ASUDOE-ProjectReport

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Summary

This is a report on an experiment run to perform a Measurement System Analysis (MSA) (see Measurement system analysis (Wikipedia)) using DOE and ANOVA on a metrology tool used in the manufacture of semiconductor products (computer chips), made in partial fulfillment of the requirements for the Coursera specialization in Design of Experiments offered by Arizona State University and taught by Douglas C. Montgomery.

For ease of peer review, the report is offered in outline form, following the details outlined in the course Project Report instructions.

Part 1

Context

NOTE: This section is not needed for the peer review, but is added in case reviewers have questions as to what is actually going on in the experiment and the meaning of the terms to describe it.

Epitaxial silicon deposition (see *Epitaxy (Wikipedia)*) is a chemical vapor deposition process to add a doped layer or layers of silicon onto a silicon wafer (substrate) to adjust doping concentration levels for optimum functioning of electronic devices in an integrated circuit (see *Integrated Circuit (Wikipedia)*). The expression "doped layer" means there are atoms other than silicon, such as boron, phosphoros or arsenic, that are incorporated into the film that control the electrical behavior of the silicon. Measurement of the dopant concentration is made via a well established relation between dopant concentration (a physical measure) and silicon resistivity (an electrical measure) (see *Converting Resistivity to Carrier Concentration (Solecon)*). The measurement instrument is a 4 point probe (see *Four-terminal Sensing (Wikipedia)*) which measures sheet resistance (see *Sheet Resistance (Wikipedia)*) which is then converted to resistivity (see *Electrical resistivity and conductivity (Wikipedia)*).

Problem Statement and Objectives of the Experiment

Problem Statement To find and prioritize areas of improvement of variability of output parameters in a silicon epitaxial deposition process.

Objectives This experiment sets out to quantify the amount of variation contributed by the measurement of the resisitivity (RES) of the deposited epitaxial silicon and to decide if measurement variability poses a large enough source of variability that it needs to be improved.

Based on the results, this experiment is expected to be followed by a confirming repeat of this experiment and, if needed, additional experiments to decrease the measurement variability. Once measurement variability has been reduced, experiments to reduce variability from the rest of the process (equipment, processing methods, operator differences, raw material differences) will be run. But the first step is to quantify the amount of variability in the measurement portion of the process. You cannot improve what you cannot measure.

Response Variable

Response Description/Name The response variable is the measurement of resistivity (RES) of a deposited epitaxial silicon film. (See the Context section above for more information.)

How it is measured Using a CDE 4 point probe. (See the Context section for more information.)

How is the measurement technique calibrated 8 wafers (standards) are measured 4 times a week and plotted on SPC Control Charts (see Control Chart (Wikipedida)).

Factors to Be Studied

Factors and their levels

The factors involved were

OPRTR There were 4 different operators: DR, KD, SB, ZV.

PART Parts were 9 measurement sites (locations) on 3 different wafers, each run on a different deposition tool, giving 27 parts.

NOTE: Why were site, wafer and tool not set up as additional factors in the model? (This note not needed to understand the analysis, only the design.) Technically, for a study with multiple wafers run on multiple tools (each wafer run on a single tool), site could be considered crossed with wafer for a given tool (each site could be expected to vary the same way for a given tool for each wafer run on that tool) and the wafer nested within tool (values for a given site would not be expected to be the same from one tool to the next). But since the objective of the experiment was to quantify measurement variability taking into account the overall variability of the parts, and not to quantify the sources of variability of the parts, the part variability was lumped into a single factor PART, and not broken out by the components site, wafer and tool.

Is a blocking variable needed?

TRIAL Since the measurements were made over a series of days and because complete randomization was not possible (see the section Notes on the Design below), a blocking variable for TRIAL was included in the initial model.

Part 2

Choice of Experimental Design

What design was chosen?

The standard design for a Measurement System Analysis (MSA) was used, consisting of a two way design with interaction and one blocking variable. The full model has all factors being random and is

$$RES_{bijk} = \mu + TRIAL_b + PART_i + OPRTR_j + (PART * OPRTR)_{ij} + \epsilon_{bijk}$$

where μ is the average of all readings.

Design/Test Matrix

The 297 rows of the design matrix with residuals for both the full model and the reduced model are included in a table at the end of this document. The table includes measurement results and residuals from both the full and the reduced models.

Notes on the Design

Analyses not available Since this was a random model, the default analysis was REML. In JMP, the following Fit Model reports are not available: power calculations; Normal (Lenthe), Bayes, and Pareto plots; Box Cox transformation; Press statistics; Durbin-Watson test.

Data not fully balanced This experiment was run in a manufacturing, production environment which means that the ability to control the execution of the experiment was limited due to the other responsbilities of the operators who were asked to make the measurements. As a consequence, not all requested runs were completed and the data is not fully balanced.

Data not completely randomized The operators measured the sites in the same way as is done in production, i.e., using an automated measurement system with a give order of measurement across the wafer. This was done to help mimic the actual process for a more reliable measure of metrology variability in actual working conditions.

Part 3

Statistical Analysis of the Data

Results

It was found that factor TRIAL was not statistically significant, so a reduced model excluding that factor was generated. The tables and plots of results are placed here together for easy comparison. The results of the model did not change much with the deletion of TRIAL.

Summary of Fit Full vs Reduced Models

Summary of Fit - Full Model

RSquare	0.811823
RSquare Adj	0.811823
Root Mean Square Error	0.208122
Mean of Response	18.80609
Observations (or Sum Wgts)	279

Summary of Fit - Reduced Model

RSquare	0.815929
RSquare Adj	0.815929
Root Mean Square Error	0.207358
Mean of Response	18.80609
Observations (or Sum Wgts)	279

REML Variance Component Estimates Full vs Reduced Models

REML Variance Component Estimates - Full Model

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Wald p-Value	Pct of Total
TRIAL	-0.006604	-0.000286	0.0001891	-0.000657	8.4537e-5	0.1303	0.000
OPRTR	0.046254	0.0020035	0.0024439	-0.002786	0.0067934	0.4123	1.054
PART	3.1094972	0.1346871	0.0392568	0.0577451	0.211629	0.0006*	70.854
OPRTR*PART	0.2328714	0.0100868	0.0051123	6.6853e-5	0.0201067	0.0485*	5.306
Residual		0.0433147	0.0048215	0.035225	0.0545668		22.786
Total		0.1900921	0.0395238	0.131388	0.2994357		100.000

-2 LogLikelihood = 52.46720309

Note: Total is the sum of the positive variance components.

Total including negative estimates = 0.189806

REML Variance Component Estimates - Reduced Model

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Wald p-Value	Pct of Total
OPRTR	0.0495847	0.002132	0.0025571	-0.00288	0.0071438	0.4044	1.123
PART	3.1295004	0.1345602	0.0392239	0.0576827	0.2114377	0.0006*	70.856
OPRTR*PART	0.2376428	0.010218	0.0051067	0.000209	0.020227	0.0454*	5.381
Residual		0.0429973	0.0047648	0.0349975	0.0541079		22.641
Total		0.1899076	0.039498	0.1312465	0.2991933		100.000

-2 LogLikelihood = 53.095939799

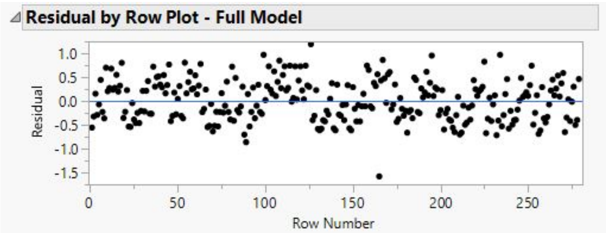
Note: Total is the sum of the positive variance components.

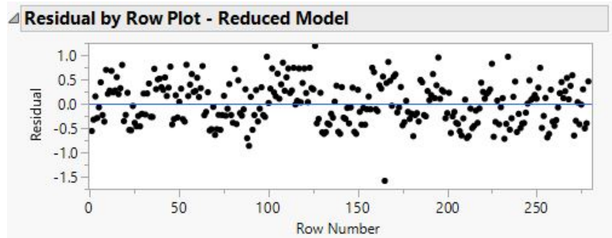
Total including negative estimates = 0.1899076

Model Adequacy (Residuals / Need for Transformation?)

Residual by Row Plot Plots of the residuals show no patterns, e.g., increasing spread of points, that would indicate the need for a transformation.

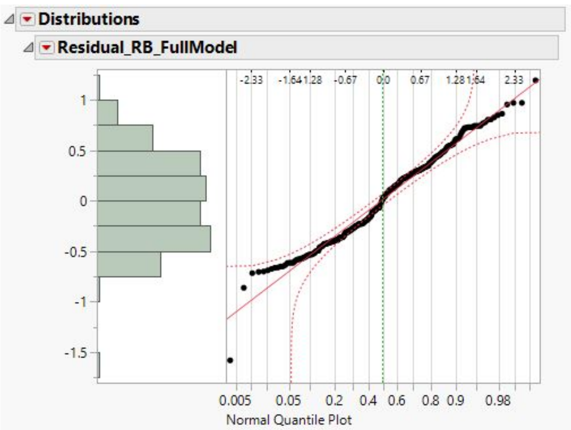
Full vs Reduced Models





Residual Normal Quantile Plot A normal probability plot of the residuals for both the full and reduced models show no outliers, no abnormal patterns. The points fall pretty much on a straight line.

Full vs Reduced Models

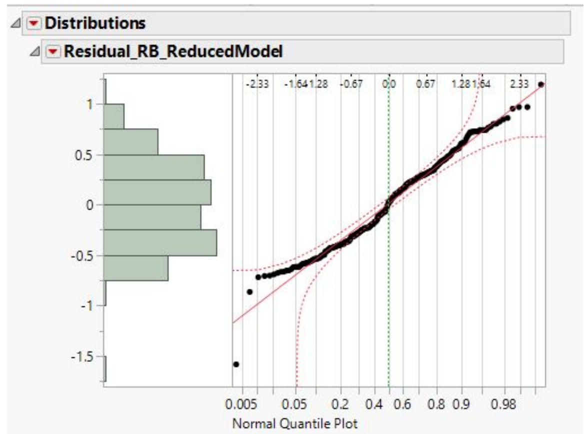


Quantiles

100.0%	maximum	1.1936548159
99.5%		1.1044148159
97.5%		0.8264548159
90.0%		0.6089548159
75.0%	quartile	0.3133548159
50.0%	median	0.0199548159
25.0%	quartile	-0.332245184
10.0%		-0.532445184
2.5%		-0.674645184
0.5%		-1.293725184
0.0%	minimum	-1.581245184

Summary Statistics

Mean	0.013143
Std Dev	0.4310352
Std Err Mean	0.0258054
Upper 95% Mean	0.0639418
Lower 95% Mean	-0.037656
N	279



Quantiles

100.0%	maximum	1.1912249512
99.5%		1.1019849512
97.5%		0.8240249512
90.0%		0.6065249512
75.0%	quartile	0.3109249512
50.0%	median	0.0175249512
25.0%	quartile	-0.334675049
10.0%		-0.534875049
2.5%		-0.677075049
0.5%		-1.296155049
0.0%	minimum	-1.583675049

Summary Statistics

Mean	0.0107131
Std Dev	0.4310352
Std Err Mean	0.0258054
Upper 95% Mean	0.0615119
Lower 95% Mean	-0.040086
N	279

Interpretation

Interaction

There was a statistically significant interaction between PART and OPRTR. It was left in the model as was OPRTR even though OPRTR was not statistically significant. OPRTR was left in the model to maintain model hierarchy, i.e., all main factors, whether statistically significant or not, that are involved in significant interactions are kept in the model. (This was in the course Project Report instructions.)

Further analysis of the interaction is needed. Breaking down the interaction by wafer and site will be done in the future.

Interpretation of the Results

Variability of the measurements consists mostly (71%) of variability due to the parts. Variability of the measurement process, independent of the parts, is due mostly to the tool (this is called Repeatability in an MSA study) which contributes 23% of the variability of the measurements. The tool is automated, so it was expected that variability due to operators (called Reproducibility in an MSA study) would be small. In this case there is an apparent OPRTR to PART interaction that contributes a small amount of variability (5%)

Conclusions and Recommendations

Conclusions

Execution Execution of the experiment did not go as planned, nor as instructed.

Objective The objective was met. Measurement variability sigma 0.21 Ω-cm. Six sigma variability is 1.26 Ω-cm which is 22% of total spec range (Percent Measurement Variation or PMV). Metrology equipment are considered adequate if the PMV is between 11 and 20% and marginally acceptable if between 21 and 30%. This tool is marginally acceptable.

Recommendations

- Repeat the study with better instructions and better execution to validate the results achieved so far.
- Supervise experiment execution more closely. Note to self: This is difficult when operators on an off (night) shift are involved, but quick review of the data upon receipt and feedback to the operators is needed to have good data integrity. Interviewing the operators on how they understood or misunderstood the instructions will help improve execution of future experiments.
- Have a better means of data collection. This experiment relied on a cumbersome data entry into a production material tracking system. Next time, entry into an Excel spreadsheet by each operator, with columns for all factors and all related data (date/time of measurement and not of data logging, measurement tool, wafer id, site id, etc.) will be used.
- Investigate the OPRTR by PART interaction. Find out if the contribution of wafer or site played a role.
- Analyze the results of the experiment from the point of view of not just the spec limits, but from the point of view of inherent process variability. Dr. Donald Wheeler explains the difference in his book EMP III (Evaluating the Measurement Process) and is included as a module in JMP: Analyze / Quality and Process / Measurement System Analysis which offers a choice of EMP or Gauge R & R methods.
- Follow up with a DOE to find improved operating conditions, e.g., range of forced current, auto-range option, auto-compression, random rotation of position upon re-measure, and other measurement recipe parameters that will decrease measurement variability.

Design Matrix and Results

```
cols_data <- c("TRIAL", "OPRTR", "PART", "RB", "Residual_RB_FullModel", "Residual_RB_ReducedModel")
print(data[,cols_data],n = length(data$RB))
```

```
## # A tibble: 279 x 6
##     TRIAL OPRTR PART     RB Residual_RB_FullModel Residual_RB_ReducedModel
##     <fct> <fct> <fct> <dbl>                 <dbl>                    <dbl>
##   1 1     SB    099-1  18.2               -0.557                   -0.560
##   2 1     SB    099-2  18.5               -0.324                   -0.327
##   3 1     SB    099-3  19.0                0.154                    0.151
##   4 1     SB    099-4  18.5               -0.290                   -0.292
##   5 1     SB    099-5  18.7               -0.0699                  -0.0724
##   6 1     SB    099-6  19.2                0.445                    0.442
##   7 1     SB    099-7  18.6               -0.229                   -0.231
##   8 1     SB    099-8  18.4               -0.364                   -0.366
##   9 1     SB    099-9  19.5                0.700                    0.698
##  10 1     SB    100-1  19                  0.206                    0.204
##  11 1     SB    100-2  19.1                0.274                    0.271
##  12 1     SB    100-3  19.5                0.680                    0.678
##  13 1     SB    100-4  19.0                0.237                    0.235
##  14 1     SB    100-5  19.1                0.277                    0.274
##  15 1     SB    100-6  19.3                0.551                    0.548
##  16 1     SB    100-7  19.0                0.200                    0.198
##  17 1     SB    100-8  19.1                0.323                    0.320
##  18 1     SB    100-9  19.6                0.803                    0.800
##  19 1     SB    053-1  18.4               -0.355                   -0.357
##  20 1     SB    053-2  18.6               -0.226                   -0.228
##  21 1     SB    053-3  19.0                0.229                    0.227
##  22 1     SB    053-4  18.3               -0.535                   -0.537
##  23 1     SB    053-5  18.2               -0.543                   -0.545
##  24 1     SB    053-6  18.8               -0.0420                  -0.0445
##  25 1     SB    053-7  18.4               -0.387                   -0.390
##  26 1     SB    053-8  18.3               -0.461                   -0.464
##  27 1     SB    053-9  18.5               -0.249                   -0.251
##  28 2     SB    099-1  18.3               -0.461                   -0.464
##  29 2     SB    099-2  18.6               -0.205                   -0.208
##  30 2     SB    099-3  19.0                0.213                    0.210
##  31 2     SB    099-4  18.6               -0.218                   -0.221
##  32 2     SB    099-5  19.0                0.215                    0.212
##  33 2     SB    099-6  19.2                0.419                    0.417
##  34 2     SB    099-7  18.5               -0.265                   -0.267
##  35 2     SB    099-8  18.5               -0.267                   -0.270
##  36 2     SB    099-9  19.5                0.721                    0.719
##  37 2     SB    100-1  19.1                0.303                    0.301
##  38 2     SB    100-2  19.3                0.503                    0.501
##  39 2     SB    100-3  19.3                0.518                    0.516
##  40 2     SB    100-4  19.1                0.345                    0.343
##  41 2     SB    100-5  19.1                0.289                    0.286
##  42 2     SB    100-6  19.3                0.546                    0.543
##  43 2     SB    100-7  19.0                0.163                    0.160
##  44 2     SB    100-8  19.1                0.337                    0.334
##  45 2     SB    100-9  19.6                0.767                    0.764
##  46 3     SB    099-1  18.4               -0.423                   -0.425
```

```
##  47 3     SB    099-2  18.5                -0.312                   -0.315
##  48 3     SB    099-3  19.0                 0.177                    0.175
##  49 3     SB    099-4  18.5                -0.278                   -0.280
##  50 3     SB    099-5  18.8                 0.0436                   0.0411
##  51 3     SB    099-6  19.1                 0.313                    0.311
##  52 3     SB    099-7  18.5                -0.312                   -0.315
##  53 3     SB    099-8  18.4                -0.364                   -0.366
##  54 3     SB    099-9  19.6                 0.806                    0.803
##  55 3     SB    100-1  19.0                 0.161                    0.159
##  56 3     SB    100-2  19.2                 0.397                    0.395
##  57 3     SB    100-3  19.4                 0.614                    0.611
##  58 3     SB    100-4  19.0                 0.247                    0.244
##  59 3     SB    100-5  19.1                 0.265                    0.262
##  60 3     SB    100-6  19.3                 0.539                    0.536
##  61 3     SB    100-7  18.9                 0.141                    0.139
##  62 3     SB    100-8  19.1                 0.325                    0.322
##  63 3     SB    100-9  19.6                 0.779                    0.776
##  64 3     SB    053-1  18.6                -0.233                   -0.235
##  65 3     SB    053-2  18.6                -0.165                   -0.167
##  66 3     SB    053-3  19.0                 0.241                    0.239
##  67 3     SB    053-4  18.2                -0.547                   -0.549
##  68 3     SB    053-5  18.3                -0.519                   -0.521
##  69 3     SB    053-6  18.7                -0.0603                  -0.0628
##  70 3     SB    053-7  18.2                -0.637                   -0.639
##  71 3     SB    053-8  18.3                -0.521                   -0.523
##  72 3     SB    053-9  18.6                -0.225                   -0.227
##  73 1     ZV    099-1  18.3                -0.532                   -0.535
##  74 1     ZV    099-2  18.6                -0.229                   -0.231
##  75 1     ZV    099-3  19.0                 0.165                    0.163
##  76 1     ZV    099-4  18.6                -0.242                   -0.245
##  77 1     ZV    099-5  18.7                -0.0983                  -0.101
##  78 1     ZV    099-6  19.2                 0.407                    0.405
##  79 1     ZV    099-7  18.6                -0.229                   -0.231
##  80 1     ZV    099-8  18.4                -0.387                   -0.390
##  81 1     ZV    099-9  19.5                 0.721                    0.719
##  82 2     ZV    099-1  18.4                -0.414                   -0.416
##  83 2     ZV    099-2  19.3                 0.485                    0.483
##  84 2     ZV    099-3  18.6                -0.190                   -0.192
##  85 2     ZV    099-4  18.6                -0.242                   -0.245
##  86 2     ZV    099-5  18.7                -0.112                   -0.114
##  87 2     ZV    099-6  19.1                 0.301                    0.299
##  88 2     ZV    099-7  18.1                -0.705                   -0.707
##  89 2     ZV    099-8  17.9                -0.862                   -0.865
##  90 2     ZV    099-9  18.9                 0.147                    0.145
##  91 3     ZV    099-1  18.3                -0.532                   -0.535
##  92 3     ZV    099-2  18.6                -0.229                   -0.231
##  93 3     ZV    099-3  19.1                 0.284                    0.282
##  94 3     ZV    099-4  18.4                -0.361                   -0.364
##  95 3     ZV    099-5  18.7                -0.0983                  -0.101
##  96 3     ZV    099-6  19.1                 0.342                    0.340
##  97 3     ZV    099-7  18.6                -0.229                   -0.231
##  98 3     ZV    099-8  18.5                -0.269                   -0.271
##  99 3     ZV    099-9  19.8                 0.971                    0.968
## 100 1     ZV    100-1  18.8                 0.0200                   0.0175
```

```
## 101 1     ZV    100-2  19.1               0.313                0.311
## 102 1     ZV    100-3  19.5               0.729                0.727
## 103 1     ZV    100-4  19.0               0.237                0.235
## 104 1     ZV    100-5  19.0               0.157                0.154
## 105 1     ZV    100-6  19.4               0.623                0.620
## 106 1     ZV    100-7  18.9               0.106                0.104
## 107 1     ZV    100-8  19.2               0.402                0.400
## 108 1     ZV    100-9  19.6               0.849                0.846
## 109 2     ZV    100-1  19.1               0.270                0.268
## 110 2     ZV    100-2  19.3               0.548                0.545
## 111 2     ZV    100-3  19.5               0.729                0.727
## 112 2     ZV    100-4  19.0               0.223                0.221
## 113 2     ZV    100-5  19.1               0.277                0.274
## 114 2     ZV    100-6  19.5               0.743                0.740
## 115 2     ZV    100-7  18.8              -0.0113              -0.0138
## 116 2     ZV    100-8  18.9               0.0650               0.0625
## 117 2     ZV    100-9  19.5               0.729                0.726
## 118 3     ZV    100-1  18.8               0.0335               0.0310
## 119 3     ZV    100-2  19.2               0.430                0.428
## 120 3     ZV    100-3  19.5               0.729                0.727
## 121 3     ZV    100-4  19.0               0.223                0.221
## 122 3     ZV    100-5  18.8               0.0369               0.0344
## 123 3     ZV    100-6  19.5               0.743                0.740
## 124 3     ZV    100-7  19.1               0.327                0.325
## 125 3     ZV    100-8  19.1               0.299                0.297
## 126 3     ZV    100-9  20.0               1.19                 1.19
## 127 1     ZV    053-1  18.4              -0.401               -0.403
## 128 1     ZV    053-2  18.5              -0.309               -0.311
## 129 1     ZV    053-3  19.0               0.229                0.227
## 130 1     ZV    053-4  18.2              -0.585               -0.587
## 131 1     ZV    053-5  18.2              -0.615               -0.617
## 132 1     ZV    053-6  18.2              -0.580               -0.582
## 133 1     ZV    053-7  18.4              -0.401               -0.403
## 134 1     ZV    053-8  18.4              -0.427               -0.429
## 135 1     ZV    053-9  18.6              -0.202               -0.205
## 136 2     ZV    053-1  18.5              -0.282               -0.284
## 137 2     ZV    053-2  18.8               0.0470               0.0445
## 138 2     ZV    053-3  19.2               0.375                0.372
## 139 2     ZV    053-4  18.2              -0.572               -0.574
## 140 2     ZV    053-5  18.2              -0.615               -0.617
## 141 2     ZV    053-6  19.1               0.344                0.342
## 142 2     ZV    053-7  18.5              -0.282               -0.284
## 143 2     ZV    053-8  18.5              -0.309               -0.311
## 144 2     ZV    053-9  18.7              -0.0832              -0.0857
## 145 3     ZV    053-1  18.4              -0.401               -0.403
## 146 3     ZV    053-2  18.7              -0.0715              -0.0740
## 147 3     ZV    053-3  19.1               0.334                0.331
## 148 3     ZV    053-4  18.2              -0.572               -0.574
## 149 3     ZV    053-5  18.2              -0.615               -0.617
## 150 3     ZV    053-6  19.1               0.291                0.289
## 151 3     ZV    053-7  18.6              -0.163               -0.166
## 152 3     ZV    053-8  18.4              -0.427               -0.429
## 153 3     ZV    053-9  18.7              -0.0832              -0.0857
## 154 1     DR    099-1  18.4              -0.427               -0.429
```

```
## 155 1      DR    099-2  18.7                -0.110                   -0.112
## 156 1      DR    099-3  18.9                 0.152                    0.149
## 157 1      DR    099-4  18.7                -0.110                   -0.112
## 158 1      DR    099-5  19.5                 0.744                    0.741
## 159 1      DR    099-6  19.4                 0.653                    0.651
## 160 1      DR    099-7  18.7                -0.110                   -0.112
## 161 1      DR    099-8  18.6                -0.150                   -0.152
## 162 1      DR    099-9  19.2                 0.382                    0.380
## 163 1      DR    100-1  19.1                 0.315                    0.313
## 164 1      DR    100-2  19.4                 0.562                    0.559
## 165 1      DR    100-3  17.2                -1.58                    -1.58
## 166 1      DR    100-4  19.2                 0.430                    0.428
## 167 1      DR    100-5  19.7                 0.862                    0.860
## 168 1      DR    100-6  19.3                 0.476                    0.473
## 169 1      DR    100-7  18.8                -0.0385                  -0.0410
## 170 1      DR    100-8  19.4                 0.562                    0.559
## 171 1      DR    100-9  19.4                 0.609                    0.607
## 172 1      DR    053-1  18.6                -0.176                   -0.178
## 173 1      DR    053-2  18.7                -0.0715                  -0.0740
## 174 1      DR    053-3  19.1                 0.347                    0.345
## 175 1      DR    053-4  18.4                -0.440                   -0.443
## 176 1      DR    053-5  18.4                -0.375                   -0.378
## 177 1      DR    053-6  18.9                 0.0636                   0.0611
## 178 1      DR    053-7  18.6                -0.163                   -0.166
## 179 1      DR    053-8  18.5                -0.309                   -0.311
## 180 1      DR    053-9  18.6                -0.202                   -0.205
## 181 2      DR    099-1  18.1                -0.664                   -0.666
## 182 2      DR    099-2  18.6                -0.229                   -0.231
## 183 2      DR    099-3  18.6                -0.190                   -0.192
## 184 2      DR    099-4  18.4                -0.361                   -0.364
## 185 2      DR    099-5  19.3                 0.493                    0.491
## 186 2      DR    099-6  19.2                 0.444                    0.441
## 187 2      DR    099-7  18.6                -0.229                   -0.231
## 188 2      DR    099-8  18.5                -0.255                   -0.258
## 189 2      DR    099-9  19.1                 0.265                    0.262
## 190 2      DR    100-1  18.9                 0.0762                   0.0737
## 191 2      DR    100-2  19.0                 0.182                    0.180
## 192 2      DR    100-3  19.4                 0.614                    0.611
## 193 2      DR    100-4  18.9                 0.120                    0.117
## 194 2      DR    100-5  19.2                 0.383                    0.381
## 195 2      DR    100-6  19.8                 0.954                    0.952
## 196 2      DR    100-7  18.9                 0.106                    0.104
## 197 2      DR    100-8  19.1                 0.285                    0.283
## 198 2      DR    100-9  19.0                 0.250                    0.247
## 199 2      DR    053-1  18.5                -0.295                   -0.298
## 200 2      DR    053-2  18.6                -0.190                   -0.192
## 201 2      DR    053-3  19.0                 0.229                    0.227
## 202 2      DR    053-4  18.2                -0.598                   -0.600
## 203 2      DR    053-5  18.5                -0.256                   -0.258
## 204 2      DR    053-6  18.6                -0.164                   -0.166
## 205 2      DR    053-7  18.4                -0.387                   -0.390
## 206 2      DR    053-8  18.4                -0.414                   -0.416
## 207 2      DR    053-9  18.2                -0.560                   -0.562
## 208 1      KD    053-1  18.1                -0.650                   -0.652
```

```
## 209 1     KD    053-2  18.5                 -0.297                   -0.299
## 210 1     KD    053-3  18.9                  0.0875                   0.0850
## 211 1     KD    053-4  18.1                 -0.701                   -0.703
## 212 1     KD    053-5  18.1                 -0.661                   -0.664
## 213 1     KD    053-6  18.7                 -0.0965                  -0.0990
## 214 1     KD    053-7  18.3                 -0.498                   -0.500
## 215 1     KD    053-8  18.3                 -0.452                   -0.454
## 216 1     KD    053-9  18.6                 -0.138                   -0.141
## 217 1     KD    100-1  18.4                 -0.390                   -0.393
## 218 1     KD    100-2  18.7                 -0.0932                  -0.0957
## 219 1     KD    100-3  19.2                  0.437                    0.434
## 220 1     KD    100-4  19.0                  0.248                    0.246
## 221 1     KD    100-5  18.9                  0.109                    0.106
## 222 1     KD    100-6  19                    0.204                    0.202
## 223 1     KD    100-7  19.0                  0.243                    0.240
## 224 1     KD    100-8  19.1                  0.299                    0.297
## 225 1     KD    100-9  19.6                  0.826                    0.824
## 226 1     KD    099-1  18.1                 -0.675                   -0.677
## 227 1     KD    099-2  18.4                 -0.371                   -0.373
## 228 1     KD    099-3  18.9                  0.0707                   0.0682
## 229 1     KD    099-4  18.4                 -0.419                   -0.422
## 230 1     KD    099-5  18.7                 -0.0684                  -0.0709
## 231 1     KD    099-6  18.9                  0.119                    0.117
## 232 1     KD    099-7  18.1                 -0.717                   -0.719
## 233 1     KD    099-8  18.4                 -0.410                   -0.412
## 234 1     KD    099-9  19.8                  0.971                    0.968
## 235 2     KD    053-1  18.3                 -0.530                   -0.532
## 236 2     KD    053-2  18.5                 -0.295                   -0.298
## 237 2     KD    053-3  18.9                  0.146                    0.144
## 238 2     KD    053-4  19.2                  0.460                    0.457
## 239 2     KD    053-5  18.2                 -0.579                   -0.581
## 240 2     KD    053-6  18.6                 -0.205                   -0.208
## 241 2     KD    053-7  18.3                 -0.494                   -0.497
## 242 2     KD    053-8  18.4                 -0.402                   -0.404
## 243 2     KD    053-9  18.4                 -0.393                   -0.396
## 244 2     KD    100-1  18.6                 -0.180                   -0.182
## 245 2     KD    100-2  18.8                  0.00835                  0.00592
## 246 2     KD    100-3  19.3                  0.484                    0.481
## 247 2     KD    100-4  18.9                  0.0845                   0.0820
## 248 2     KD    100-5  18.9                  0.121                    0.118
## 249 2     KD    100-6  19.0                  0.185                    0.183
## 250 2     KD    100-7  18.9                  0.108                    0.106
## 251 2     KD    100-8  19.1                  0.334                    0.332
## 252 2     KD    100-9  19.5                  0.743                    0.740
## 253 3     KD    053-1  18.3                 -0.494                   -0.497
## 254 3     KD    053-2  18.6                 -0.248                   -0.250
## 255 3     KD    053-3  18.9                  0.123                    0.120
## 256 3     KD    053-4  18.1                 -0.689                   -0.691
## 257 3     KD    053-5  18.2                 -0.616                   -0.619
## 258 3     KD    053-6  19.1                  0.292                    0.290
## 259 3     KD    053-7  18.4                 -0.364                   -0.366
## 260 3     KD    053-8  18.3                 -0.449                   -0.452
## 261 3     KD    053-9  18.5                 -0.332                   -0.335
## 262 3     KD    100-1  18.7                 -0.0715                  -0.0740
```

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## 263 3      KD    100-2  19.0                 0.221                    0.219
## 264 3      KD    100-3  19.2                 0.449                    0.447
## 265 3      KD    100-4  18.9                 0.120                    0.117
## 266 3      KD    100-5  19.0                 0.262                    0.259
## 267 3      KD    100-6  19.3                 0.534                    0.531
## 268 3      KD    100-7  18.9                 0.0943                   0.0918
## 269 3      KD    100-8  19.2                 0.372                    0.369
## 270 3      KD    100-9  19.4                 0.589                    0.586
## 271 3      KD    099-1  18.1                -0.651                   -0.653
## 272 3      KD    099-2  18.4                -0.347                   -0.349
## 273 3      KD    099-3  18.8                 0.0352                   0.0327
## 274 3      KD    099-4  18.4                -0.419                   -0.422
## 275 3      KD    099-5  18.8                -0.0139                  -0.0164
## 276 3      KD    099-6  19.1                 0.300                    0.297
## 277 3      KD    099-7  18.3                -0.503                   -0.505
## 278 3      KD    099-8  18.4                -0.398                   -0.400
## 279 3      KD    099-9  19.3                 0.463                    0.460
```