BRANZ

STUDY REPORT

NO. 40 (1992)
FIRE RESISTANCE OF NEW ZEALAND CONCRETES

C A Wade

The work reported here was funded by the
Foundation for Research Science and Technology
from the Public Good Science Fund

ISSN: 0113-3675

PREFACE

BRANZ undertook the work reported here primarily to establish the validity of current data for Fire Resistance Ratings of concrete. The work was conducted in two parts. The first part studied the fire resisting performance of 130 mm thick unloaded concrete slabs of differing aggregate type and was reported in BRANZ Study Report SR 34. This report concludes the project and includes recommendations for change to the minimum slab thicknesses and cover to steel for New Zealand concretes.

ACKNOWLEDGEMENTS

The author acknowledges the invaluable efforts of Mr J de Ruiter, for instrumenting and transporting the concrete specimens and for conducting the fire tests. BRANZ is also grateful to the staff of the Cement and Concrete Association of New Zealand for casting the concrete slabs and donating the high strength pair for inclusion in the study, and to the Foundation for Research, Science and Technology for funding the research.

This report is intended for researchers in fire engineering, code writers and as a background document for designers and approving authorities.

FIRE RESISTANCE OF NEW ZEALAND CONCRETES - PART 2

BRANZ Study Report SR 40

C A Wade

REFERENCE

Wade, C.A. 1992. Fire Resistance of New Zealand Concretes - Part 2. Building Research Association of New Zealand, BRANZ Study Report SR 40. Judgeford, New Zealand.

KEYWORDS

From Construction Industry Thesaurus, BRANZ Edition: Aggregate; BRANZ; Concrete; Damage; Fire; Fire Resistance; New Zealand; Rating; Reinforced Concrete; Spalling; Walls.

ABSTRACT

The thicknesses of concrete elements required to achieve various fire resistance ratings (FRR) in New Zealand are notional and are based on overseas building codes and test results. Because of the variations in the properties of the constituent aggregates, a test programme was undertaken to determine the reliability of the notional ratings when applied to concrete containing locally produced aggregates. Two series of tests were conducted. The first series was reported in BRANZ Study Report SR 34 while this report covers the second series and concludes the work. Recommendations are made for changes to the minimum required slab thicknesses and minimum required concrete cover to reinforcing steel to achieve specified fire resistance ratings.

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INTRODUCTION

This study was conducted to provide information on the fire resistance of concrete cast using New Zealand aggregates, so that currently adopted fire resistance ratings published in MP9 (SANZ, 1989) could be reviewed and revised if necessary. Fire resistance ratings for concrete contained in MP9 are based on overseas tests and on overseas standards and codes of practice.

The properties of the aggregate, which accounts for approximately 80 percent of the concrete by weight, have a significant effect on the thermal transmission characteristics of the concrete. Therefore, geological differences between aggregates commonly found in New Zealand and many overseas aggregates potentially have an important influence, and indicate the importance of confirming the validity of the fire resistance values currently used in this country.

An initial series of tests were carried out on unloaded slabs 130 mm thick using different types of aggregate from throughout New Zealand. The results of this work were published by Woodside, de Ruiter and Wade (1991). It was determined that further work was needed to confirm the relationship between fire resistance and thickness, and so allow recommendations to be made regarding the fire resistance of New Zealand concretes. This further work is the subject of this report.

METHOD

Aggregate Selection and Preparation of Specimens

From the initial series of fire resistance tests conducted in Part 1 of this study (Woodside, de Ruiter and Wade, 1991), a selection of aggregate types was made for further investigation at different thicknesses to the 130 mm thickness already tested. The aggregates selected were identified in the original study as having significantly (statistically) different fire resistances and were: Alluvial Quartz, Quarried Greywacke, Quarried Andesite, Limestone and Pumice. Slabs of either 60 mm (Alluvial Quartz, Quarried Greywacke, Limestone and Pumice) or 175 mm (Alluvial Quartz and Quarried Greywacke) were prepared depending on the insulating performance previously demonstrated by the aggregate type. 175 mm Quarried Greywacke slabs were chosen for examination in both horizontal and vertical orientations to assess the effect of orientation on the fire resistance.

In addition, 175 mm thick high strength Quarried Greywacke slabs were selected to provide information on its fire performance and spalling characteristics (although only in an unloaded state). These slabs contained a superplasticiser "RB1000" used at the rate of 5 kg/m^3. The aggregate types and slab nominal thickness selected for testing are summarised in Table 1.

A full description of the fabrication, mix design, and concrete tests of concrete specimens is given in Cement and Concrete Association Report No 90/76 (1991). Details of the mix design are given in Appendix 1, while the geographic source of the aggregates is given in Figure 1. The quarried greywacke aggregate used in this second series of tests was from Hongoeka Bay, Plimmerton.

Two slabs, each 1 m by 1 m, were cast for each aggregate type concrete and thickness selected. The 60 mm slabs incorporated a 665 steel reinforcing mesh while the 175 mm slabs incorporated a steel reinforcing grid made of HD12 bars at 250 mm centres. High tensile wire of 1.4 mm diameter was strung across the mould to support 1.0 mm diameter, sheathed, type K thermocouples at a pre-determined depth within each slab.

Concrete was placed into the mould after positioning the reinforcing steel at mid-depth and fastening the sheathed thermocouples to their support wires. Wells, for relative humidity sensing devices, were cast using formers that could be removed afterwards.

Relative Humidity Measurement

The slabs were stored, spaced from each other and dried in ambient conditions, initially at the Porirua premises of the Cement and Concrete Association of New Zealand during the 28-day curing period and then at BRANZ laboratories in Judgeford.

The relative humidity (RH) sensor was a stretched membrane coated on both sides with gold; the moisture sensitive membrane forming a dielectric, and the gold forming the electrodes of a capacitor.

Each slab had at least two RH sensors installed in plastic tube-lined wells reaching to mid-depth of the slab. The sensors were sealed into each well with silicone rubber sealant.

Each RH sensor was connected to a 50 channel terminal box which converted the capacitance into a dc voltage to give a direct reading of relative humidity. The system has an inherent reading error of within 2.5%.

Fire Test Method

The concrete slabs were tested in the 1.0 m by 2.2 m diesel-fired pilot furnace at BRANZ laboratories, Judgeford. As for the first series of tests, the ISO 834 (1975) test standard was followed. Testing was carried out between January and May 1991.

The specimens were tested unloaded in a vertical orientation and fastened to a frame using four bolts, two on each side at approximately one quarter and three quarters height. These bolts were inserted into pre-drilled holes in the side of each specimen holder. They were thus partially restrained against thermal expansion but not to the extent where such restraint would significantly affect their fire performance.

Nine tests were conducted in this series, involving a combination of five different aggregate types and two thicknesses. One of the tests was on a high strength concrete specimen.

The measured thickness around the edge of each slab was recorded and is shown in Table 2.

Temperature Measurement

The unexposed surface temperature of each slab was measured to determine the fire resistance according to the procedure and performance criteria described in ISO 834 (1975). Failure by the insulation criterion occurs when the average temperature of the unexposed face rises by more than 140°C or when the maximum temperature at any point rises by more than 180°C. The other criteria for failure are loss of integrity or structural adequacy (stability) which do not usually occur before insulation failure for unloaded concrete elements.

Five type K chromel/alumel disc thermocouples were fixed to the unexposed face of each slab in accordance with ISO 834. Each 60 mm and 175 mm thick specimen also had two and four sheathed "internal" thermocouples respectively placed at various depths for measuring temperatures within the concrete slabs as shown in Figures 2 and 3. These internal thermocouples were fixed to high tensile wire strung parallel to the face and located to within 1 mm of the specified depth. The reinforcing steel was instrumented with type K thermocouple wire joined with a "quick-tip" at the hot junction and fastened to the steel with epoxy resin.

A thermocouple made from a "quick-tip" connection was attached to the fire-exposed face in a slight indentation. This was held in place by a washer pressing on to the ceramic insulator carrying the thermocouple wires. The washer was screwed to the hot face using a 6 mm "Dynabolt".

Datalogging

The thermocouples were connected to a Hewlett-Packard HP 3497 data acquisition unit (DAU) which monitored the 24 thermocouples used in each test every minute. The DAU was controlled by a Hewlett-Packard series 9000 computer.

RESULTS

Temperatures on the Unexposed Face of the Concrete Slabs

Figures 4 to 12 show the average temperature on the unexposed face for each pair of slabs tested. The average temperature was determined from the 10 disc thermocouples used on both slabs.

Temperatures Within the Concrete Slabs

Figures 13 to 21 show the average temperature at pre-determined locations within the slab. These locations were 20 mm and 40 mm from the fire-exposed face for the 60 mm thick slab, and 35 mm, 70 mm, 105 mm and 140 mm from the fire-exposed face for the 175 mm slabs. The internal thermocouple temperatures are the average of the two thermocouples at each depth, in each slab.

Furnace, Hot Face and Reinforcing Steel Temperatures

Figures 22 to 30 show the average temperature of the furnace gases, fire-exposed (hot) face of the slabs, reinforcing steel and unexposed face of the slabs. The furnace gas temperature represents the average of four furnace thermocouples. The fire-exposed face and reinforcing steel temperatures also represent the average of four thermocouples, two in each slab. The unexposed face temperature represents the average of ten thermocouples as before.

Variation of Temperature with Distance from the Exposed Face

Internal temperature measurements were used to derive Figures 31 to 33 showing how the concrete temperature varied with distance from the fire exposed face for alluvial quartz, dacite and pumice aggregate concretes. The latter two Figures used data reported in Woodside et al (1991) while the former was from the current study.

ANALYSIS

Statistical Significance of Results

To give a statistical validation, a pair of slabs of the selected aggregate and thickness was fire tested. Each slab was instrumented with the five "key" thermocouples on the unexposed face as required by the test standard.

To calculate a 95% confidence level in the time taken for the average temperature to exceed a 140°C rise, the ten individual thermocouples from both slabs were used to calculate the mean time for the 140°C rise to be exceeded and the standard error in the mean calculated. Then using "T" tables a 95% confidence level in the mean was determined. Table 3 shows the mean time for 140°C rise to be exceeded and the 95% confidence limits to which these results are likely to be repeatable, for the specimens tested.

Correction to Standard Moisture (Humidity) Conditions

As the test specimens had not reached equilibrium moisture conditions or a "standard" condition of 75% relative humidity at mid-depth of each slab, it was necessary to apply a correction (to standard moisture conditions) to the mean time for 140°C rise to be exceeded and the 95% confidence interval. The method used followed a procedure described by Abrams and Gustaferro (1968), and results in approximately a 1% change in fire resistance for a 5% change in mid-depth relative humidity. The corrected values for the mean time for a 140°C temperature rise to be exceeded and the 95% confidence limits for this mean time are also given in Table 3.

Relationship Between Fire Resistance and Slab Thickness

The relationship between fire resistance (as measured by the insulation criterion) and slab thickness was approximated with an empirical correlation described by Abrams and Gustaferro (1968) who proposed a power curve expression as follows.

$$R = Ct^n$$

where: R = fire resistance

t = slab thickness

C, n = constants determined from least squares regression analysis (usings logs) of the test data

This expression was applied to the test data, where a concrete aggregate type had been tested at more than one thickness. The concrete types therefore considered were: alluvial quartz, quarried andesite, quarried greywacke, limestone and pumice. The lower 95% confidence limit for the mean time taken to exceed a 140°C temperature rise corrected to a standard moisture condition of 75% RH at slab mid-depth was used in the curve fitting. The constants C and n determined are given in Table 4.

These constants were then used to derive values of thickness for given fire resistance periods for each of the five aggregate types and these are shown in Table 5. In addition, equivalent values for the dacite aggregate were estimated using the constant n determined for quarried andesite, as the initial study (Woodside, de Ruiter and Wade, 1991) showed that the performance of dacite and quarried andesite was not significantly different.

Cover to Reinforcing Steel

In structural concrete elements, the reinforcement temperature has a significant impact on the structural adequacy of the member due to the reduction in steel strength that results with an increase in temperature. A minimum concrete cover to reinforcing steel is then necessary to prevent the steel reaching its critical temperature and possibly leading to member collapse. This minimum cover depends on the type of concrete and steel used, amount of load, and the structural system employed.

For simply supported elements carrying design loads the critical steel temperature can be taken as 550°C for hot rolled reinforcing steel and 450°C for cold-worked steel tendons (Morris, Read and Cooke, 1988). Figures 31 to 33 were used to determine the distance from the fire exposed face for which the concrete reaches these critical temperatures. Table 6 gives these distances (or covers) for the alluvial quartz, dacite and pumice aggregate type concretes for fire resistance periods ranging from 30 minutes to 240 minutes.

DISCUSSION

Grouping of Aggregate Types for Regulatory Purposes

For simplicity in specifying concrete types for regulatory purposes it is necessary to group the different types of aggregate into classes with similar fire resisting performance. The performance of each group would be governed by the least insulating concrete in that group. Any aggregates not included in this test study can be treated as belonging to the lowest performing group until such a time as comparative test data becomes available.

Class A: quartz, greywacke, basalt & any others not specifically mentioned below

Class B: dacite, phonolite, andesite, rhyolite, limestone

Class C: pumice

The fire resistance (insulation) for these three classes and for the current MP9 (SANZ, 1989) requirements, versus thickness are shown in Figure 34.

Performance of High Strength Concrete Slabs

A pair of high strength concrete slabs cast using Quarried Greywacke aggregate were tested in the vertical orientation and can be compared with the normal-strength slabs also tested in the same orientation. The actual thickness of the slabs differed slightly, being 170 mm and 175 mm respectively for the high-strength and normal-weight slabs. The high-strength slab also contained a super-plasticiser (RB1000 at 5 kg/m^3) not added to any of the other slabs.

The corrected results showed that the 95% confidence interval for the mean was 278-302 (290 min mean) minutes for the high strength slab, and 274-285 (280 min mean) minutes for the normal-strength slab. They are statistically different at the 1% significance level.

Effect of Orientation

Pairs of 175 mm thick Greywacke Slabs were tested in both the horizontal and vertical orientations. The corrected results showed that the 95% confidence interval for the mean was 274-285 minutes (280 min mean) for the vertical slabs, and 285-297 minutes (291 min mean) for the horizontal slab. These differences are statistically significant at the 1% level.

During the test of the horizontal slabs, pools of moisture were observed lying on the upper surfaces of the slabs, which slowly evaporated away as the test progressed. The reason for the better performance of the horizontal slab is postulated to be due to the presence of this moisture keeping the upper surface cool. In the vertical orientation the moisture driven out of the slab is able to run down and off the unexposed face.

Spalling

No destructive spalling was observed for any of the slabs tested. Some localised surface spalling did occurred in some slabs. These slabs were the 60 mm quarried andesite, 60 mm pumice and the 175 mm high strength quarried greywacke.

As these tests were conducted on unloaded specimens, the fact that no destructive spalling occurred should not be taken as being indicative of what may happen in identical, but highly stressed specimens.

RECOMMENDATIONS

1. Requirements for fire resistance of concrete elements, contained in the publication MP9 (SANZ, 1989) should be updated. A new classification system for grouping the different types of aggregate is proposed as follows:

Class A: quartz, greywacke, basalt & any others not specifically mentioned below
Class B: dacite, phonolite, andesite, rhyolite, limestone
Class C: pumice

2. The minimum slab thickness required to achieve a specified level of fire resistance (Insulation), and based on the insulation performance for each class of aggregate is shown in Table 7 and these are recommended for inclusion in MP9. These requirements are applicable to both loadbearing and non-loadbearing walls and slabs.

3. The minimum cover required to limit temperature rises on reinforcing or prestressing steel to below critical values for different classes of aggregate is shown in Table 8 and these are recommended for inclusion in MP9. These requirements are applicable only to loadbearing walls and simply-supported slabs. Requirements for slabs with moment continuity over supports may be less stringent than these, and the data provided in AS 3600 (SAA, 1988) should be considered for adoption.

4. The insulation performance of high-strength concrete slabs should be taken as being no less than for the normal-weight equivalent.

5. The New Zealand Concrete Structures Code, NZS 3101 (SANZ, 1982), should include a section on design for fire resistance, containing fire resistance data for New Zealand concretes.

CONCLUSIONS

1. The fire resistance of concretes cast using New Zealand sourced aggregates, in general, provide better performance than is currently provided for in MP9 (SANZ, 1989). The fire resistance data for concrete elements contained in MP9 (SANZ, 1989) should be updated as recommended in this report.

2. The cover to reinforcement requirements provided for in MP9 (SANZ, 1989) are in some instances insufficient to prevent reinforcing or prestressing steel from reaching critical temperatures. The requirements in MP9 should be updated as recommended in this report.

3. There was a difference noted between the fire resisting (Insulation) performance of the high-strength quarried greywacke slabs compared with their normal-strength counterparts. The high-strength slabs recorded a fire resistance approximately 3.5% greater than the normal-strength slabs.

4. The effect of orientation on the fire resistance of unloaded slabs is such that a worse result is achieved with a vertical orientation compared with a horizontal orientation. The cooling effects of moisture ponding on the upper surface of horizontal slabs is postulated as being the main reason for the better performance achieved in the horizontal orientation.

5. No destructive spalling of any of the concrete slabs was observed in any of the tests, including the high-strength specimens. No loads were applied during the tests so these observations should not be taken as necessarily being indicative of likely performance of equivalent specimens which are carrying significant load.

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APPENDIX 1: MIX DESIGN AND TEST DATA

CONCRETE SLAB	MATERIAL QUANTITIES PER CUBIC METRE COARSE AGGREGATE 19 mm kg	 COARSE AGGREGATE 10 mm kg	 SAND Concrete kg	 SAND Dune kg	 CEMENT kg	 WATER kg	BATCH VOLUME m3	W/C RATIO	MIX	SLUMP mm	DENSITY (fresh) kg/m3	AIR %	MEASURED YIELD m3	f'c 28 days MPa
quarried greywacke 175 mm vertical	537	541	811	87	295	171.8	0.10	0.58	1	50	2385	1.7	1.024	
									2	60	2363	2.0	1.034	38.0
									3	50	2376	1.5(5)	1.028	
									4	80	2397	1.9	1.027	34.0
quarried greywacke 175 mm horizontal									1	40	2381	2.2	1.026	
									2	30	2387	1.9	1.023	35.0
									3	70	2381	2.2	1.026	
									4	50	2394	1.8	1.020	39.0
quarried greywacke 60 mm	537	541	811	87	295	171.8	0.08	0.58	1	40	2387	2.1	1.024	40.0
									2	50	2379	2.1	1.027	34.5
alluvial quartz 175 mm	526	514	811	87	295	168.5	0.10	0.57	1	10	2370	2.9	1.013	
									2	60	2358	2.5	1.019	36.5
									3	60	2338	3.3	1.027	
									4	40	2350	3.0	1.022	37.0
alluvial quartz 60 mm	595(2)	395(2)	860(2)	93(2)	295	168.5	0.08	0.57	1	20	2347	3.2	1.026	32.5
									2	30	2362	2.9	1.019	33.0
limestone 60 mm	270(3)	636(3)	811	87	295	168.5	0.08	0.57	1	0	2247	3.9	1.009	30.0
									2	0	2240	3.9	1.012	31.5
pumice 60 mm	104(4)	425(4)	811	87	295	163.6	0.08	0.55	1	200	1910	2.7	0.988	17.5
									2	130	1910	3.0	0.988	18.5
quarried andesite 60 mm	545	543	811	87	295	168.5	0.08	0.57	1	50	2421	1.8	1.012	41.5
									2	50	2410	1.9	1.017	42.0
high strength quarried greywacke 175 mm		930	820		500	165.0	0.10	0.33	1	500(1)	2427	1.2	0.996	
									2	425(1)	2393	2.3	1.009	80.0
									3	395(1)	2415	2.2	1.001	
									4	380(1)	2424	1.9	0.997	84.0

NOTES

1. Flow
2. A 16 mm "all in" aggregate was supplied instead of the 19 mm used previously and blended with the 10 mm aggregate. Because of this, a compensation in the sand proportions was required to maintain consistency of the alluvial quartz mixes.
3. The two sizes of limestone aggregate were tested to find the maximum unit mass for the blended aggregates.
4. The 19 mm pumice was found to be unsuitable for the mix design specified by Works Central Laboratories due to a variation in the grading of the aggregate supplied, from the aggregate originally used. Therefore the appropriate changes were made in the aggregate blend to produce a similar concrete as before.
5. Theoretical

AGGREGATE TYPE	TESTED THICKNESS (NOMINAL)		
	60 mm	130 mm (1)	175 mm
alluvial quartz	yes	y	y
alluvial greywacke	no	y	n
quarried greywacke	y	y	y
quarried basalt	n	y	n
quarried dacite	n	y	n
phonolite	n	y	n
quarried andesite	y	y	n
rhyolite	n	y	n
limestone	y	y	n
alluvial andesite	n	y	n
pumice	y	y	n
high strength	n	n	y
Note (1) reported in BRANZ Study Report SR 34			

Table 1 Concrete Type and Thickness Tested

AGGREGATE TYPE	THICKNESS (mm)	
	Mean	Standard Deviation
quarried andesite (60)	62.5	3.0
quarried greywacke (60)	61.5	1.5
quarried greywacke (175 vert)	175.4	2.1
quarried greywacke (175 hor)	175.2	4.0
alluvial quartz (60)	63.7	1.7
alluvial quartz (175)	175.6	2.0
limestone (60)	62.4	1.4
pumice (60)	63.7	1.6
high strength (175)	170.3	3.2

Note : measurements were taken from the edge of the slabs

Table 2 Measured Thickness of Slabs

Table 3 Test Results

AGGREGATE TYPE	THICKNESS (nom) mm	AS MEASURED BY TEST			CORRECTED TO A STD MOISTURE CONDITION OF 75% RELATIVE HUMIDITY AT MID-DEPTH	
		RELATIVE HUMIDITY %	MEAN TIME TO EXCEED 140K TEMP RISE min	95% CONFIDENCE INTERVAL IN THE MEAN min	MEAN TIME TO EXCEED 140K TEMP RISE min	95% CONFIDENCE INTERVAL IN THE MEAN min
alluvial quartz	60	90	48.8	46.5-51.1	46.2	44.2-48.4
	175	79	278.5	269.3-287.7	276.5	267.3-285.7
quarried greywacke	60	87	47.4	46.1-48.7	45.4	44.2-46.7
(vertical)	175	87	287.1	281.9-292.3	279.5	274.3-284.6
(horizontal)	175	82	295.2	289.2-301.1	291.2	285.3-297.1
(high strength)	175	77	291.5	279.4-303.6	290.2	278.2-302.3
limestone	60	90	67.0	64.0-79.0	63.5	60.6-66.4
pumice	60	80	90.4	84.5-96.5	88.8	83.0-94.7
quarried andesite	60	82	58.8	57.0-60.6	57.6	55.8-59.4

AGGREGATE TYPE	THICKNESS t (mm)	TIME TO EXCEED 140K RISE LOWER 95% CONFIDENCE LIMIT CORRECTED TO STANDARD MOISTURE CONDITION, R (min)	R = C t ^n		
			CORRELATION COEFFICENT	CONSTANTS	
			r	C	n
Alluvial Quartz	64 130 176	44 151 267	1.00	0.027	1.775
Quarried Greywacke	62 130 175	44 162 274	1.00	0.031	1.759
Quarried Andesite	63 130	56 184	1.00	0.06	1.648
Limestone	62 130	61 204	1.00	0.068	1.645
Pumice	64 130	83 290	1.00	0.053	1.767

Table 4 : Relationship Between Slab Thickness and Time to Exceed 140 K Temperature Rise

FIRE RESISTANCE** (min)	CONCRETE AGGREGATE TYPE					
	Alluvial Quartz (mm)	Quarried Greywacke (mm)	Dacite* (mm)	Quarried Andesite (mm)	Limestone (mm)	Pumice (mm)
30	50	50	45	43	41	36
60	74	74	68	66	62	53
90	93	93	87	85	79	67
120	109	110	103	101	94	79
180	137	138	132	129	120	100
240	161	162	157	153	143	117

Note** - based on insulation criteria
Note* - estimated

Table 5 Slab Thickness Versus Fire Resistance

AGGREGATE TYPE	CRITICAL TEMP (C)	DISTANCE FROM FIRE EXPOSED FACE (mm)					
		Time (min)					
		30	60	90	120	180	240
Alluvial Quartz	550	7	15	25	35	49	61
	450	10	23	36	47	63	75
Dacite	550	7	19	26	34	47	-
	450	13	25	35	44	58	-
Pumice	550	8	18	24	28	34	42
	450	13	23	30	35	43	51

Table 6 Distances From Fire Exposed Face at which Critical Temperatures are reached

FIRE RESISTANCE (Insulation) (min)	THICKNESS (mm)		
	Class A	Class B	Class C
30	50	45	40
60	75	70	55
90	95	90	70
120	110	105	80
180	140	135	100
240	165	160	120

Table 7 : Minimum Recommended Slab Thickness

AGGREGATE CLASS		COVER TO FACE OF STEEL (mm)					
		FIRE RESISTANCE (min)					
		30	60	90	120	180	240
Class A & B	Reinforcing	10	10	20	30	45	55
	Prestressing	10	20	30	45	60	70
Class C	Reinforcing	10	15	20	25	30	40
	Prestressing	10	20	25	30	40	45

Table 8 : Minimum Recommended Cover to Steel

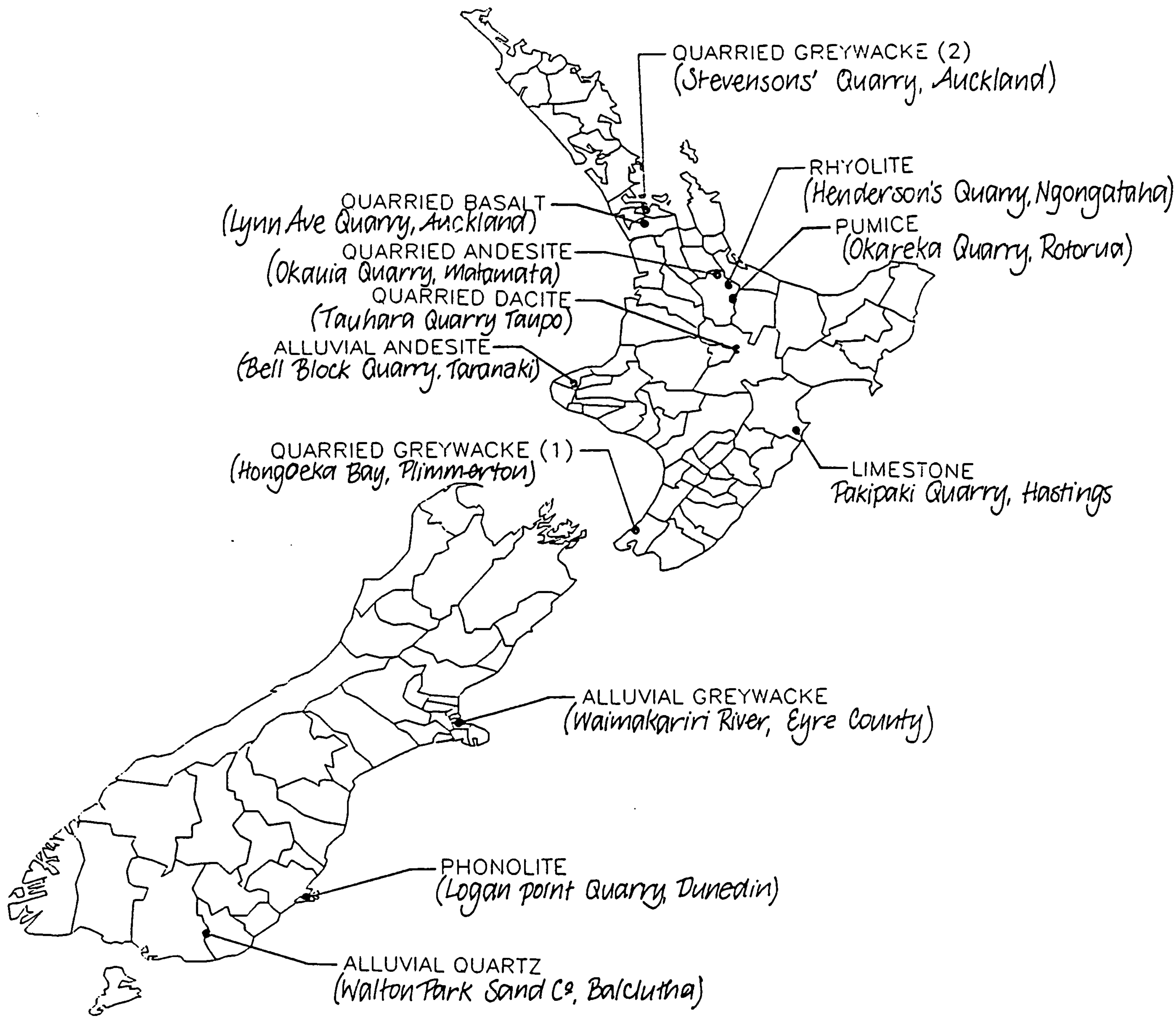

Figure 1 Geographic Source of Concrete Aggregates

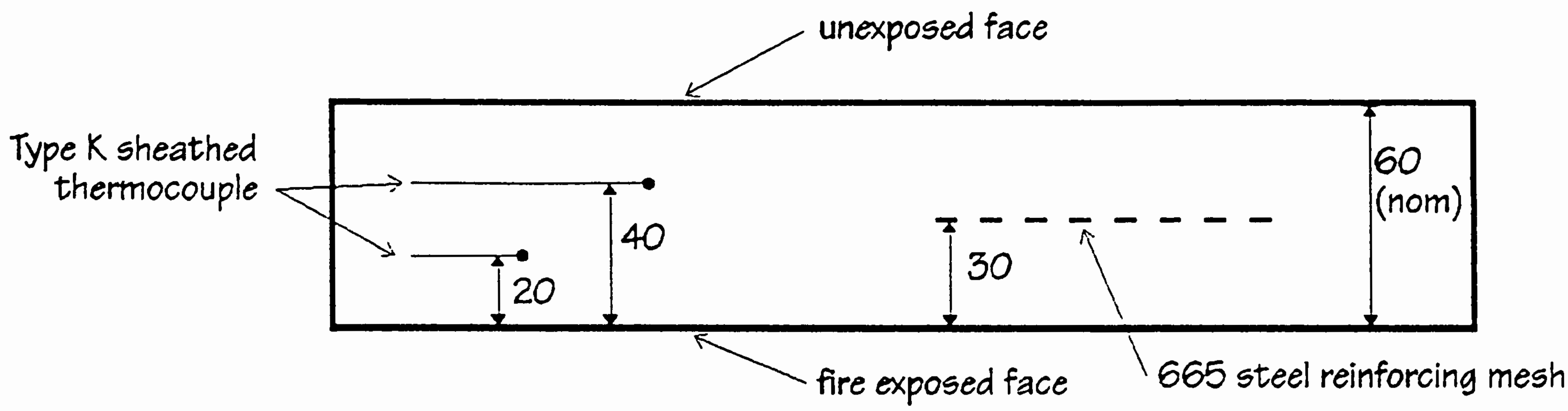

Figure 2 Cross-section Through 60 mm Slabs Showing Location of Thermocouples and Reinforcement

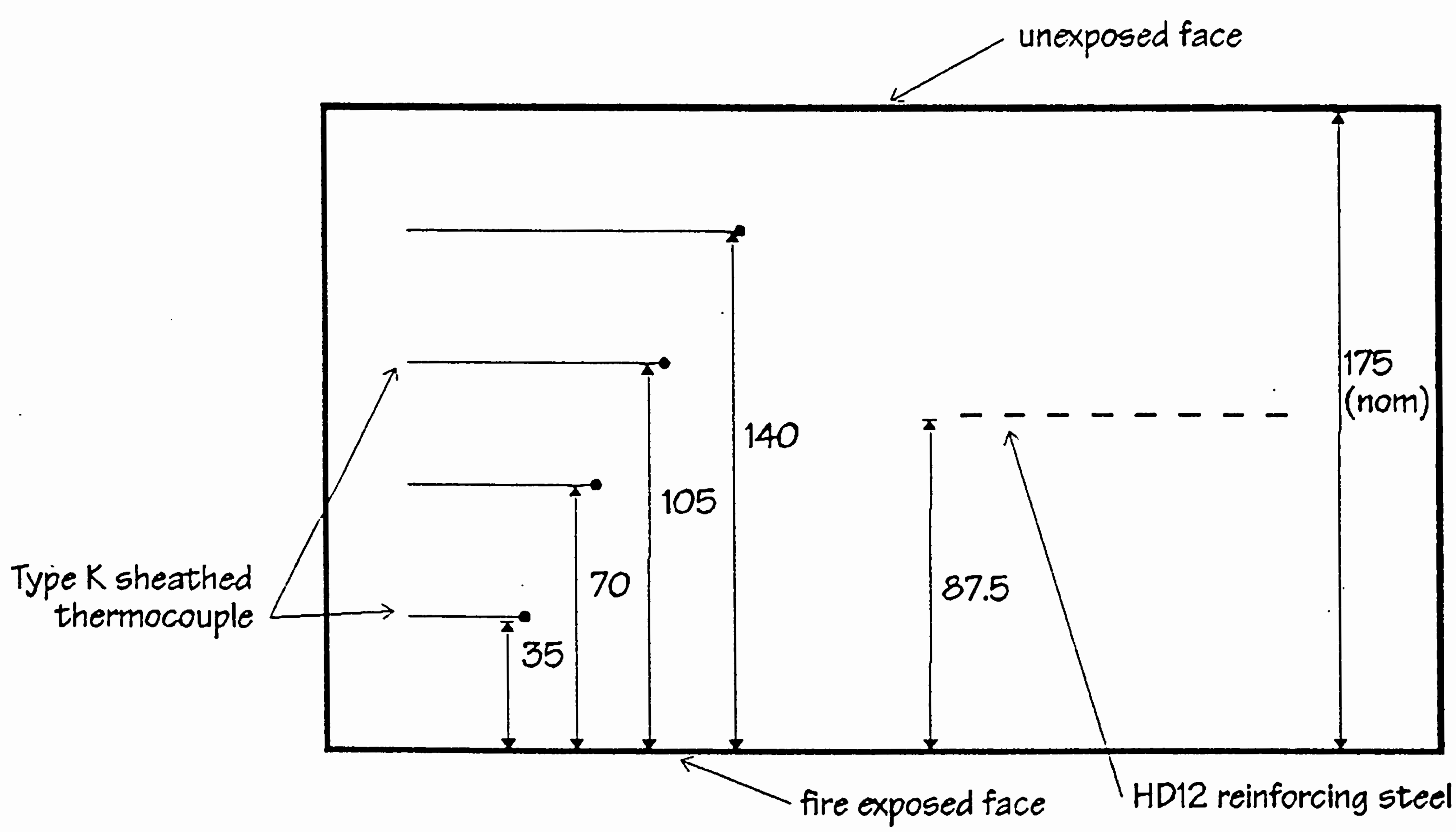

Figure 3 Cross-section Through 175 mm Slabs Showing Location of Thermocouples and Reinforcement

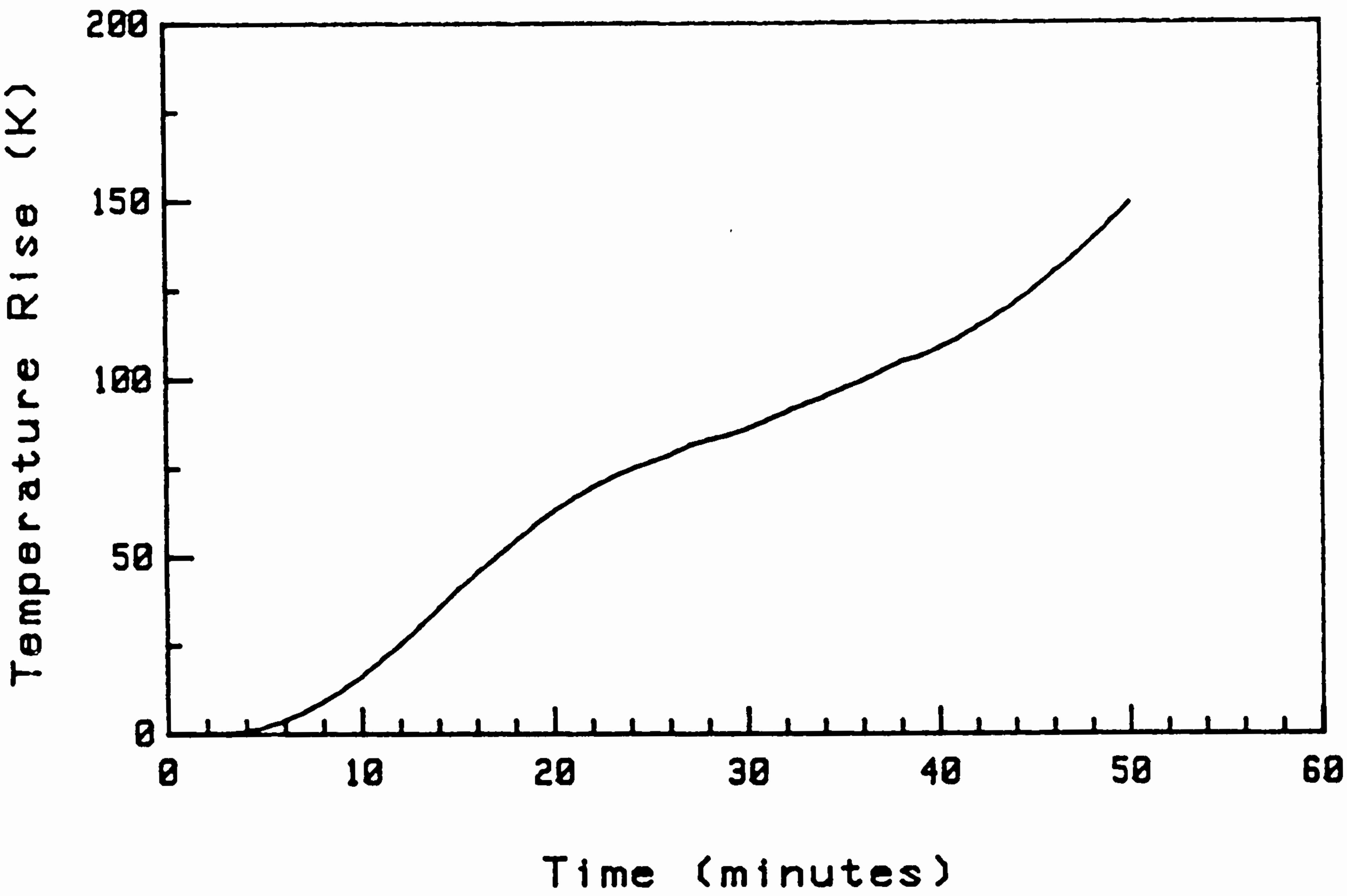

Figure 4 60 mm Alluvial Quartz - Unexposed Face

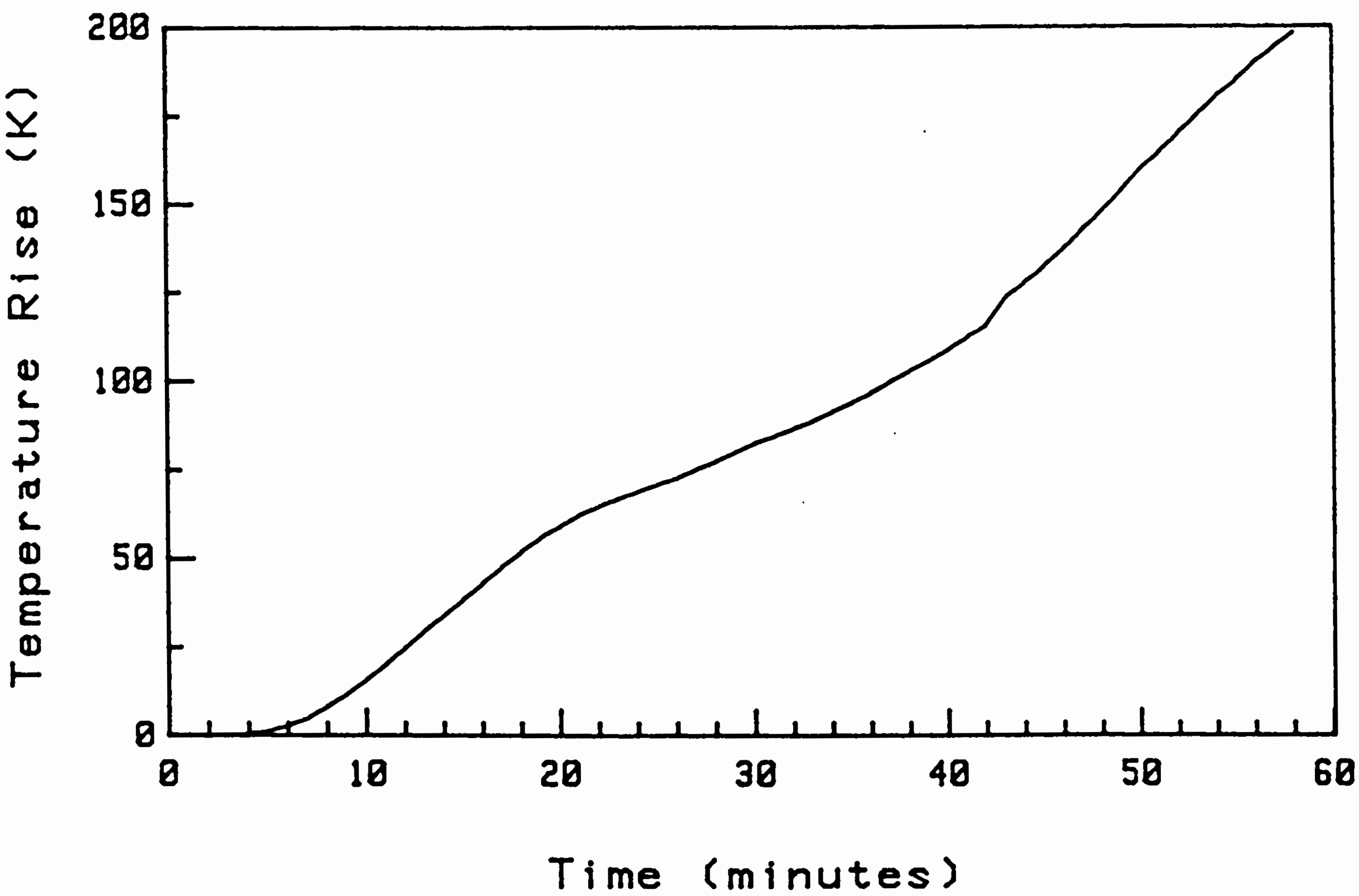

Figure 5 60 mm Greywacke - Unexposed Face

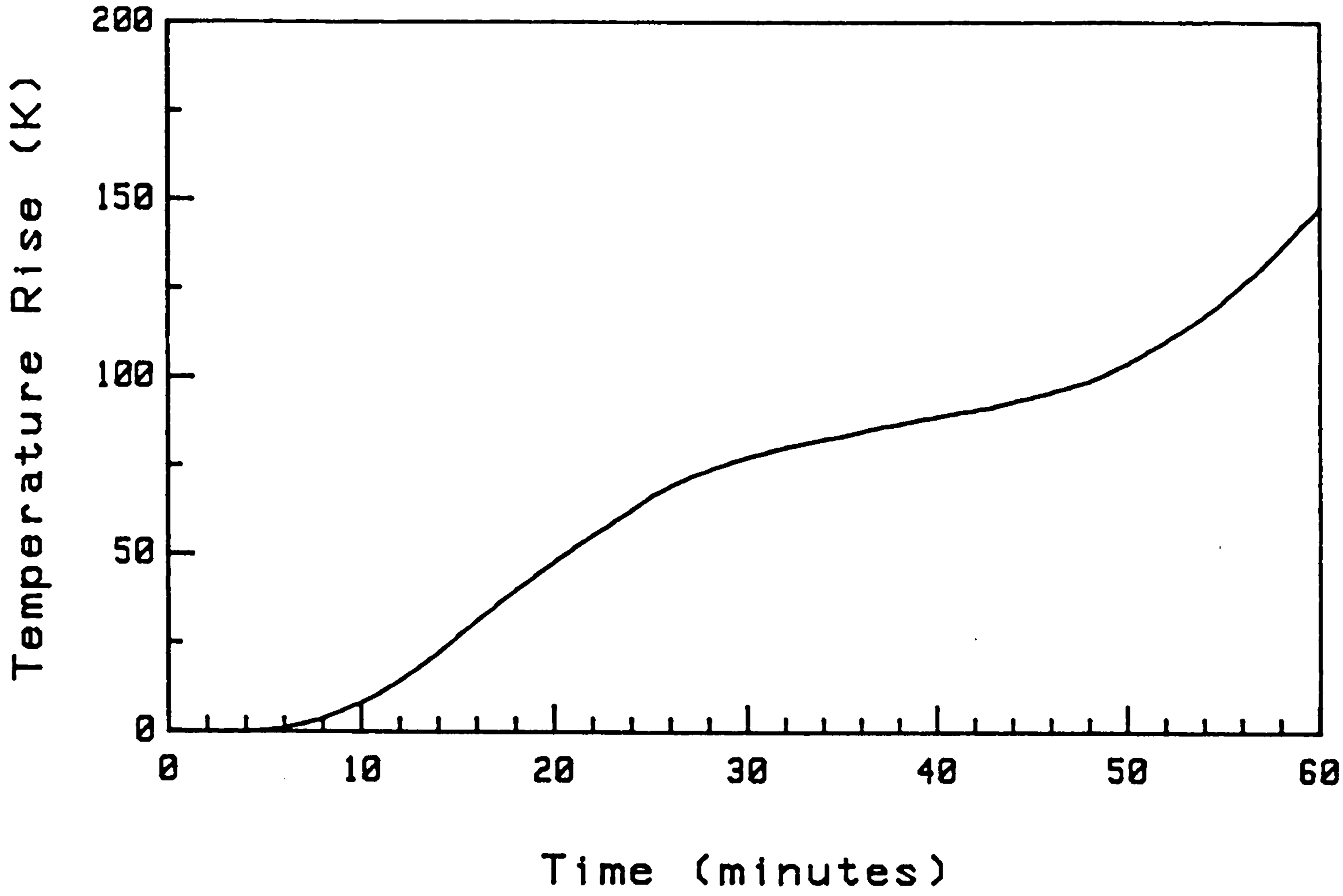

Figure 6 60 mm Quarried Andesite - Unexposed Face

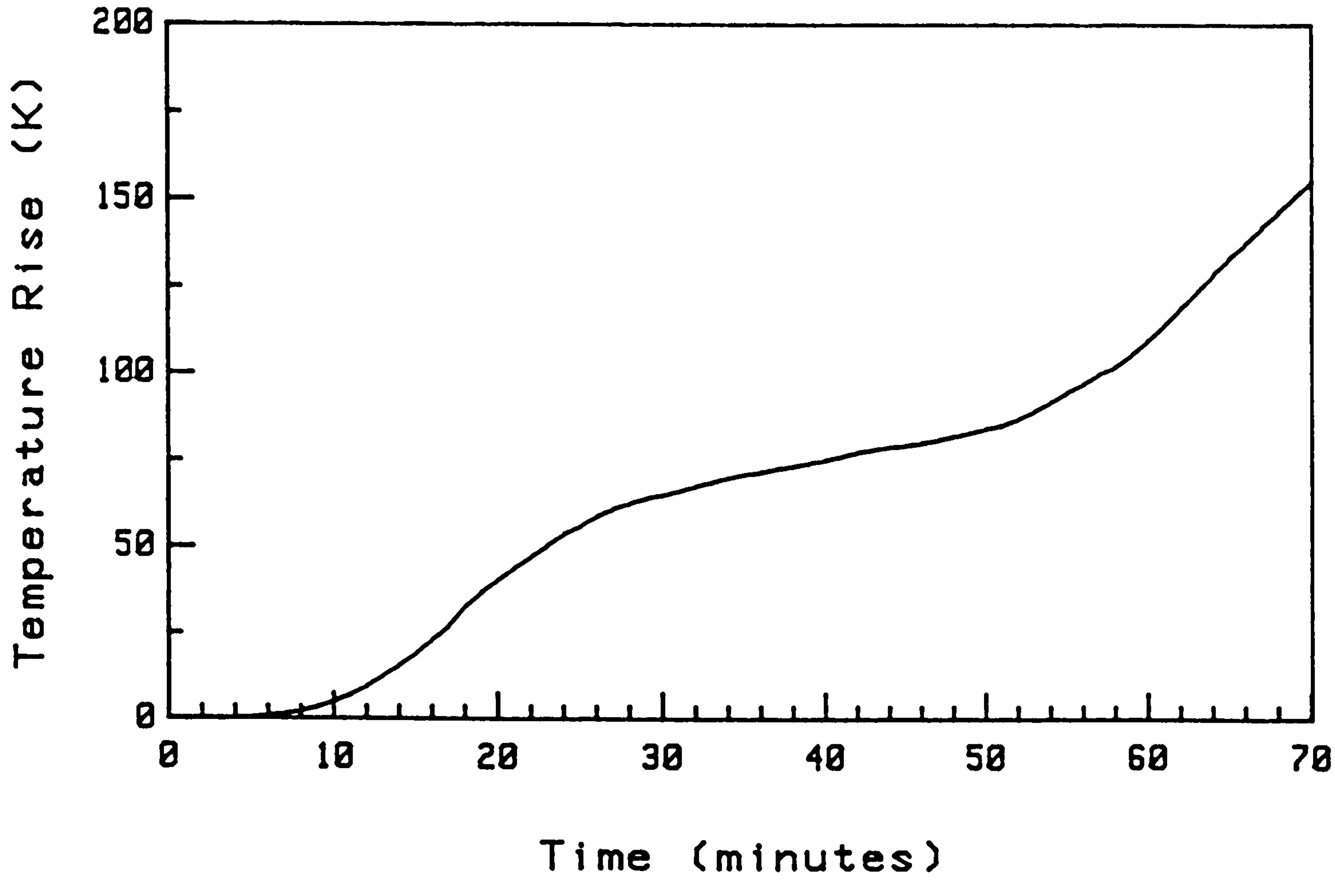

Figure 7 60 mm Limestone - Unexposed Face

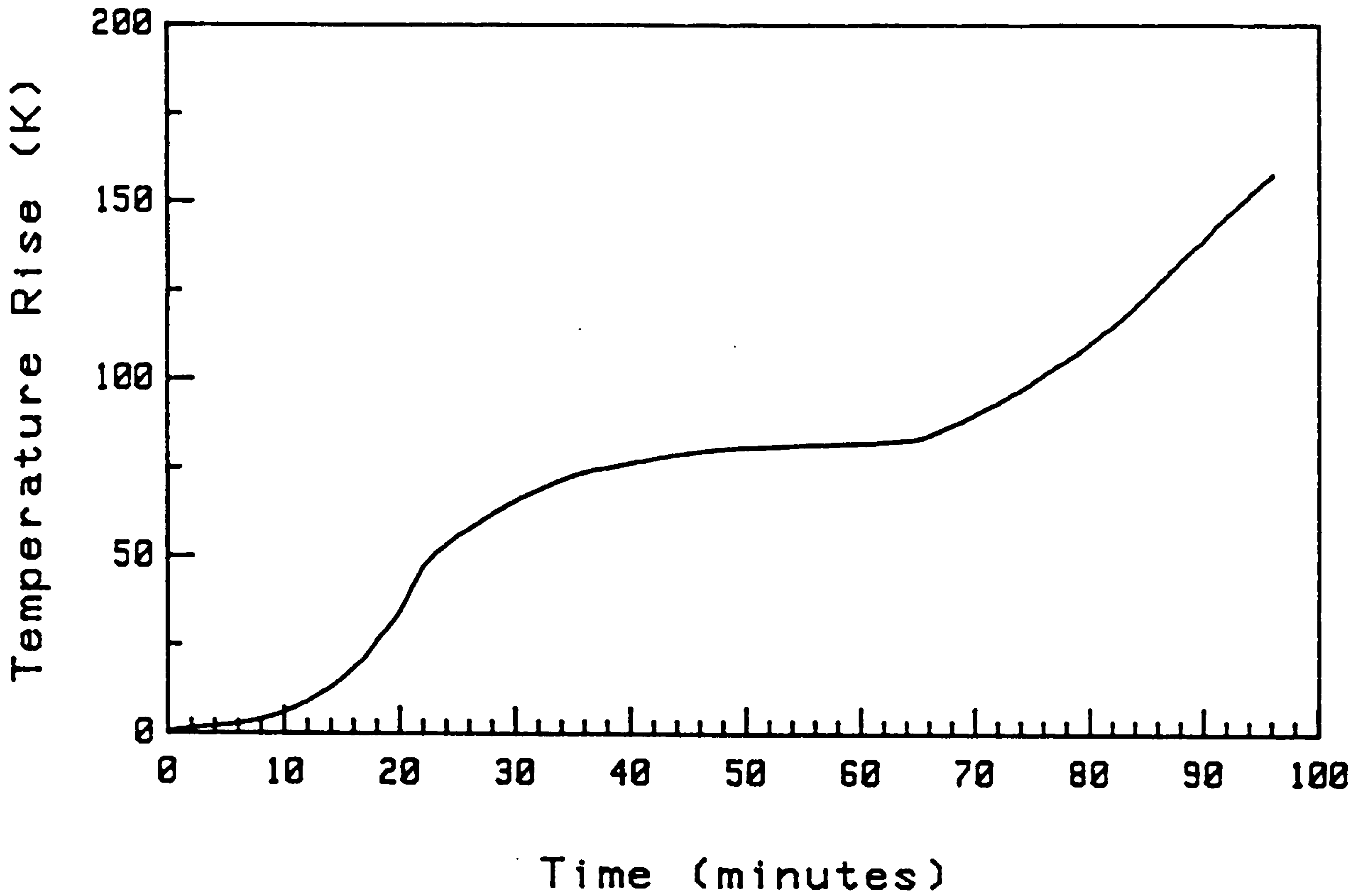

Figure 8 60 mm Pumice - Unexposed Face

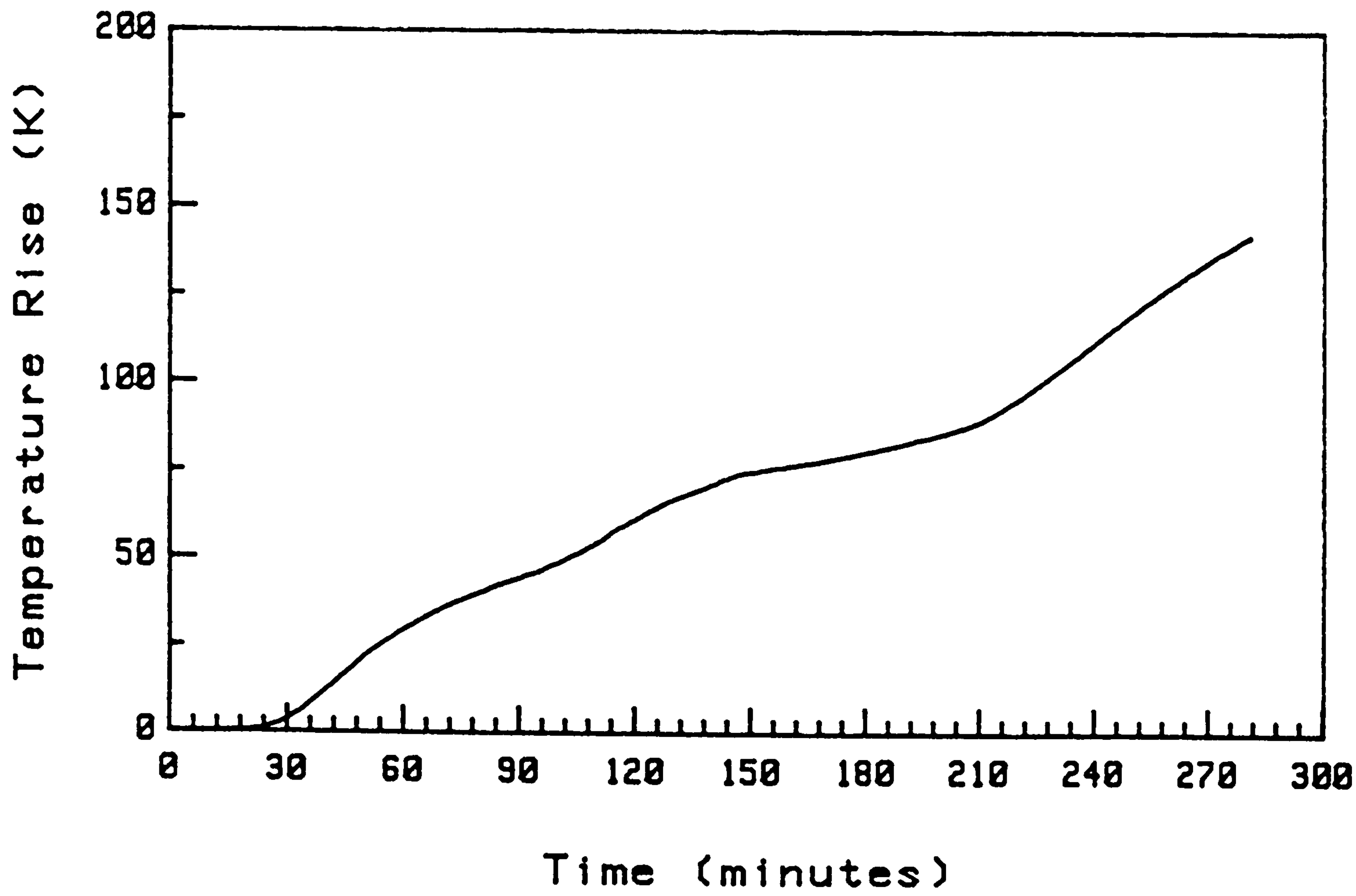

Figure 9 175 mm Alluvial Quartz - Unexposed Face

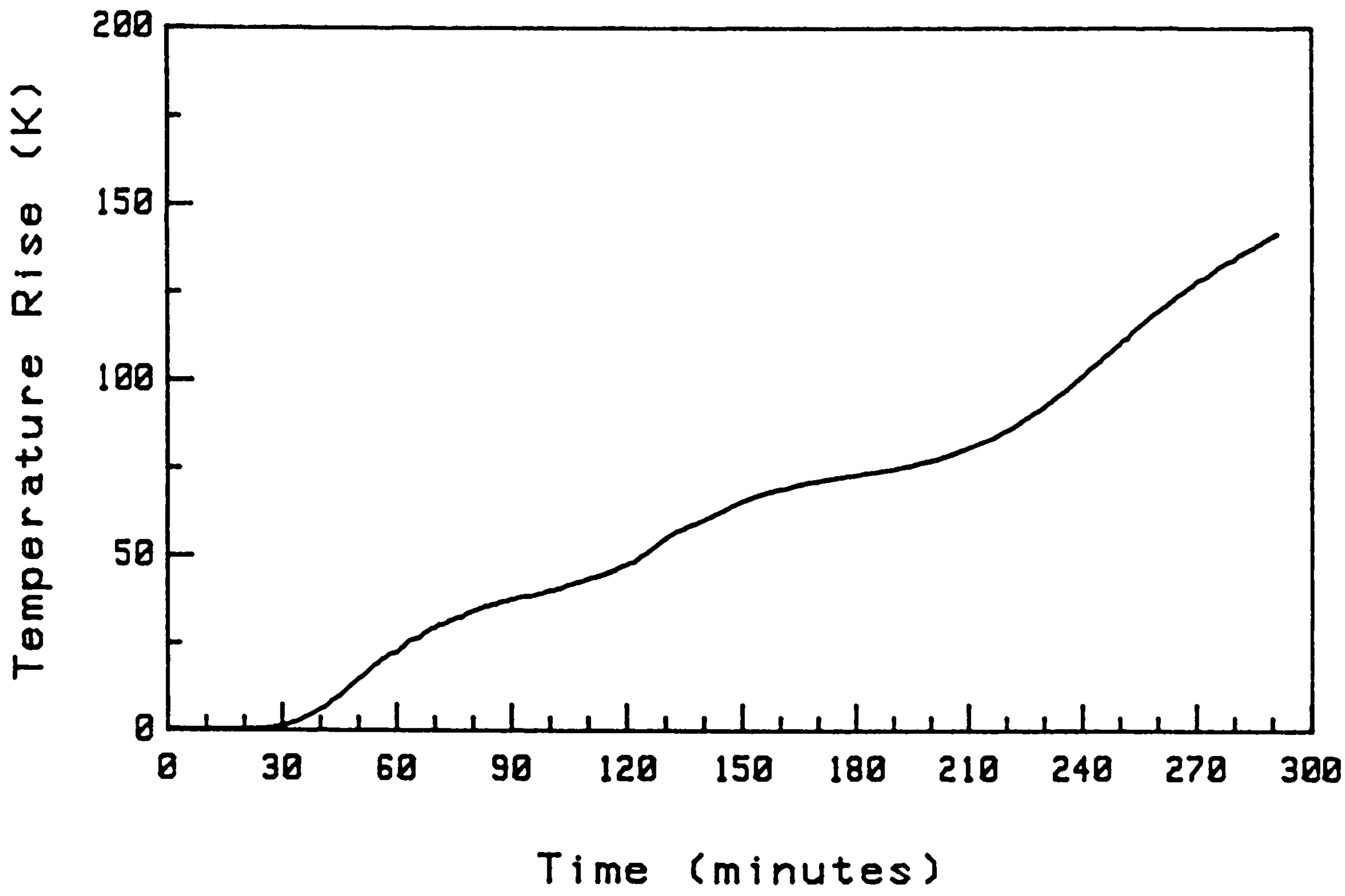

Figure 10 175 mm Vertical Greywacke - Unexposed Face

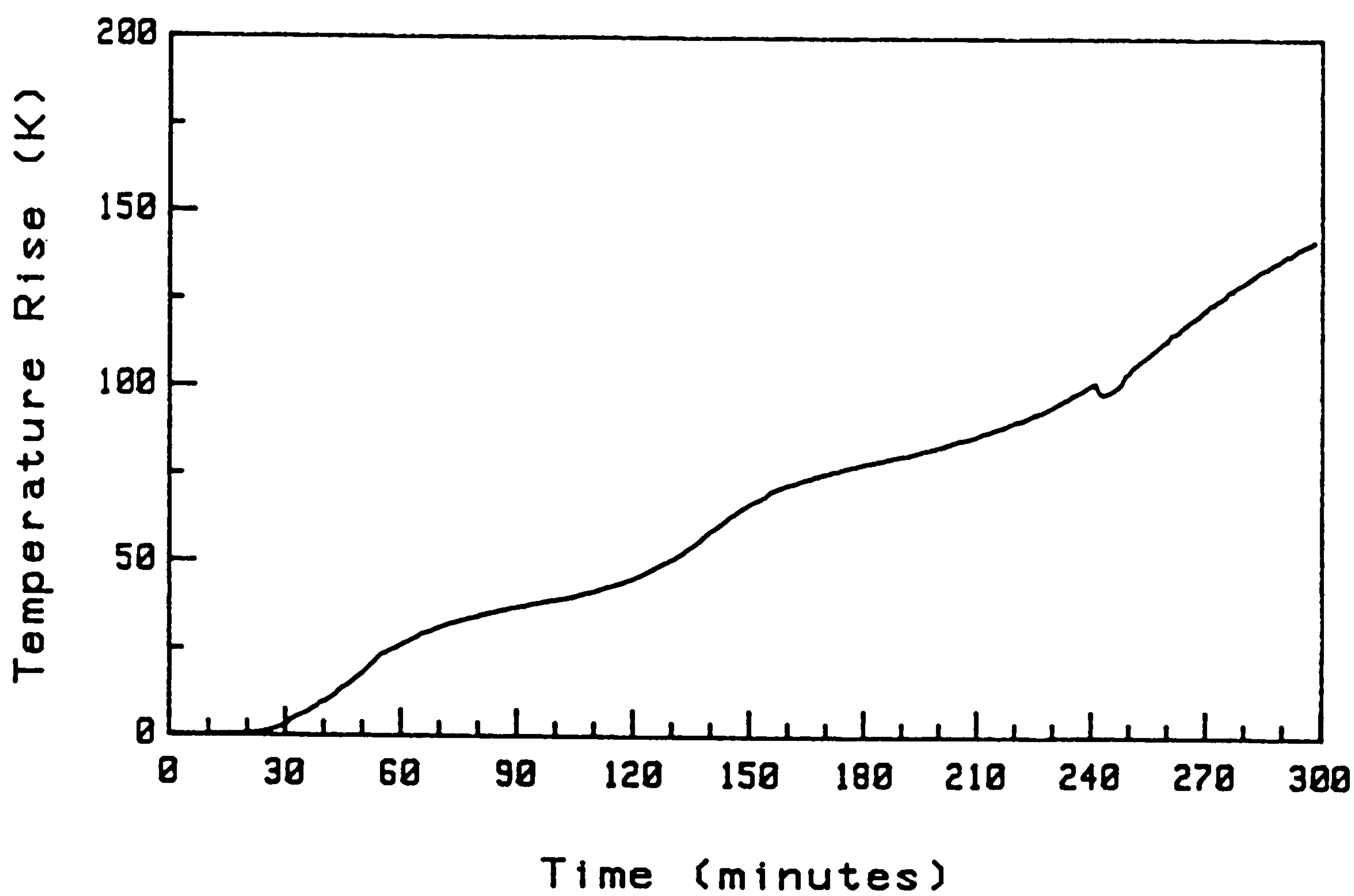

Figure 11 175 mm Horizontal Greywacke - Unexposed Face

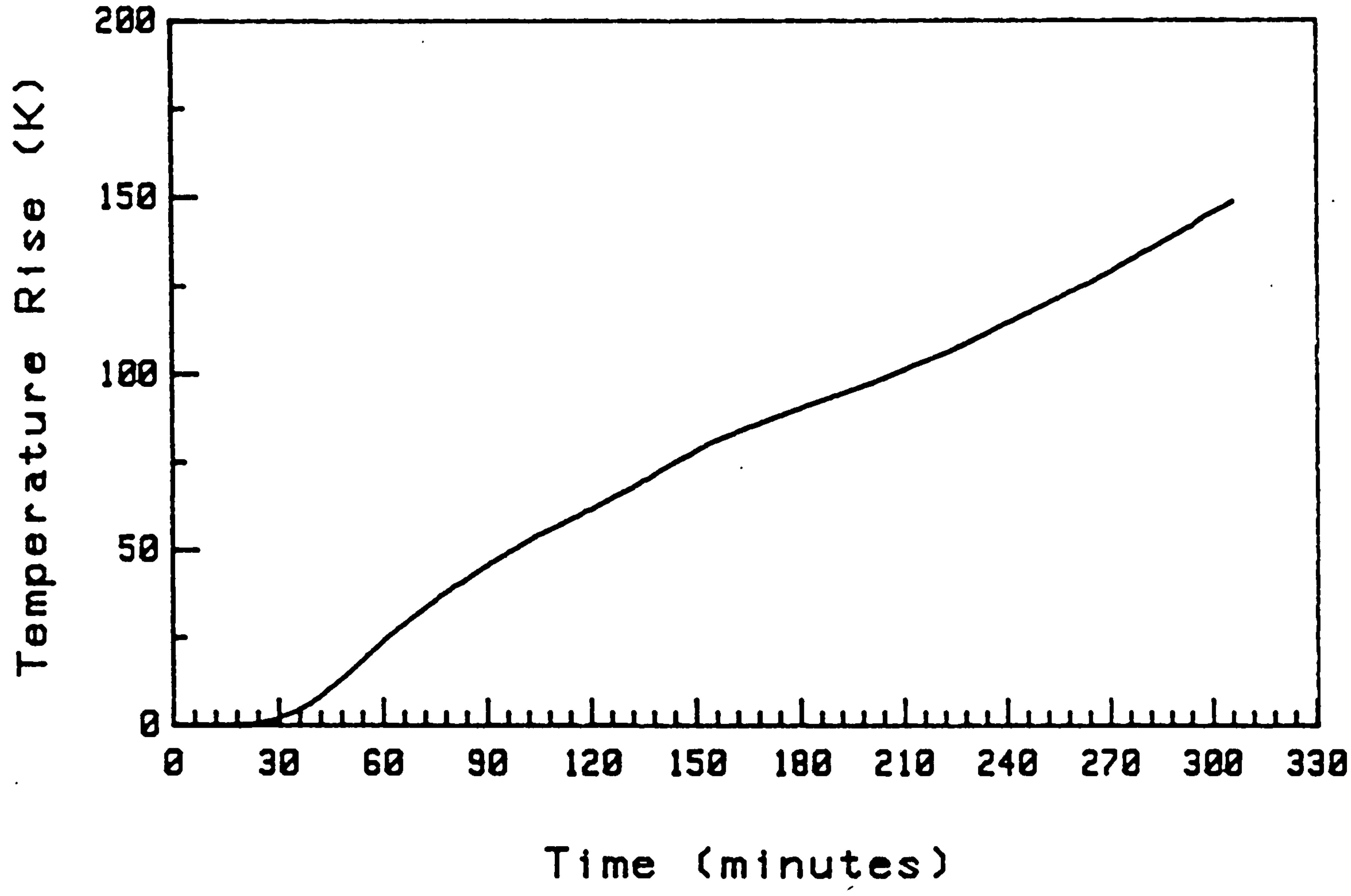

Figure 12 175 mm High Strength Greywacke - Unexposed Face

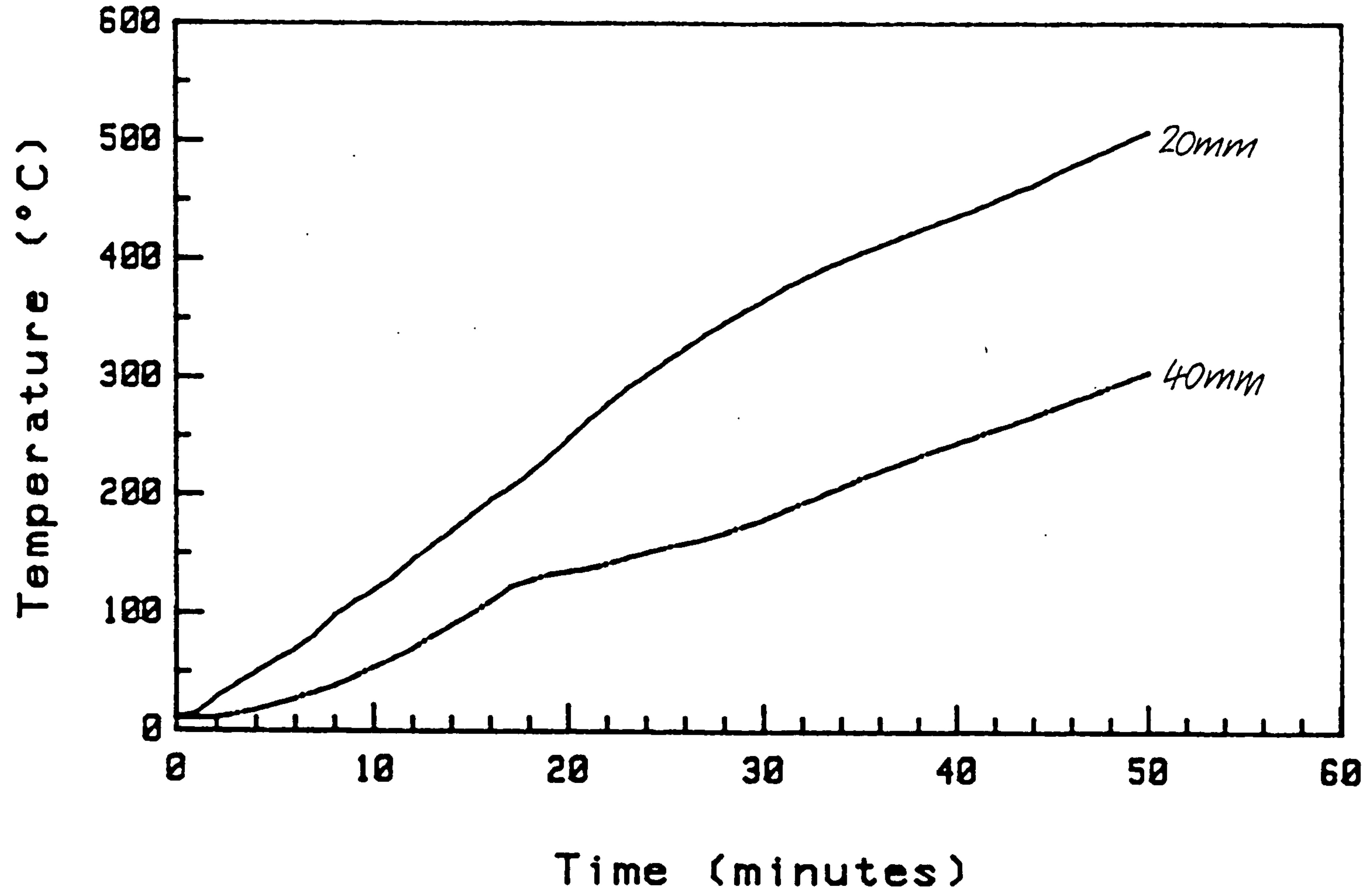

Figure 13 60 mm Alluvial Quartz - Internal Temperatures

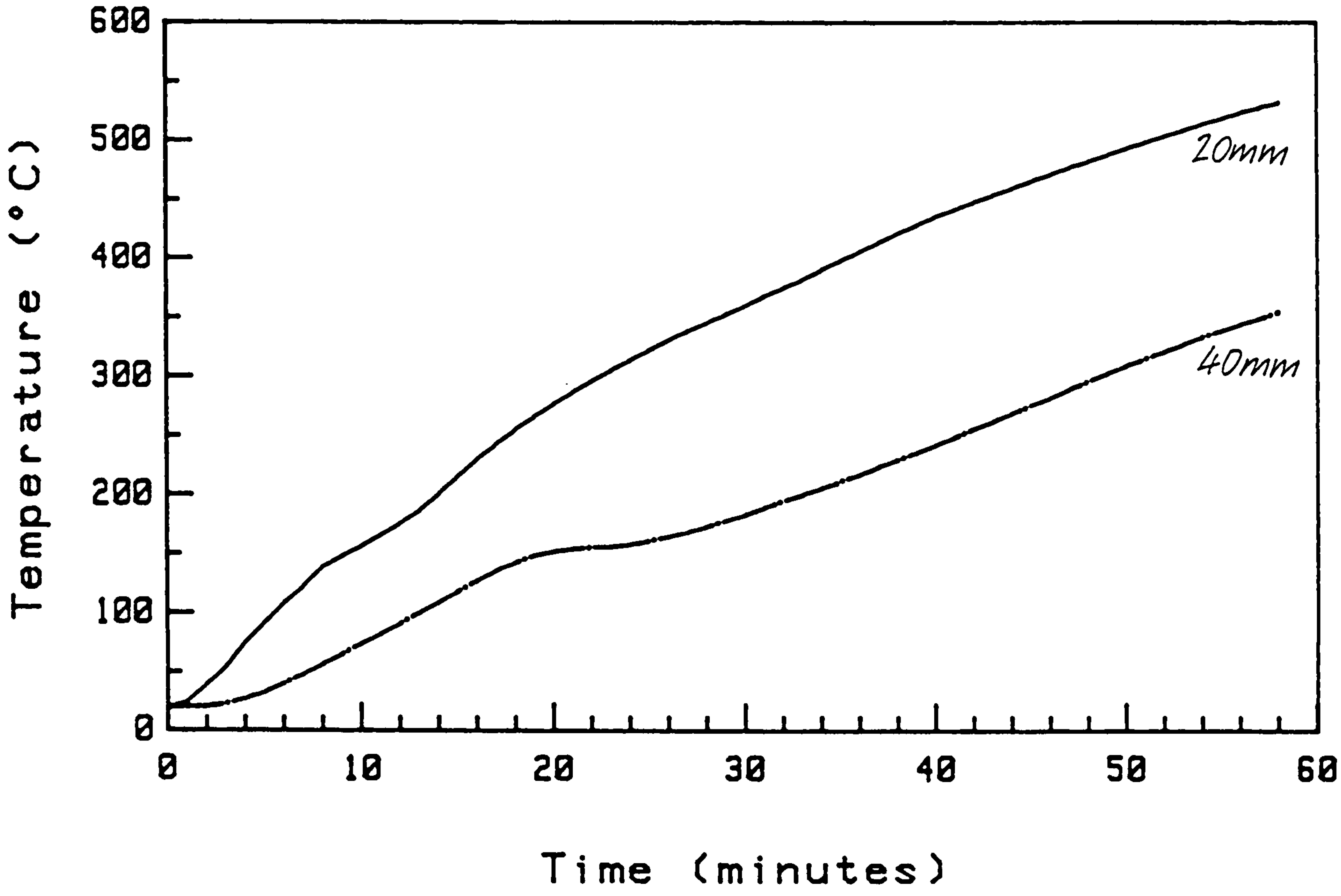

Figure 14 60 mm Greywacke - Internal Temperatures

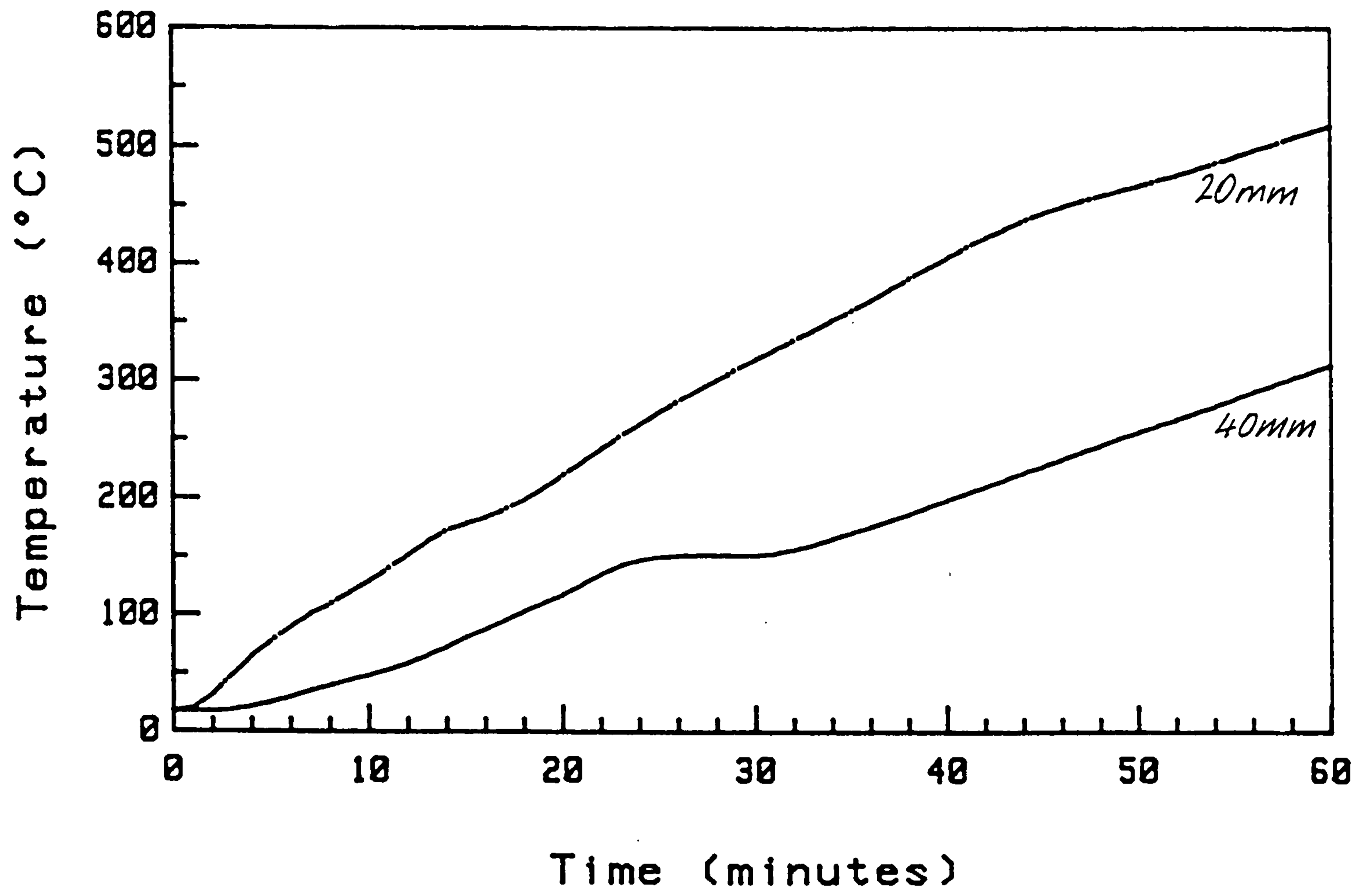

Figure 15 60 mm Quarried Andesite - Internal Temperatures

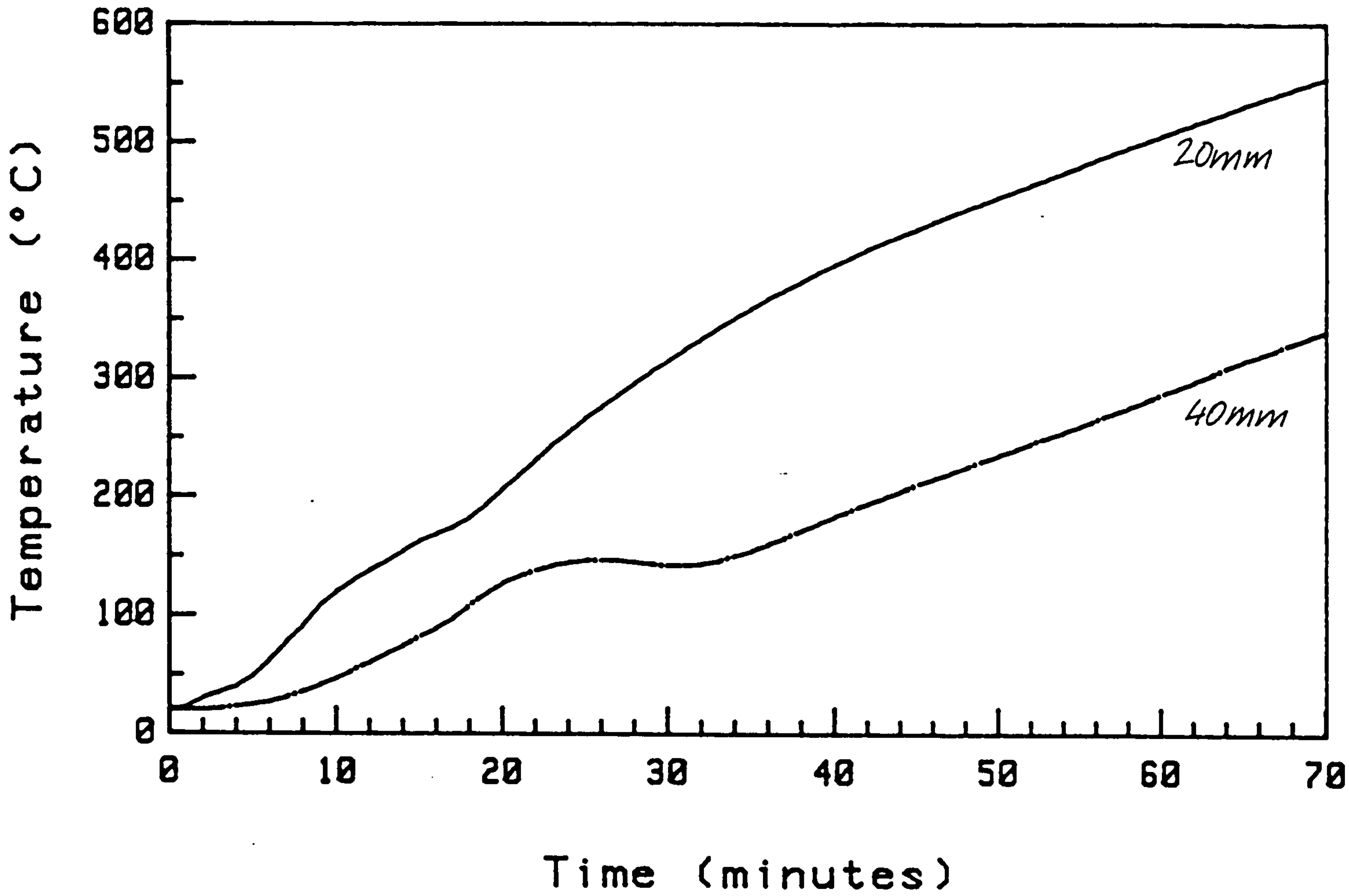

Figure 16 60 mm Limestone - Internal Temperatures

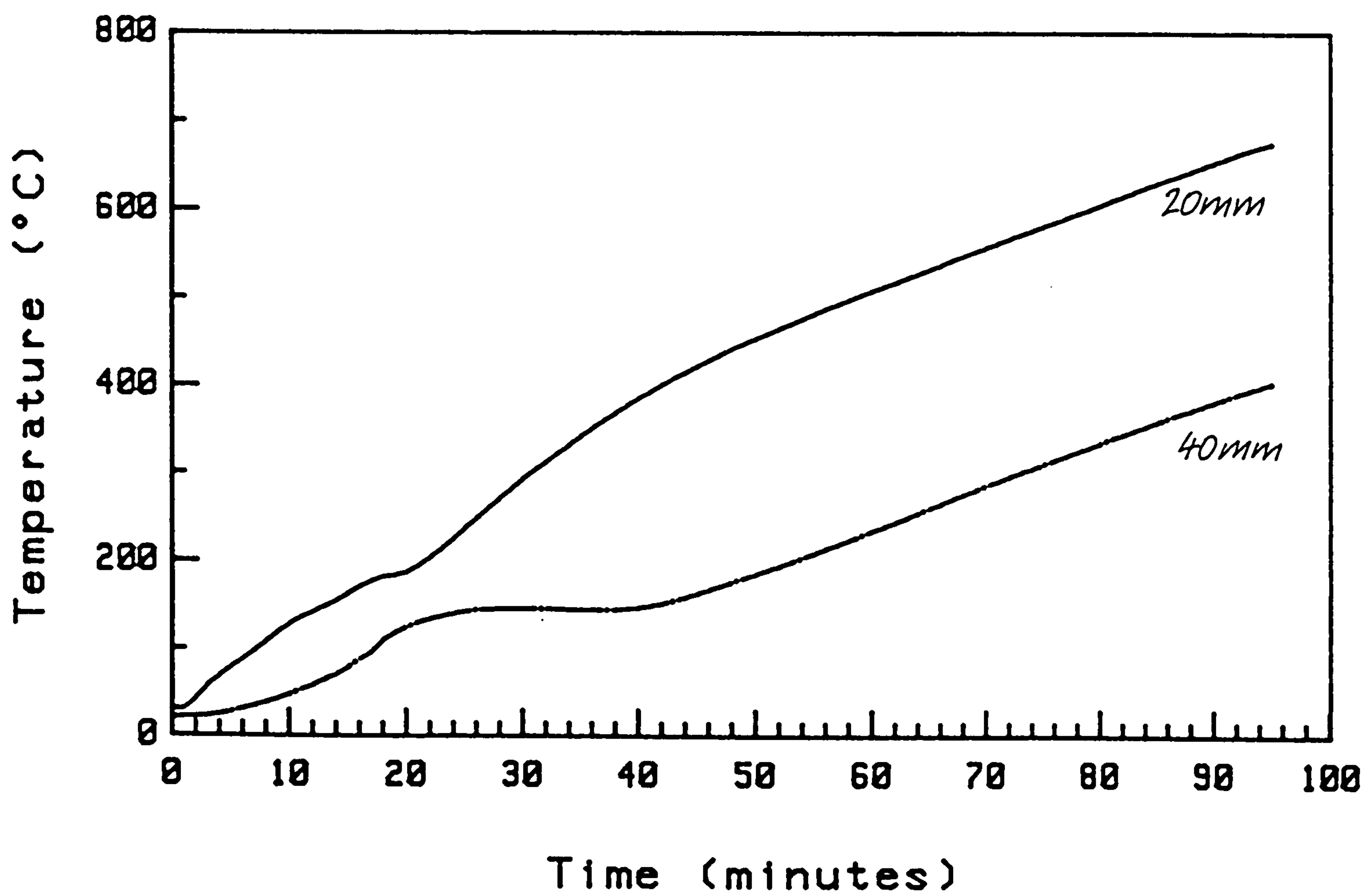

Figure 17 60 mm Pumice - Internal Temperatures

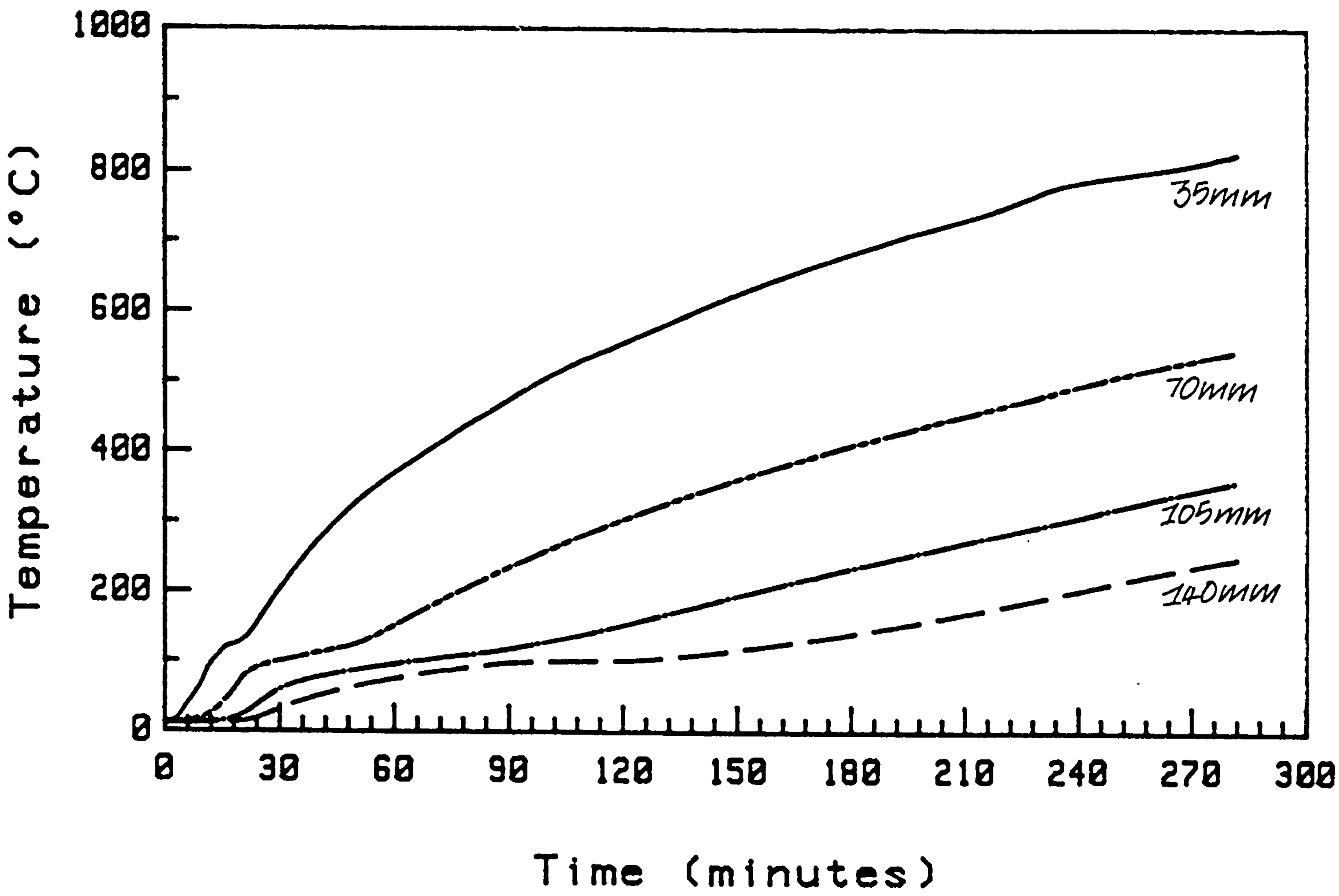

Figure 18 175 mm Alluvial Quartz - Internal Temperatures

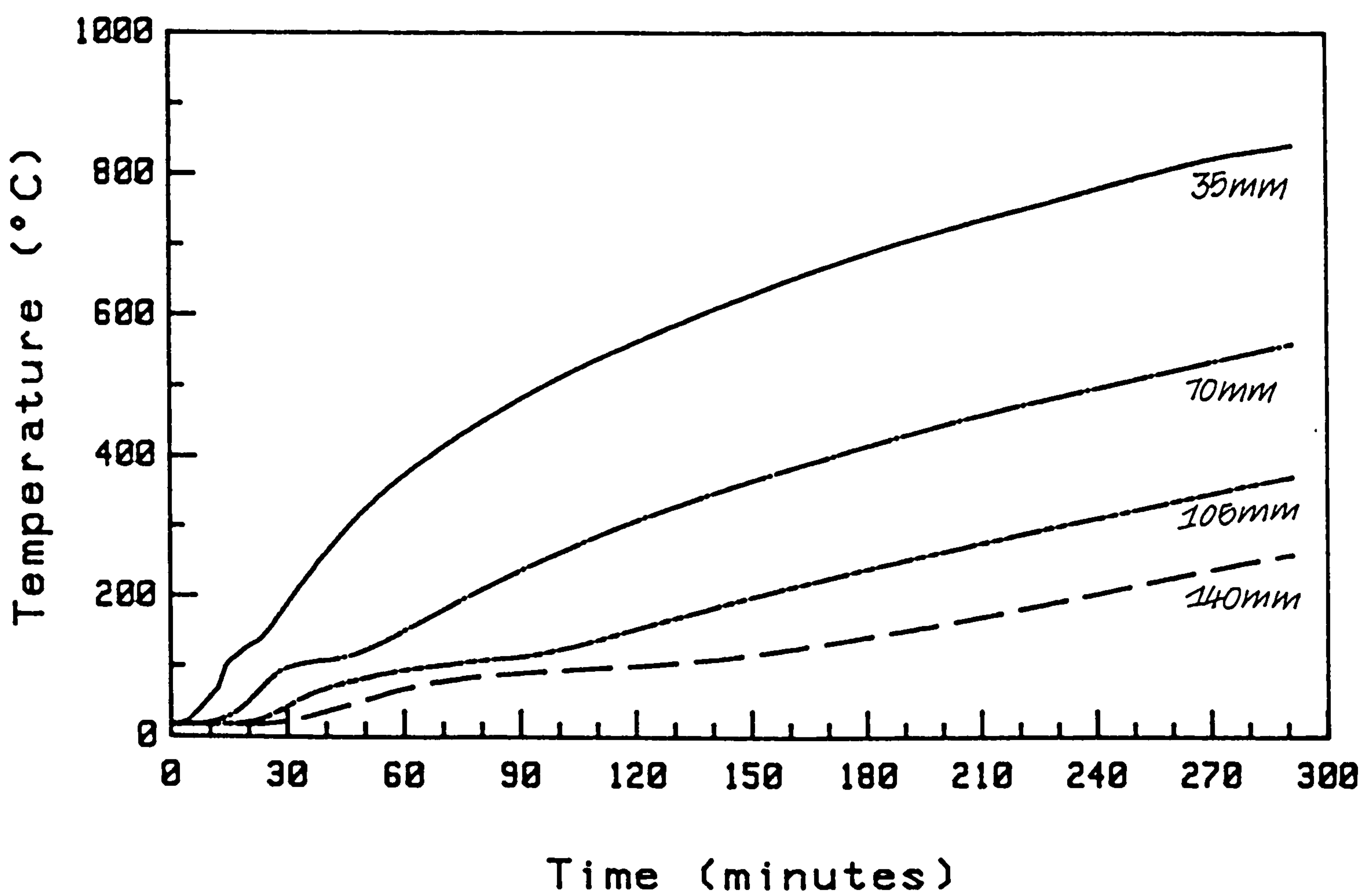

Figure 19 175 mm Vertical Greywacke - Internal Temperatures

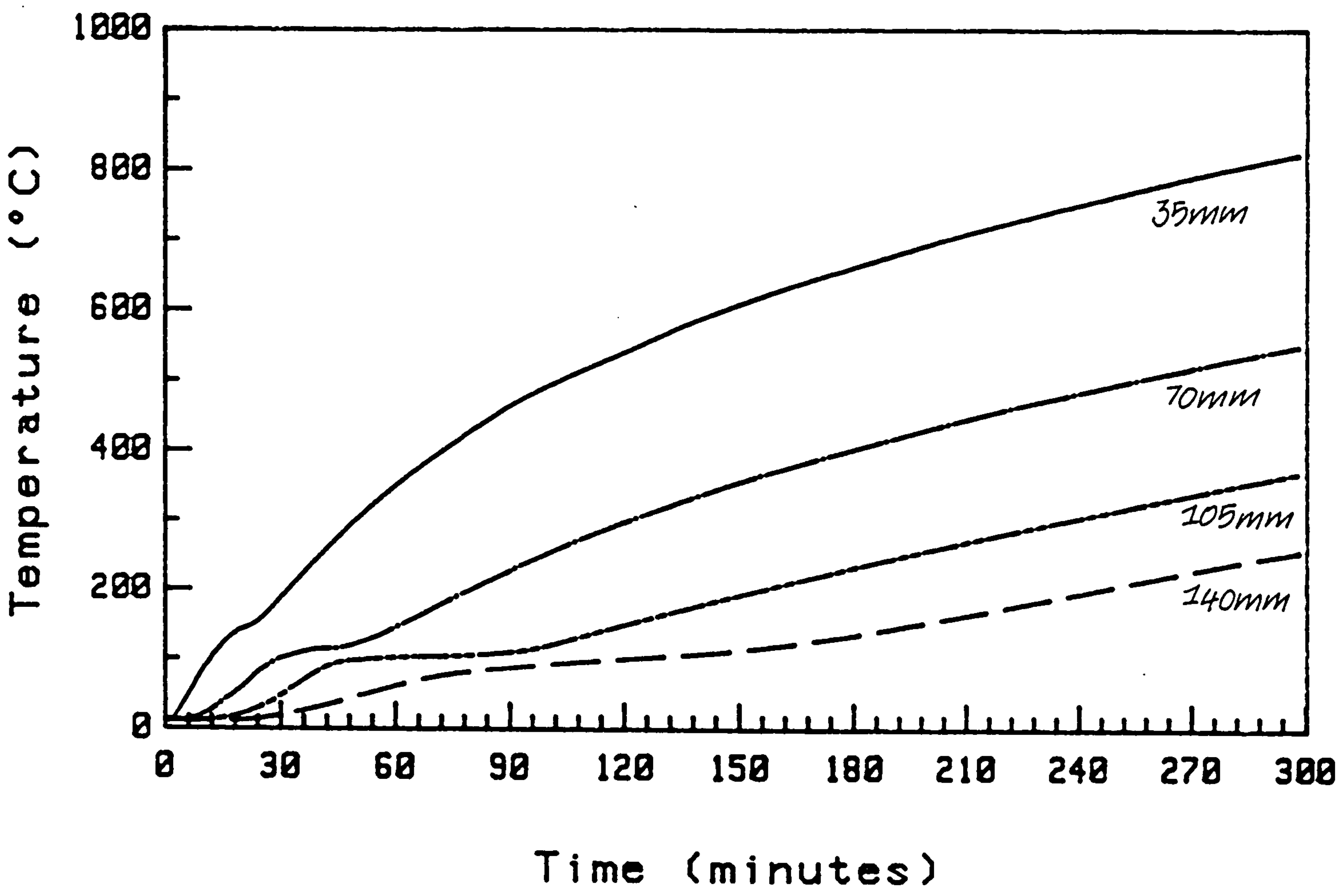

Figure 20 175 mm Horizontal Greywacke - Internal Temperatures

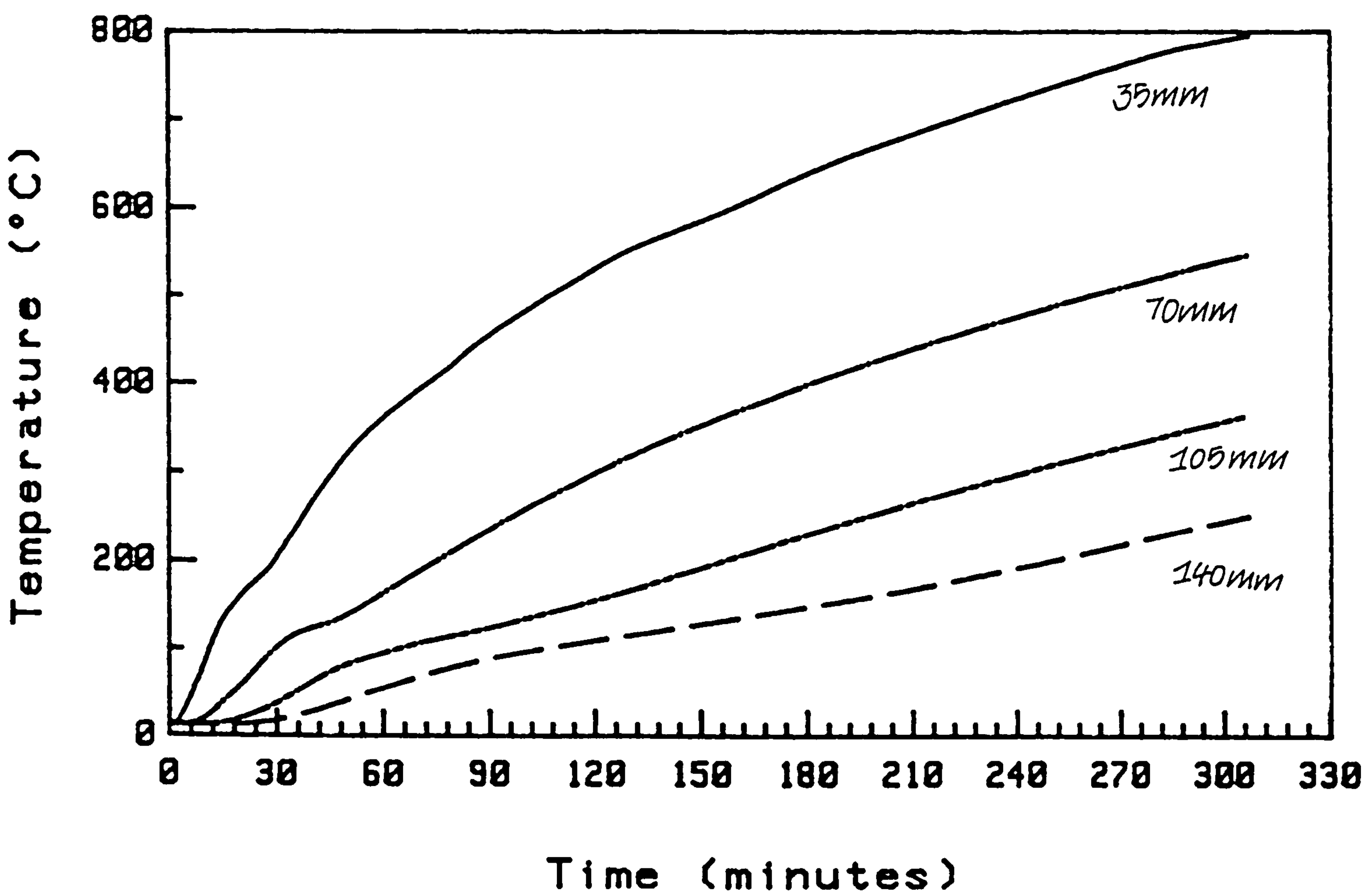

Figure 21 175 mm High Strength Greywacke - Internal Temperatures

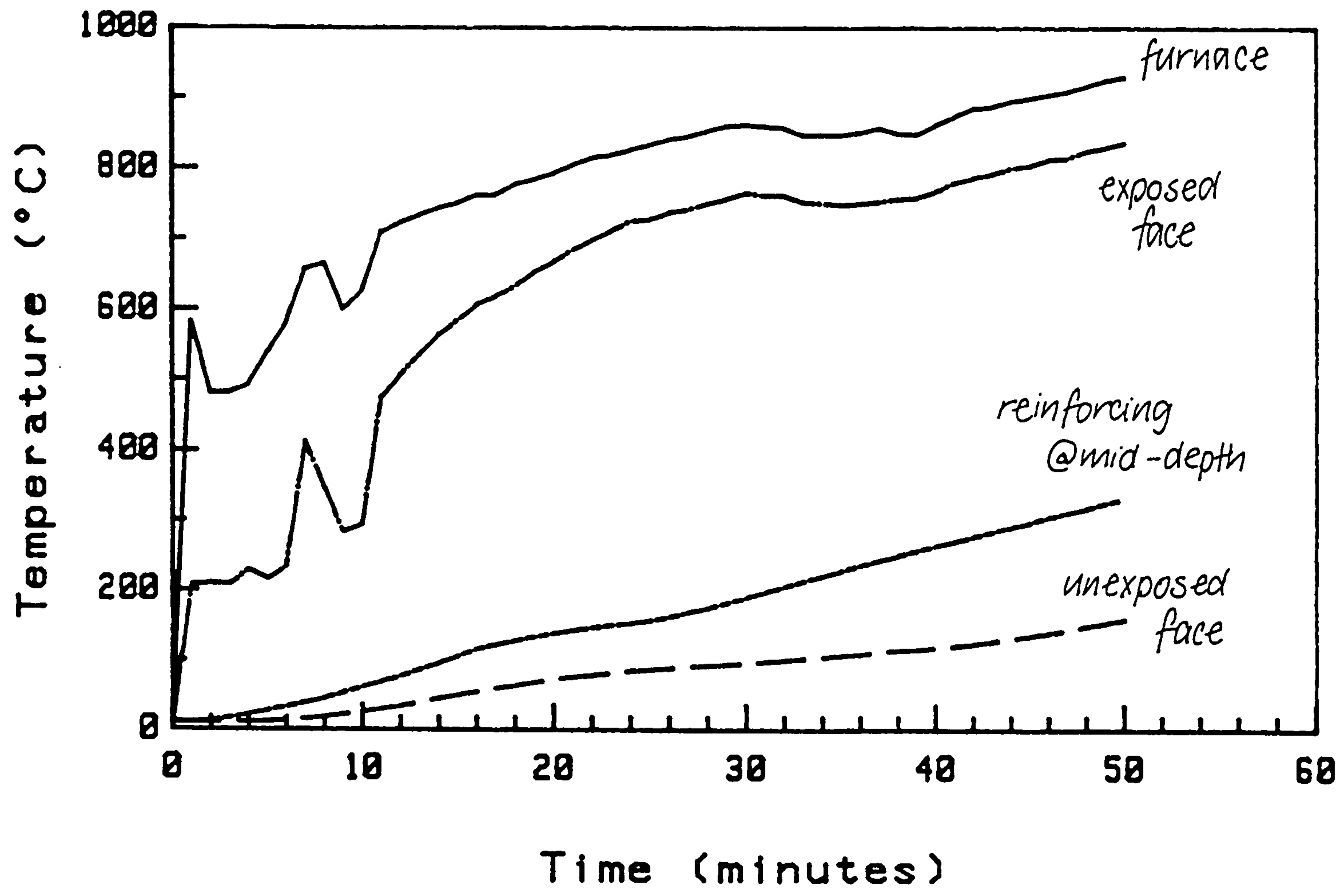

Figure 22 60 mm Alluvial Quartz - Surface and Steel Temperatures

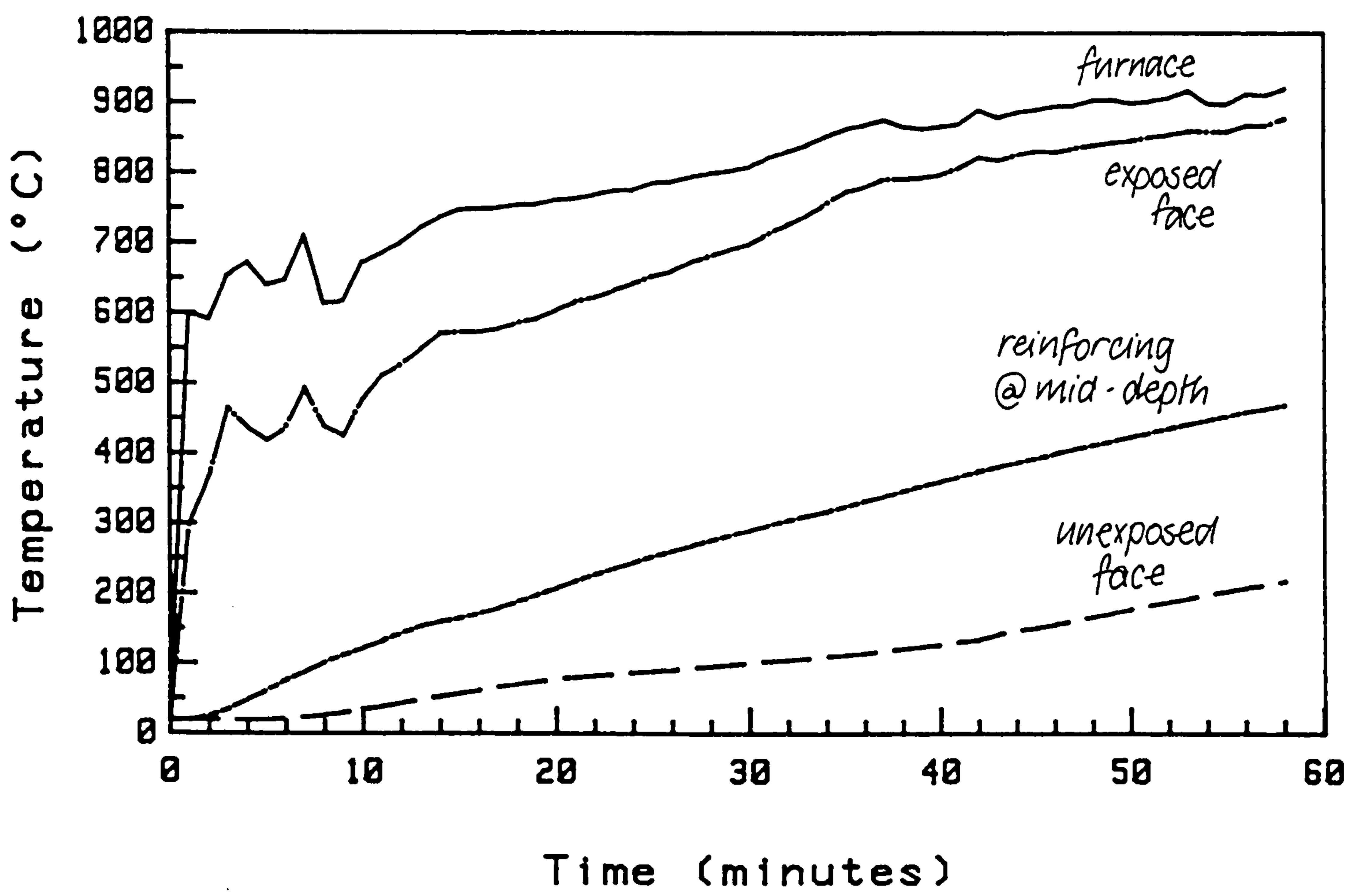

Figure 23 60 mm Greywacke - Surface and Steel Temperatures

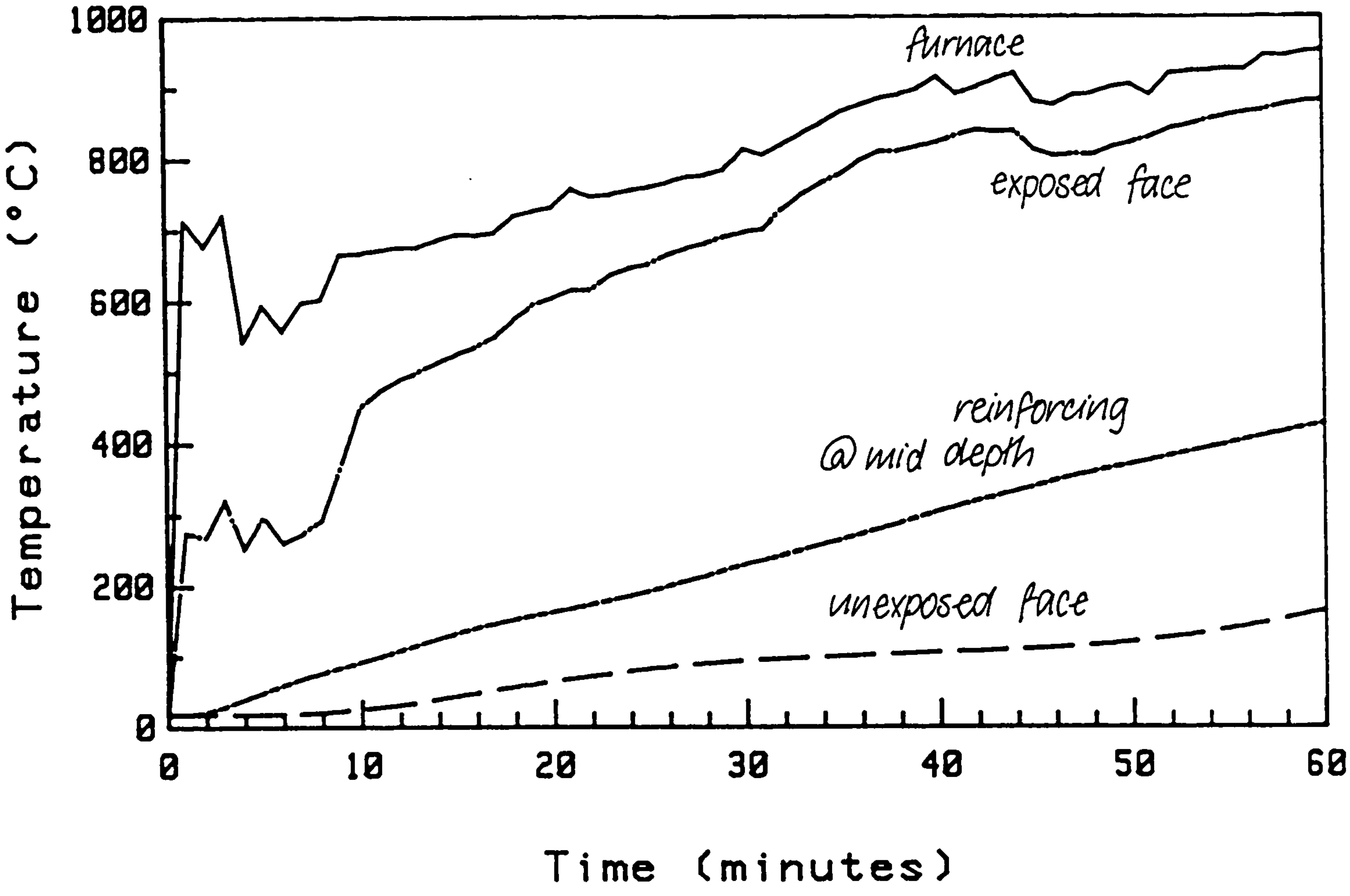

Figure 24 60 mm Quarried Andesite - Surface and Steel Temperatures

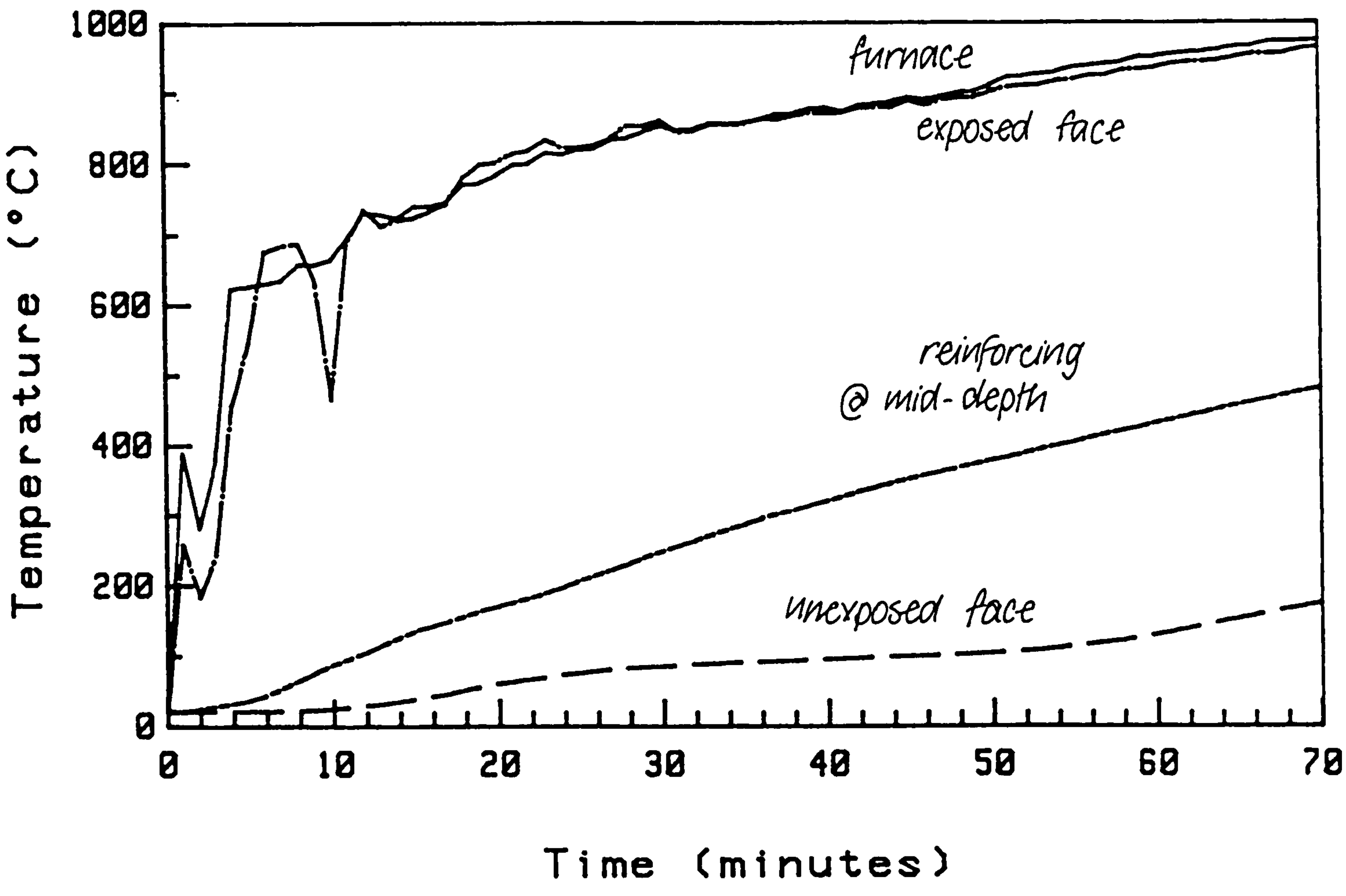

Figure 25 60 mm Limestone - Surface and Steel Temperatures

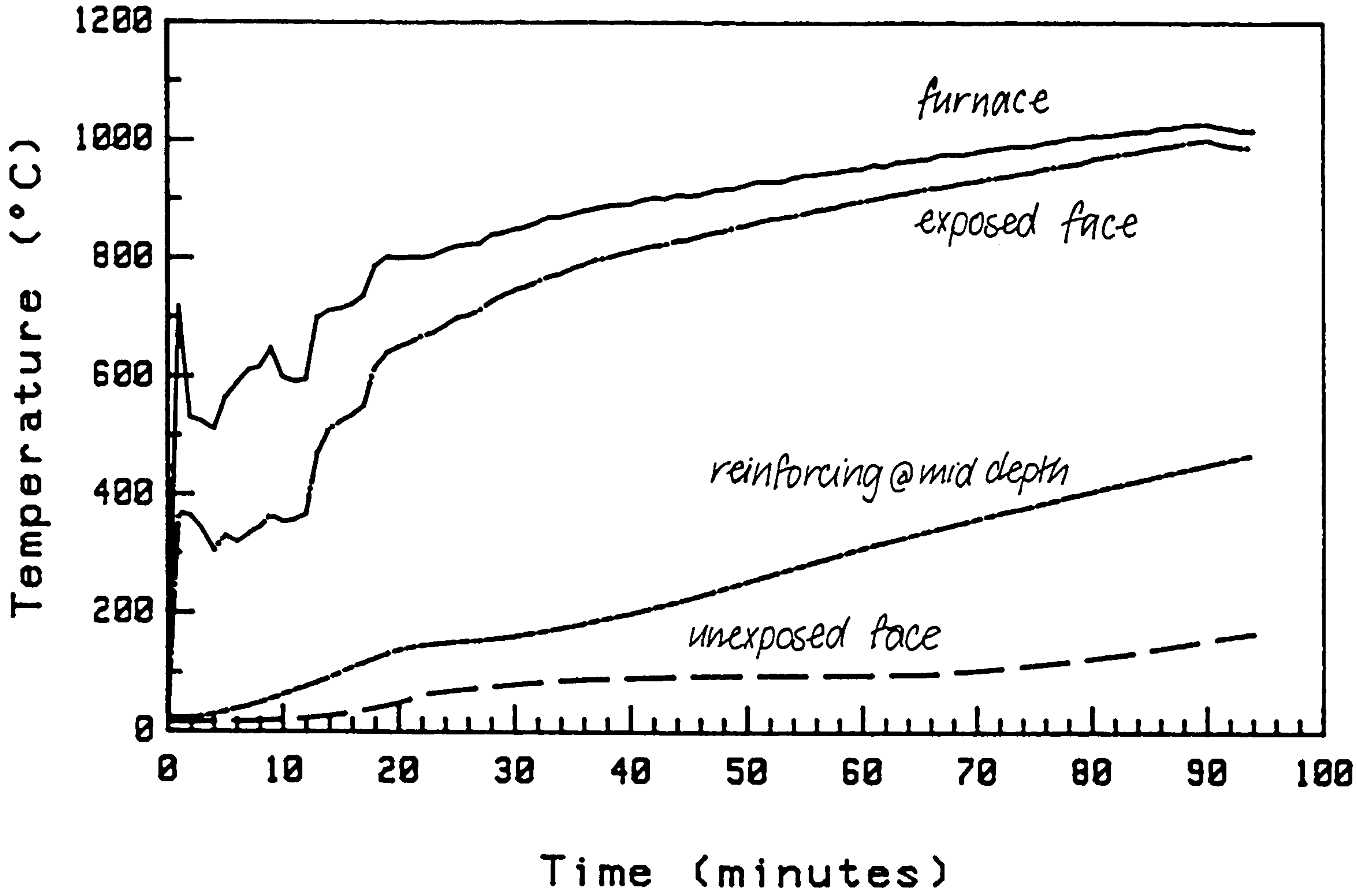

Figure 26 60 mm Pumice - Surface and Steel Temperatures

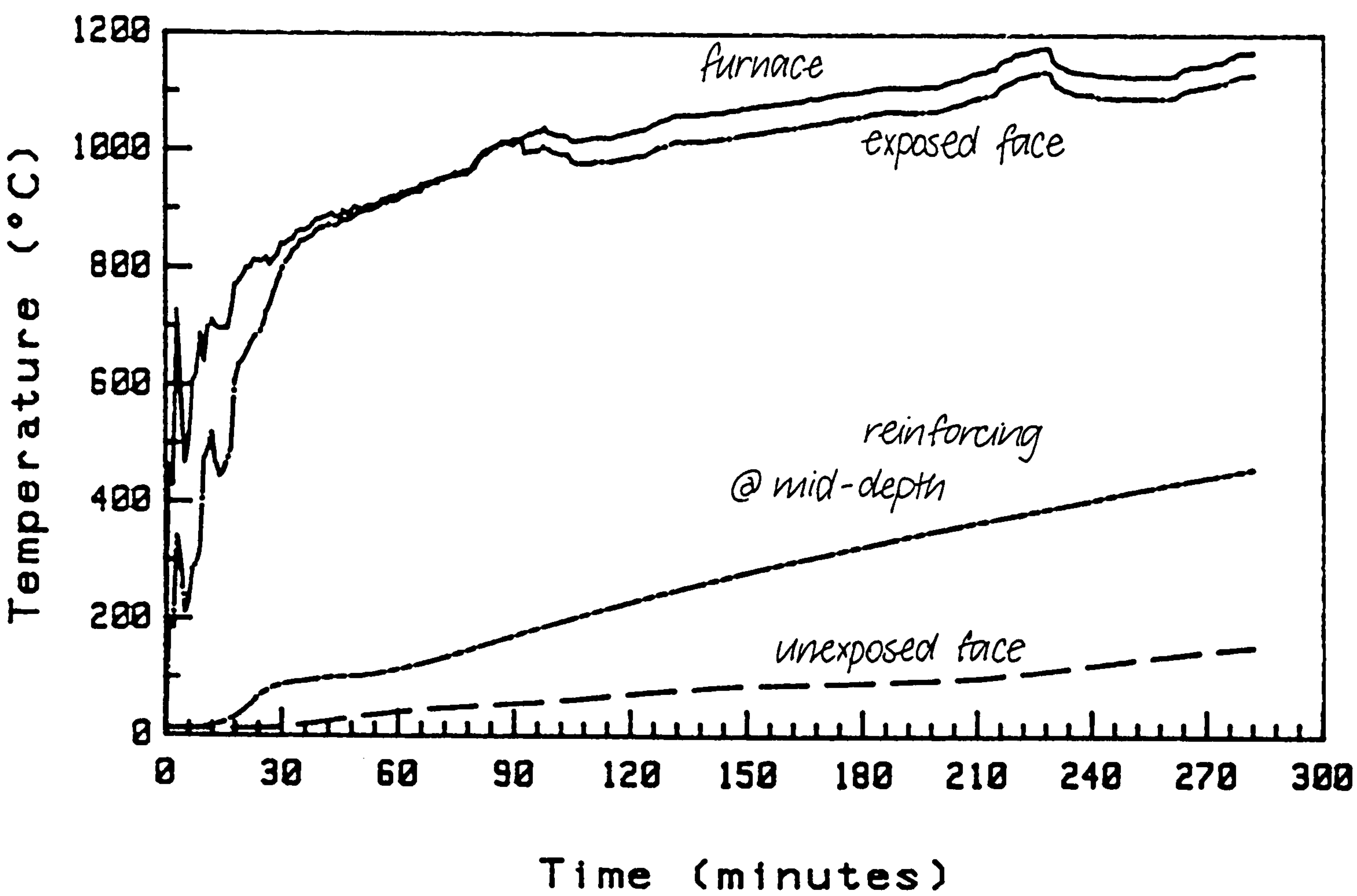

Figure 27 175 mm Alluvial Quartz - Surface and Steel Temperatures

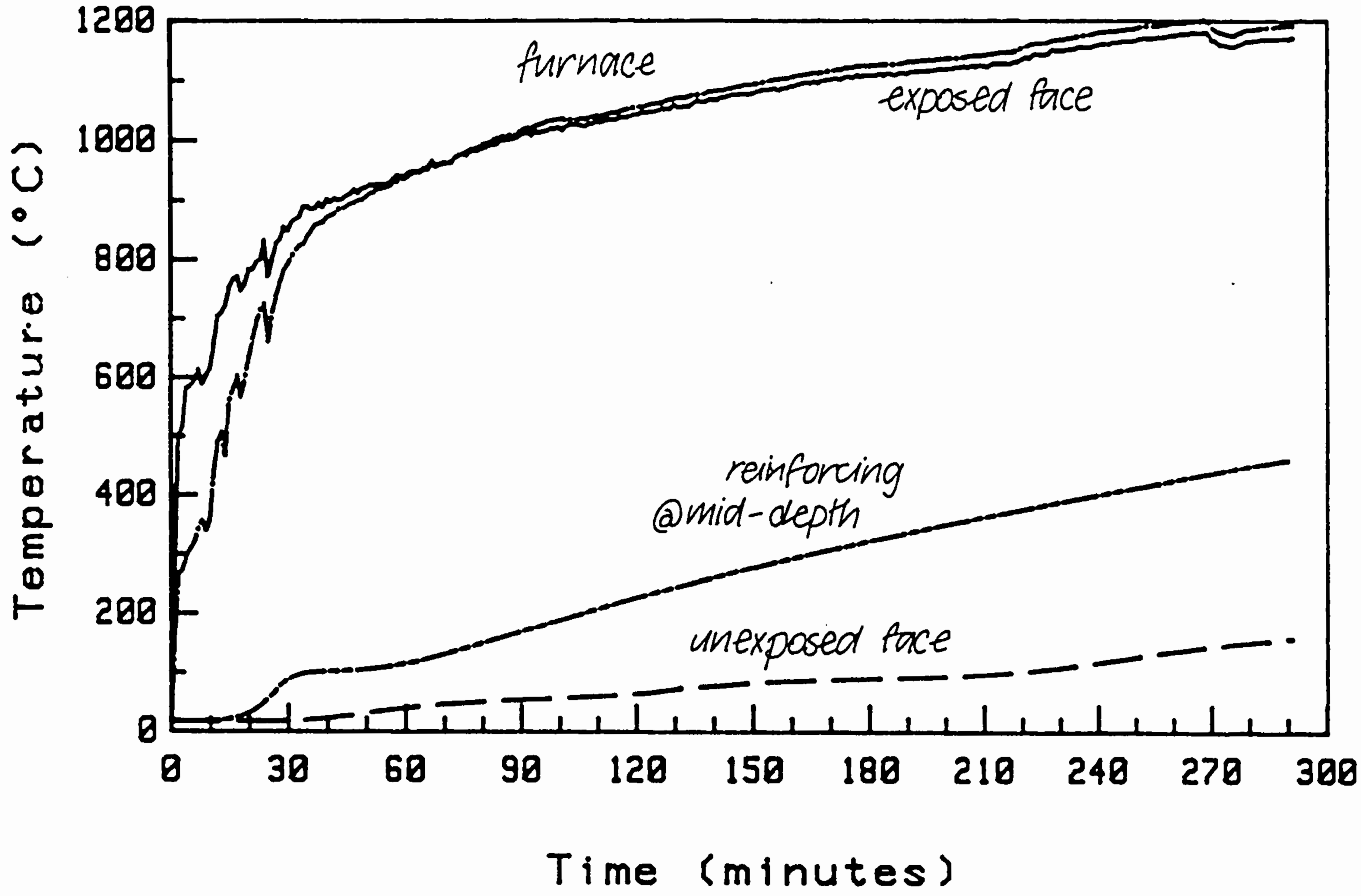

Figure 28 175 mm Vertical Greywacke - Surface and Steel Temperatures

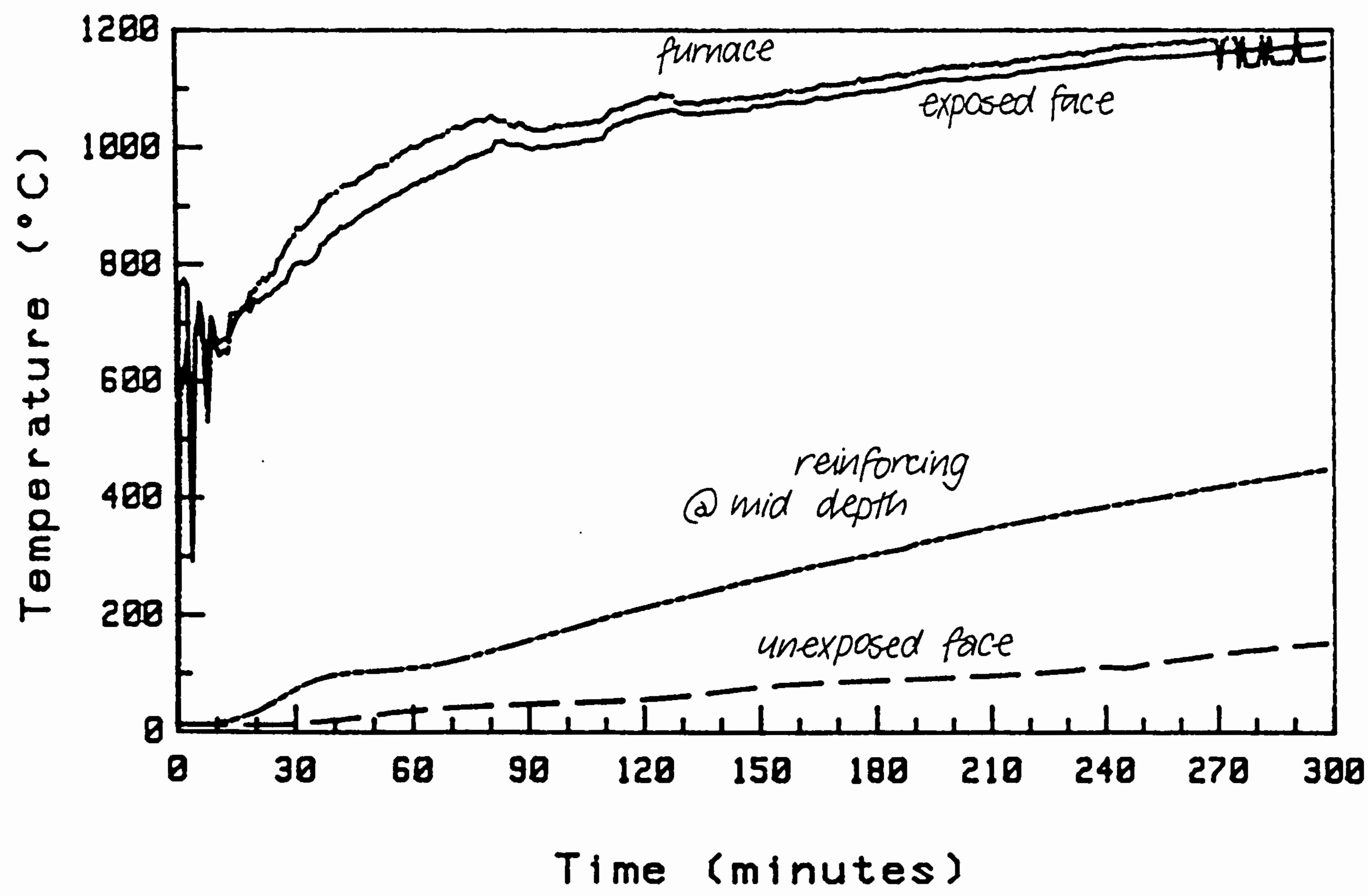

Figure 29 175 mm Horizontal Greywacke - Surface and Steel Temperatures

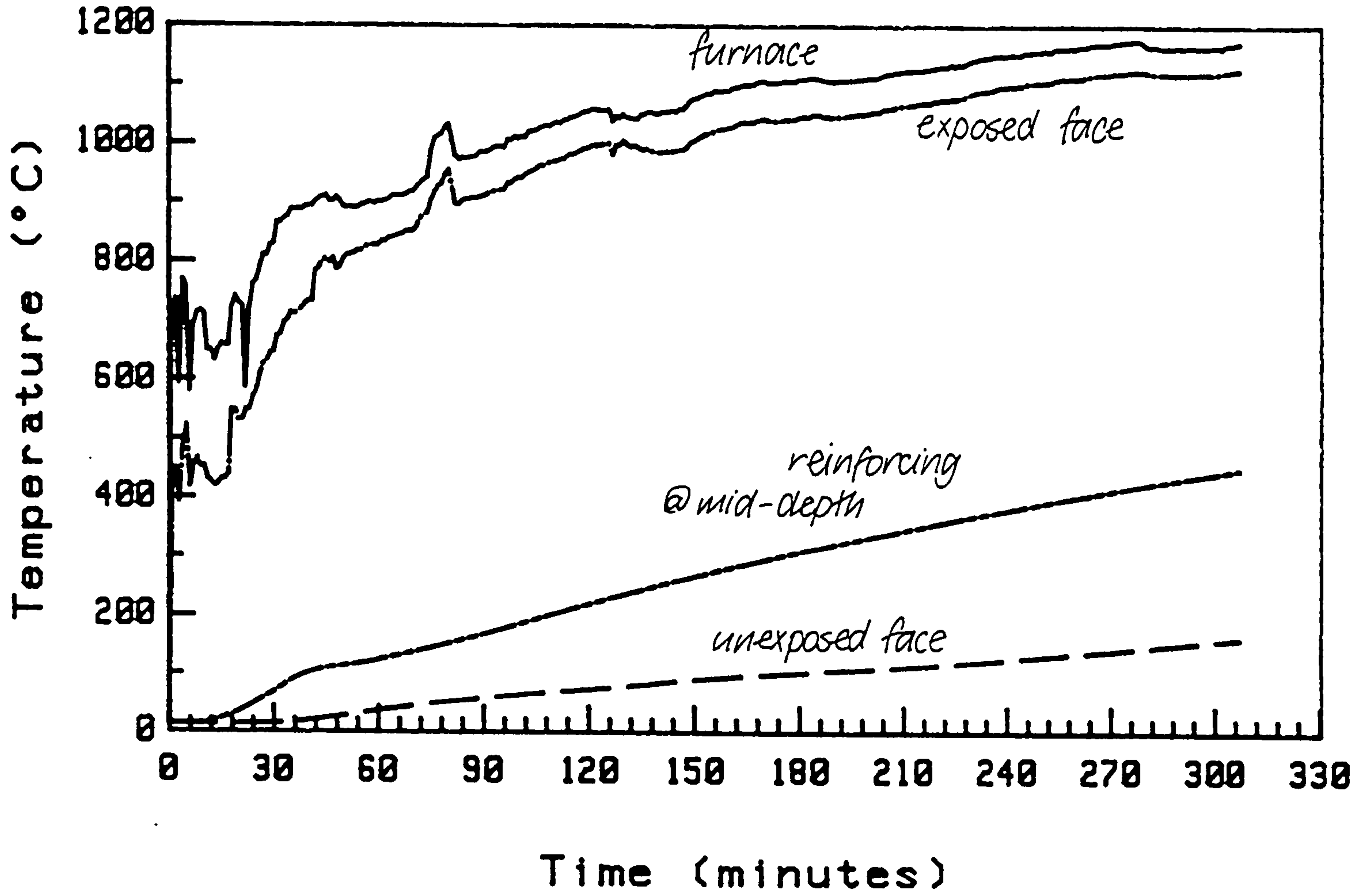

Figure 30 175 mm High Strength Graywacke - Surface and Steel Temperatures

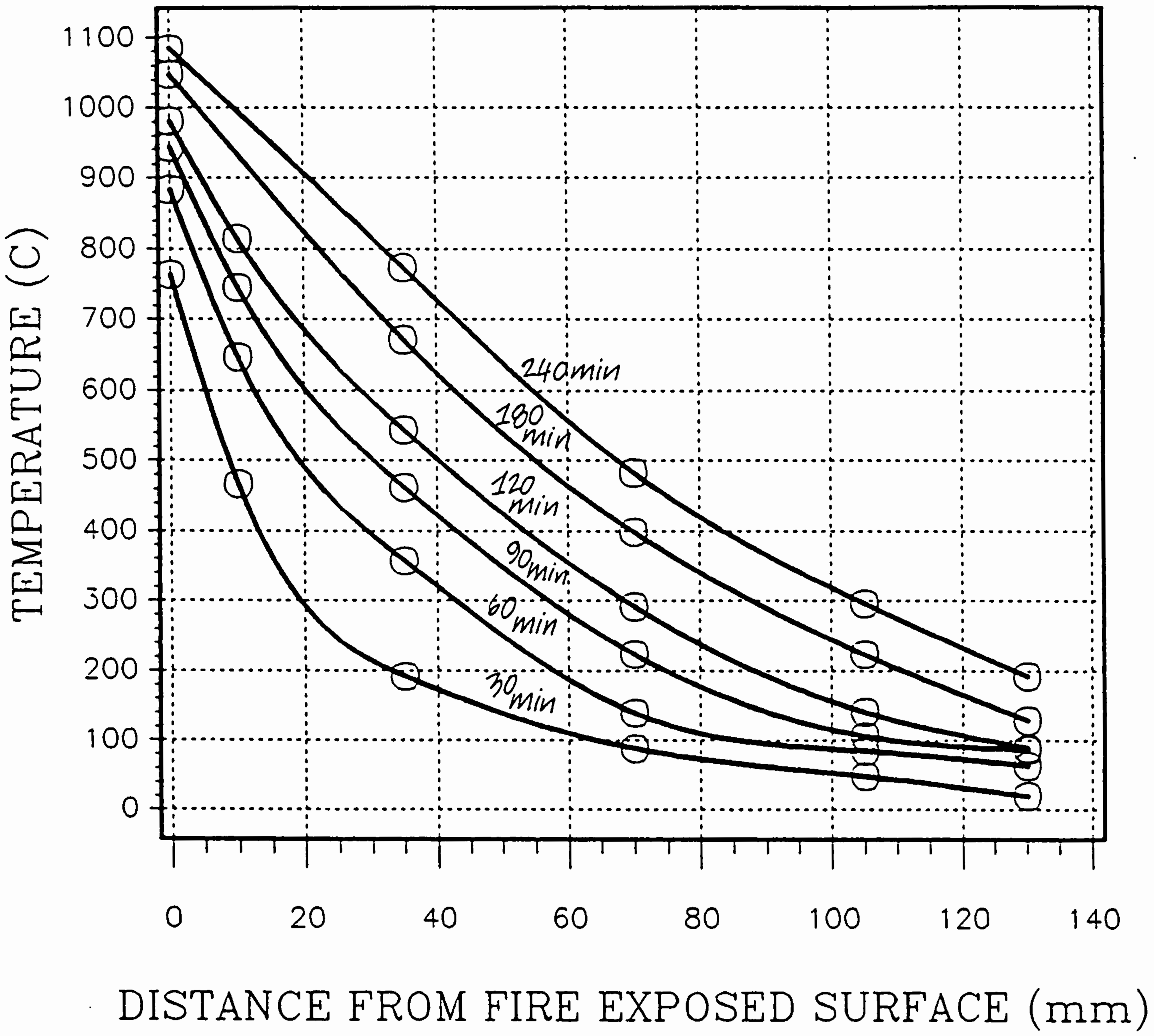

Figure 31 Temperatures Within Alluvial Quartz Concrete Slab

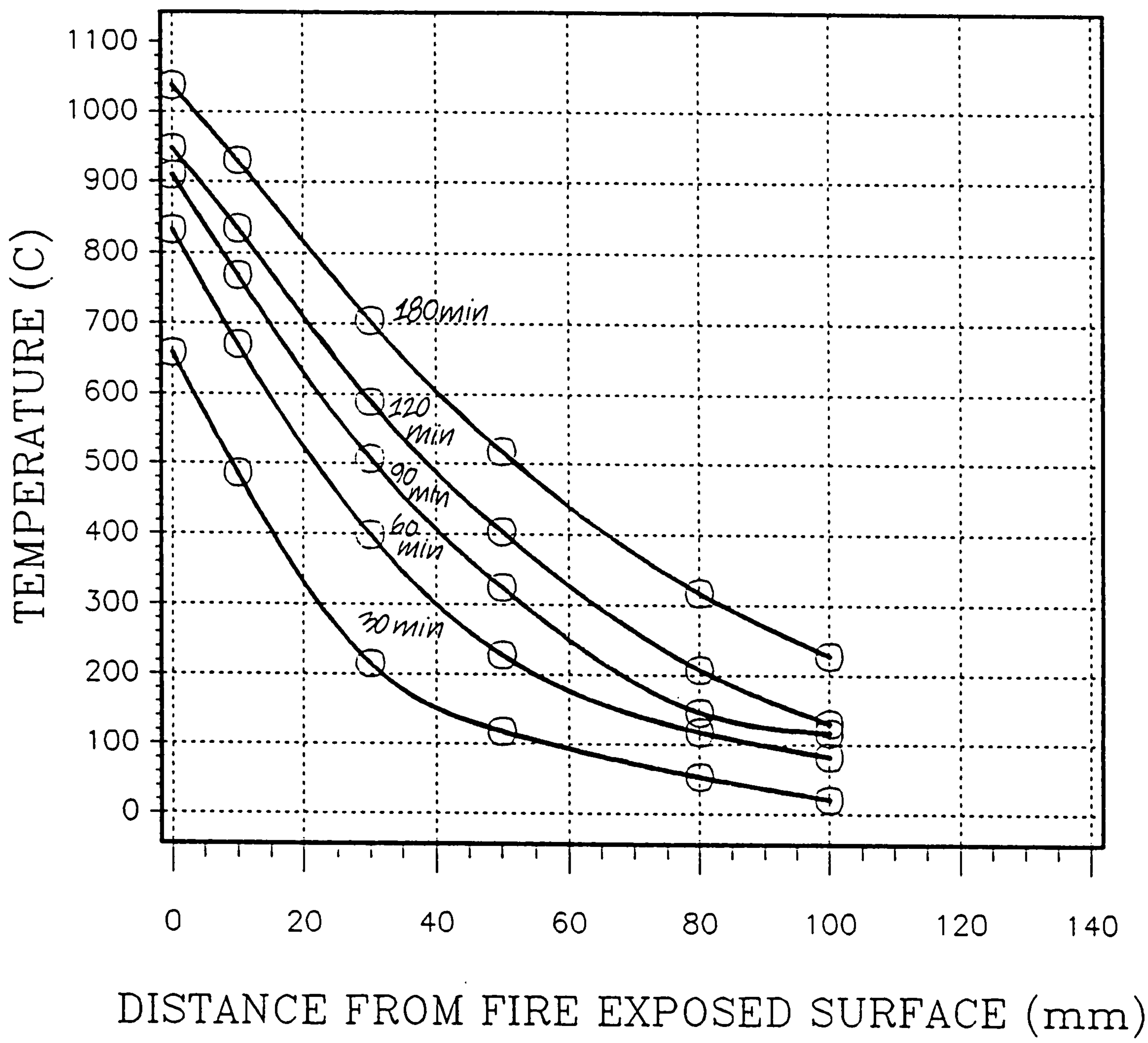

Figure 32 Temperatures Within Dacite Concrete Slab

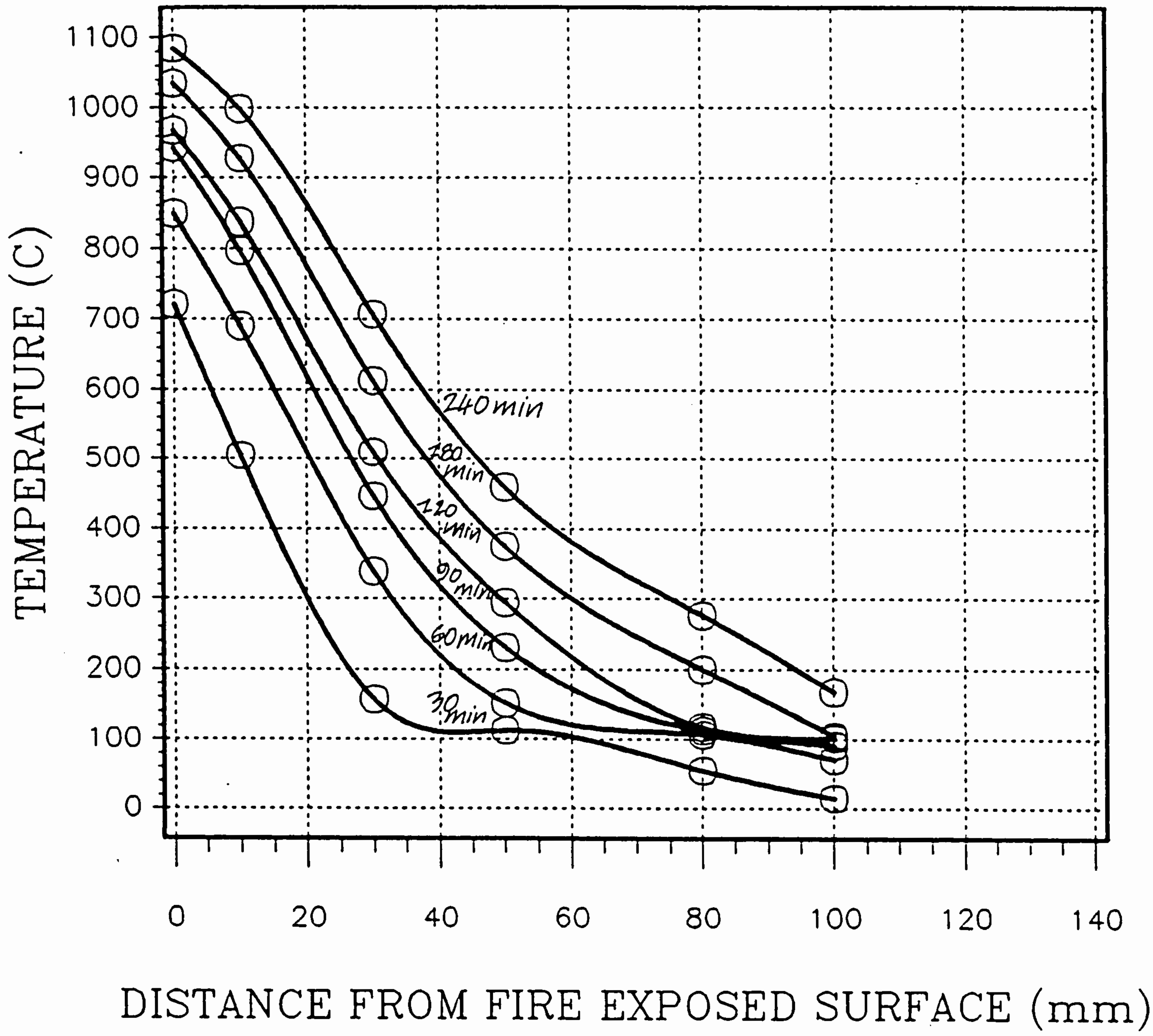

Figure 33 Temperatures Within Pumice Concrete Slab

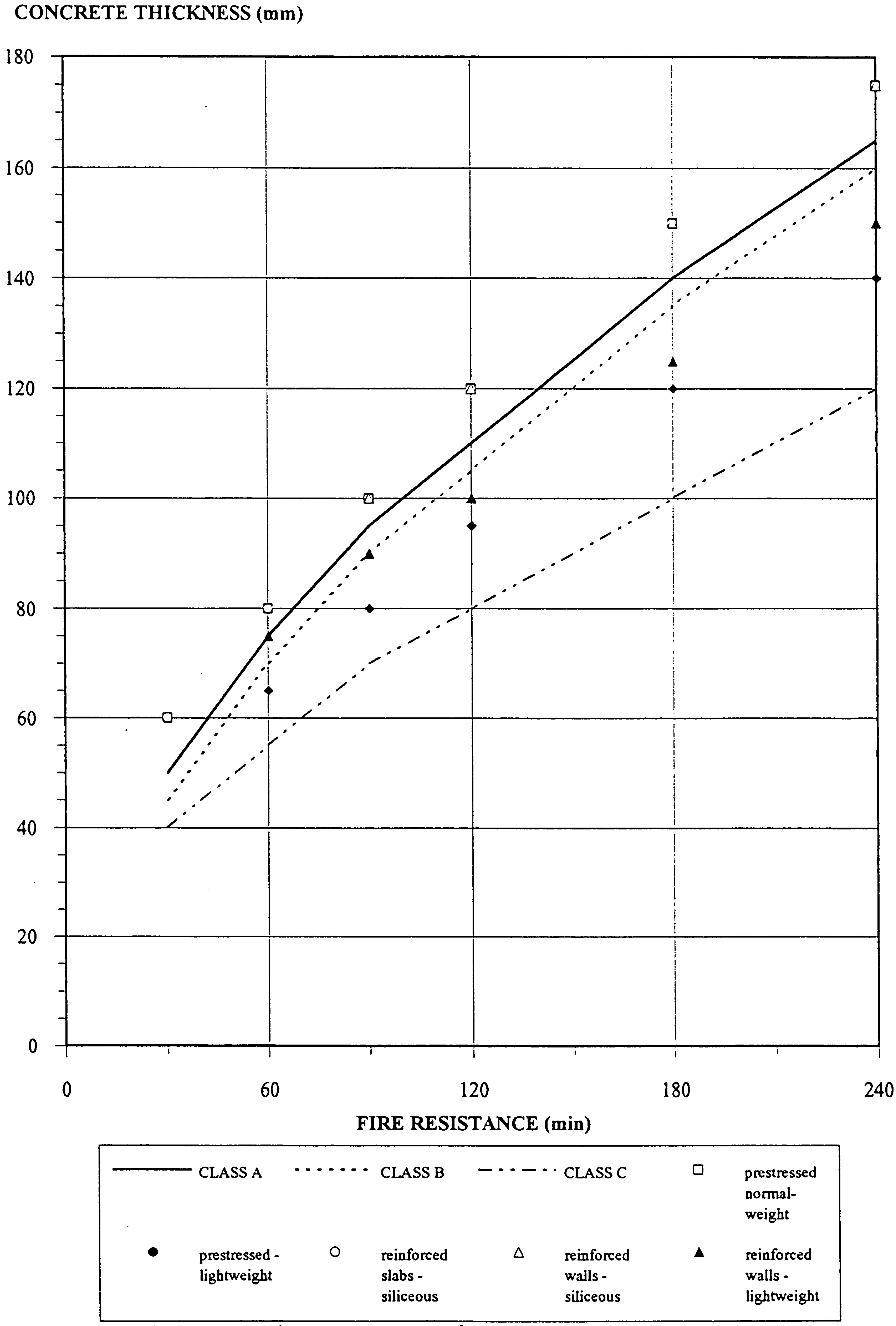

Figure 34 Concrete Thickness Versus Fire Resistance For Class A, B and C Aggregates Compared with MP9

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HEAD OFFICE AND RESEARCH CENTRE

Moonshine Road, Judgeford
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REGIONAL ADVISORY OFFICES

AUCKLAND
Telephone - (09) 524-7018
FAX - (09) 524-7069
290 Great South Road
PO Box 17-214
Greenlane

WELLINGTON
Telephone - (04) 235-7600
FAX - (04) 235-6070
Moonshine Road, Judgeford

CHRISTCHURCH
Telephone - (03) 663-435
FAX - (03) 668-552
GRE Building
79-83 Hereford Street
PO Box 496