ON-LINE B.O.S. CONTROL EXPERIMENTS*

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ABSTRACT

This report gives the aims, details, and conclusions of on-line B.O.S. control experiments carried out at Newcastle Steelworks over a two week period in early 1982.

INTRODUCTION

Observations of oxygen lance electrical current measurements from the B.O.F. are known to give useful information on blow hardness. It is also known that with this information, relatively minor variations to furnace lance practice can reduce slop, improve yield, assist in meeting phosphorous specifications, and reduce lining wear.

Research to date has been primarily the development of tools for signal processing of the lance currents and the analysis of performance of existing control practice. Also studied are conservative control actions to avoid slopping and high phosphorous levels. A natural question of interest to both research and operator practice which emerges from this work is as follows. Can the Lance Current Measurement reliably guide more radical furnace control actions than is current practice so as to achieve improved performance? Can we, for example, guarantee sufficiently hard blowing in the first three quarters of the heat to give blow stability, slop avoidance, and high decarburization rates, and yet not preclude the possibility of achieving phosphorous specificcations by appropriate control actions in the last few minutes?

The experiments reported here are of more radical B.O.F. control actions than is usual Newcastle practice. These are guided by the Lance Current Measurements to achieve improved performance. The emphasis in the experiments is to assess the response of the Lance Current Measurements to the more radical control actions and to formulate possible control strategies worthy of further investigation, rather than to demonstrate at this stage the superiority of some particular control strategy.

The control actions assessed are as follows:

1. Late ore and or lime drops to achieve lower phosphorous levels without the need to blow softly and risk slopping.

2. The equivalence in terms of blow hardness of large lance height and oxygen flow rate changes.

3. The effect of sudden oxygen cuts on the trace.

4. The effectiveness of implementing a controlled hardening or softening of the blow as follows. Achieve the desired state using oxygen flow rate adjustments,which are continuously variable,and then reset lance height and flow rate similtaneously so as to maintain this condition while at the same time achieving a suitable flow rate.

5. The possibility of consistently ensuring negative trace regimes in the middle third of the heat simply by appropriate lance practice.

6. The stability of negative trace regimes to large lance height and flow rate changes.

7. The effect of large short term increases in the lance height in the last few minutes of the blow.

8. The extent to which for the very stable negative regimes oxygen flow rate can be increased beyond the usual upper limit without exceeding stack temperature limits. Likewise in the last few minutes of the blow when temperature normally declines.

RESULTS

1. Late Ore/lime drops

HEAT 61636:

Description: The lance currents appear as a "classical" positive trace save for heavy seiching of the bath and in addition there is a portion of associated suspected periodic shorting to near zero due to excessive lance swinging. A 1½ tonne late ore (FeO) drop at 3½ minutes before the end of the blow, and following one minute after a 1 tonne lime drop, does not significantly influence the relatively hard and stable blowing pattern. Certainly there is not a distinct hardening or softening of the blow indicated by a regime change, although there could be change in the pattern parameters, not clearly discernable by the eye. If anything, the lime drop softens the blow for perhaps 15 seconds, reducing the trace magnitude. This level subsequently picks up. Perhaps the blow was softening anyway and the lime drop hardens it a little. Also, the ore drop, if anything, hardens the blow a little and stops the lance swinging/seiching. The effects are estimated to be less than those associated with a 5-10 cm lance height change. With a final 1605 ^{o}C temperature, and carbon .08%, the final 0.32% phosphorus is not considered significantly different from what was predicted from the trace by G. Kemlo assuming no late ore/lime drops. Likewise the slag analysis of 10.2% FeO is no surprise. The stack temperatures on the ore drop increased but not excessively.

Conclusion: It would take a more detailed computer analysis of the signal to detect the nature of the response of the hard stable blowing pattern. The response as could be assessed has no greater significance than a 5-10 cm lance height change, and a statistical investigation would be necessary to pin down results more accurately.

HEAT 61661

Description: Again "classical" positive traces are in evidence, but seiching and lance swinging does not obscure the detail. The lime (1 tonne) is dropped 2½ minutes before the end of the blow and ore (1½ tonnes) is dropped 1 minute later. The immediate response of the trace is to increase the span for the fluctuations, and subsequent response is obscured by lance height changes which are of 9 cm and 7 cm respectively. For these latter changes, the effects are immediate and clearer. The final temperature is low (1580 °C) and the phosphorus is too low (.010%), but not that much lower than expected for such a low final temperature.

Conclusion: The conclusion of the previous heat is reinforced in that the effects on the trace of late drops are no more significant than 5-10 cm lance height changes. A later ore/lime drop, with a low final temperature as here, appears to have some effect to reduce the phosphorus level.

HEAT 61689

Description: Here, with "classical positive traces", one tonne of lime is dropped 7 minutes before the end of the blow with perhaps a mild softening of the blow. Three minutes later, 1 tonne of ore is dropped with a distinct softening of the blow for 15 seconds, then a return to the previous hardness for 15 seconds, then a softening with slop of 4.5 severity. The signals are obscured by lance shorting.

Conclusion: The earlier lime/ore drop in the high decarburization part of the heat allows a build up of foam and slop.

HEAT 61690

Description: Again on classical positive traces, 1 tonne of ore is dropped 2½ minutes before the end of the heat. There is no late lime drop. If anything, the signal level increases and the blow hardens marginally. Again there is no guaranteed low phosphorus level since .037%is a little on the high side.

Conclusion: Here, without the lime, there is again no significant conclusion in favour of a late ore drop.

HEAT 61691

Description/Conclusion: Similar to previous heat.

HEAT 61692

Description: Here 2 tonnes of ore are dropped without lime two minutes before the end of the heat. There is an instant softening of the trace followed by a hardening before collapse. The temperature in the stack (324 °C) becomes close to its upper limit and the flame becomes brillant and intense white, but only a .03% phosphorus level follows.

Conclusion: It seems that 2 tonnes late drop is an upper limit.

HEAT 61693

Description: Here 1 tonne of each of lime and ore are simultaneously dropped 2 minutes before the end of the blow. The blow is relatively soft compared to other heats at this point. There is followed a hardening of the blow and an increase in signal strength until the next lance height change 1½ minutes later.

Conclusion: This trace more than any other pointed to a significant blow hardening from a lime/ore drop and an increase in signal strength for a minute or so. The drop occurred without any associated lance height change. The phosphorus level achieved is low at .014% but the temperature is also low at 1560 °C. From this trace, one could reasonably conjecture that the hardening of the blow and increase in ore level in the last few minutes cancelled each other out as far as dephosphorzation is concerned. Perhaps a better strategy is a late drop and similtaneously a larger lance height increase than otherwise planned.

HEAT 62027

Description: Here 1 tonne of ore, 1 tonne of lime and .200 FeSi is added 6½ minutes before the end of the blow. There is an instant softening followed by hardening to a negative trace also linked with oxygen surges.

HEAT 62028

Description: Here 1 tonne of lime is dropped 2 minutes before the end of the blow while the trace is switching between positive and negative. If anything, the trace softens during the drop then firms negative. This is a high carbon heat. The lime itself does not appear to bring the phosphorus level down, being .043%.

Conclusion: Again we infer that adding lime or ore should be compensated by raising the lance similtaneously, perhaps 10 cm or more in order that the lime have an effect. This should be tested further.

HEAT 62029

Description: Here with negative regimes established following positive ones, a 1 tonne lime drop (two minutes before the end of the blow) together with a simultaneous 80 cm lance height increase for 1 minute achieve a softening of the blow. Also in this, a high carbon heat, there is achieved a phosphorus level of .032%. There is a little subsequent slop.

Conclusion: This heat, although not well documented because the clamp is off inexplicably for 30 seconds after the drop, is a promising one. The strategy may well achieve low phosphorus levels in high carbon heats.

Section Conclusions: The addition of ore and lime in the last few minutes of the blow, in itself, is not an adequate phosphorus control device. For it to be effective it must be used with lance height increases possibly large ones (1 metre) of short duration (30-60 seconds). It is not clear that the late drops then enhance the effect of the lance changes or whether it is inconsequential. One suspects that there should be a contribution of the lime and ore but more studies are necessary to sort out the effect of the lance height changes and the late drops. The best approach on this appears to be to explore what can be achieved with lance height adjustments alone, and then assess the enchancement of the late drops.

The brillant white flame in the vessel after a 2 tonne late ore drop had less effect on the trace than a 10 cm lance height change suggesting that the lance signals are not influenced by the flame emerging from the slag.

2. Oxygen flow rate changes

HEAT 61638

Oxygen flow rate is increased from 510 cu.m/min to 550 cu.m/min for 20 seconds at 11 minutes before heat end. The classical positive trace shows a significant hardening indicated by a reduced span of high frequency intractions, although the trending increase in signal level is arrested. The effect dampens out before another 20 seconds is completed.

HEAT 61662

Here a 1 minute increase from 508 to 565 cu. m/min at 12½ minutes before blow end is seen to have a significant hardening effect on the positive trace. Three minutes later a reduction to 260 cu.m/min for 40 seconds gives a dramatic softening of the blow with a gradual rehardening as the flow is gradually increased back to 510 cu.m/min. No slopping occurred. Corresponding to the softening is an average signal level reduction.

HEAT 62007 (similar also to 62028)

An oxygen flow rate increase from 525 - 550 cu.m/min is introduced for 2 minutes during a hard negative trace. No increase in cross over temperature 300 °C is noted, only 3 sprays of 4 are on.

HEAT 62011

Here the effects of oxygen surges, not operator instigated, are seen on the trace. Cuts to zero are seen to reduce signal level to zero. This has been observed elsewhere also.

HEAT 61870, 61871, 61874

Here oxygen reductions applied early and late in the heat with predominantly negative traces can be studied. The late cut "enhances" the effect of a high blow two minutes before the end of the heat.

Conclusion:

1. Reductions and increases in oxygen flow rate are seen to have more effect on the positive traces earlier in the heat.
2. It appears that oxygen flow rate changes are equivalent to lance height changes as far as the trace is concerned. This is studied subsequently.
3. Oxygen flow rate is continously adjustable and as a control variable does not suffer the disadvantage of the lance height adjustment which causes the signal to dissappear during lance height changes. It seems reasonable to use oxygen flow rate more than at present in furnace control along with lance height changes to keep the average flow rate where desired.
4. The fact that the trace disappears with an oxygen cut indicates that the signal is reaction dependent, rather than simply a thermocouple effect involving the lance, slag, and vessel walls and shell.
5. Further stack temperature and spray observations should be made with oxygen flow rate increases throughout a heat in positive and negative regimes. Perhaps stack CO analysis is important do in conjunction with this so as to give a higher intensity blow when safe to do so. With higher oxygen flow rates, then higher lance heights can be used to achieve the same blow hardness, thus increasing heat time and reducing the probability of lance failure due to metallization, see also section 5.

3. Equivalence of lance heights and oxygen flow rate

HEAT 61834

A lance height reduction of 15 cm and flow rate decrease of 100 cu.m/min similtaneously applied are seen to have a cancelling effect, save that lance swinging is stopped. This confirms a conjecture developed during the trials earlier. This conjecture could well be explored further.

4. High blowing towards the end of a heat

HEAT 61637

Here with classical positive traces, the lance is raised 1 meter for 25 seconds three minutes before the end of the blow. Some slop followed. The high blow comes after lifting of lance from 178 cm to 193cm one minute earlier. The intention was for the high blow to be later in the blow. This incident led to improved high blow practice in later tests, setting a boundary for more reasonable lance practice in which only the one lance raising occurs for 30 seconds to 1 minute at about 2 minutes before the end of the blow.

HEAT 61872 → 5

Illustrates practice of blowing hard early to achieve negative traces, then raising lance 1 meter for 30 seconds or so 2 minutes before the end of the heat. Desired phosphorus levels are achieved with no slopping and a stable blow. These are low carbon heats.

HEAT 62028

Another "boundary" in lance practice is defined with this high carbon heat. With hard blowing up to $1\frac{3}{4}$ minutes before the end of the heat, the lance is raised only ½ meter for 1 minute and subsequently another 30 cm for the remaining time. The phosphorus level is too high.

HEAT 62029

A similar high carbon heat to the one above, an improved lance practice is to raise the lance 80 cm 2 minutes before the end, then lower 50 cm, with a 10 second high blow at the end. This heat also had a 1 tonne line drop 2 minutes before the end and achieved a reasonable phosphorus level of .032%.

HEAT 62011

Here an operator absence meant that the lance was raised 73 cm for 3 minutes before the end from a hard blowing negative trace. There was no subsequent slop, which is interesting.

Conclusion: The above lance practice controlled by lance signals is simple to implement and appears effective. It is justified by present understanding of what is happening inside the B.O.S. and could be improved further. In particular, it is not known for certain whether the negative trace route to the latter part of the blow can be garanteed by early lance practice or infact how much better it is than alternative routes.

5. Miscellaneous results

HEAT 61635, 61689

Simple experiments involving rocking of the vessel during a heat are carried out. No adverse effects are observed when rocking at 5 or so times a minute is implemented. Perhaps a softening of the blow is achieved, although the objective is simply to stir the melt more when scrap is present.

HEAT 61873

A low lance height early in the blow and 410 cu.m/min oxygen flow rate caused metallization on the lance. The flow rate was cut early to slow slight slopping and a subsequent lance decrease (operator initiated) has no apparent positive effect but probably caused the metallization.

HEAT 61875

A high blow (1 metre raise) midway in the heat while with a negative trace produced a hissing sound indicating a low slag level. The negative signal is restored on return.

HEAT 62025

A negative trace developes 10 minutes before the end and is unaffected by a 30 cm lance height increase 2 minutes before the end for at least 1 minute. This indicates the high degree of stability of this regime.

HEAT 62027

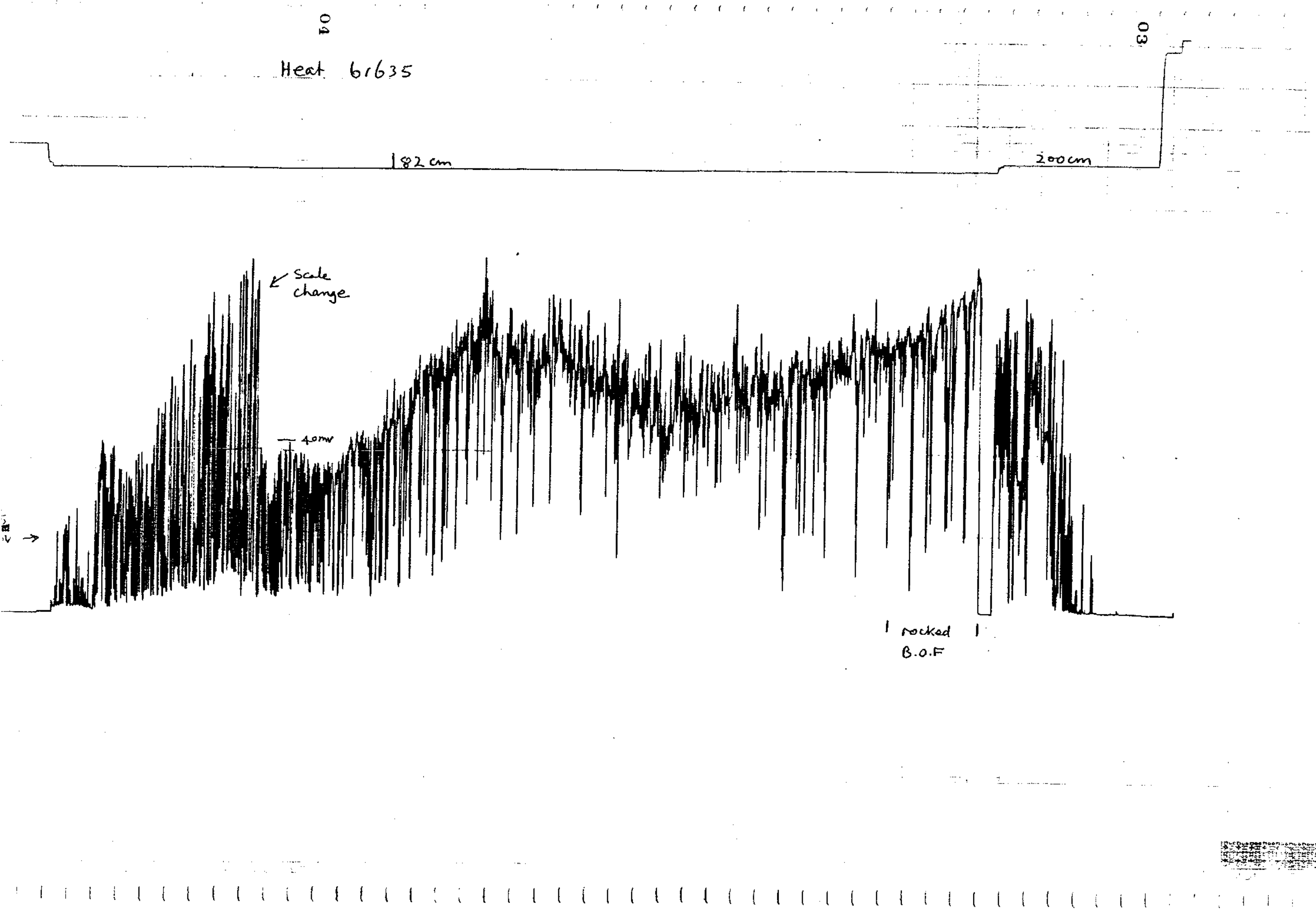
A reblow here with no additions and a low lance produces a negative signal for over one minute, indicating that the negative signal exists with little or no slag contact with the lance.

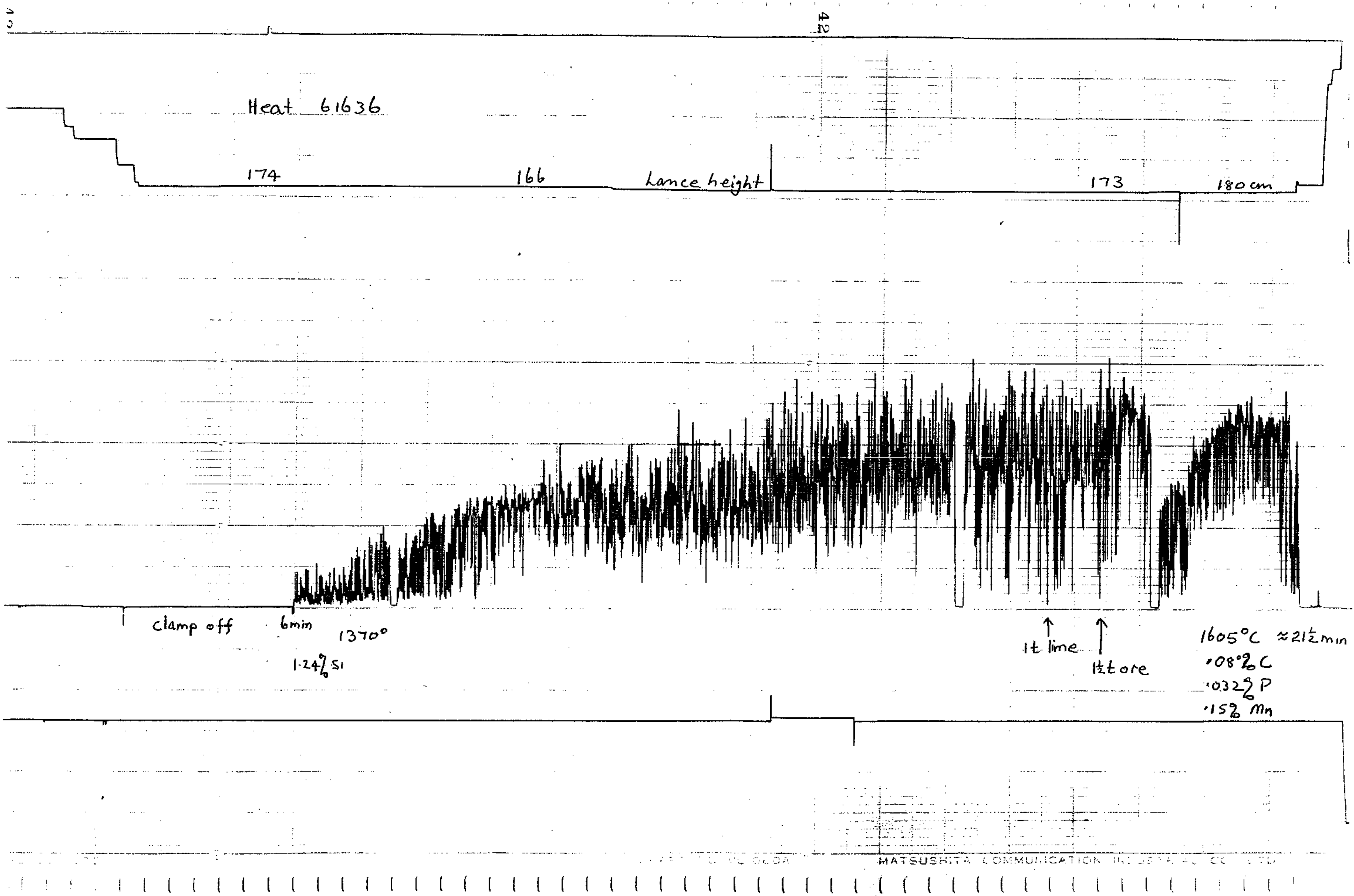
Overall Conclusions:

1. More information is now available on the response of B.O.S. controls on the lance signals, which can be interpreted in terms of a reasonably consistent theory.
2. A specific control strategy evolved using lance trace feedback control. This strategy aimed at eliminating slop, speeding up the heat, meeting phosphorus specifications, reducing lining wear and increasing lance life.
3. When the lance current signals are enriched in the near future using load resistor switching, it is thought that improved end-point predictions can be achieved, along with improved control in the first third of the heat.

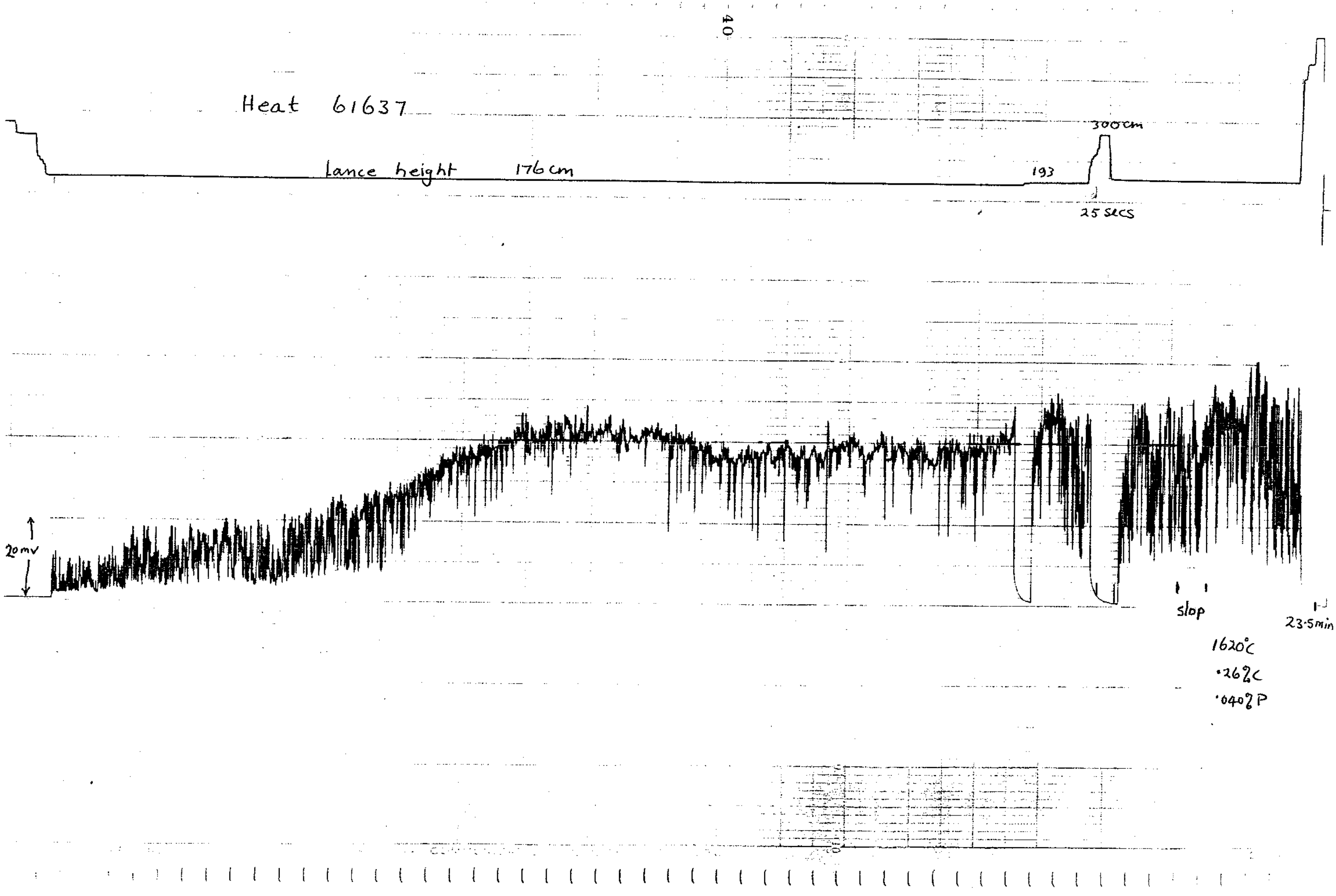
Acknowledgement

The author wishes to acknowledge the direct help, suggestions and experience of John Mathieson, Gary Kemlo and Steve Tucker in carrying out the work of this report.

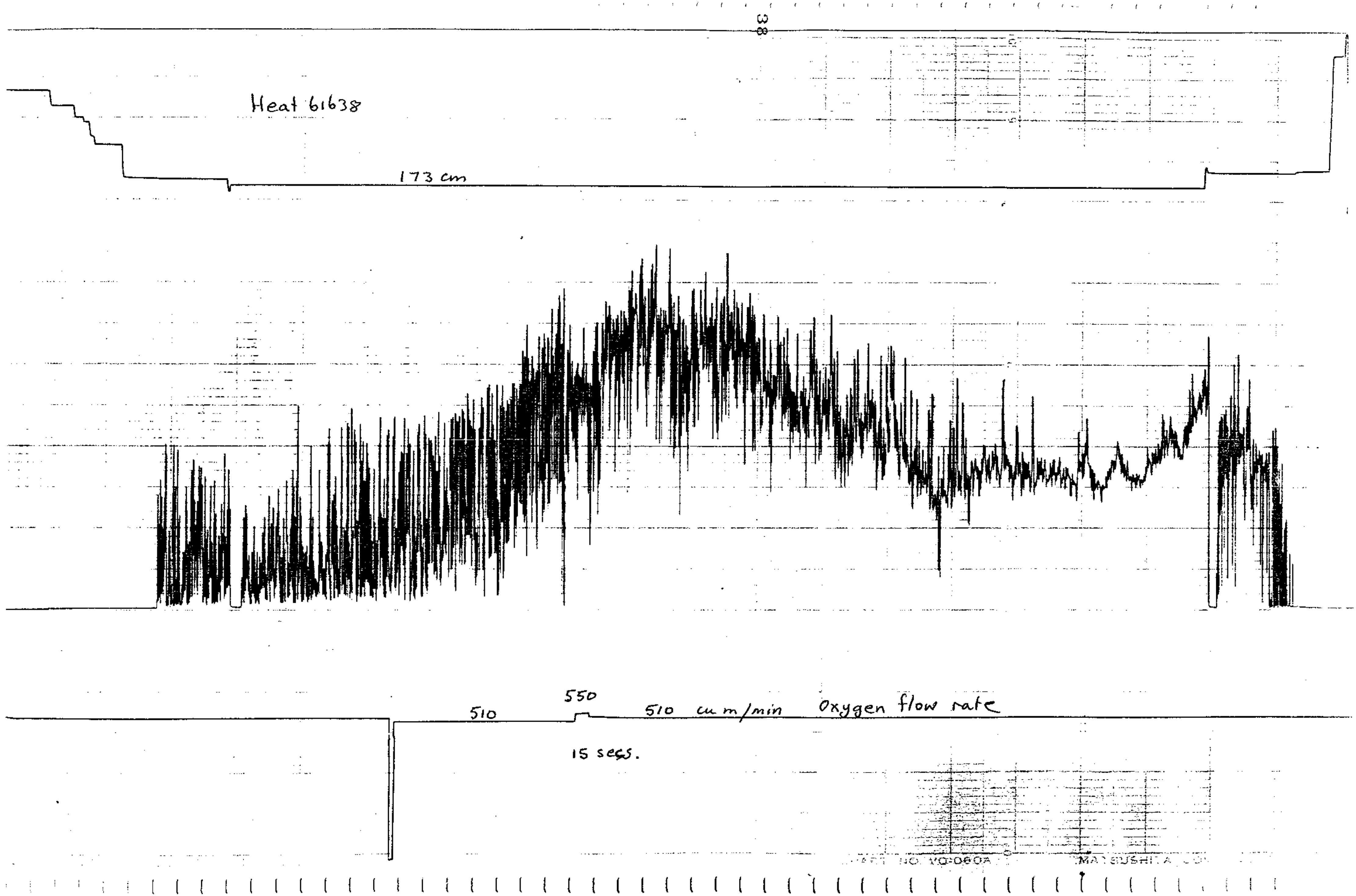

04
03
Heat 61635
182 cm
200cm
Scale change
40mv
rocked B.O.F

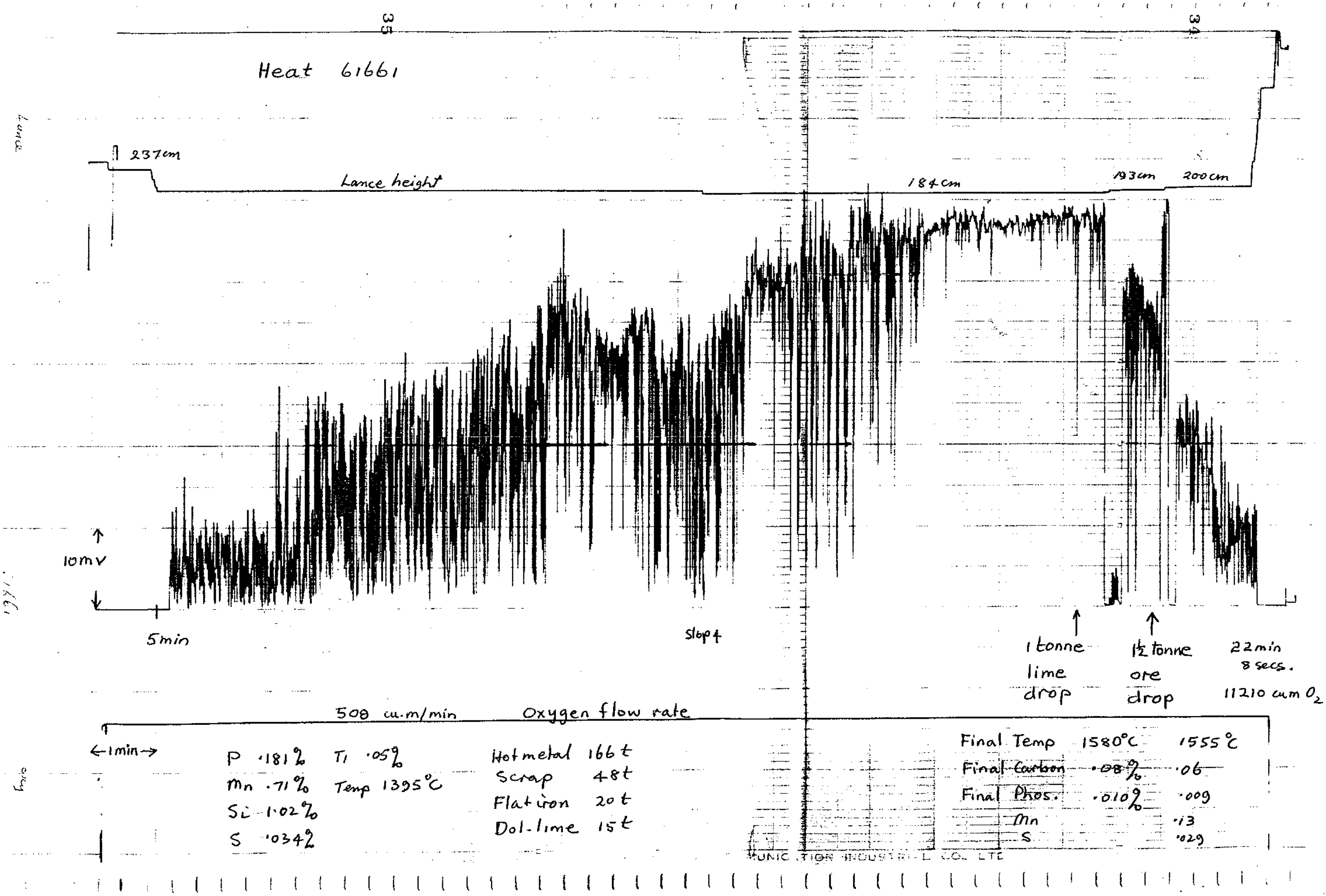


42
Heat 61636
174
166
Lance height
173
180 cm
clamp off
6 min
1370°
1.24% Si
1t lime
1½t ore
1605°C ≈21½ min
.08% C
.032% P
.15% Mn
MATSUSHITA COMMUNICATION INDUSTRIAL CO LTD

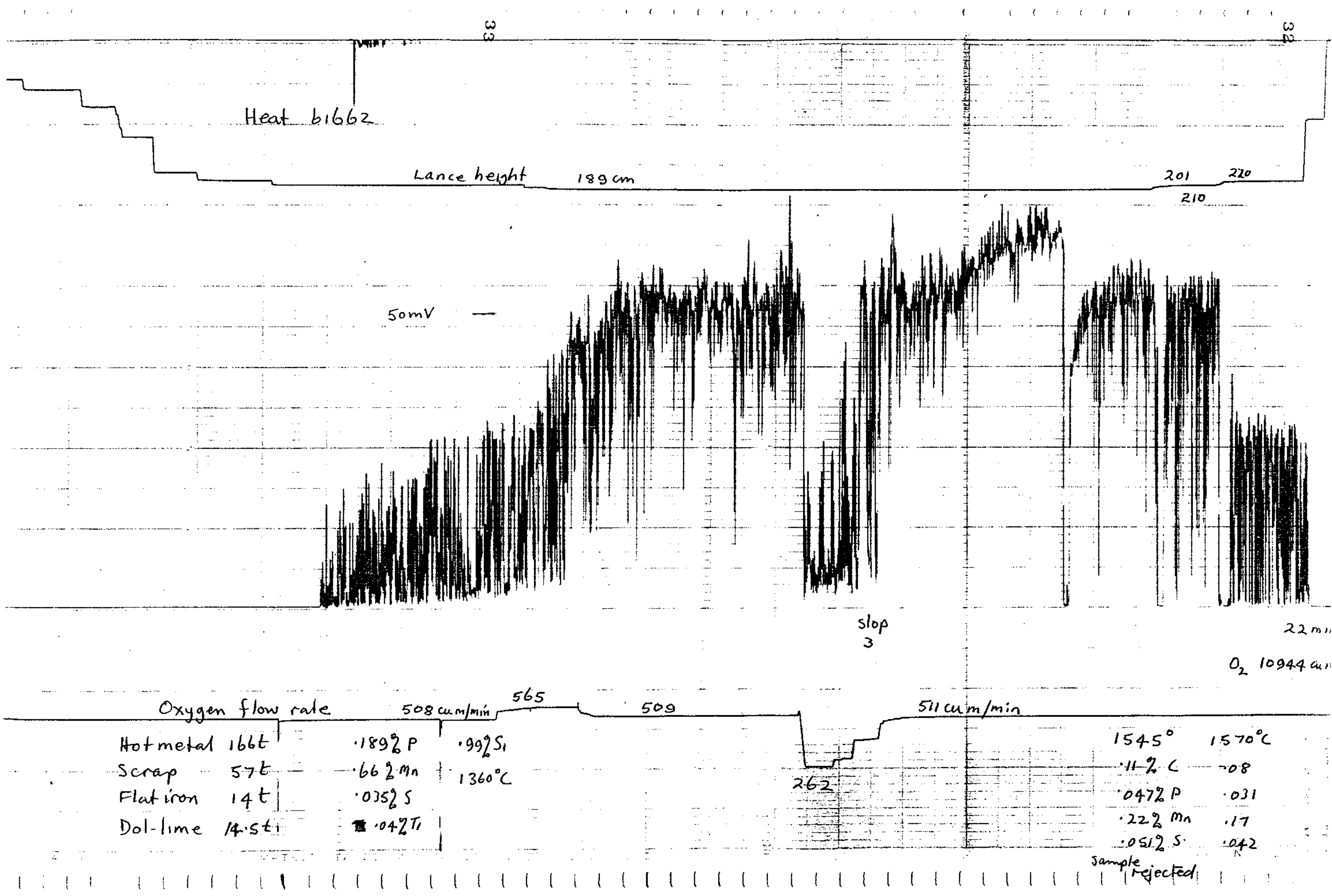


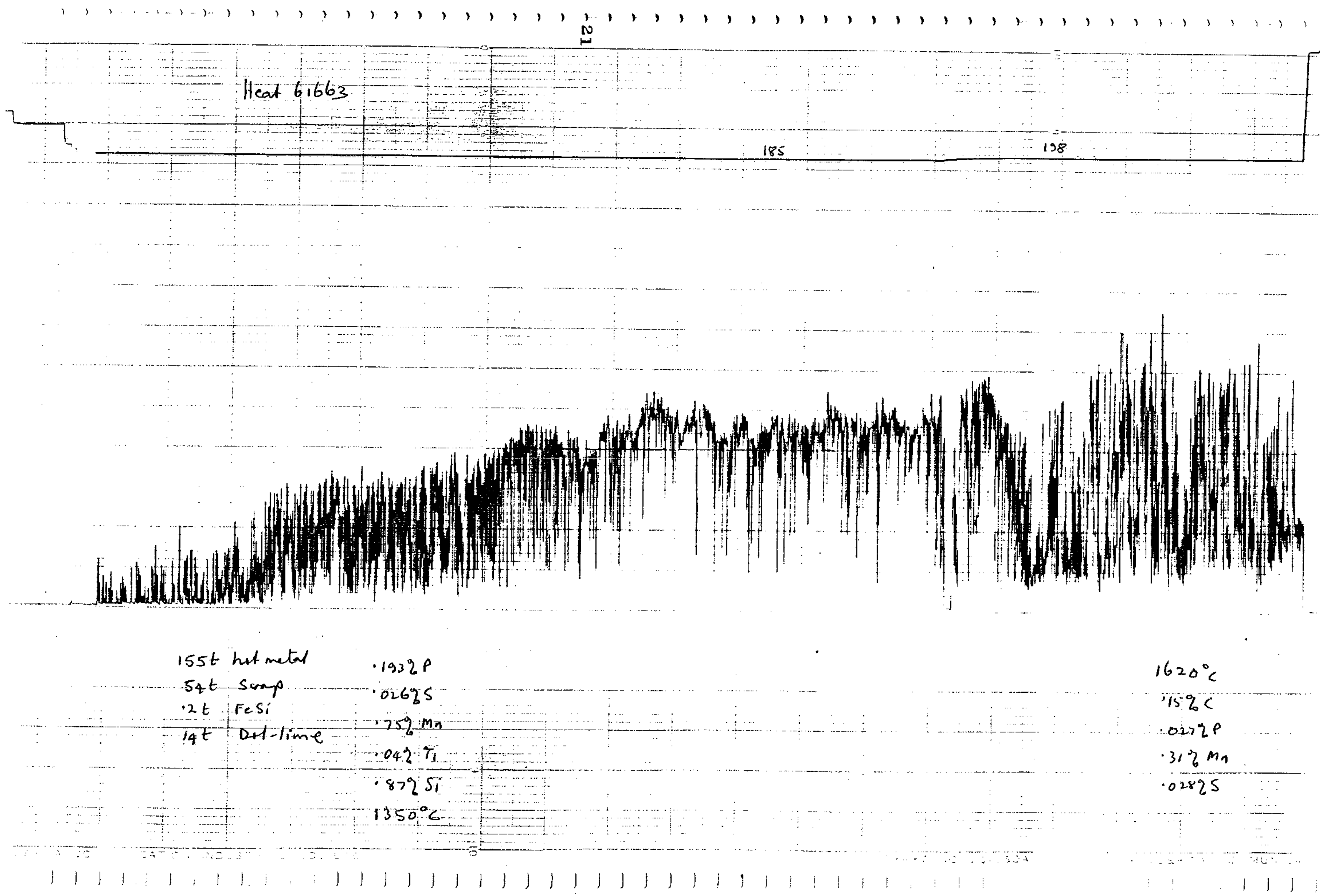
40
Heat 61637
lance height 176 cm
193
300 cm
25 secs
20mv
slop
23·5min
1620°C
·26%C
·040%P

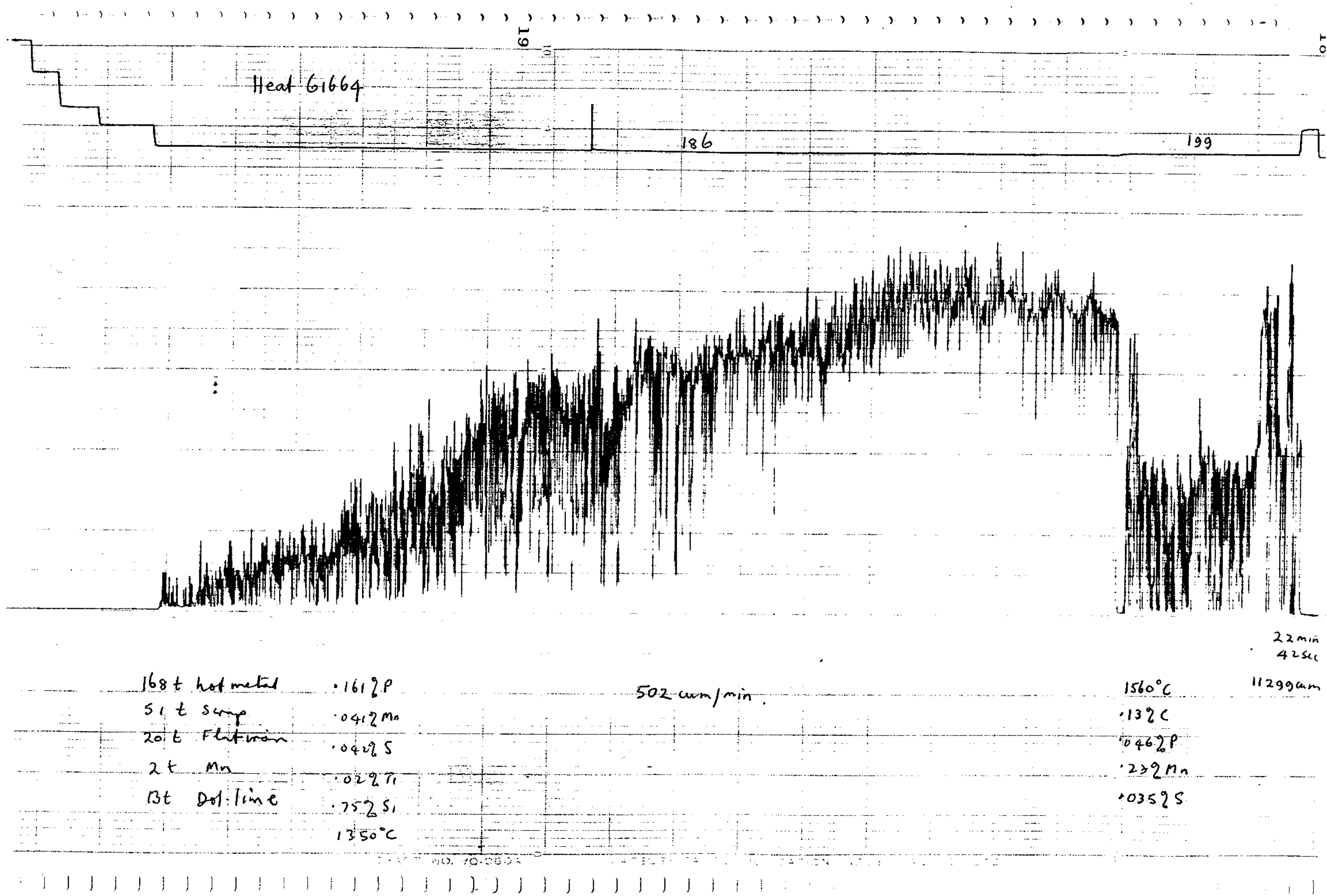

38
Heat 61638
173 cm
510
550
510 cu m/min Oxygen flow rate
15 secs.

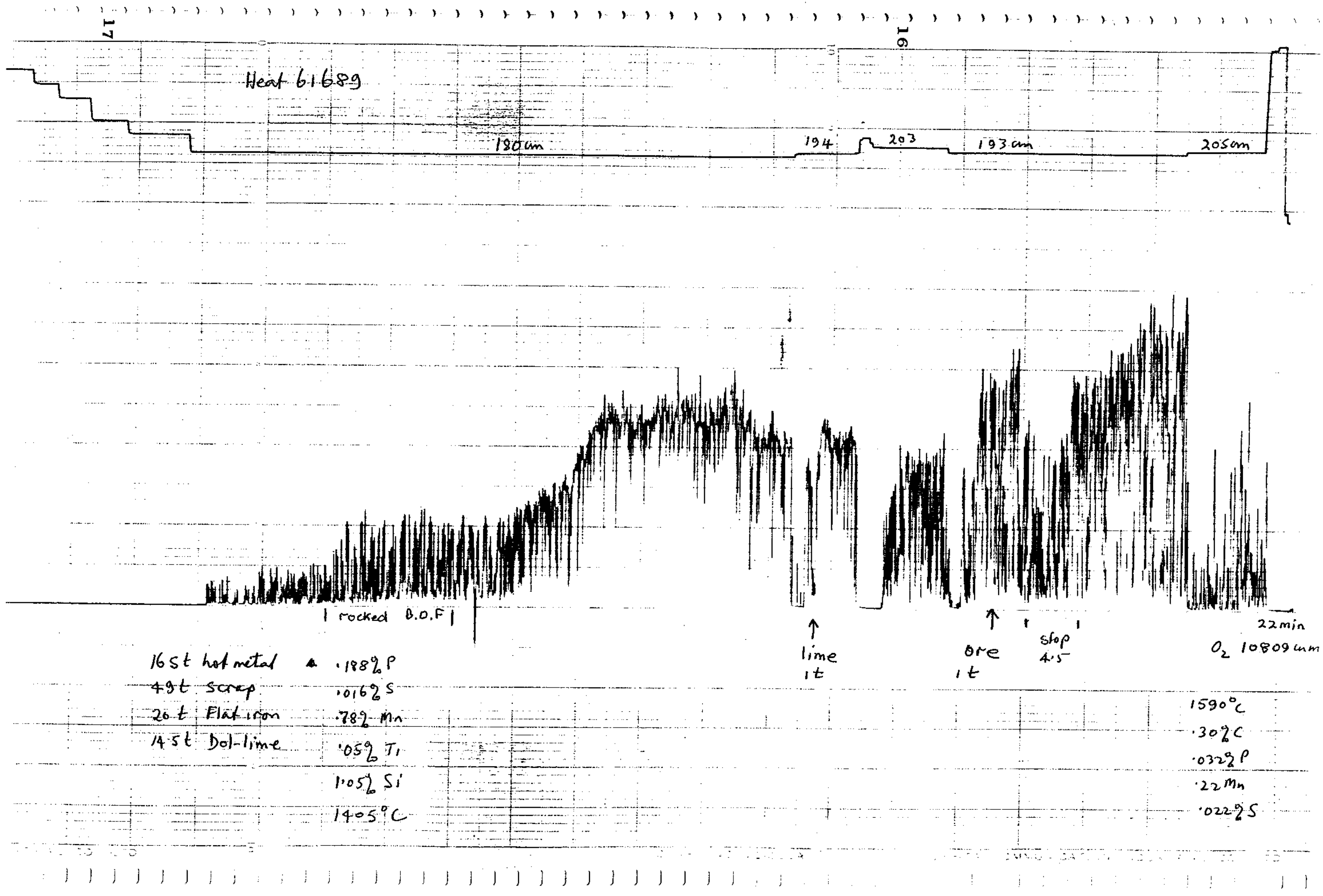


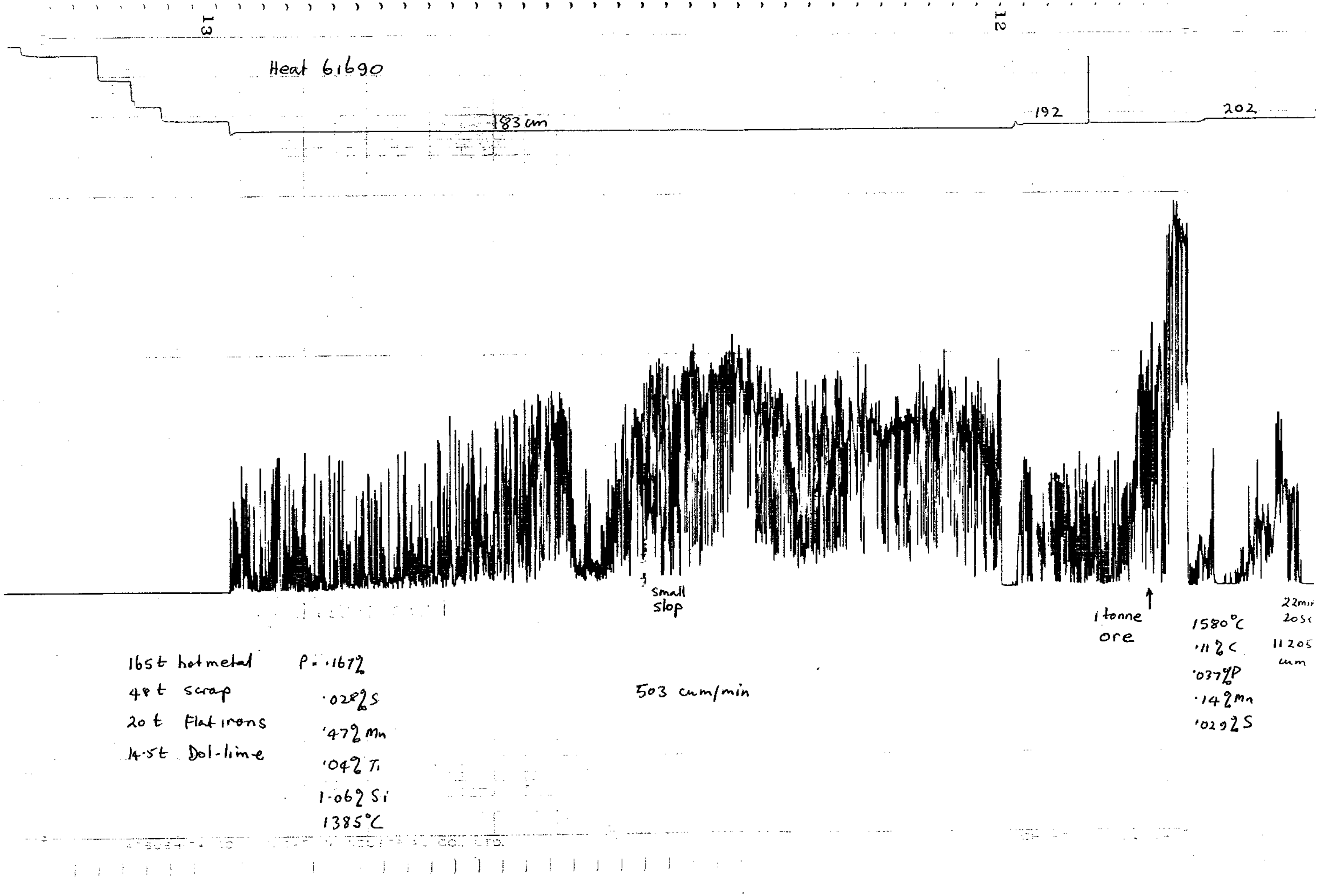
35
34
Heat 61661
237cm
Lance height
184cm
193cm
200cm
10mV
5min
Slop4
1 tonne lime drop
1½ tonne ore drop
22min 8 secs.
11210 cu m O_2
500 cu.m/min
Oxygen flow rate
←1min→
P ·181%
Mn ·71%
Si 1·02%
S ·034%
Ti ·05%
Temp 1395°C
Hot metal 166t
Scrap 48t
Flat iron 20t
Dol-lime 15t
Final Temp 1580°C 1555°C
Final Carbon ·08% ·06
Final Phos. ·010% ·009
Mn ·13
S ·029


33
32
Heat 61662
Lance height 189 cm
201
220
210
50mV
slop
3
22 min
O_2 10944 cum
Oxygen flow rate
508 cum/min
565
509
511 cum/min
262
Hot metal 166t
Scrap 57t
Flat iron 14t
Dol-lime 14.5t
·189% P
·66% Mn
·035% S
·04% Ti
·99% Si
1360°C
1545°
·11% C
·047% P
·22% Mn
·051% S
1570°C
·08
·031
·17
·042
Sample rejected

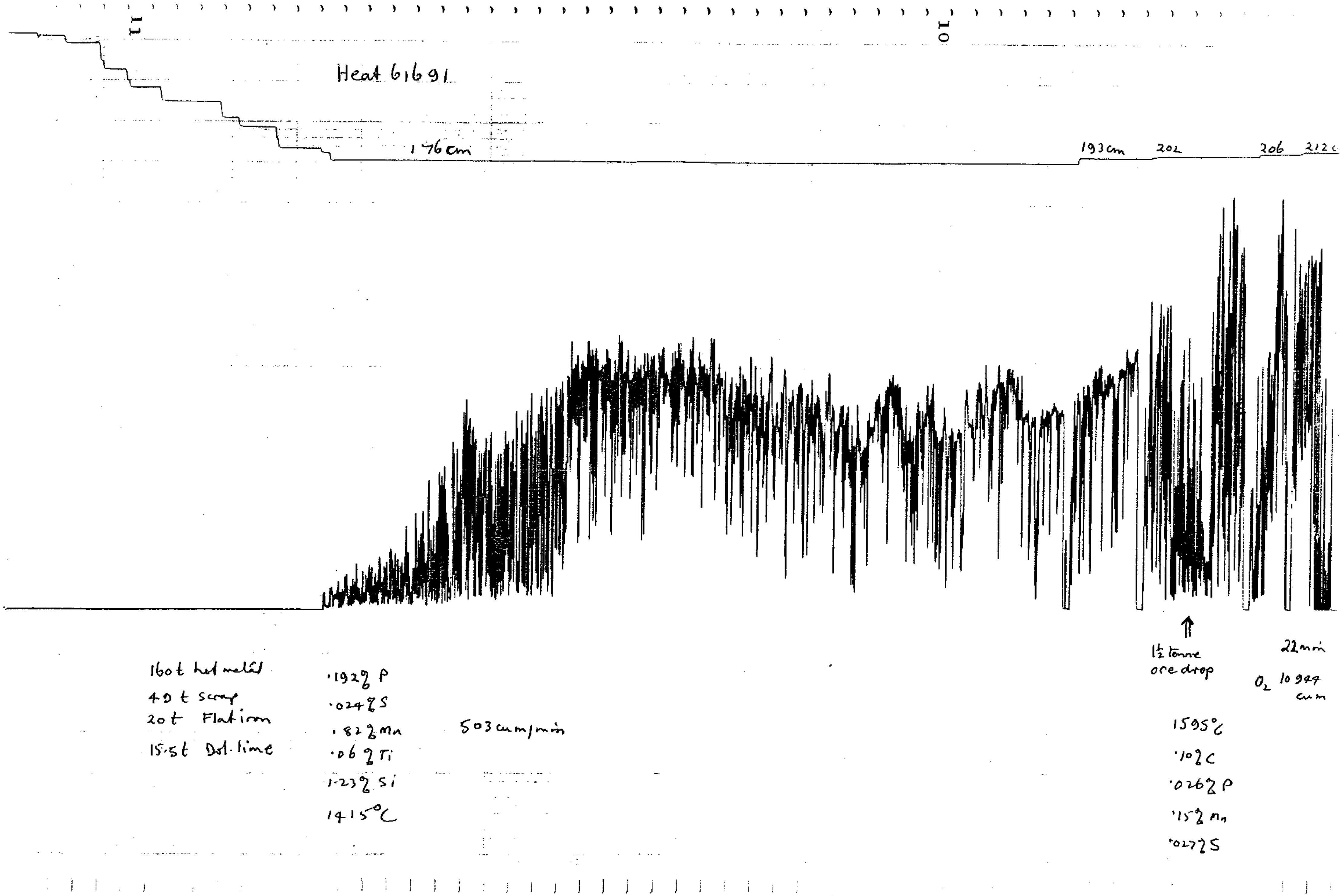

21
Heat 61663
185
198
155t hot metal
54t Scrap
·2t FeSi
14t Dol-lime
·193% P
·026% S
·75% Mn
·04% Ti
·87% Si
1350°C
1620°C
·15% C
·027% P
·31% Mn
·028% S


19
18
Heat 61664
186
199
22 min 42 sec
1129 gum
168 t hot metal
51 t scrap
20 t Flotiron
2 t Mn
13 t Dol. lime
.161 % P
.041 % Mn
.042 % S
.02 % Ti
.75 % Si
1350°C
502 cum/min.
1560°C
.13 % C
.046 % P
.23 % Mn
.035 % S

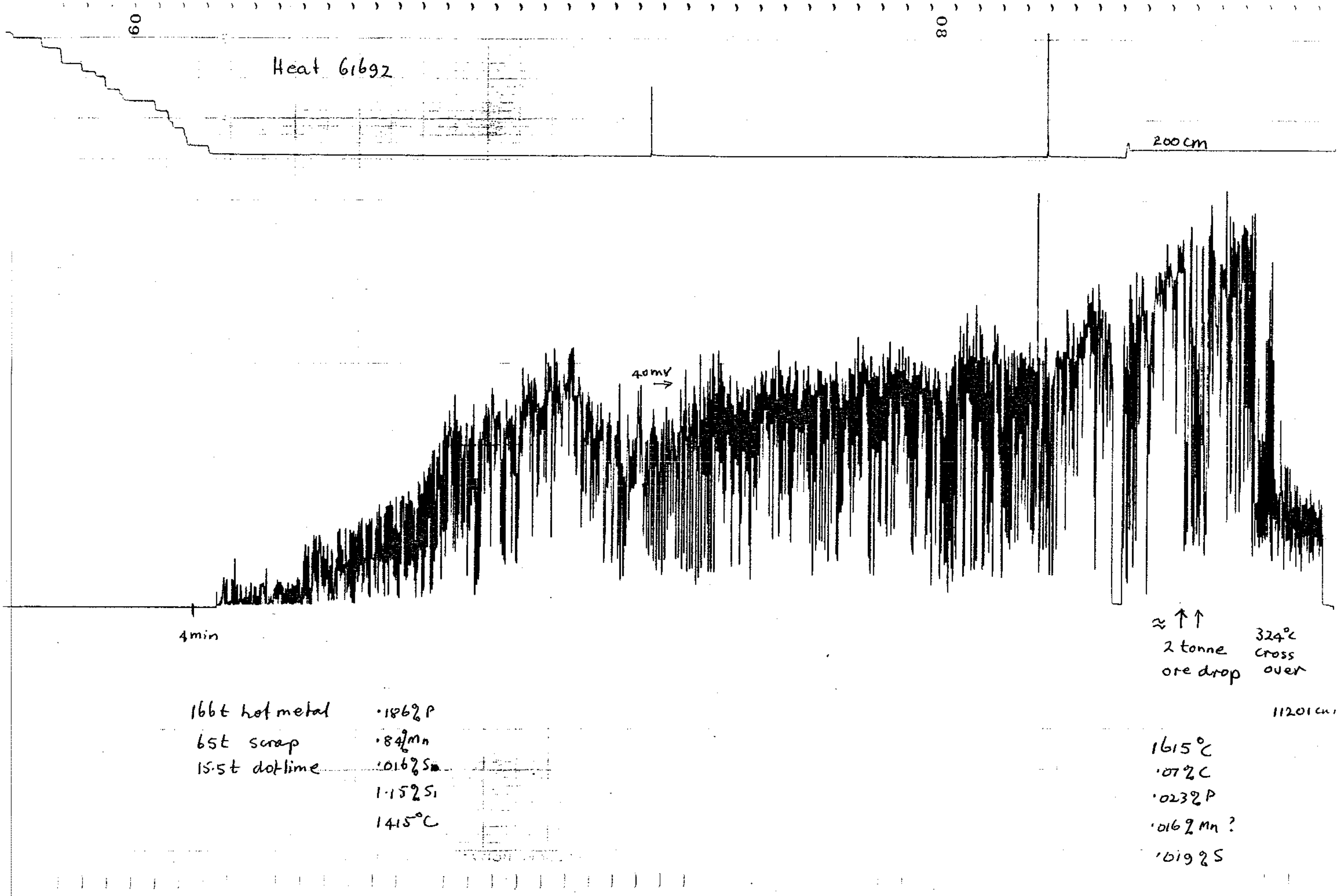

17
16
Heat 61689
180cm
194
203
193cm
205cm
| rocked B.O.F |
lime 1t
ore 1t
stop 4.5
22min
O2 10809 cum
16st hot metal
49t scrap
26t Flat iron
14.5t Dol-lime
·188% P
·016% S
·78% Mn
·05% Ti
1·05% Si
1405°C
1590°C
·30% C
·032% P
·22 Mn
·022% S

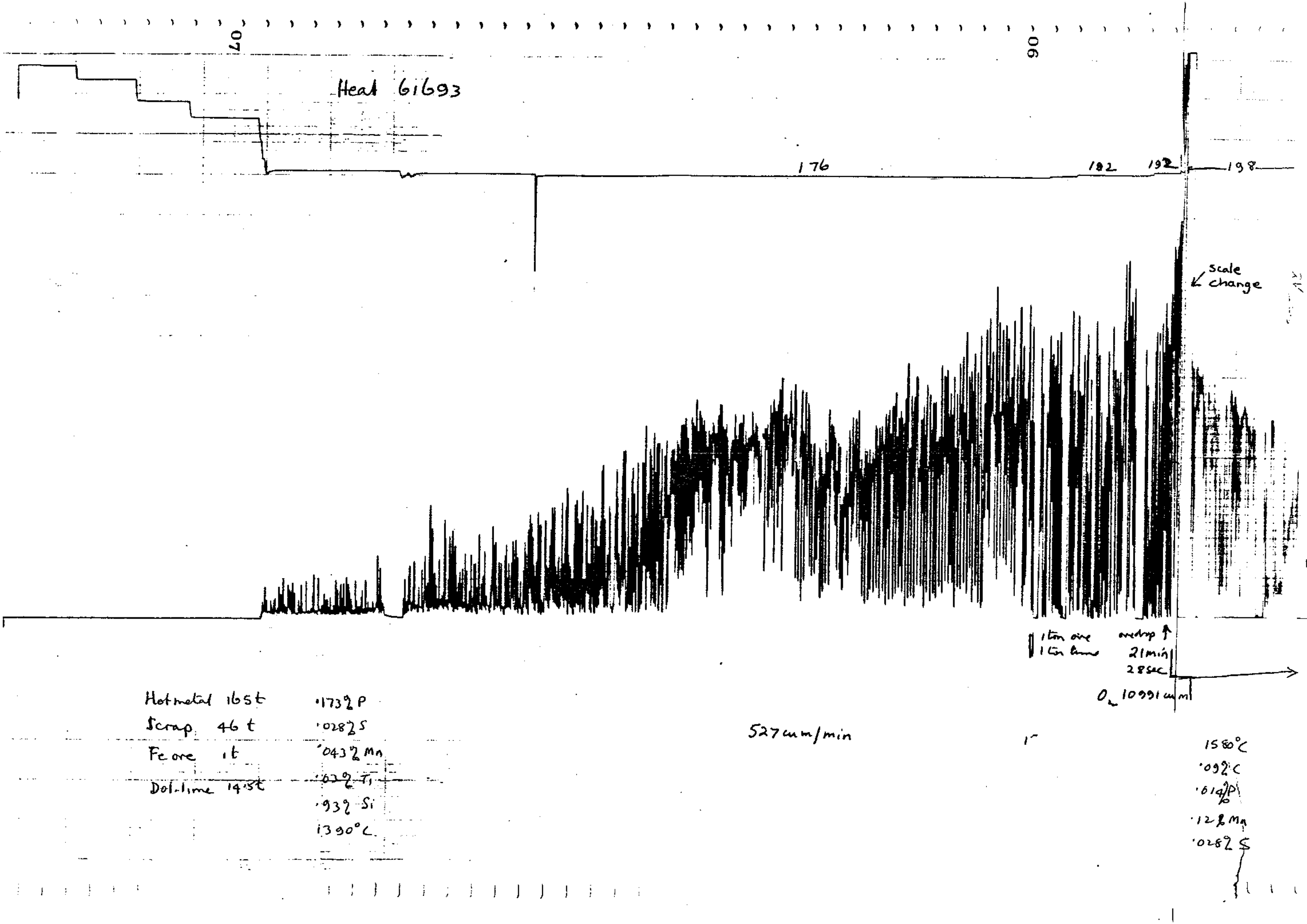


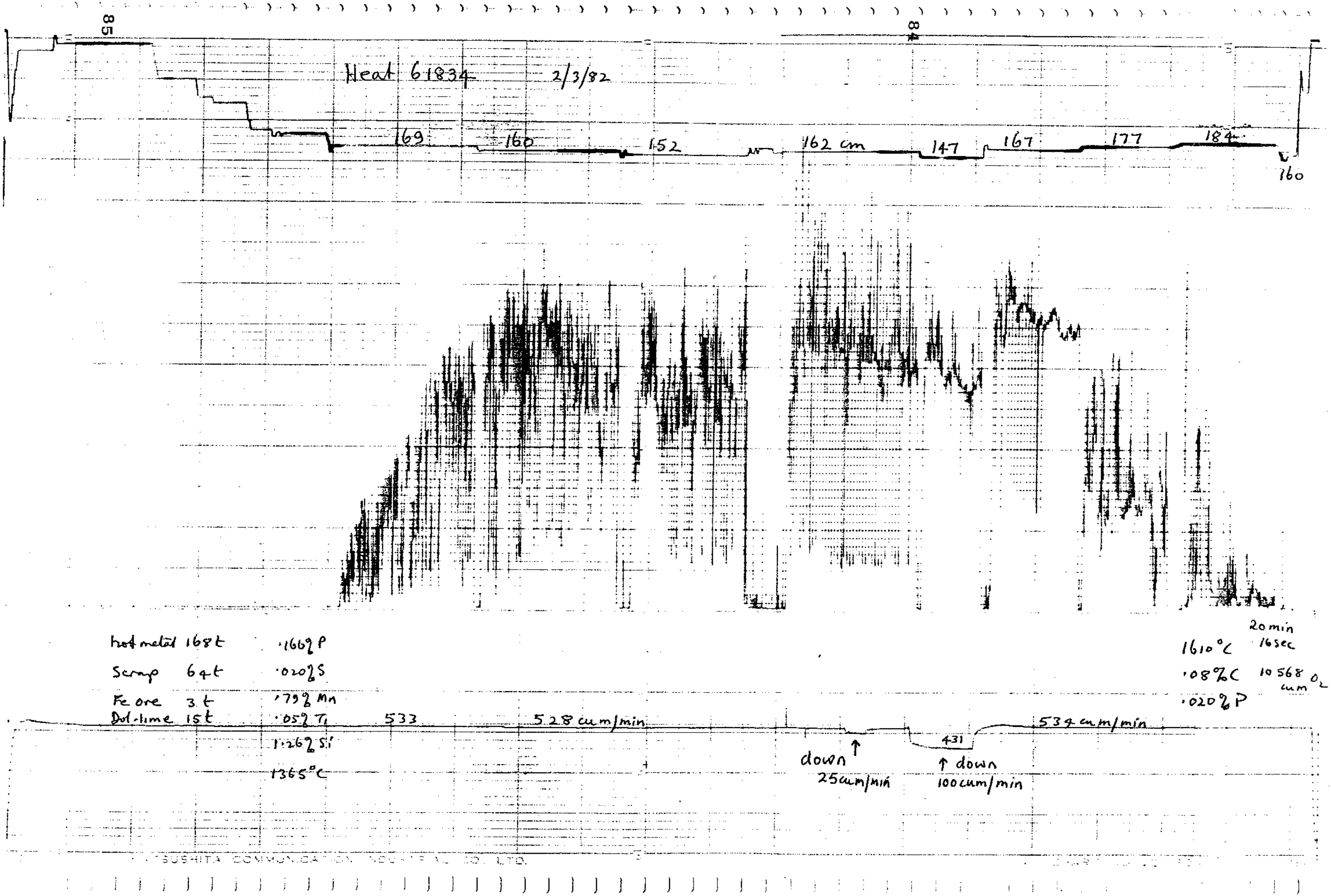
13
12
Heat 61690
183 cm
192
202
small slop
1 tonne ore
22 min 20 sec
11205 cum
1580°C
·11 % C
·037 % P
·14 % Mn
·029 % S
165 t hot metal
48 t scrap
20 t Flat irons
14·5 t Dol-lime
P = ·167 %
·028 % S
·47 % Mn
·04 % Ti
1·06 % Si
1385°C
503 cum/min



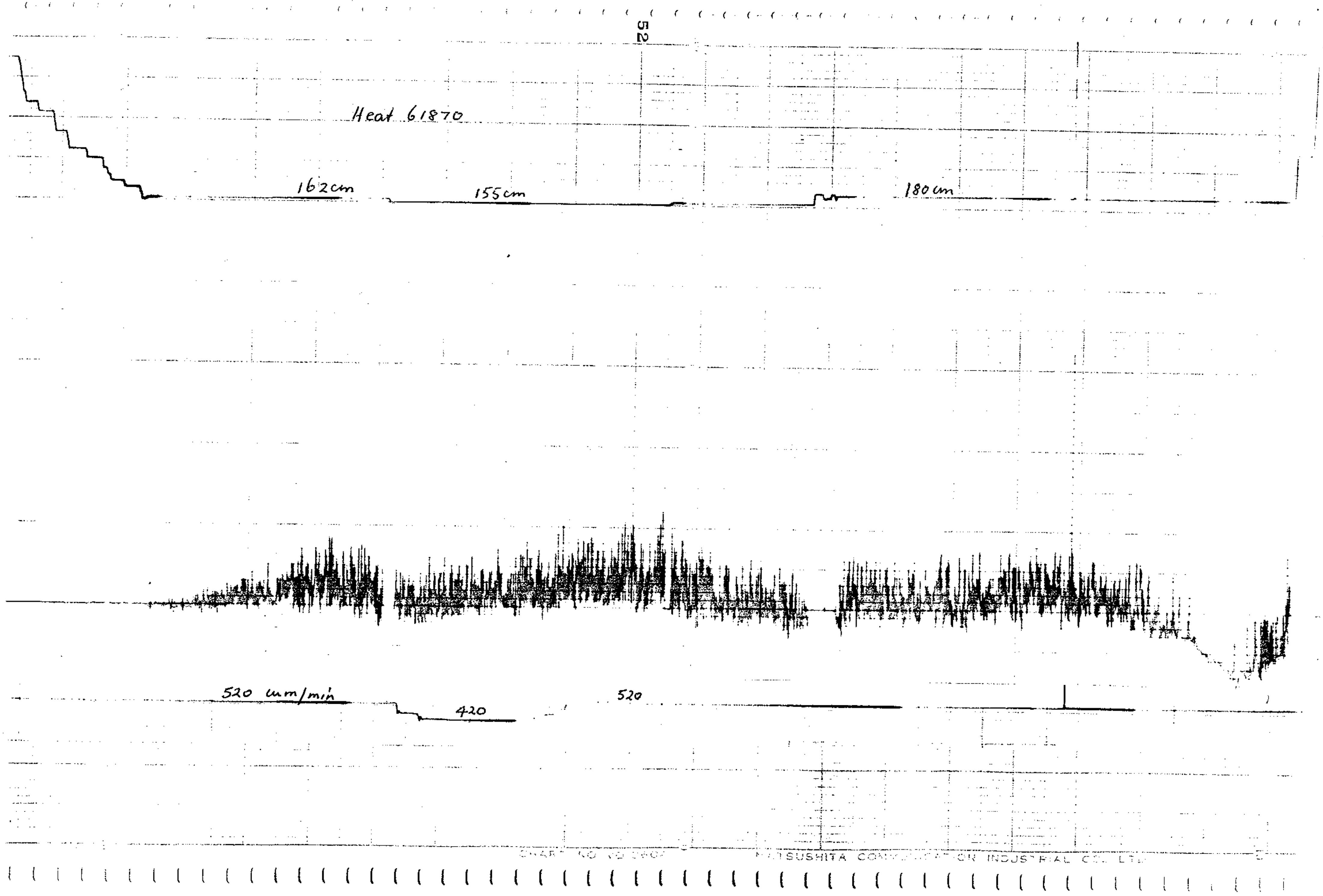
11
10
Heat 61691
176cm
193cm
202
206
212c
160t hot metal
40t scrap
20t Flatiron
15.5t Dol. lime
·192% P
·024% S
·82% Mn
·06% Ti
1·23% Si
1415°C
503 cum/min
1½ tonne ore drop
22 min
O_2 10 947 cum
1595°C
·10% C
·026% P
·15% Mn
·027% S

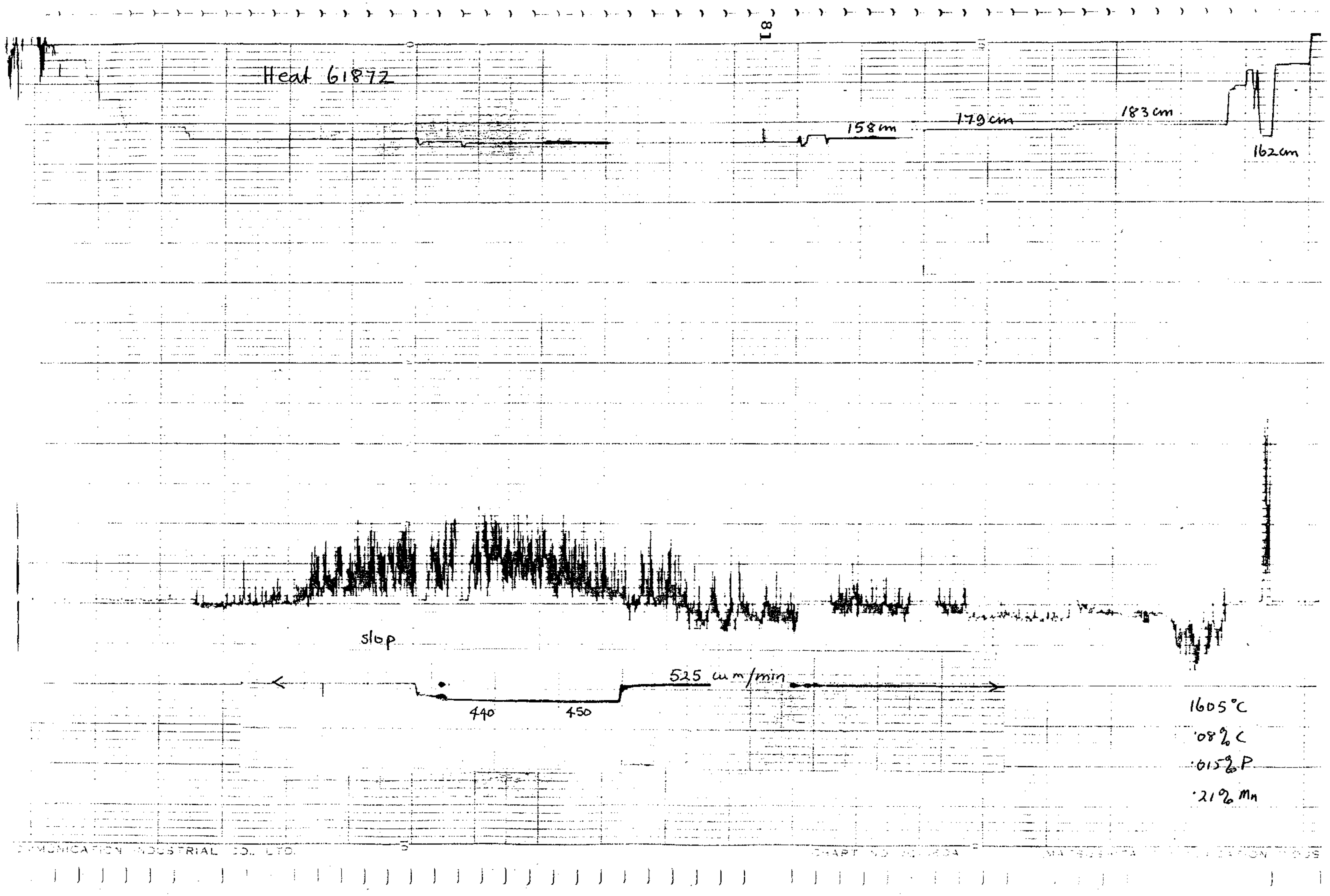

60
80
Heat 61692
200cm
40mV
4min
≈ ↑↑
2 tonne
ore drop
324°C
cross
over
166t hot metal
65t scrap
15.5t dolime
·186%P
·84%Mn
·016%S
1·15%Si
1415°C
1615°C
·07%C
·023%P
·016%Mn ?
·019%S


Heat 61693
07
06
176
182
192
198
scale change
1 ton ore
1 ton lime
overdrop
21 min
28 sec
0
10991 mm
527 mm/min
Hot metal 165 t
Scrap 46 t
Fe ore 1 t
Dol-lime 14.5 t
·173% P
·028% S
·043% Mn
·02% Ti
·93% Si
1390°C
1580°C
·09% C
·014% P
·12% Mn
·028% S

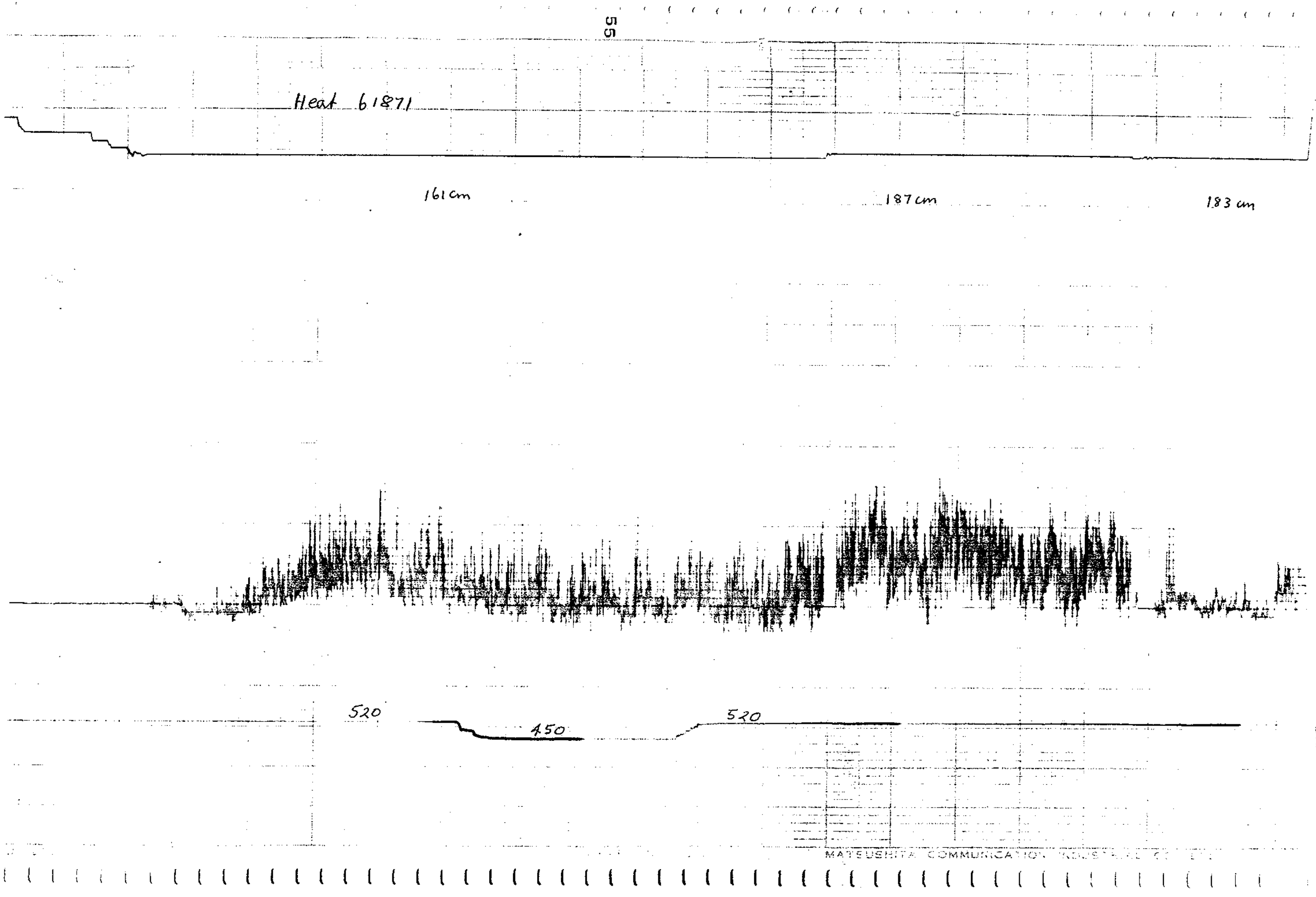


85
84
Heat 61834
2/3/82
169
160
152
162 cm
147
167
177
184
160
hot metal 168t
Scrap 64t
Fe ore 3t
Dol-lime 15t
.166% P
.020% S
.79% Mn
.05% Ti
1.26% Si
1365°C
533
528 cum/min
down ↑
25cum/min
431
↑ down
100cum/min
534 cum/min
20min 16sec
1610°C
.08% C
.020% P
10568 cum O_2


52
Heat 61870
162cm
155cm
180cm
520 um/min
420
520



Heat 61872
81
158 cm
179 cm
183 cm
162 cm
slop
525 cm/min
440
450
1605°C
·08% C
·015% P
·21% Mn


55
Heat 61871
161cm
187cm
183 cm
520
450
520
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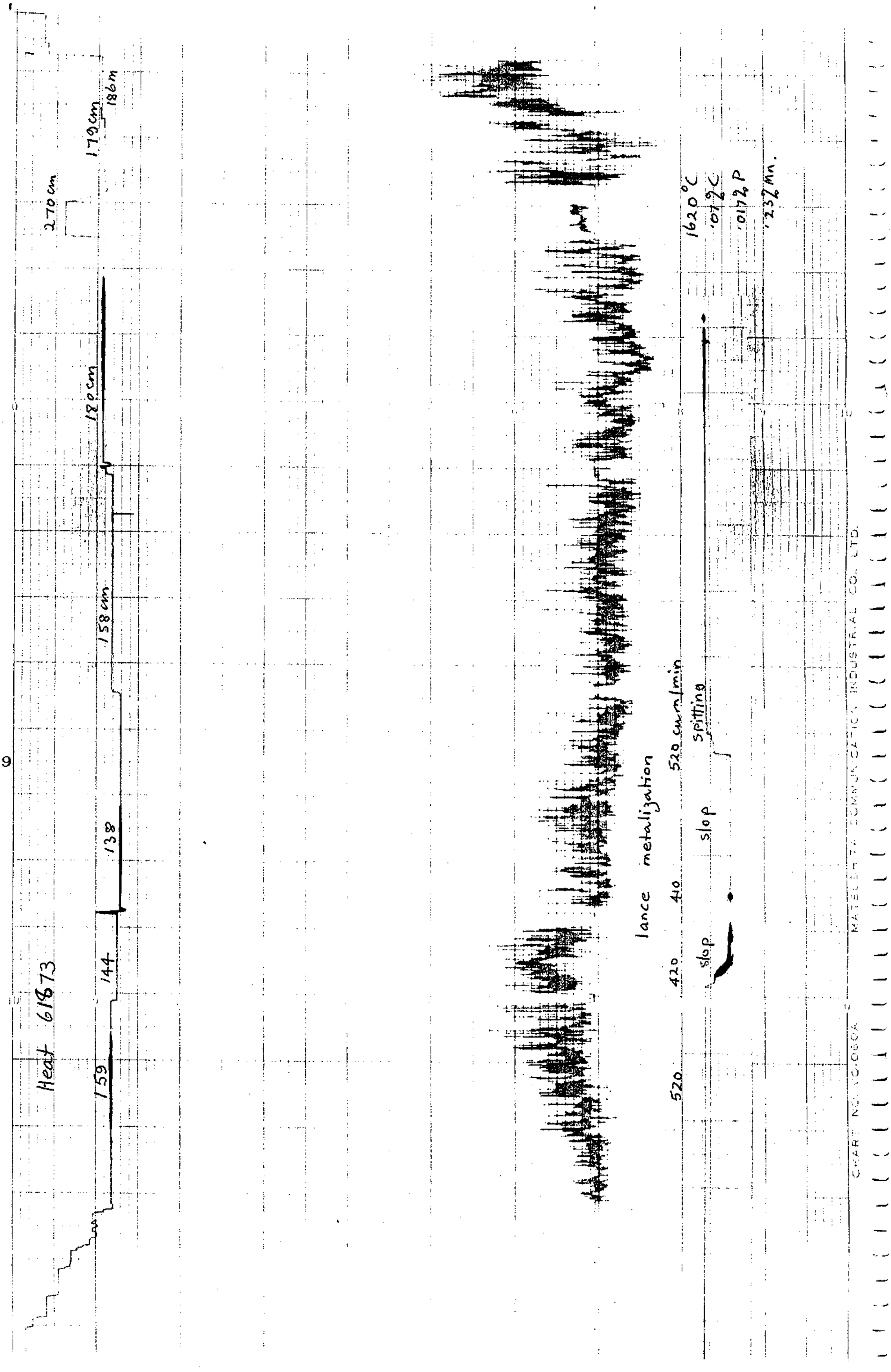
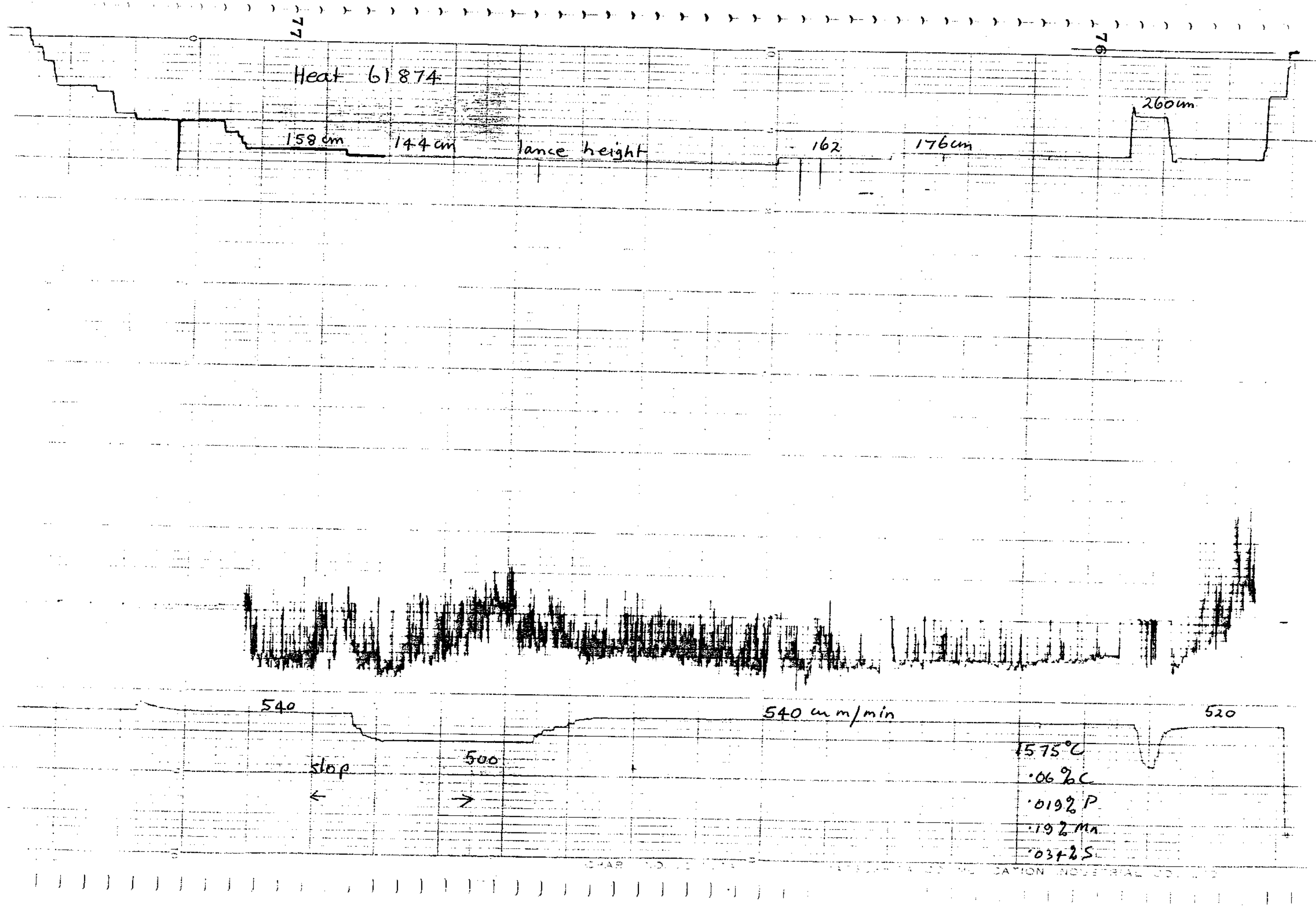
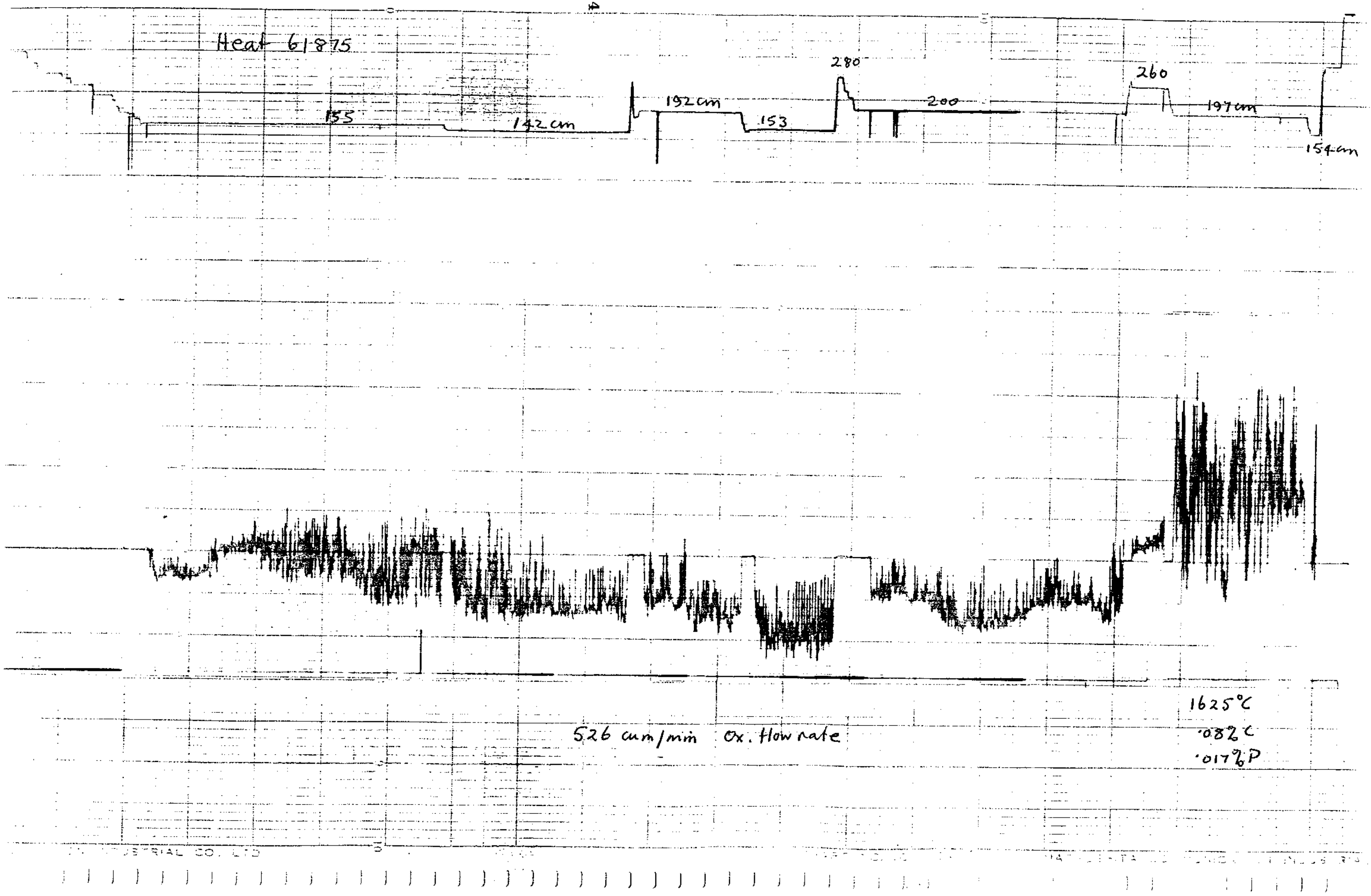
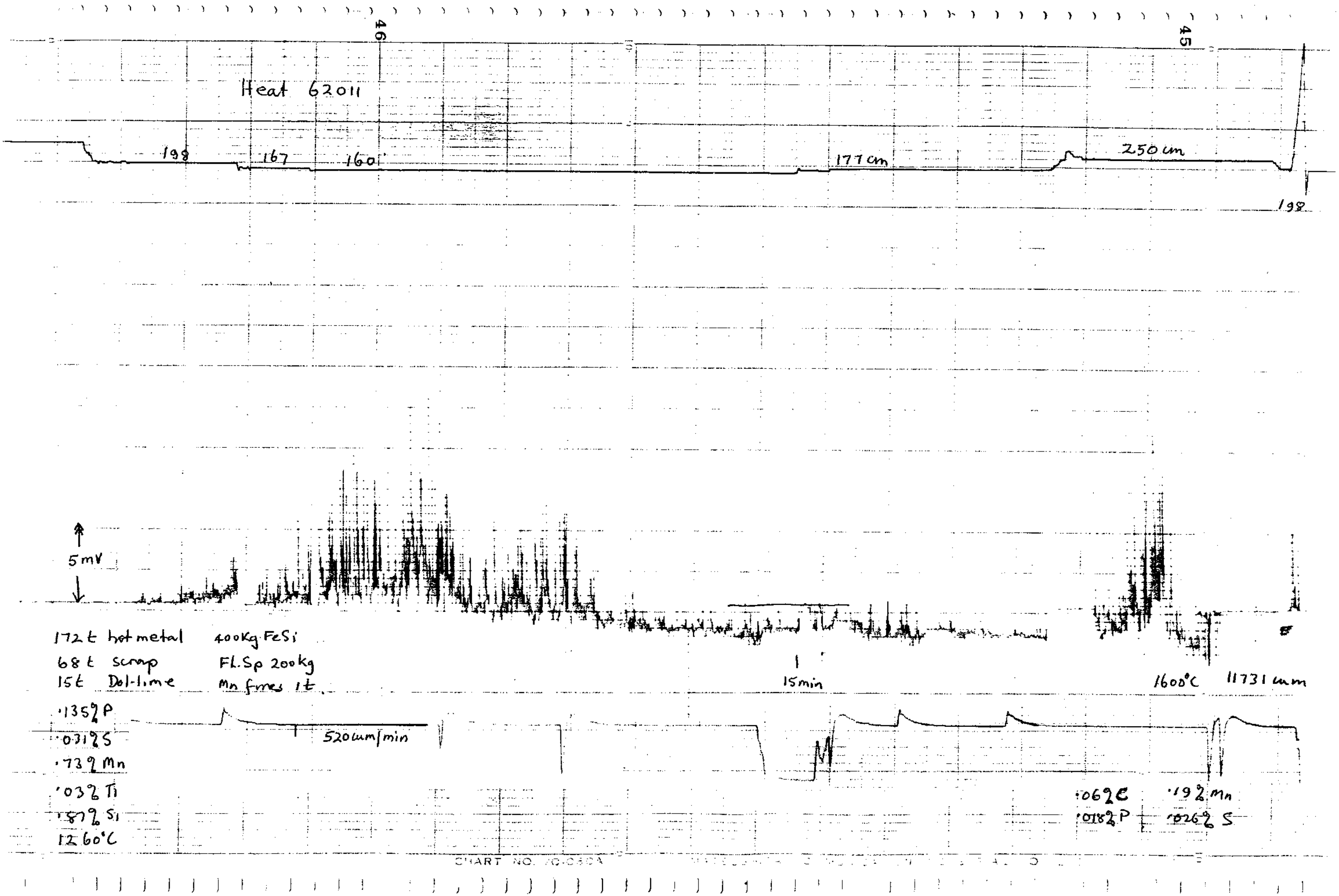

Heat 61673
270 cm
170 cm
186m
180cm
158 cm
138
144
159
lance metalization
520
420
410
520 cu m/min
slop
slop
spitting
1620°C
.07%C
.017%P
.23% Mn.
CHART NO. 10-0604
MATSUSHITA COMMUNICATION INDUSTRIAL CO. LTD.

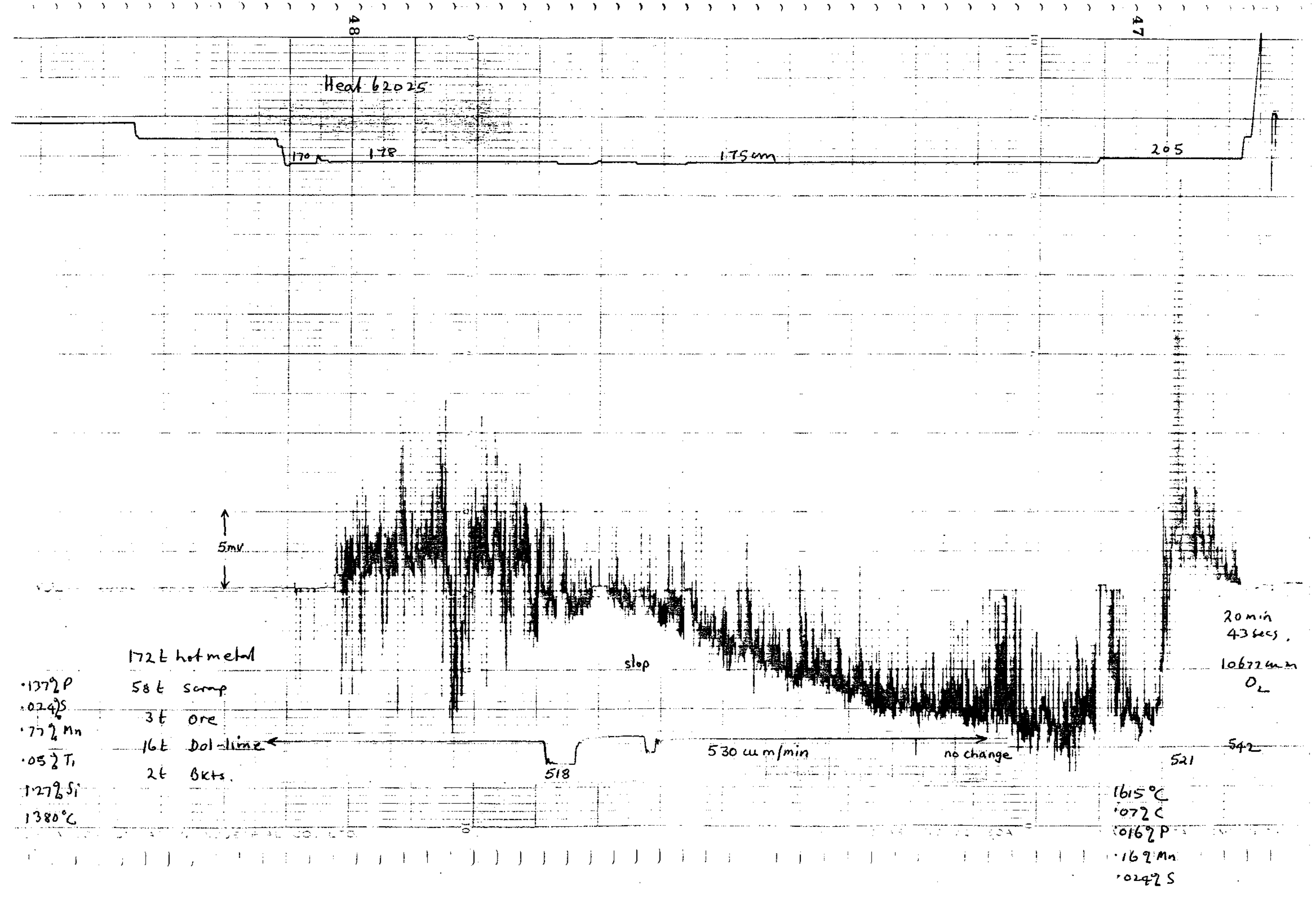


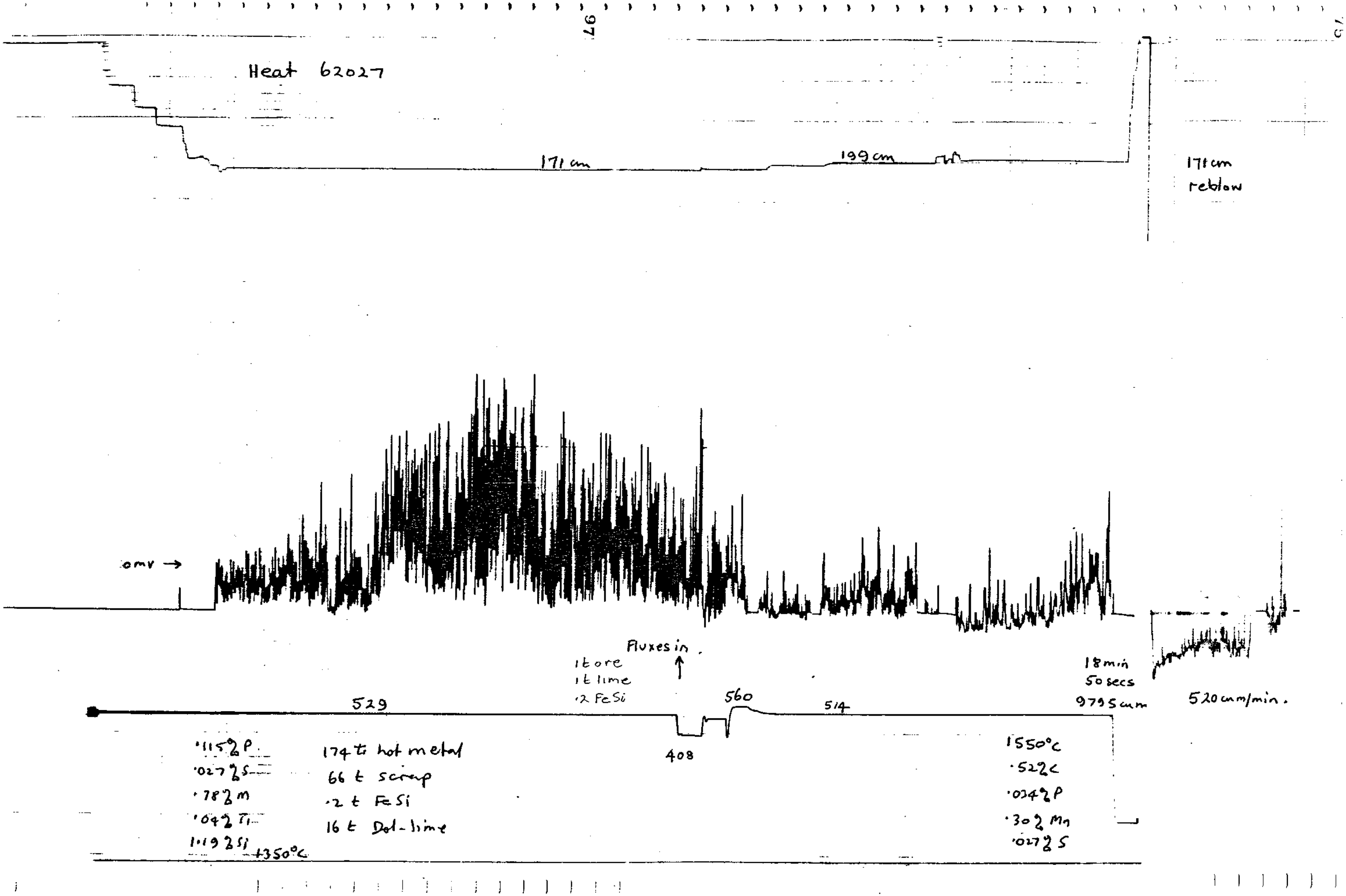
77
76
Heat 61874
260cm
158 cm
144 cm
lance height
162
176cm
540
540 cm m/min
520
slop
500
1575°C
·06%C
·019% P
·19% Mn
·0342S

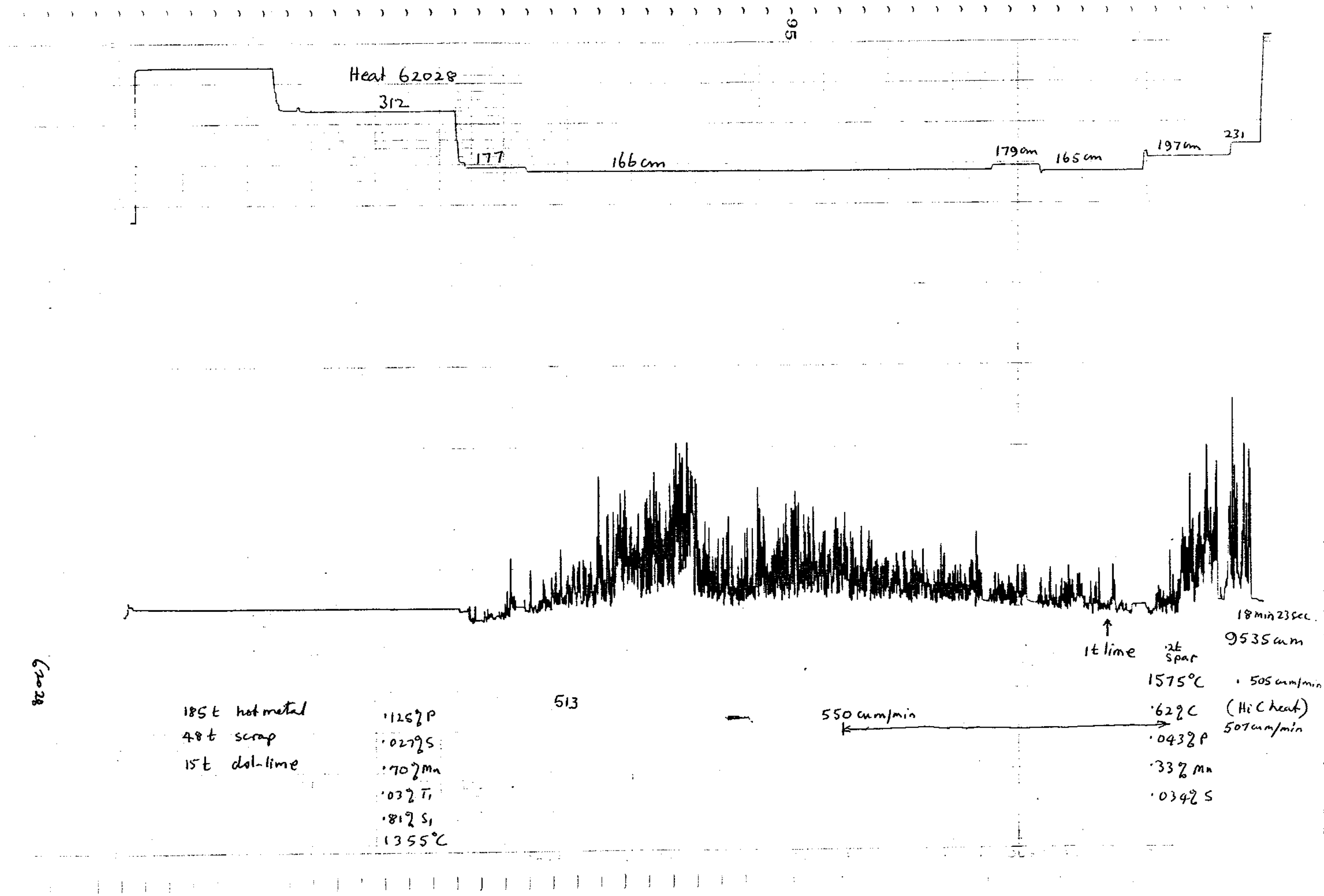

Heat 61875
155
142 cm
192 cm
153
280
200
260
197 cm
154 cm
526 cum/min Ox. flow rate
1625°C
·082 C
·017% P



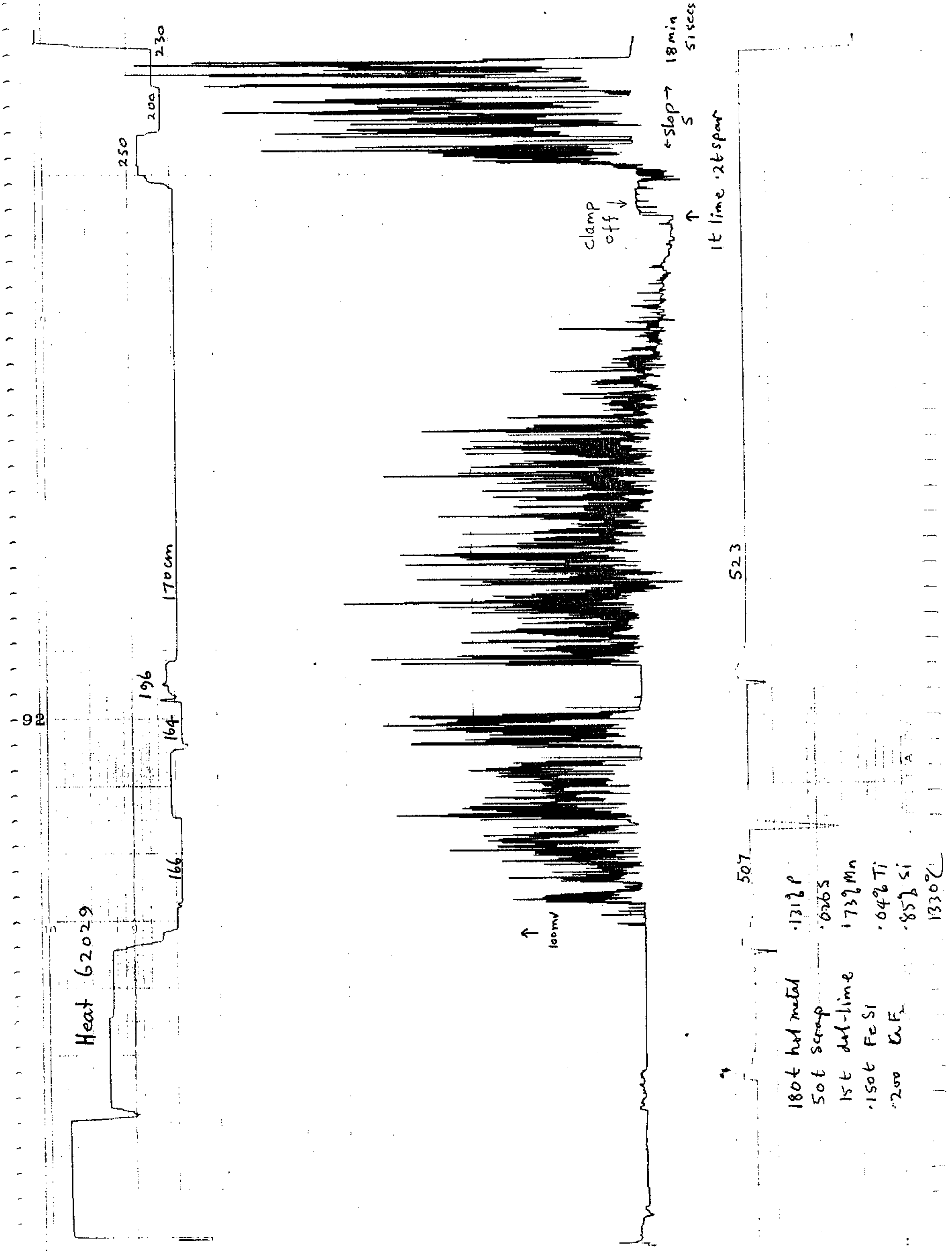
45
46
Heat 62011
198
167
160
177 cm
250 cm
198
5 mV
172 t hot metal
68 t scrap
15 t Dol-lime
400 Kg FeSi
Fl. Sp 200 kg
Mn fines 1t.
15 min
1600°C
11731 mm
·135% P
·031% S
·73% Mn
·03% Ti
·87% Si
1260°C
520 mm/min
·06% C
·018% P
·19% Mn
·026% S


48
47
Heat 62025
170
178
175cm
205
5mV
172t hot metal
58t scrap
3t ore
16t Dol-lime
2t Bkts.
.137% P
.024% S
.77% Mn
.05% Ti
1.27% Si
1380°C
slop
518
530 cu m/min
no change
521
542
20 min
43 secs.
10672 cu m
O2
1615°C
.07% C
.016% P
.16% Mn
.024% S


97
Heat 62027
171 cm
199 cm
171 cm
reblow
0 mv →
Fluxes in.
1t ore
1t lime
·2 FeSi
529
560
514
408
18 min
50 secs
9795 cm
520 cm/min.
·115 % P
·027 % S
·78 % m
·04 % Ti
1·19 % Si
1350°C
174 t hot metal
66 t scrap
·2 t FeSi
16 t Dol-lime
1550°C
·52 % C
·034 % P
·30 % Mn
·027 % S



95
Heat 62028
312
177
166 cm
179 cm
165 cm
197 cm
231
18 min 23 sec
9535 cum
1t lime
·2t spar
1575°C
·505 cum/min
(Hi C heat)
507 cum/min
·62% C
·043% P
·33% Mn
·034% S
550 cum/min
513
185t hot metal
48t scrap
15t dol-lime
·125% P
·027% S
·70% Mn
·03% Ti
·81% Si
1355°C
62028



Heat 62029
180t hot metal
50t scrap
15t dol-lime
·150t Fe Si
·200 CaF2
·131% P
·0265
·73% Mn
·04% Ti
·85% Si
1330°C
507
523
100mV
166
164
196
170cm
250
200
230
92
clamp off
1t lime ·2t spar
←stop→
5
18 min 51 secs