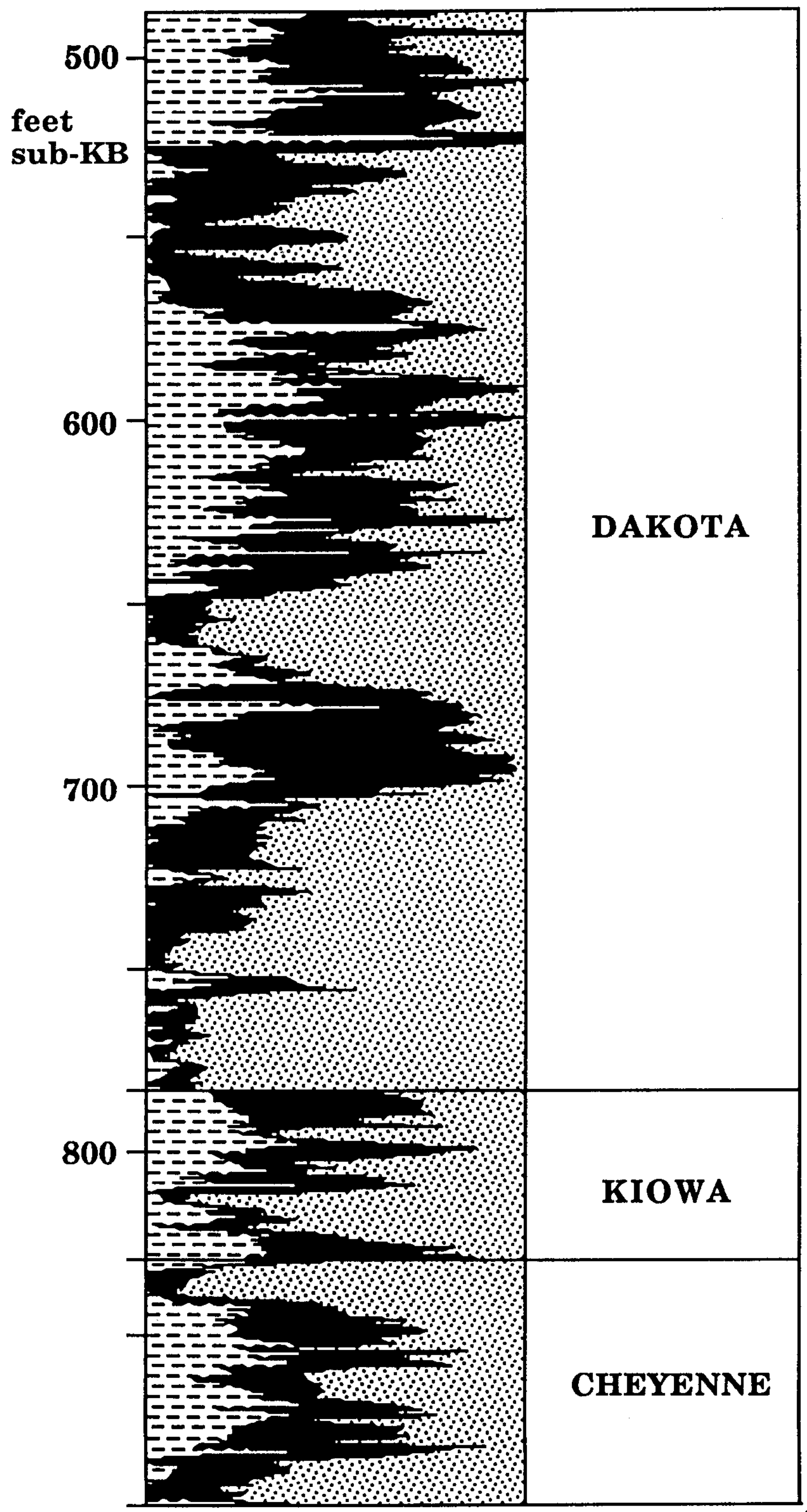
```
WELL NAME:    BRAUN
LOCATION:     ELLIS                         DATE:        1/25/88
DEPTH:         488.00 TO    895.00 BY    .50 FEET
LOGS:         UMAA        RHOMAA
COMPONENTS:   HI-Z   LO-Z   SS
```

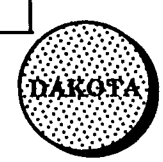



```
INPUT COEFFICIENTS:
                HI-Z     LO-Z     SS
UMAA           13.20     7.00     4.79
RHOMAA          3.02     3.08     2.64

EQUATIONS EQUAL UNKNOWNS      N+1=M

SOLUTION CALCULATED BY MATRIX INVERSION ....
```



COMPOSITION PROFILE





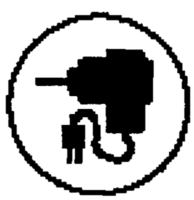
BOTTOM-UP METHODS :

Statistical power tools to locate electrofacies

SUPERVISED :

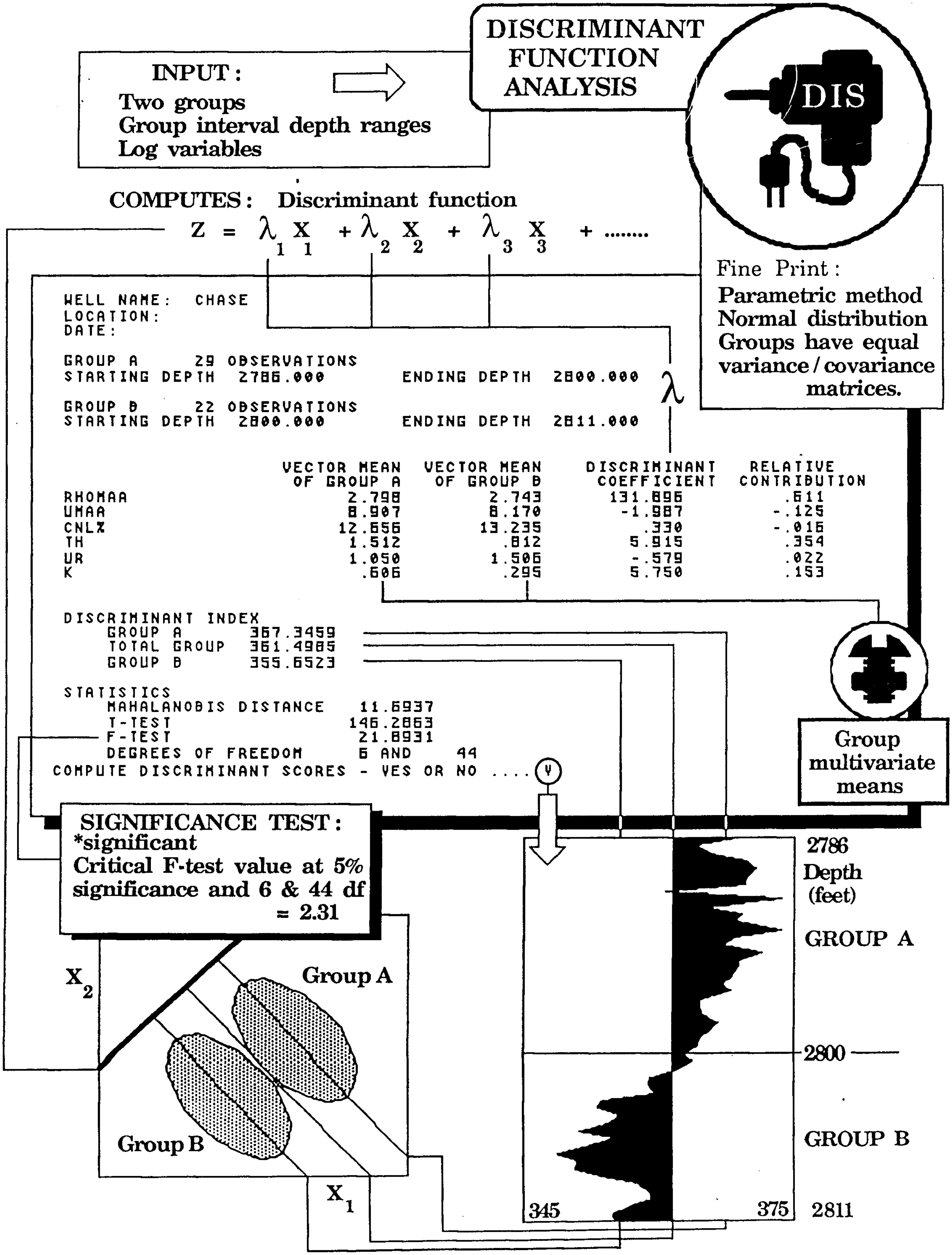
Discriminant function analysis

UNSUPERVISED :



Principal component analysis

Cluster analysis


DISCRIMINANT FUNCTION ANALYSIS
DIS
INPUT:
Two groups
Group interval depth ranges
Log variables
COMPUTES: Discriminant function
$Z = \lambda_1 X_1 + \lambda_2 X_2 + \lambda_3 X_3 + ...$
Fine Print:
Parametric method
Normal distribution
Groups have equal variance / covariance matrices.
WELL NAME: CHASE
LOCATION:
DATE:
GROUP A 29 OBSERVATIONS
STARTING DEPTH 2786.000 ENDING DEPTH 2800.000
GROUP B 22 OBSERVATIONS
STARTING DEPTH 2800.000 ENDING DEPTH 2811.000
λ
VECTOR MEAN OF GROUP A
VECTOR MEAN OF GROUP B
DISCRIMINANT COEFFICIENT
RELATIVE CONTRIBUTION
RHOMAA 2.798 2.743 131.896 .611
UMAA 8.907 8.170 -1.987 -.125
CNL% 12.656 13.235 .330 -.016
TH 1.512 .812 5.915 .354
UR 1.050 1.506 -.579 .022
K .606 .295 5.750 .153
DISCRIMINANT INDEX
GROUP A 367.3459
TOTAL GROUP 361.4985
GROUP B 355.6523
STATISTICS
MAHALANOBIS DISTANCE 11.6937
T-TEST 146.2863
F-TEST 21.8931
DEGREES OF FREEDOM 6 AND 44
COMPUTE DISCRIMINANT SCORES - YES OR NO .... Y
Group multivariate means
SIGNIFICANCE TEST:
*significant
Critical F-test value at 5% significance and 6 & 44 df = 2.31
X_2
Group A
Group B
X_1
2786
Depth (feet)
GROUP A
2800
GROUP B
345
375
2811

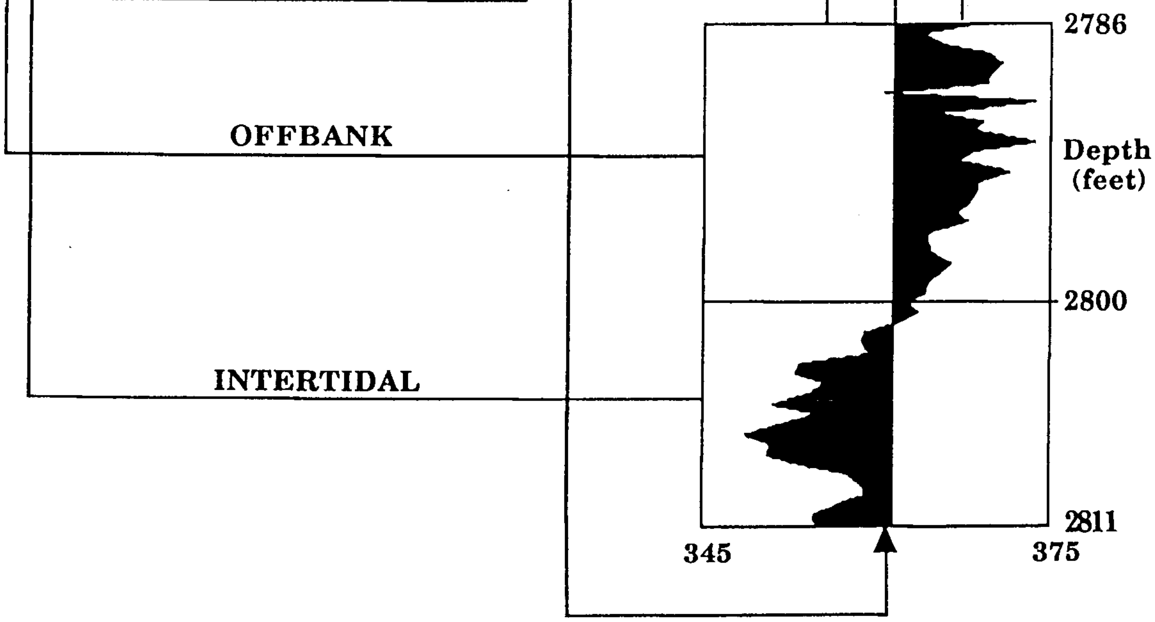
DISCRIMINATION BETWEEN OFFBANK AND INTERTIDAL CARBONATE FACIES IN THE WINFIELD LIMESTONE BASED ON 6 LOG VARIABLES

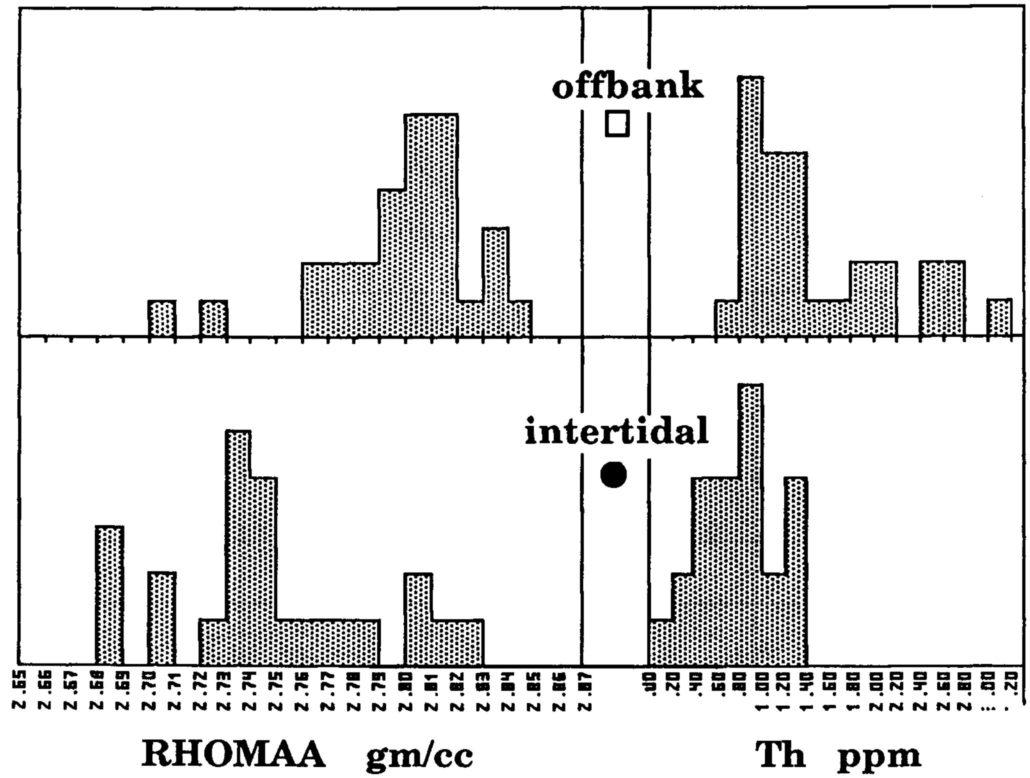
```
WELL NAME:  CHASE                                    TERRALOG
LOCATION:
DATE:

GROUP A        29 OBSERVATIONS
STARTING DEPTH   2786.000        ENDING DEPTH  2800.000

GROUP B        22 OBSERVATIONS
STARTING DEPTH   2800.000        ENDING DEPTH  2811.000
```

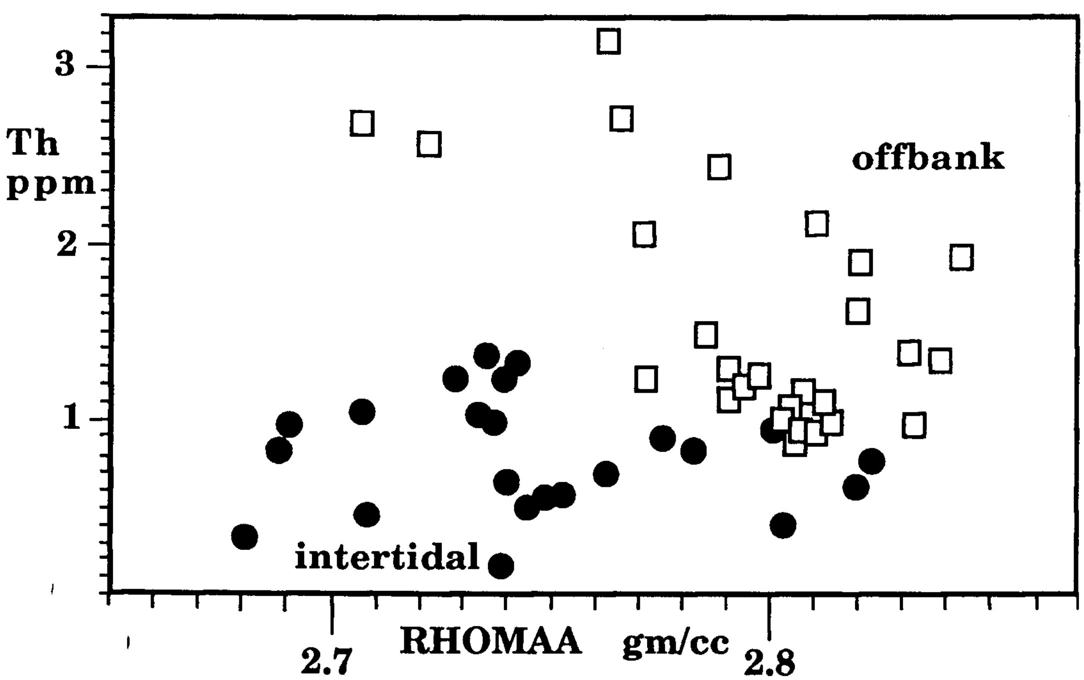
	VECTOR MEAN OF GROUP A	VECTOR MEAN OF GROUP B	DISCRIMINANT COEFFICIENT	RELATIVE CONTRIBUTION	
RHOMAA	2.798	2.743	131.896	.611	*
UMAA	8.907	8.170	-1.987	-.125	
CNL%	12.656	13.235	.330	-.016	
TH	1.512	.812	5.915	.354	*
UR	1.050	1.506	-.579	.022	
K	.606	.295	5.750	.153	

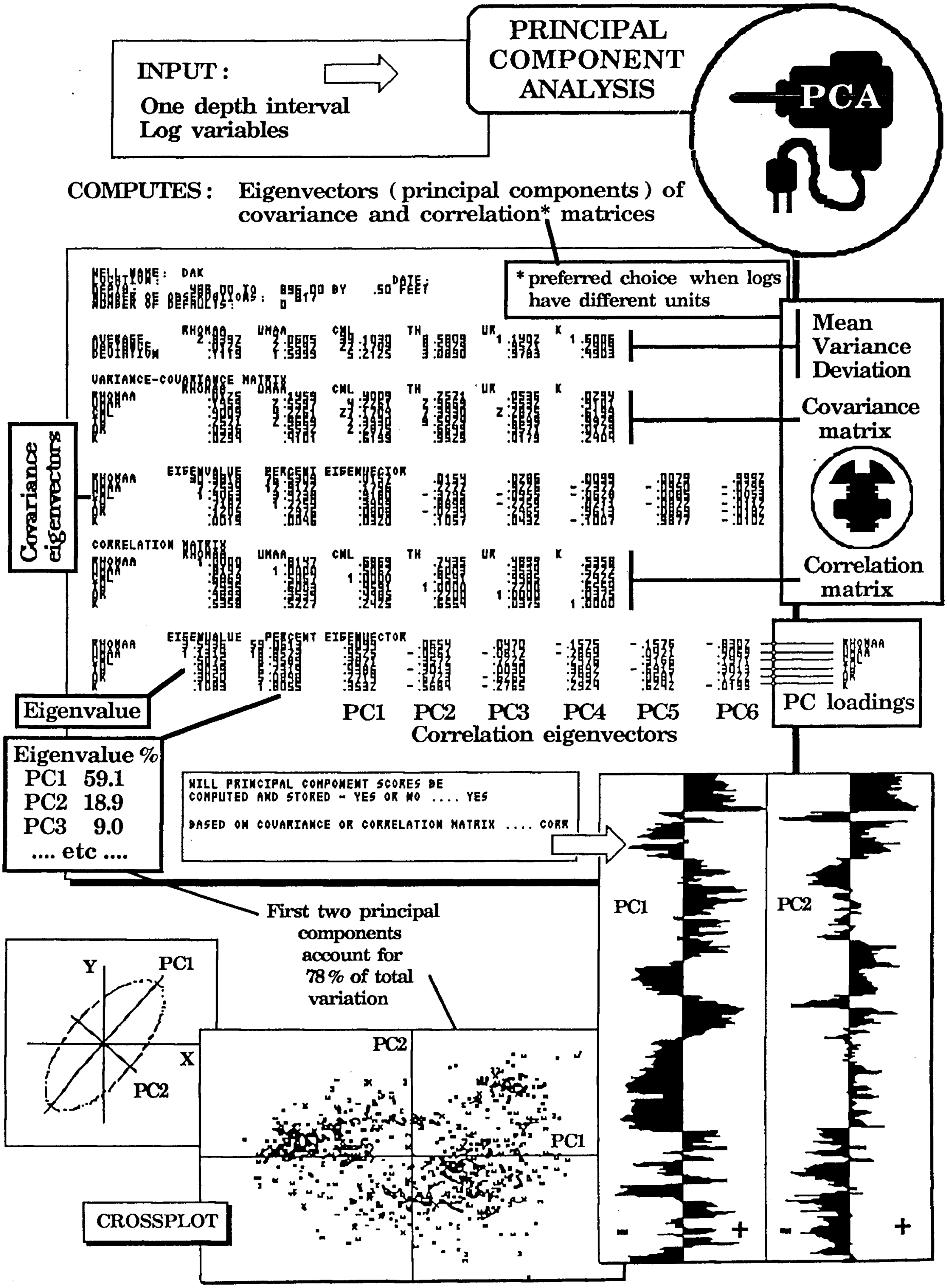
```
DISCRIMINANT INDEX
    GROUP A         367.3459
    TOTAL GROUP     361.4985
    GROUP B         355.6523

STATISTICS
    MAHALANOBIS DISTANCE     11.6937
    T-TEST                  146.2863
    F-TEST                   21.8931
    DEGREES OF FREEDOM       6 AND     44
COMPUTE DISCRIMINANT SCORES - YES OR NO ....(Y)
```

*significant
Critical F-test value at 5% significance and 6 & 44 df = 2.31




offbank
intertidal
RHOMAA gm/cc
Th ppm


3
Th
ppm
2
1
offbank
intertidal
2.7
RHOMAA gm/cc
2.8


PRINCIPAL COMPONENT ANALYSIS
PCA
INPUT :
One depth interval
Log variables
COMPUTES : Eigenvectors (principal components) of covariance and correlation* matrices
* preferred choice when logs have different units
Mean
Variance
Deviation
Covariance matrix
Correlation matrix
Covariance eigenvectors
PC loadings
Eigenvalue
Eigenvalue %
PC1 59.1
PC2 18.9
PC3 9.0
.... etc ....
PC1 PC2 PC3 PC4 PC5 PC6
Correlation eigenvectors
WILL PRINCIPAL COMPONENT SCORES BE COMPUTED AND STORED - YES OR NO .... YES
BASED ON COVARIANCE OR CORRELATION MATRIX .... CORR
First two principal components account for 78 % of total variation
PC1
PC2
Y
X
CROSSPLOT
-
+

PRINCIPAL COMPONENT ANALYSIS OF LOGS IN LOWER CRETACEOUS SANDSTONES AND SHALES

Input log variables :
RHOMAA
UMAA
CNL neutron
Thorium
Uranium
Potassium

Input logs are standardized to eliminate influence of different measurement units. The variance - covariance matrix is then the correlation matrix. The eigenvectors of the correlation matrix are the principal components of the standardized logs, and the eigenvalues express the relative amount of the total variation accounted for by each principal component.

Correlation matrix

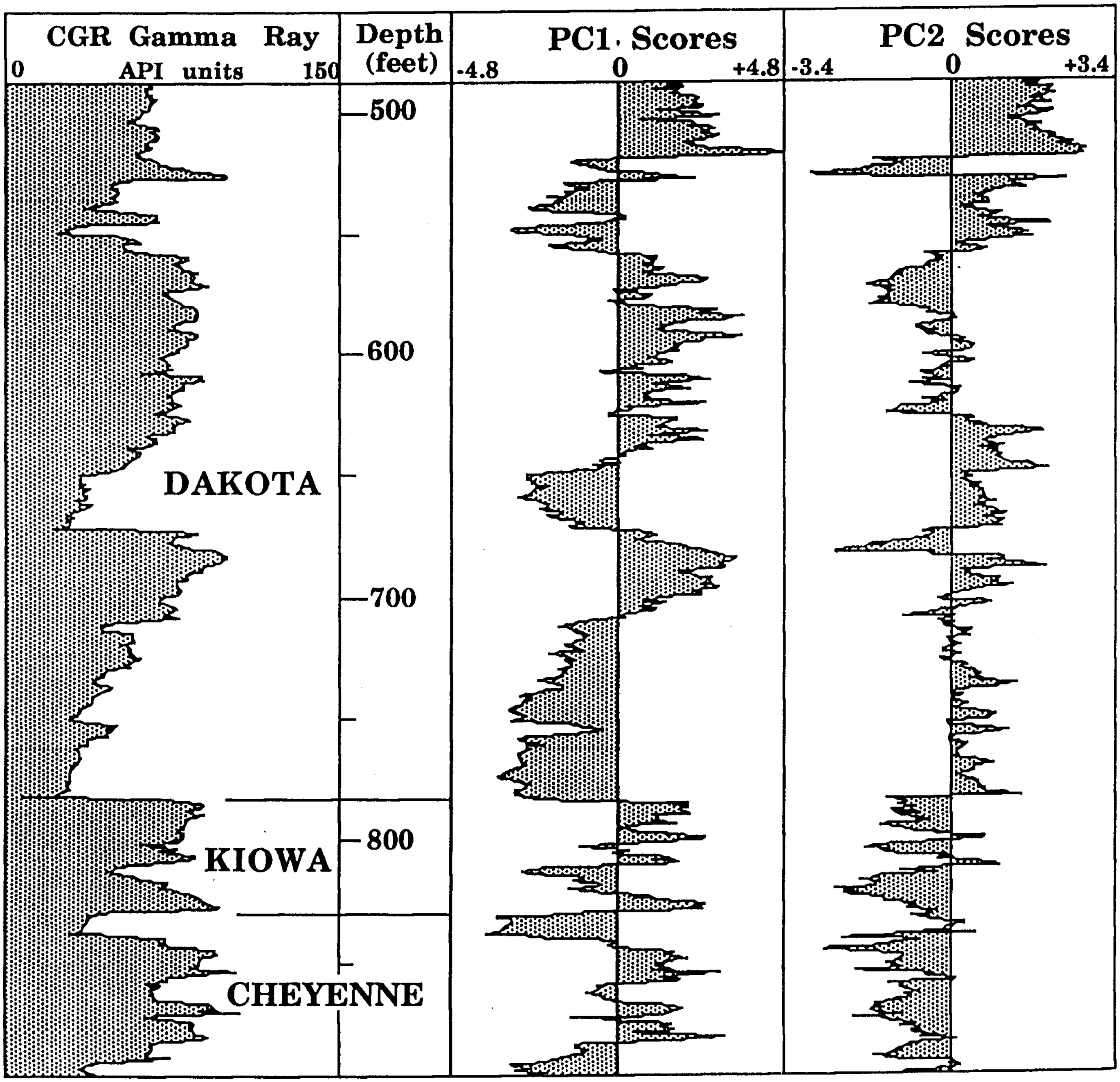
	RHOMAA	UMAA	CNL	TH	UR	K
RHOMAA	1.0000	.8147	.6869	.7435	.4899	.5358
UMAA	.8147	1.0000	.5067	.6003	.3534	.5227
CNL	.6869	.5067	1.0000	.4591	.4485	.2425
TH	.7435	.6003	.4591	1.0000	.2200	.6554
UR	.4899	.3534	.4485	.2200	1.0000	.0375
K	.5358	.5227	.2425	.6554	.0375	1.0000

Principal component eigenvectors

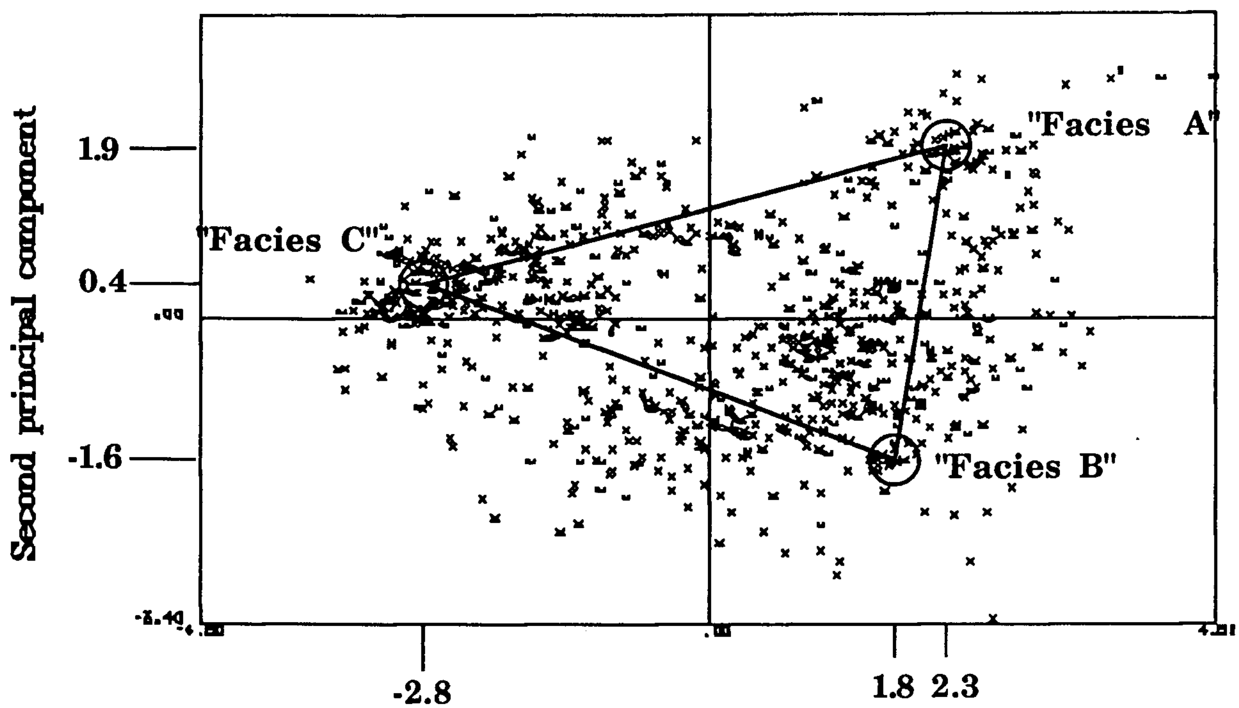
	PC1	PC2	PC3	PC4	PC5	PC6
RHOMAA	.5044	.0654	.0470	-.1575	-.	
UMAA	.4525	-.0461	-.0817	-.7864	.	
CNL	.3871	.3572	.7225	.2476	.	
TH	.4386	-.3013	.0030	.3842	-.	Etc.
UR	.2714	.6723	-.6265	.2492	.	
K	.3532	-.5684	-.2765	.2924	.	
Eigenvalue %	59%	19%	8 %	7 %	5 %	2 %

principal component scores

PRINCIPAL COMPONENT SCORE LOGS



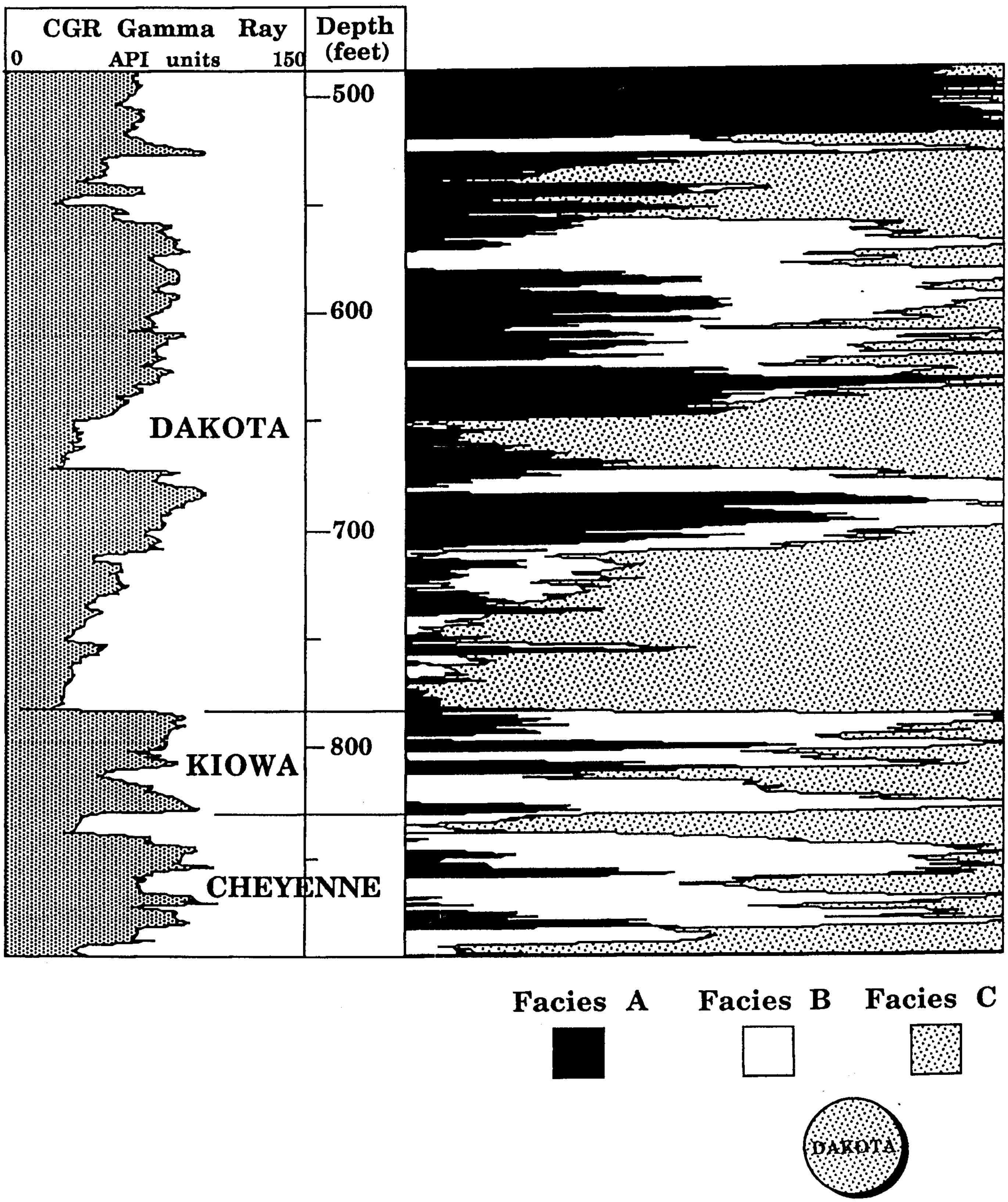
PATTERN RECOGNITION OF ELECTROFACIES
ON CROSSPLOT OF FIRST TWO PRINCIPAL COMPONENTS

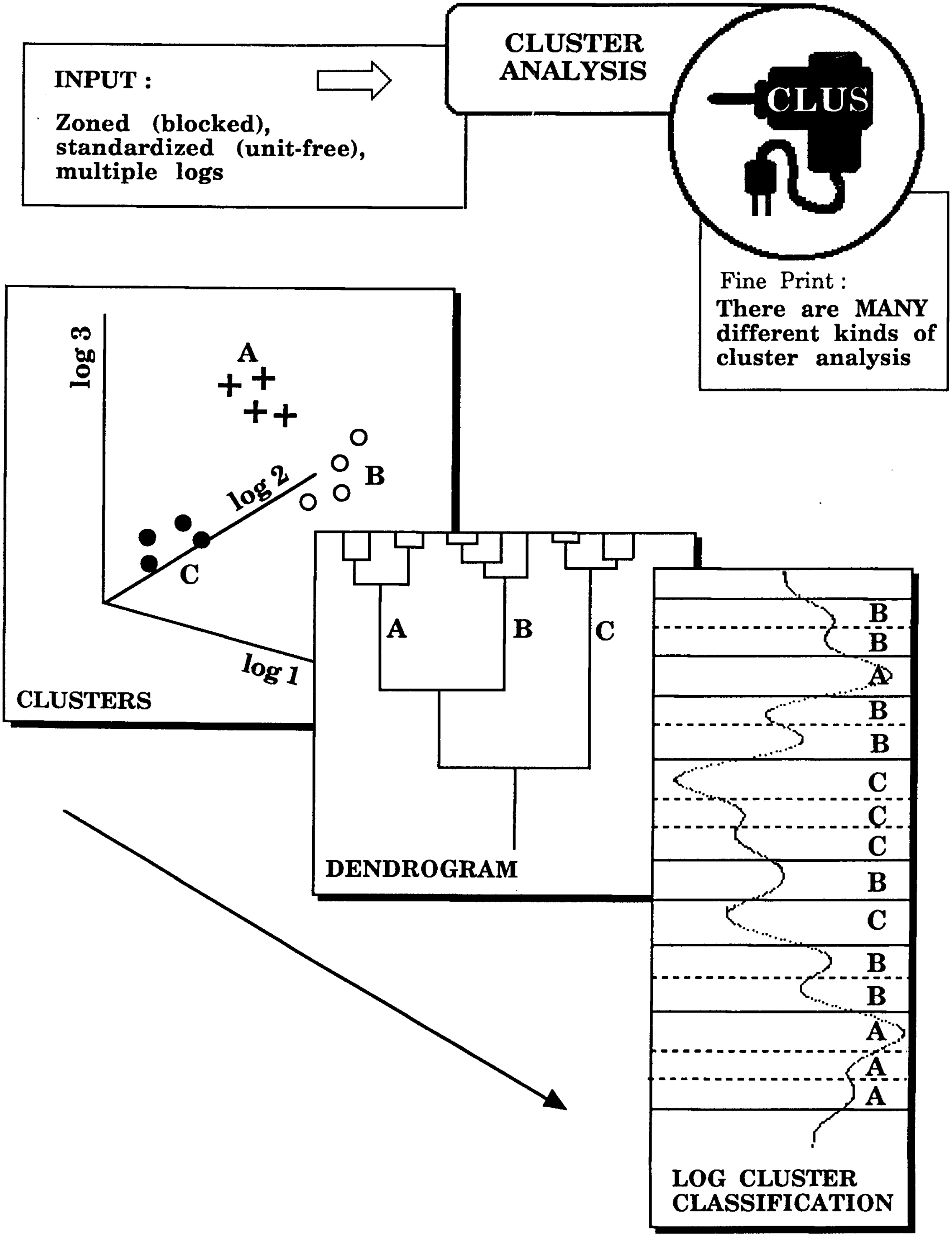


PC score coefficients for compositional analysis by matrix algebra solution :

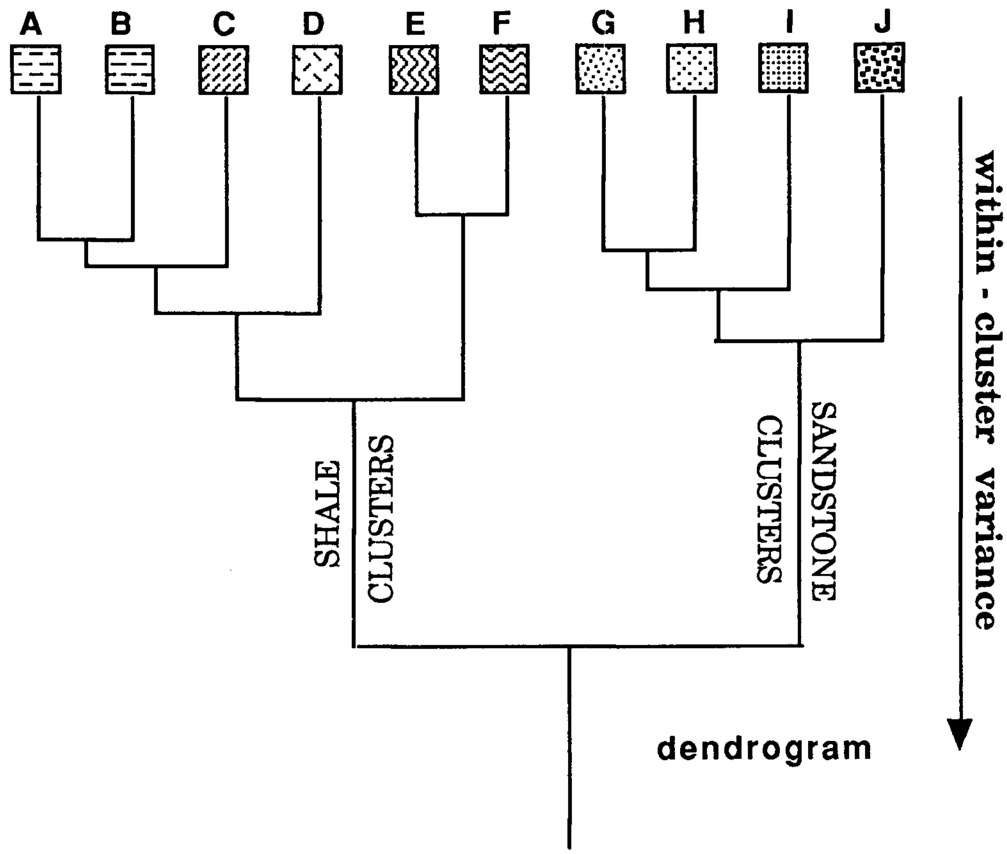
	PC1	PC2
Electrofacies A	2.3	1.9
B	1.8	-1.6
C	-2.8	0.4

Matrix algebra solution of electrofacies located on crossplot of first and second principal components of RHOmaa, Umaa, Φn, Th, U, K

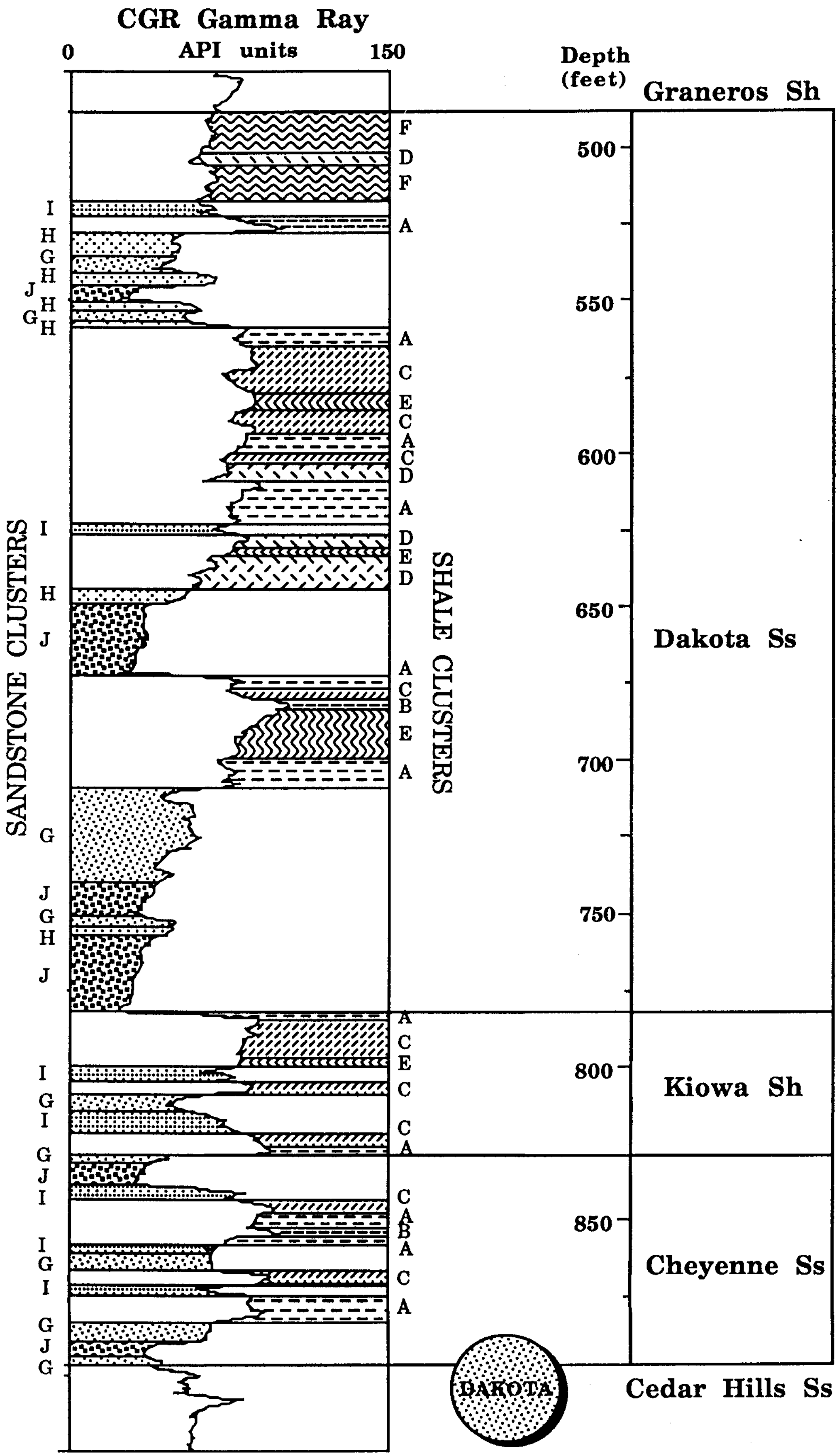



INPUT :
Zoned (blocked), standardized (unit-free), multiple logs
CLUSTER ANALYSIS
CLUS
Fine Print :
There are MANY different kinds of cluster analysis
log 3
log 2
log 1
A
B
C
CLUSTERS
A
B
C
DENDROGRAM
B
B
A
B
B
C
C
C
B
C
B
B
A
A
A
LOG CLUSTER CLASSIFICATION

CLUSTER ANALYSIS OF ZONES IN A SANDSTONE - SHALE SEQUENCE



Class	n	$\overline{\text{Rhomaa}}$	$\overline{\text{Umaa}}$	$\overline{\text{Phin}}$	$\overline{\text{K}}$	$\overline{\text{U}}$	$\overline{\text{Th}}$
A	24	2.91	7.7	37.4	1.8	0.9	11.2
B	3	2.91	7.7	37.3	2.3	0	15.2
C	16	2.89	8.5	32.7	2.2	1.0	10.5
D	9	2.91	8.3	32.1	1.6	2.4	8.9
E	8	3.01	8.1	42.5	1.8	2.2	12.0
F	9	2.94	8.6	43.2	1.6	2.9	8.6
G	20	2.74	5.8	29.6	1.3	0.9	6.6
H	7	2.82	6.0	32.9	1.1	2.1	8.0
I	9	2.81	7.1	28.9	1.9	0.1	8.9
J	18	2.69	5.1	31.6	1.0	0.4	3.9



CGR Gamma Ray
0
API units
150
Depth
(feet)
Graneros Sh
500
550
600
650
700
750
800
850
Dakota Ss
Kiowa Sh
Cheyenne Ss
Cedar Hills Ss
SANDSTONE CLUSTERS
SHALE CLUSTERS
DAKOTA
F
D
F
A
I
H
G
H
J
H
G
H
A
C
E
C
A
C
D
A
D
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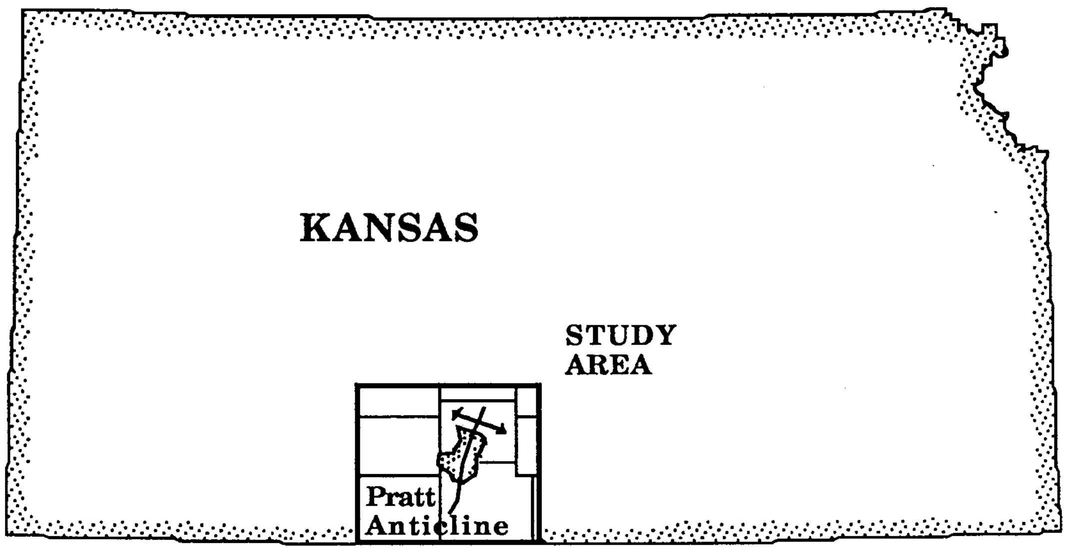
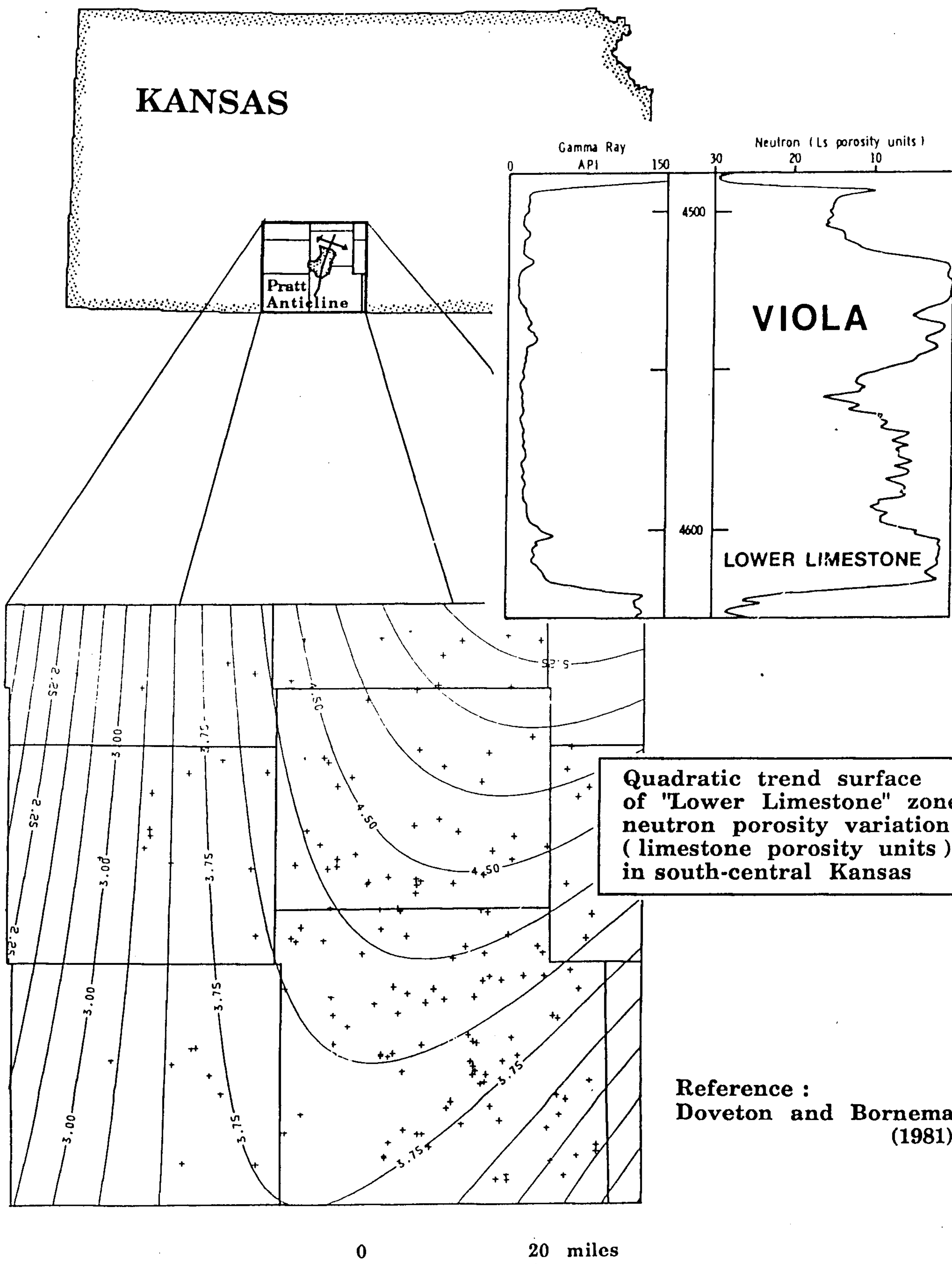
I
G
J
G

MAPPING APPLICATIONS

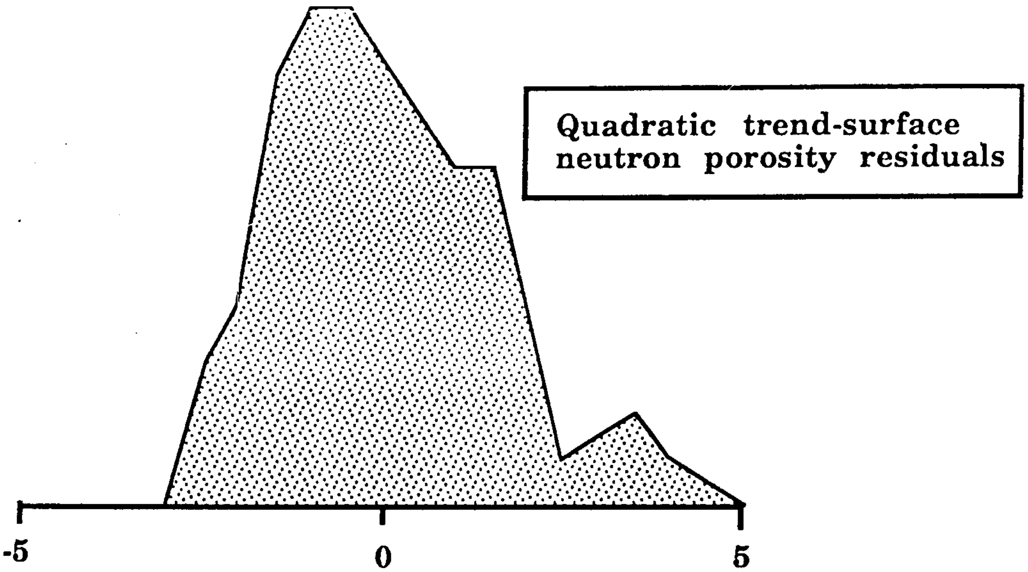


* LOG NORMALIZATION BY TREND - SURFACE ANALYSIS
* COMPLEX CARBONATE FACIES MAPPING IN THE VIOLA LIMESTONE
* THREE - DIMENSIONAL MAPPING OF SHALE CONTENT OF THE SIMPSON GROUP FROM MOMENT INTERPOLATION OF GAMMA-RAY LOGS

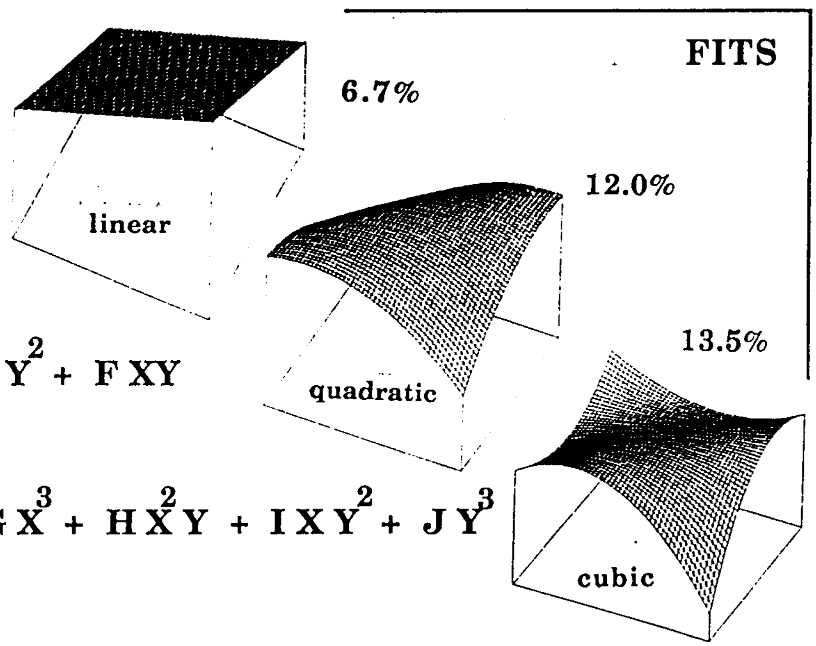


Quadratic trend surface of "Lower Limestone" zone neutron porosity variation (limestone porosity units) in south-central Kansas

Reference : Doveton and Bornemann (1981)



$$\hat{\Phi}_n = A + BX + CY + DX^2 + EY^2 + FXY + GX^3 + HX^2Y + IXY^2 + JY^3$$

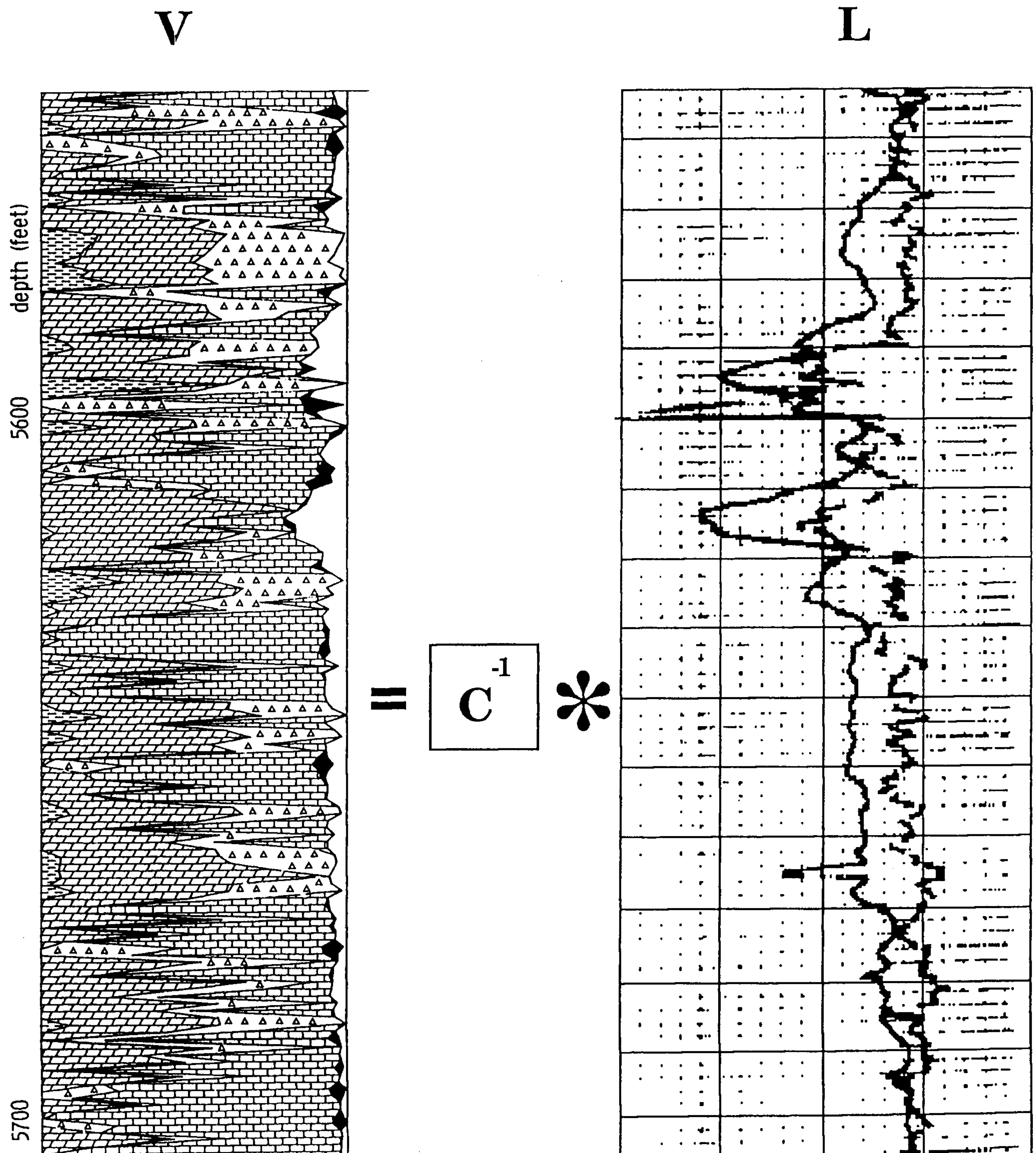


Source of Variation	Sum of Squares	DF	Mean Squares	F Ratio
Linear regression	27.22	2	13.61	5.73*
Linear deviation	377.62	159	2.37	
Quadratic–linear regression	21.41	3	7.14	3.13*
Quadratic deviation	356.22	156	2.28	
Cubic-quadratic regression	5.99	4	1.50	0.65
Cubic deviation	350.23	152	2.30	
Total variation	404.85	161		

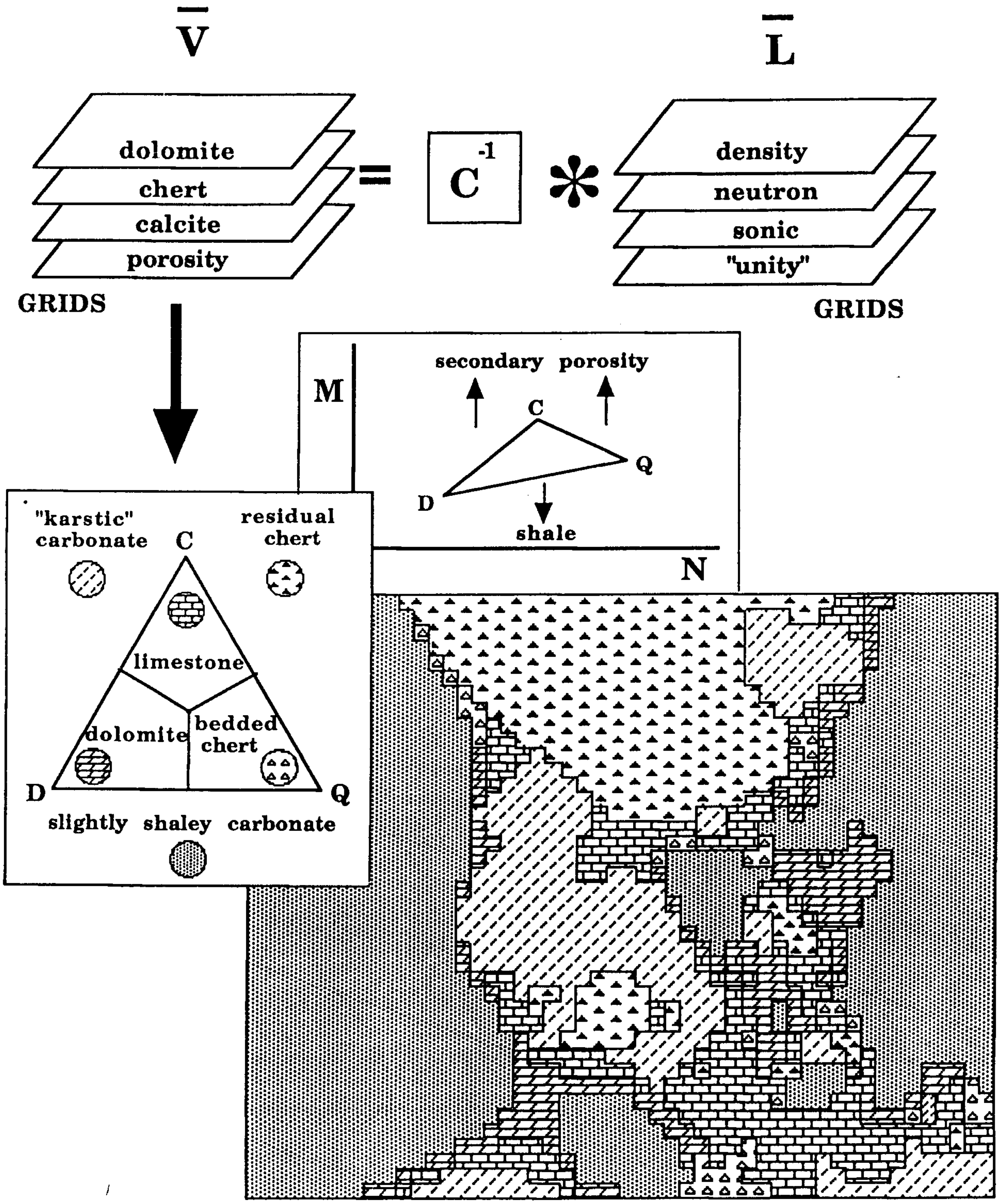
*Significant at 5 percent level.

MATRIX ALGEBRA SOLUTION APPLIED TO VIOLA LIMESTONE SECTION MINERAL AND FLUID COMPOSITIONS

$$CV = L \quad \therefore \quad V = C^{-1} L$$

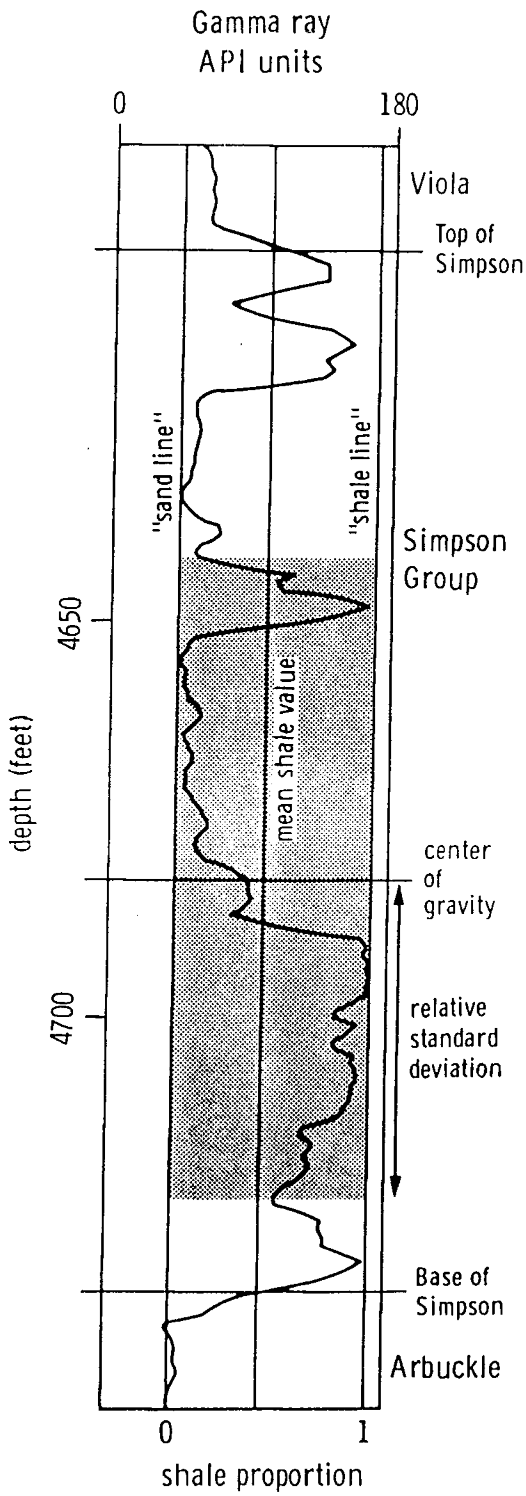


MATRIX ALGEBRA SOLUTION APPLIED TO VIOLA LIMESTONE LITHOFACIES MAPPING BY GRID-TO-GRID OPERATIONS



Reference: Bornemann and Doveton (1983)

GAMMA-RAY LOG MOMENTS AND POLYNOMIAL REGRESSION



MOMENTS	
$v_1 = \Sigma S d / \Sigma S$	center of gravity
$v_2 = \Sigma S d^2 / \Sigma S$	dispersion
$v_3 = \Sigma S d^3 / \Sigma S$	skewness
$v_4 = \Sigma S d^4 / \Sigma S$	kurtosis

$v_m = \Sigma S d^m / \Sigma S$	

POLYNOMIAL REGRESSION

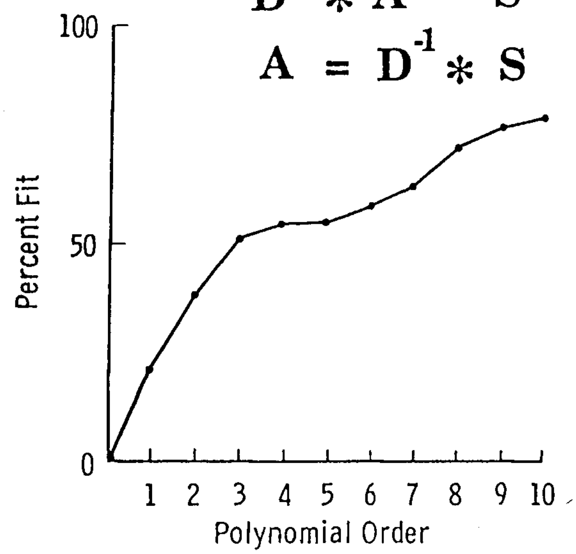
$$\hat{S} = a + bd + cd^2 + \dots d^m$$

matrix solution

$$\begin{bmatrix} n & \Sigma d & \Sigma d^2 & . & \Sigma d^m \\ \Sigma d & \Sigma d^2 & . & . & . \\ \Sigma d^2 & . & . & . & . \\ . & . & . & . & . \\ \Sigma d^m & . & . & . & \Sigma d^{2m} \end{bmatrix} \begin{bmatrix} a \\ b \\ c \\ . \\ . \end{bmatrix} = \begin{bmatrix} \Sigma S \\ \Sigma S d \\ \Sigma S d^2 \\ . \\ \Sigma S d^m \end{bmatrix}$$

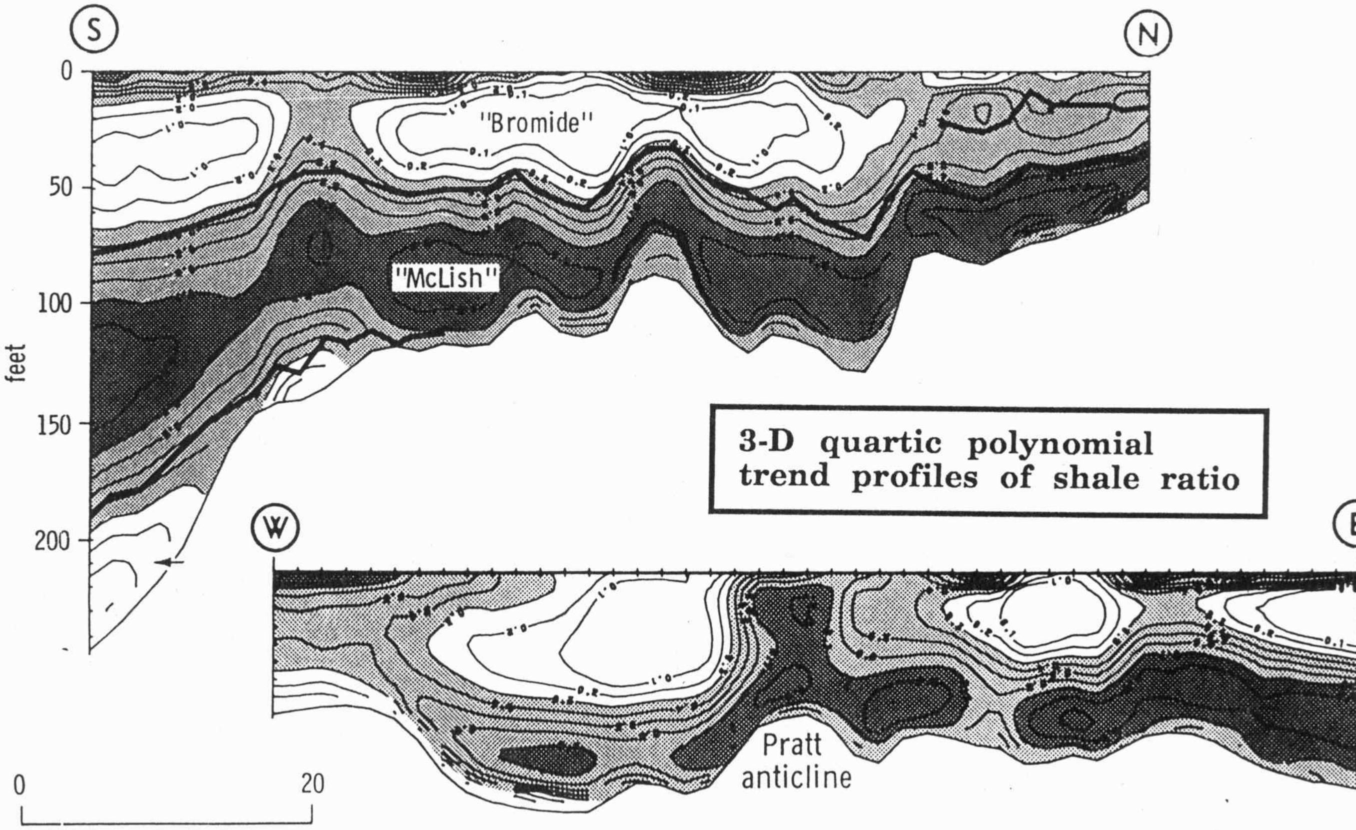
$$D * A = S$$

$$A = D^{-1} * S$$



INTERPOLATION OF GAMMA-RAY SHALE MOMENTS BETWEEN WELLS TO GENERATE THREE-DIMENSIONAL TREND MODEL

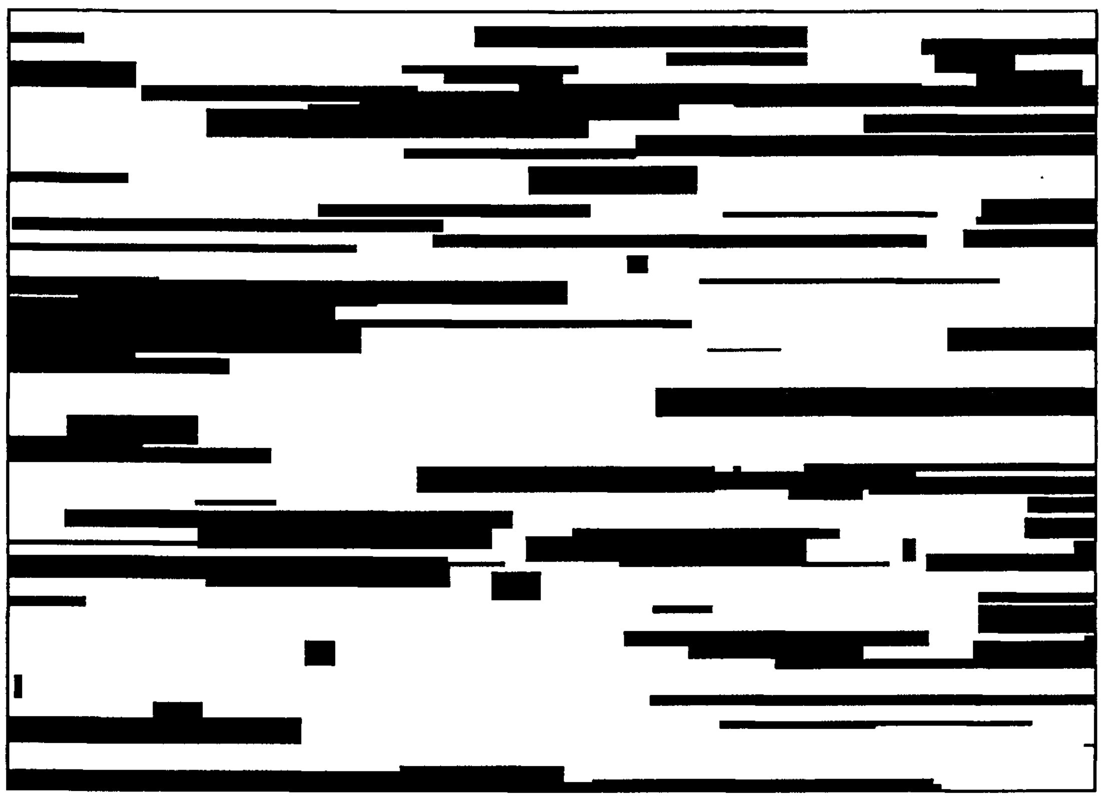
Shale ratio map



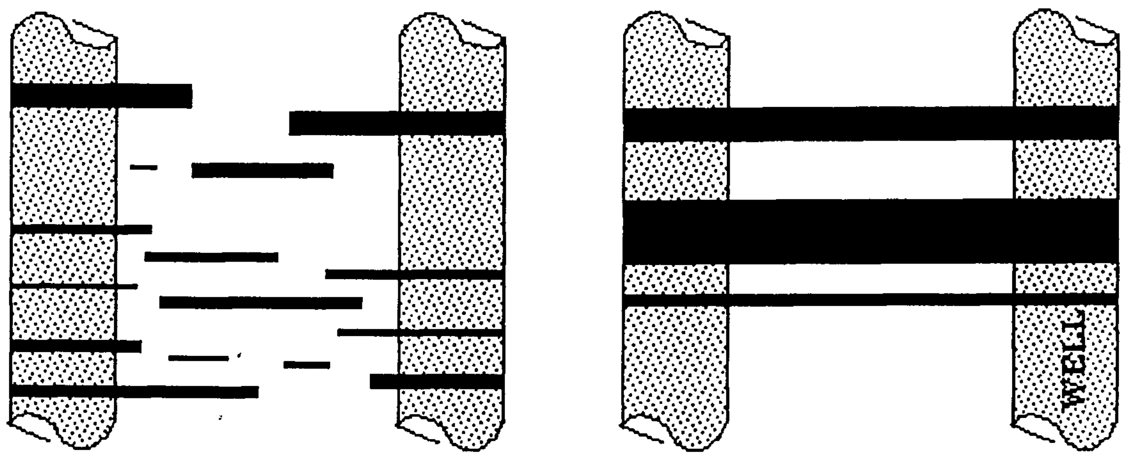
3-D quartic polynomial trend profiles of shale ratio

Reference: Doveton, Zhu, and Davis (1984)

SHALE CONTINUITY IN RESERVOIRS

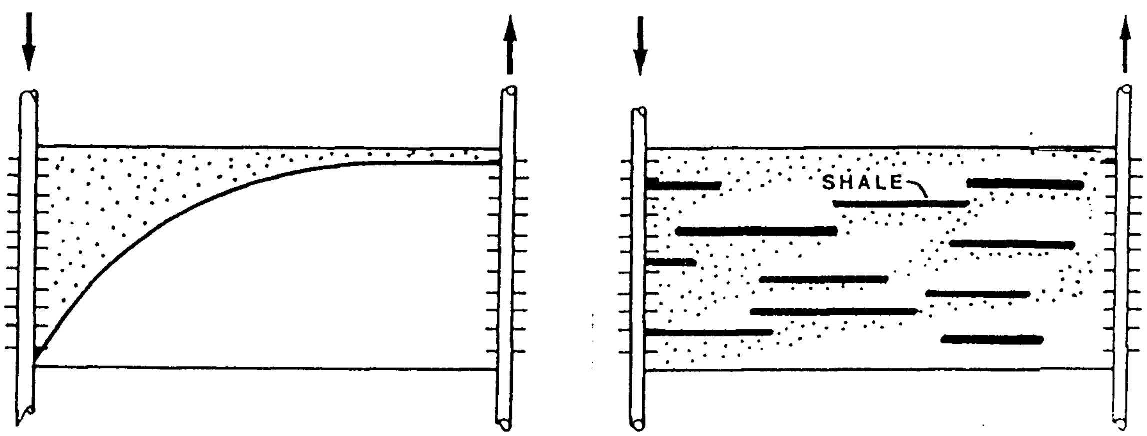


LATERAL CONTINUITY OF SHALES IN RESERVOIR MODELLING



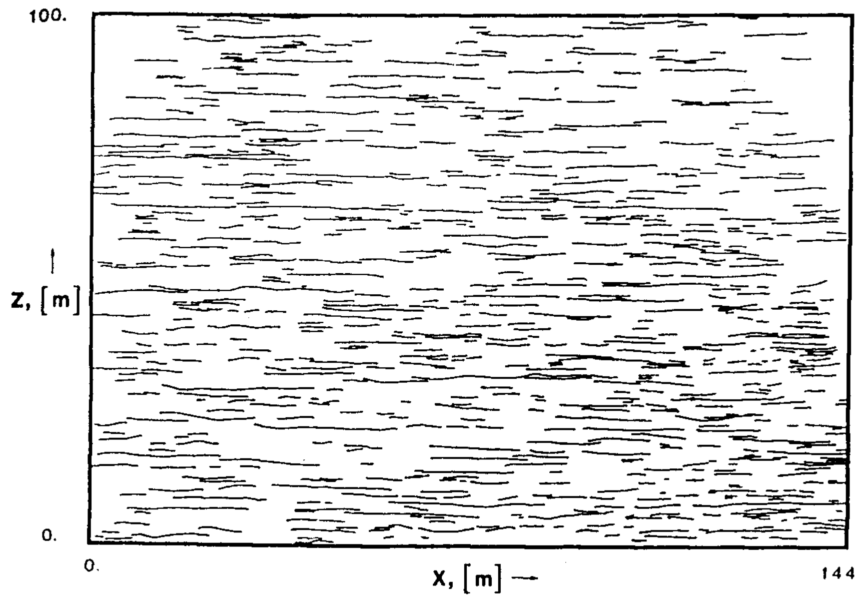
Stochastic shales Deterministic shales

after Haldorsen and Lake (1984)

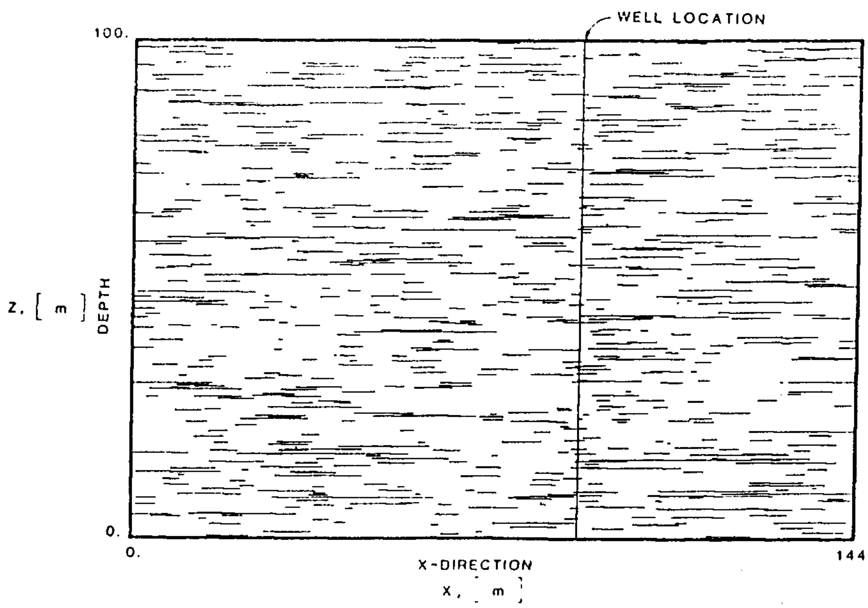


Homogeneous reservoir (left) and reservoir with stochastic shales (right). In horizontal drives, these shales may be advantageous because of increased vertical sweep (as shown in figure). (However, they may reduce vertical sweep in vertical drives.)
From Haldorsen and Chang (1986)

OUTCROP OCCURRENCE AND SIMULATION OF STOCHASTIC SHALES



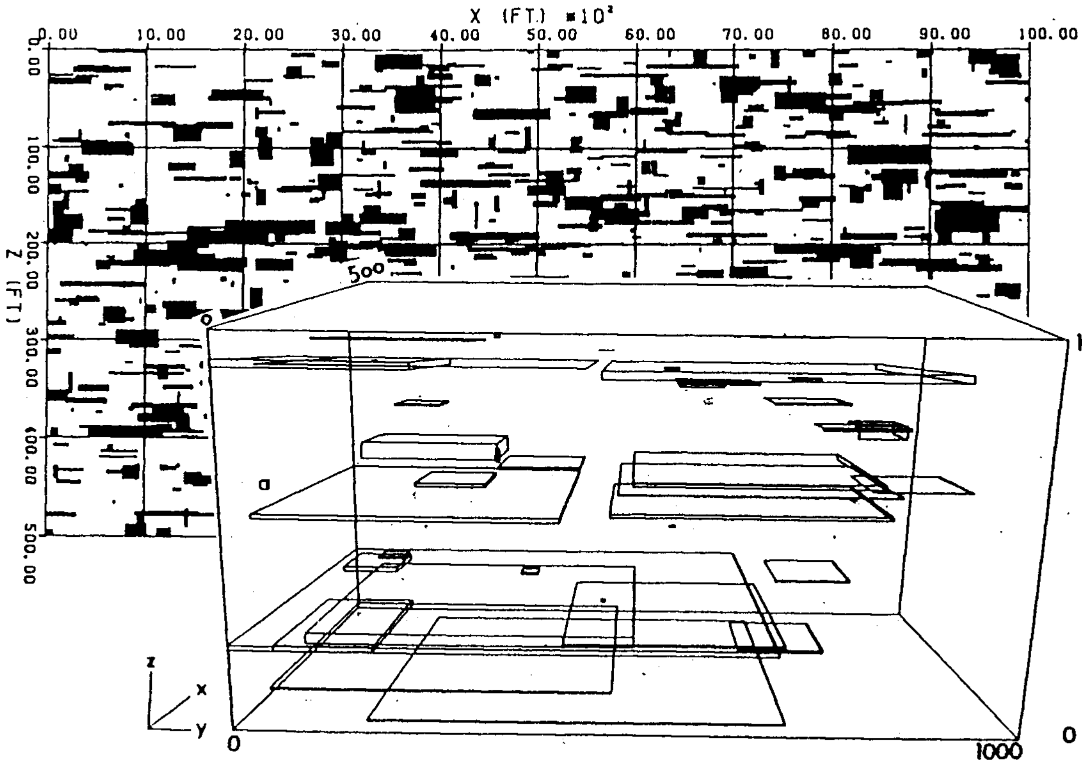
Actual shale distribution in an outcrop of the Assakao (fluvial) Sandstone



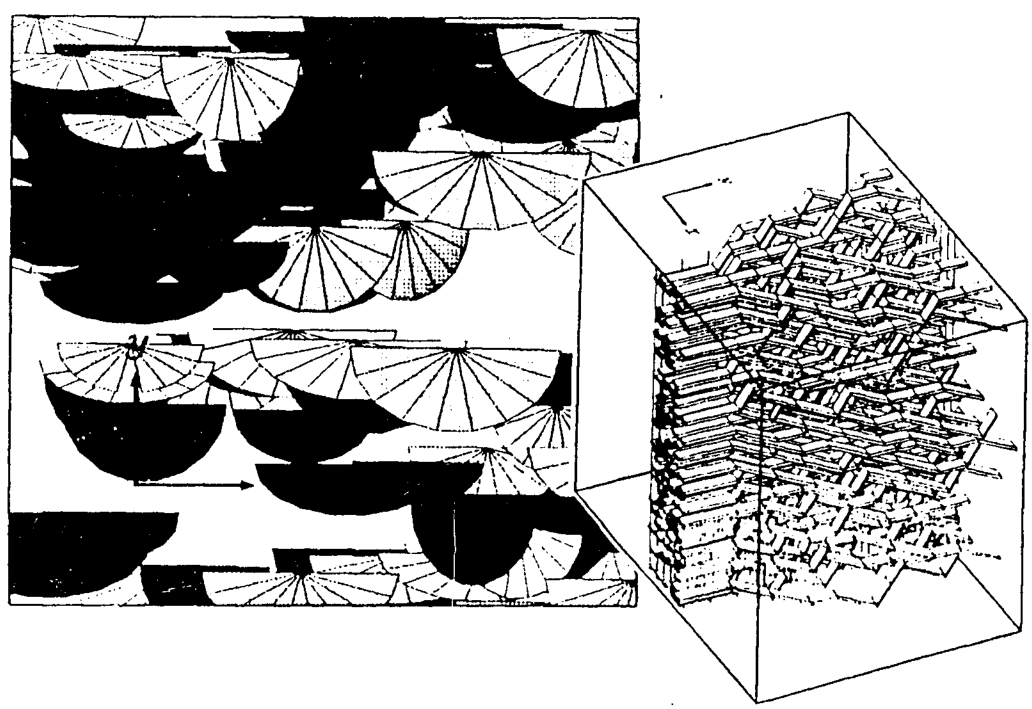
Synthetic cross-section generated from parameters of the Assakao Sandstone outcrop

from Haldorsen and Chang (1986)

2-D AND 3-D STOCHASTIC SIMULATION MODELS OF SHALES AND CHANNEL SANDSTONES

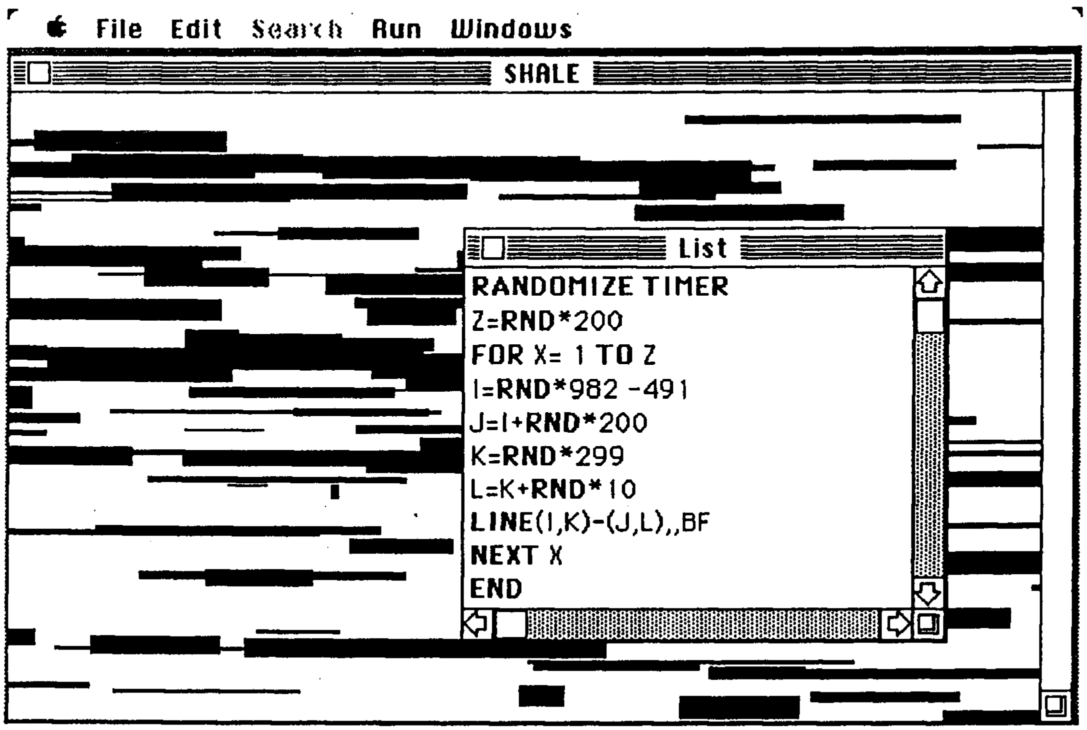


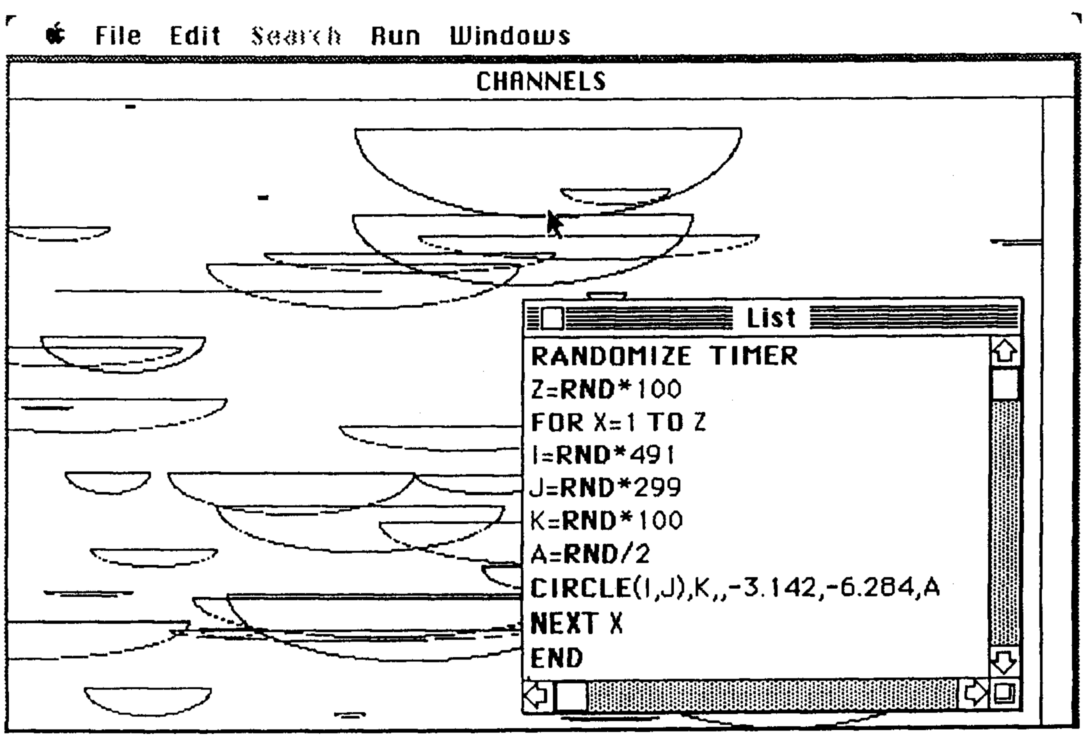
from Haldorsen and Lake (1984)



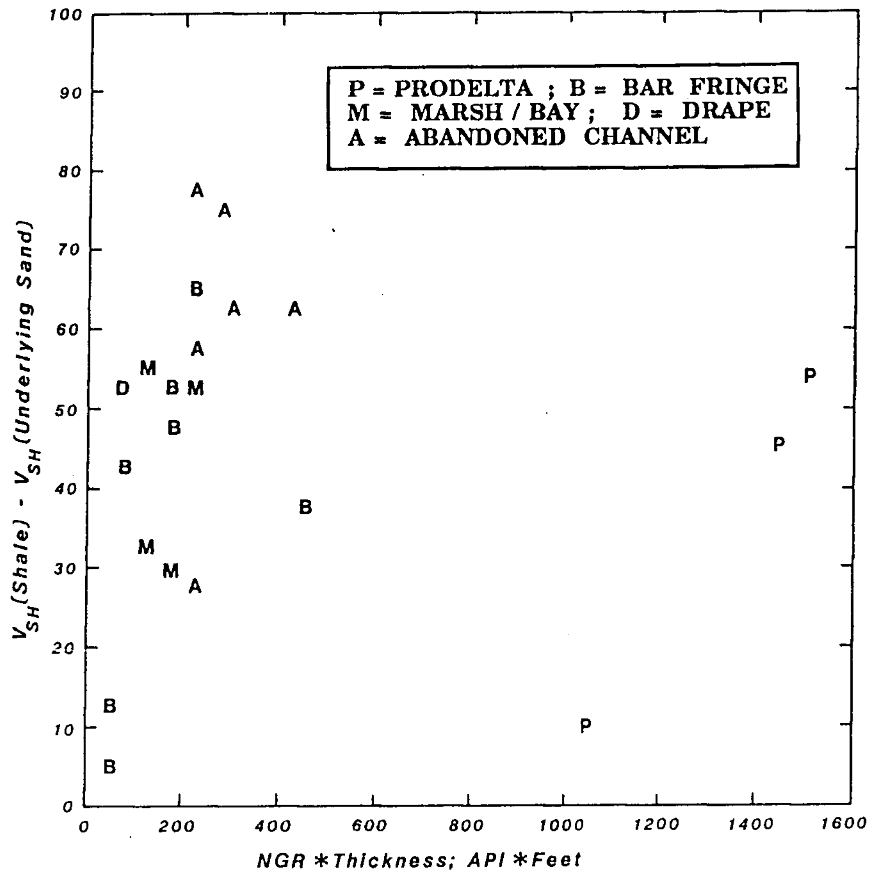
from Haldorsen and MacDonald (1987)

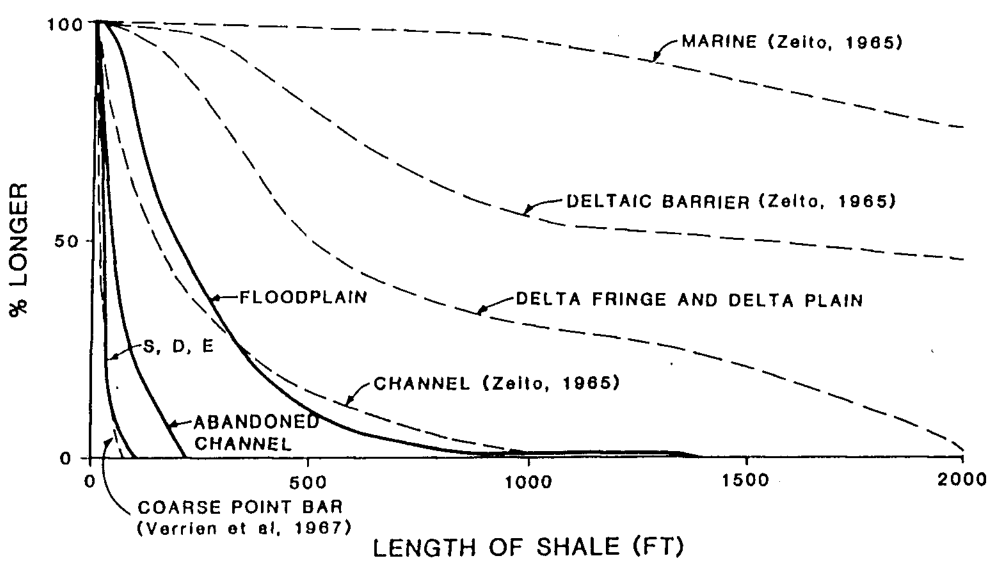
SIMPLE BASIC PROGRAMS FOR SIMULATION OF RANDOM SHALES AND SANDSTONE CHANNELS





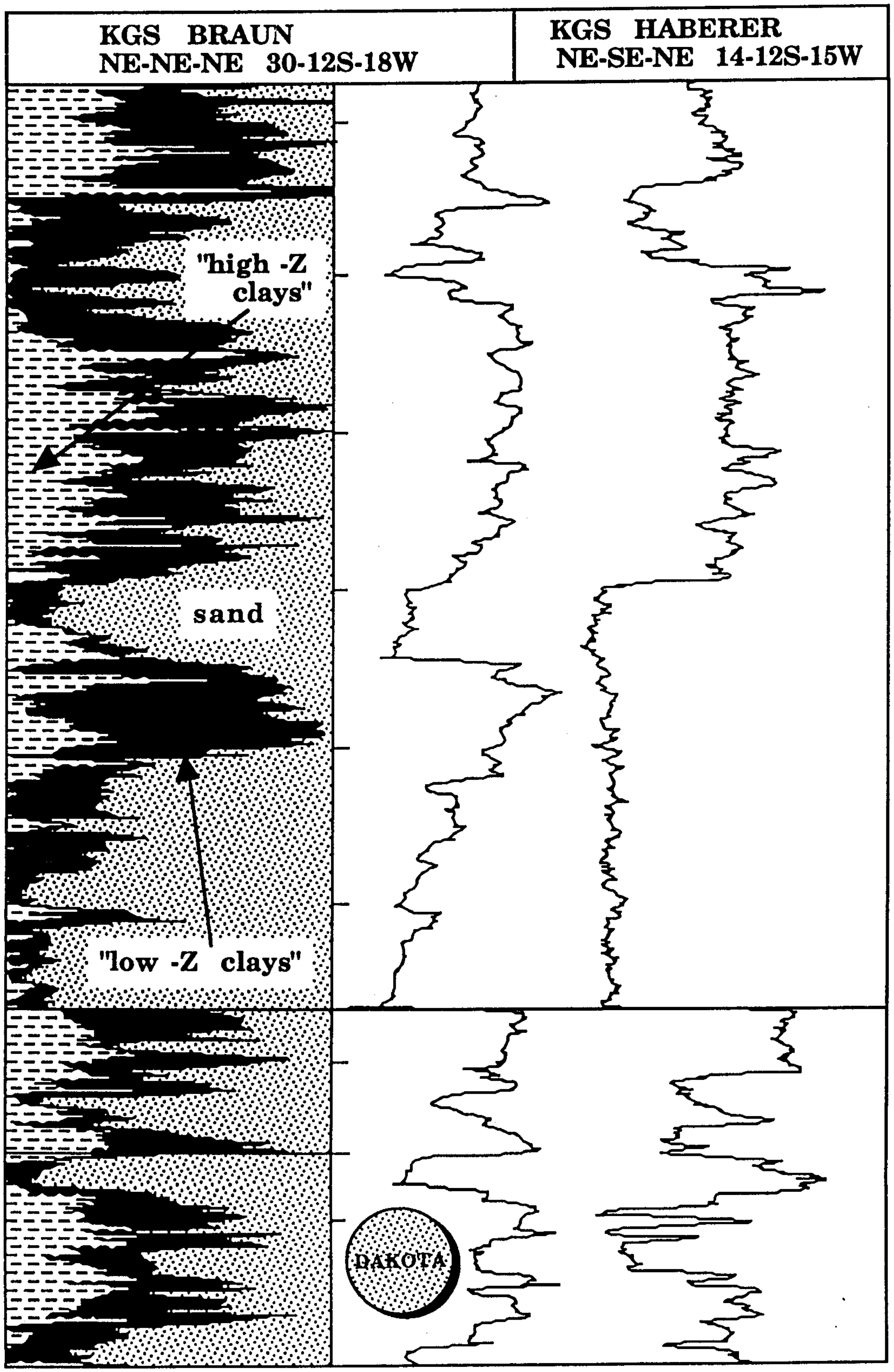
GEOLOGIC PREDICTION OF SHALE CONTINUITY, COMBINING FACIES RECOGNITION FROM LOGS WITH PROBABLE LATERAL EXTENT OBSERVED FROM OUTCROP STUDIES



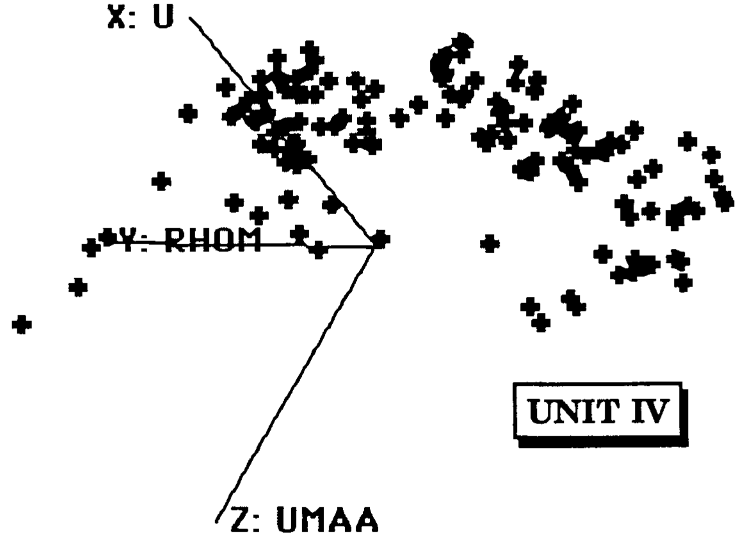


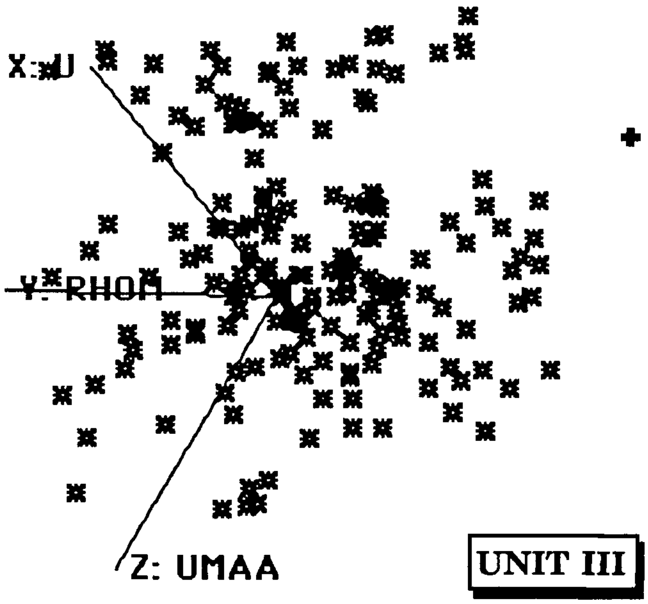
From Geehan et al (1986)

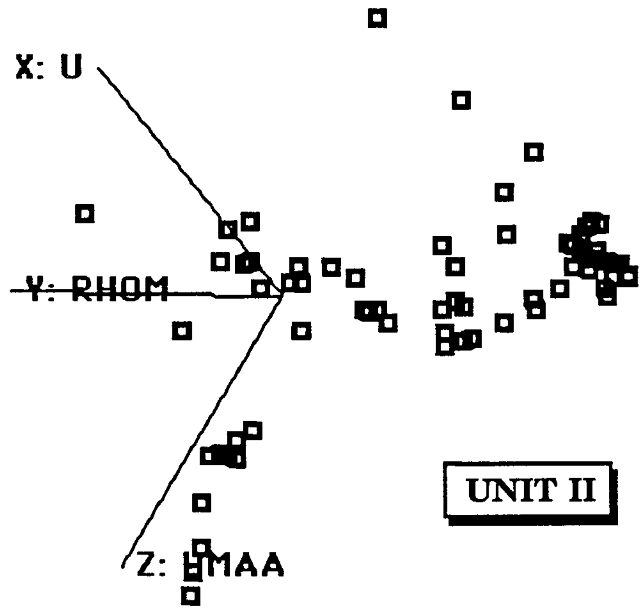
EXAMPLE OF POTENTIAL LINKAGE BETWEEN SHALE CONTINUITY AND SHALE LOG CHARACTER

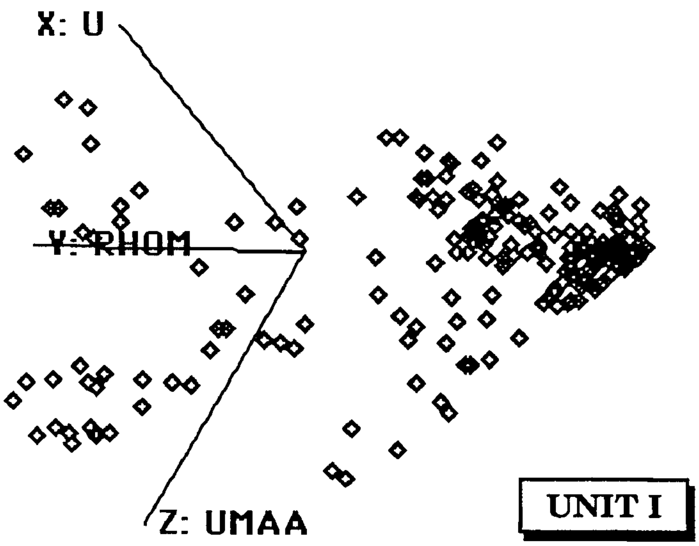


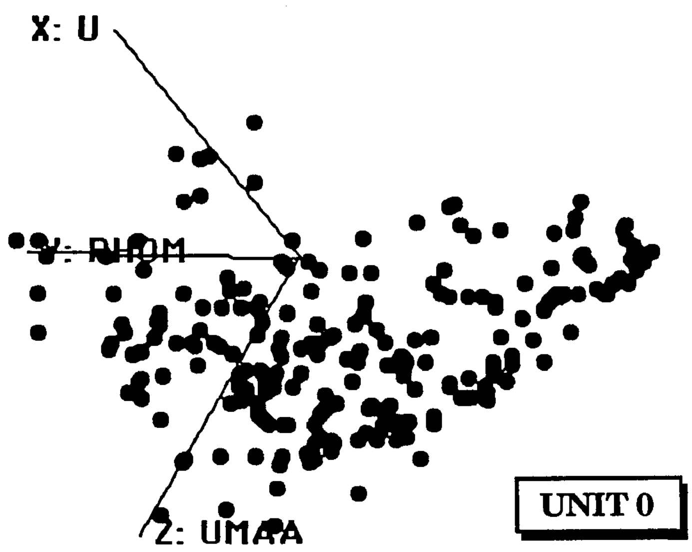
KGS Braun Lower Cretaceous
U - Rhomaa - Umaa crossplots

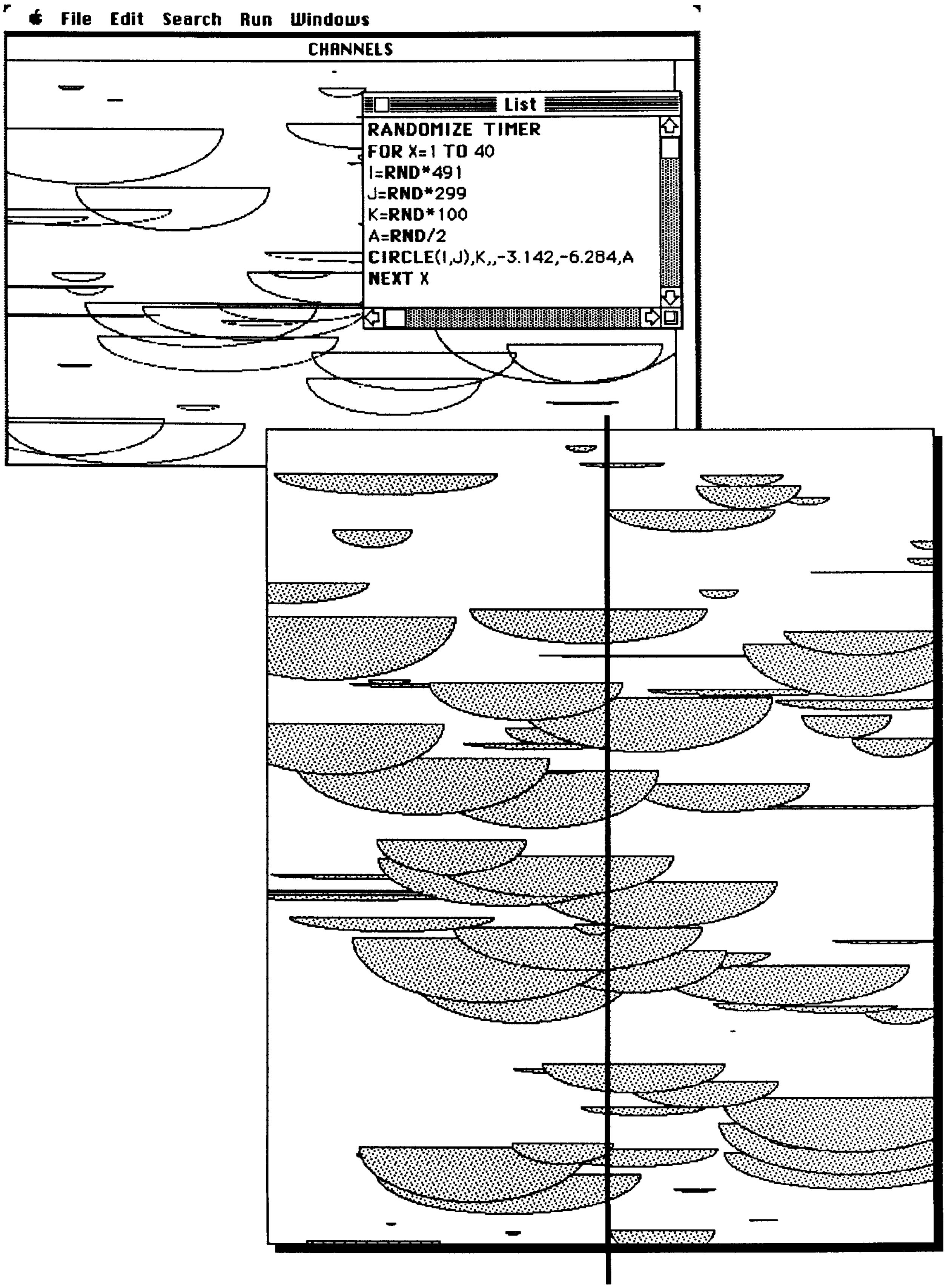











File Edit Search Run Windows
CHANNELS
List
RANDOMIZE TIMER
FOR X=1 TO 40
I=RND*491
J=RND*299
K=RND*100
A=RND/2
CIRCLE(I,J),K,,-3.142,-6.284,A
NEXT X