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APPENDICES

APPENDIX A

MOLECULAR WEIGHT

Aluminum, Al	Molecular weight = 26.9815
Calcium, Ca	Molecular weight = 40.08
Oxygen, O	Molecular weight = 15.9994
Sulfer, S	Molecular weight = 32.064
Silicon Si	Molecular weight = 28.086
Ferrite, Fe	Molecular weight = 55.847
Magnesium, Mg	Molecular weight = 24.312
Sodium, Na	Molecular weight = 22.9898
Potassium K	Molecular weight = 39.102

APPENDIX B

CHEMICAL COMPOSITION OF PORTLAND CEMENT TYPE I AND MAE MOH FLY ASH

Chemical Composition	OPC Type I (Red Elephant)	Mae Moh Fly Ash
SiO_2	20.10	34.80
Fe_2O_3	2.93	14.17
Al_2O_3	5.52	18.15
CaO	63.77	22.62
MgO	1.50	3.02
SO_3	2.55	3.64
Na_2O	0.28	0.9
K_2O	0.45	2.19
Free Lime	NA	0.72

APPENDIX C

CHEMICAL TEST RESULTS

Reference pattern: 04-0733

Name : Calcium Hydroxide
Name : Portlandite, syn
Formula : Ca(OH)2
Elements : H, O, Ca
Groups : OH
Subfiles : Inorganic, Minerals, Common phases, NBS patterns, Forensics, Educational patterns, Cement phases
Pattern deleted: NO

Radiation : Cu KÁ
Wavelength : 1.54186

d value	Angle	Rel.Int.
4.9000	18.104	74
3.1120	28.686	23
2.6280	34.118	100
2.4470	36.728	3
1.9270	47.165	42
1.7960	50.840	36
1.6870	54.385	21
1.6340	56.303	1
1.5570	59.358	3
1.4840	62.597	13
1.4490	64.287	13
1.3140	71.847	8
1.2280	77.775	1
1.2110	79.079	1
1.1762	81.906	3
1.1432	84.809	11
1.1275	86.275	2
1.0599	93.331	12
1.0366	96.097	5
1.0143	98.939	7
0.9551	107.641	4
0.9369	110.743	1
0.8979	118.318	1
0.8838	121.452	2
0.8760	123.299	1
0.8623	126.771	2
0.8495	130.328	6
0.8140	142.557	5

Reference pattern: 42-0551

Name : Calcium Silicate
Formula : Ca3SiO5
Elements : O, Si, Ca
Groups : --
Subfiles : Inorganic, Cement phases
Pattern deleted: NO

Radiation : Cu KÁ
Wavelength : 1.54186

d value	Angle	Rel.Int.
5.9300	14.940	12
5.4900	16.145	4
3.8700	22.981	3
3.8610	23.035	4
3.5280	25.244	4
3.5170	25.324	2
3.2460	27.478	3
3.1810	28.051	4
3.0360	29.420	40
3.0250	29.530	75
2.9680	30.110	12
2.9620	30.173	25
2.7730	32.283	85
2.7480	32.585	45
2.7380	32.708	75
2.6900	33.308	6
2.6900	33.308	6
2.6040	34.442	100
2.4440	36.775	9
2.3230	38.765	9
2.3160	38.886	20
2.1810	41.400	60
2.1650	41.720	15
2.1600	41.821	7
2.0650	43.843	3
1.9800	45.829	5
1.9740	45.977	10
1.9350	46.958	7
1.9300	47.087	13
1.8320	49.772	7
1.8250	49.976	5
1.8200	50.123	6
1.7640	51.830	55
1.7580	52.020	30
1.6940	54.142	2
1.6890	54.316	2
1.6400	56.079	5
1.6400	56.079	5
1.6260	56.605	5

d value	Angle	Rel.Int.
1.6230	56.719	15
1.5390	60.123	20
1.5390	60.123	20
1.5260	60.689	1
1.5220	60.865	2
1.5130	61.266	2
1.4890	62.363	10
1.4870	62.456	10
1.4850	62.550	10
1.4800	62.785	5
1.4710	63.214	2
1.4710	63.214	2
1.4620	63.648	4
1.4570	63.892	10
1.4260	65.452	1
1.4030	66.664	2
1.4030	66.664	2
1.3690	68.546	5
1.3690	68.546	5

Reference pattern: 41-1451

Name : Calcium Aluminum Sulfate Hydroxide Hydrate
Name : Ettringite, syn
Formula : Ca6Al2(SO4)3(OH)12!26H2O
Elements : H, O, Al, S, Ca
Groups : H2O, OH, SO4
Subfiles : Inorganic, Minerals, Common phases, Cement phases, Corrosion products
Pattern deleted: NO

Radiation : Cu KÁ
Wavelength : 1.54186

d value	Angle	Rel.Int.
9.7200	9.098	100
8.8500	9.995	4
7.2000	12.293	1
5.6100	15.797	76
4.9700	17.847	12
4.8590	18.258	6
4.6890	18.926	17
4.4250	20.067	1
4.0170	22.129	3
3.8730	22.963	31
3.6730	24.232	4
3.5980	24.745	7
3.4750	25.636	23
3.2660	27.307	5
3.2400	27.530	21
3.1010	28.790	1
3.0110	29.670	4
2.8060	31.894	6
2.7720	32.295	25
2.7140	33.005	1
2.6960	33.232	7
2.6760	33.487	1
2.6140	34.306	16
2.5600	35.053	29
2.5220	35.598	2
2.4850	36.147	2
2.4300	36.994	1
2.4160	37.216	1
2.3990	37.490	6
2.3440	38.404	2
2.2300	40.450	8
2.2060	40.910	22
2.1830	41.361	5
2.1510	42.005	13
2.1280	42.481	2
2.1210	42.628	5
2.0800	43.510	2

d value	Angle	Rel.Int.
2.0580	43.999	3
2.0220	44.825	1
2.0000	45.345	1
1.9710	46.051	2
1.9440	46.728	11
1.9030	47.797	1
1.8700	48.694	1
1.8500	49.255	3
1.8420	49.484	5
1.8300	49.830	3
1.8100	50.419	4
1.7840	51.206	1
1.7840	51.206	1
1.7660	51.767	4
1.7450	52.437	2
1.7230	53.159	2
1.7050	53.765	2
1.6770	54.737	3
1.6620	55.273	5
1.6600	55.345	5
1.6200	56.834	8
1.5980	57.689	2
1.5830	58.288	3
1.5740	58.654	3
1.5600	59.232	1
1.5330	60.383	1
1.5070	61.537	2
1.4940	62.131	1
1.4590	63.794	1
1.4270	65.401	1
1.4120	66.184	1
1.4120	66.184	1
1.3880	67.480	1
1.3570	69.238	1
1.3390	70.305	1
1.3140	71.847	1
1.3070	72.292	2
1.2900	73.399	1
1.2790	74.136	2
1.2790	74.136	2
1.2610	75.377	1
1.2520	76.014	2
1.2250	78.002	2
1.2250	78.002	2
1.2180	78.536	1
1.1940	80.432	1
1.1750	82.008	1
1.1750	82.008	1

d value	Angle	Rel.Int.
1.1580	83.479	1
1.1320	85.849	1
1.1270	86.323	1
1.1030	88.684	2
1.1030	88.684	2
1.1010	88.888	1
1.0840	90.664	1
1.0340	96.418	1
1.0340	96.418	1
1.0290	97.043	1
1.0290	97.043	1

Philps Analytical X-Ray B.V. PC-APD,Diffraction software

Sample identification: EA 4#
Data measured at: 20-Nov-2001 8:12:00

Diffractometer type: PW3710 BASED
Tube anode: Cu
Generator tension [kV]: 45
Generator current [mA]: 35
Wavelength Alpha1 []: 1.54060
Wavelength Alpha2 []: 1.54439
Intensity ratio (alpha2/alpha1): 0.500
Divergence slit: 1½
Receiving slit: 0.1
Monochromator used: YES

Start angle [½2Õ]: 10.020
End angle [½2Õ]: 69.980
Step size [½2Õ]: 0.040
Maximum intensity: 2798.410
Time per step [s]: 1.600
Type of scan: CONTINUOUS

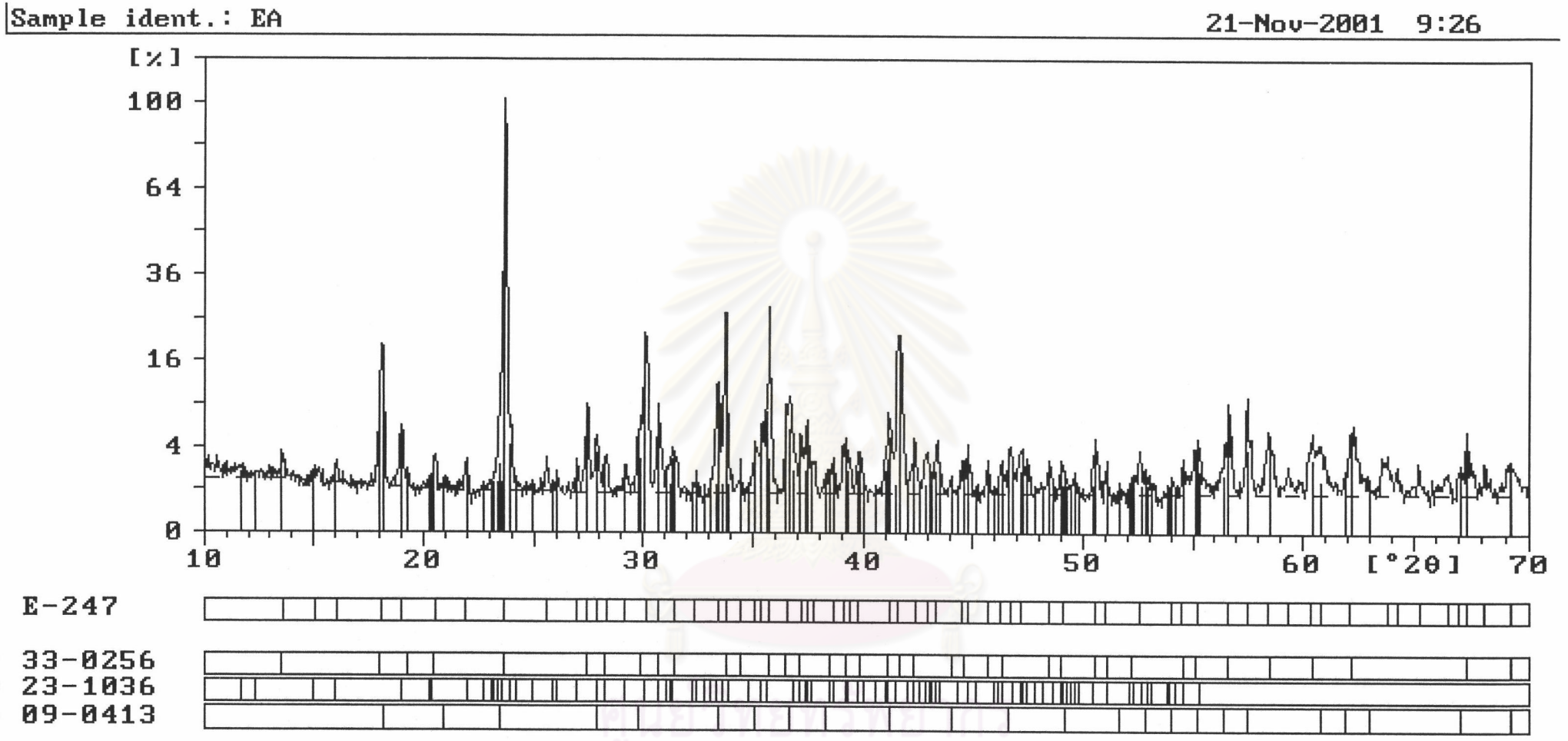
Peak positions defined by: Minimum of 2nd derivative of peak
Minimum peak tip width: 0.00
Maximum peak tip width: 1.00
Peak base width: 2.00
Minimum significance: 0.75
Number of peaks: 66

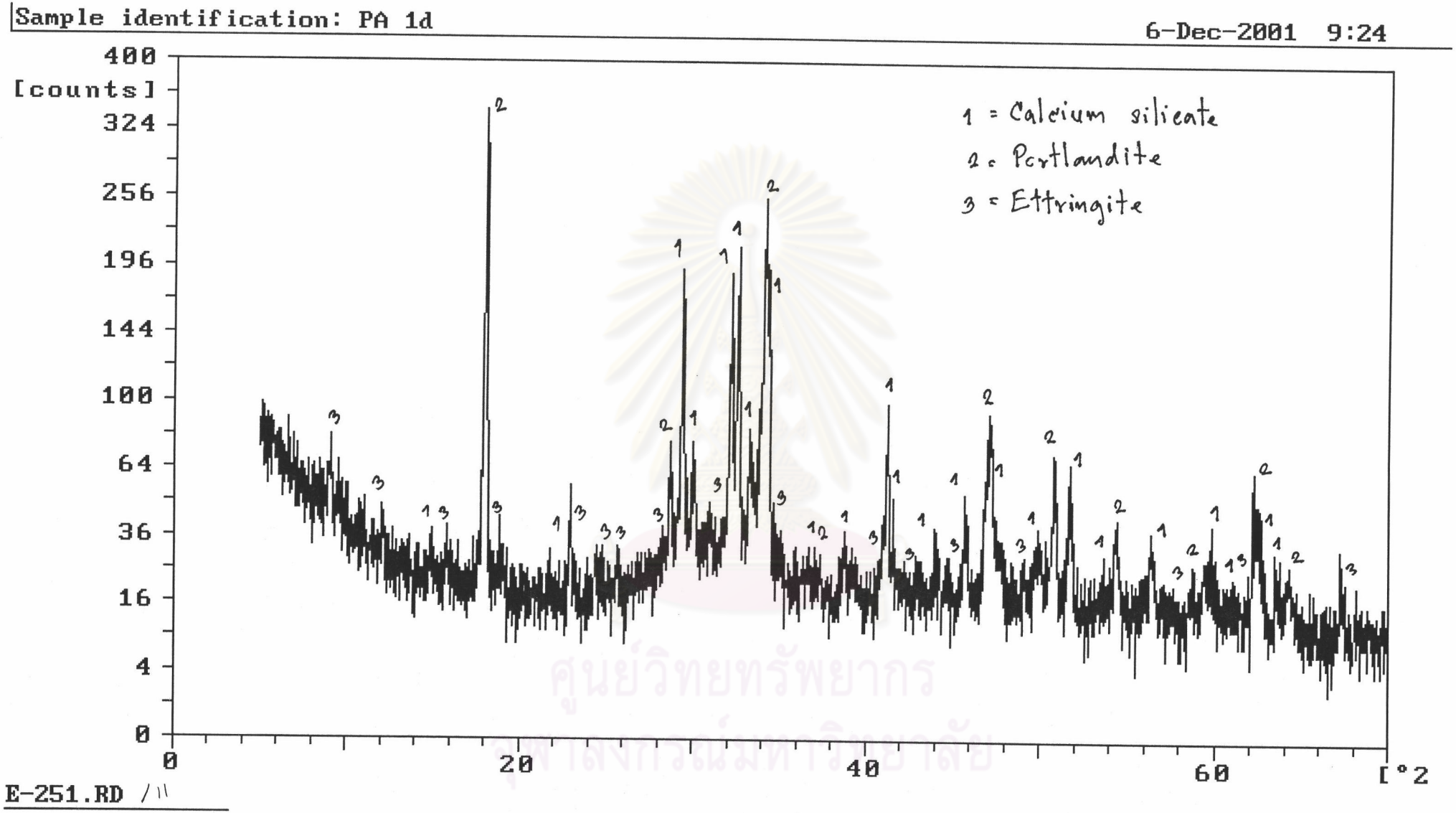
Angle [½2Õ]	d-value Á1 []	d-value Á2 []	Peak width [½2Õ]	Peak int [counts]	Back. int [counts]	Rel. int [%]	Signif.
13.585	6.5128	6.5289	0.120	35	42	1.2	1.01
15.090	5.8665	5.8809	0.480	14	38	0.5	1.51
16.045	5.5194	5.5330	0.160	40	36	1.4	1.18
18.110	4.8944	4.9065	0.160	502	32	17.9	6.25
19.000	4.6671	4.6786	0.120	139	31	5.0	1.30
20.550	4.3185	4.3291	0.120	61	28	2.2	0.86
21.960	4.0443	4.0542	0.160	55	26	2.0	1.21
23.700	3.7512	3.7604	0.160	2798	25	100.0	14.41
25.600	3.4769	3.4854	0.160	50	25	1.8	1.31
26.985	3.3015	3.3096	0.080	56	24	2.0	2.39
27.445	3.2472	3.2552	0.120	222	24	7.9	1.47
27.860	3.1998	3.2076	0.160	119	24	4.2	2.07
28.295	3.1516	3.1593	0.160	64	24	2.3	1.25
29.190	3.0569	3.0644	0.160	45	24	1.6	0.95
30.115	2.9651	2.9724	0.200	576	24	20.6	7.89
30.720	2.9081	2.9152	0.200	188	24	6.7	4.61
31.430	2.8440	2.8510	0.320	69	24	2.5	2.14
32.350	2.7652	2.7720	0.200	14	24	0.5	0.77
33.415	2.6794	2.6860	0.120	320	24	11.4	1.54
33.775	2.6517	2.6582	0.160	655	24	23.4	7.24
34.450	2.6013	2.6077	0.200	21	24	0.8	0.91
35.130	2.5525	2.5587	0.120	98	24	3.5	1.55

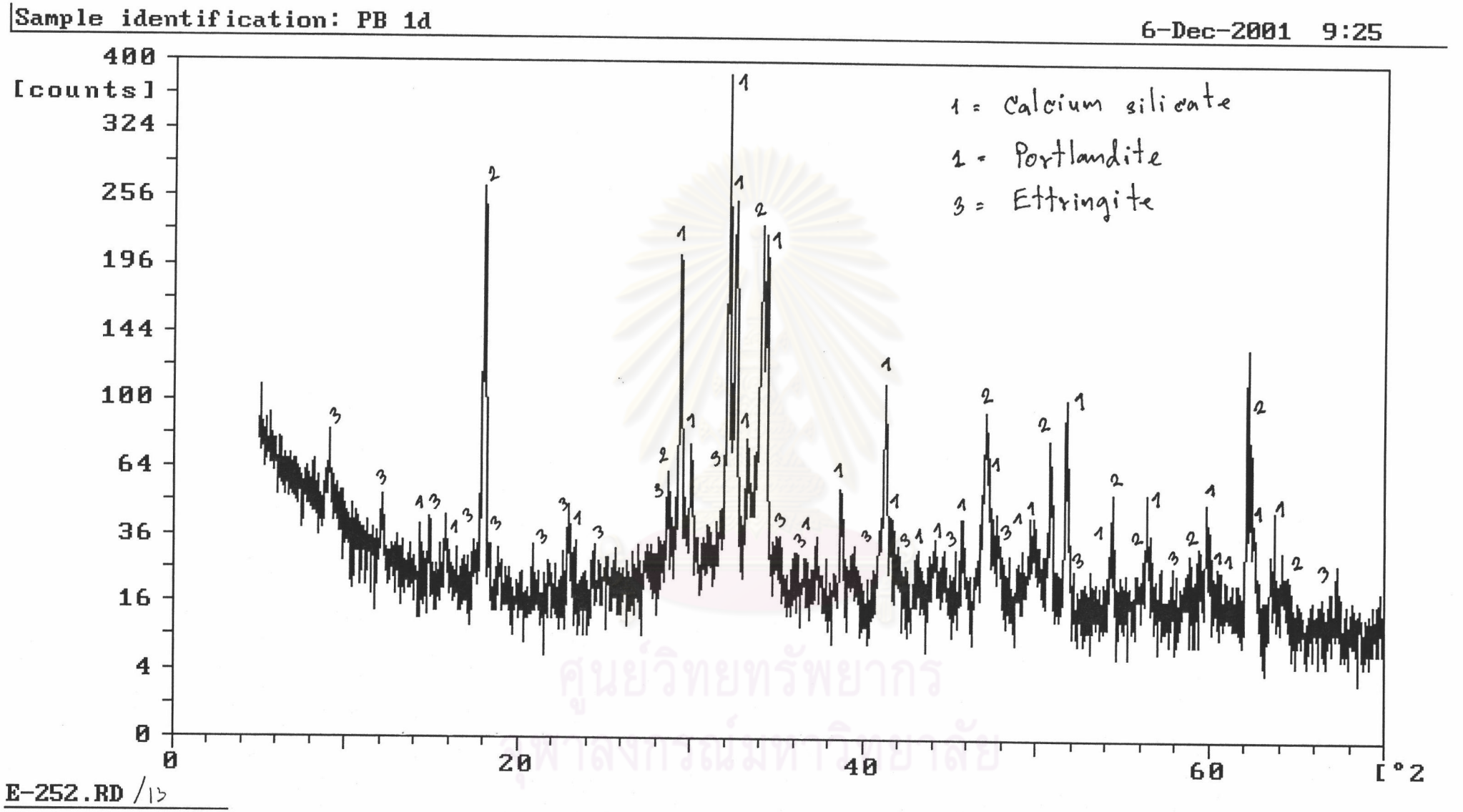
File: E-247.DI

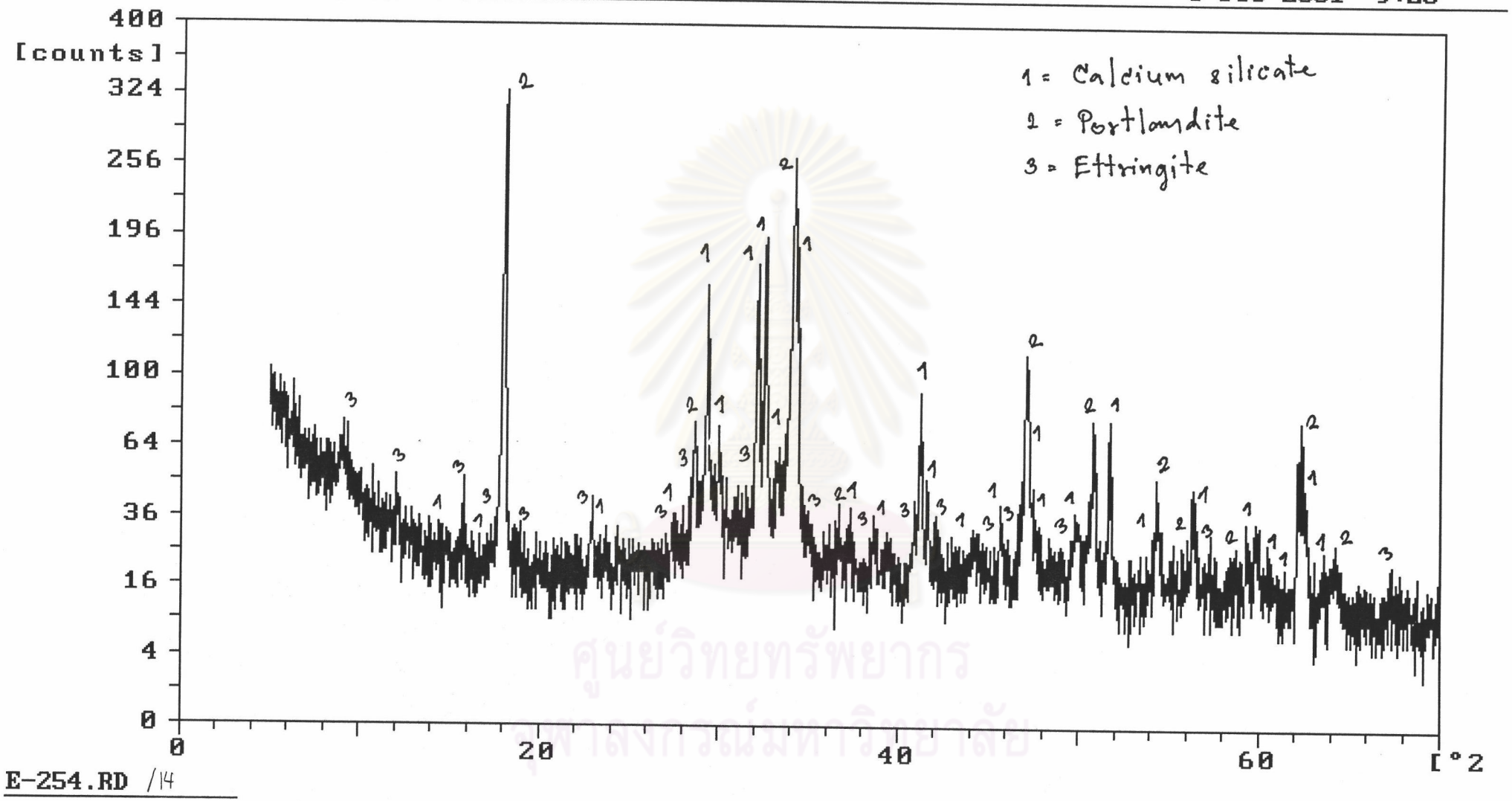
Philps Analytical X-Ray B.V. PC-APD,Diffraction software

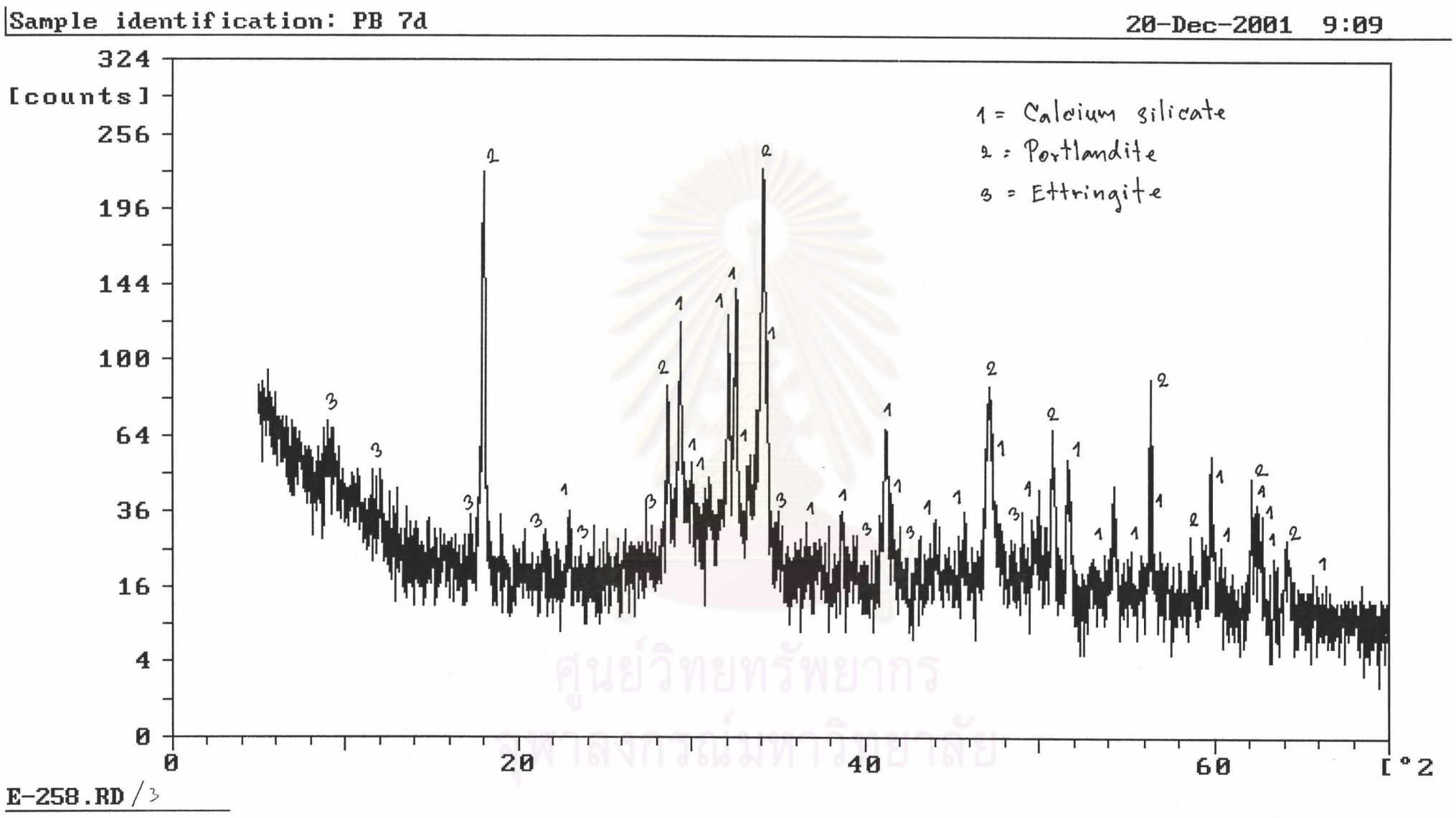
Angle [½2Õ]	d-value Á1 []	d-value Á2 []	Peak width [½2Õ]	Peak int [counts]	Back. int [counts]	Rel. int [%]	Signif.
35.415	2.5326	2.5388	0.080	166	24	5.9	1.85
35.770	2.5082	2.5144	0.160	372	24	13.3	3.94
36.580	2.4545	2.4606	0.320	207	24	7.4	10.25
37.165	2.4172	2.4232	0.120	130	24	4.6	0.89
37.445	2.3998	2.4057	0.120	169	24	6.0	1.06
37.770	2.3799	2.3857	0.120	49	24	1.8	1.72
38.665	2.3268	2.3326	0.120	62	23	2.2	2.11
39.125	2.3005	2.3062	0.160	72	23	2.6	1.53
39.385	2.2859	2.2916	0.160	46	23	1.7	0.94
39.790	2.2636	2.2692	0.200	74	23	2.6	1.86
41.195	2.1896	2.1950	0.160	193	23	6.9	1.73
41.610	2.1687	2.1740	0.160	511	23	18.3	3.03
42.375	2.1313	2.1366	0.120	104	23	3.7	4.56
42.920	2.1055	2.1107	0.200	74	23	2.6	1.51
43.340	2.0861	2.0912	0.160	85	23	3.0	0.94
44.480	2.0352	2.0402	0.120	37	23	1.3	1.01
44.810	2.0210	2.0260	0.120	71	23	2.5	3.02
45.700	1.9837	1.9886	0.160	36	23	1.3	0.97
46.290	1.9598	1.9646	0.160	50	23	1.8	0.83
46.675	1.9445	1.9493	0.160	86	23	3.1	1.37
47.205	1.9239	1.9286	0.200	83	23	3.0	1.66
48.490	1.8759	1.8805	0.200	26	23	0.9	1.02
49.070	1.8550	1.8596	0.160	48	23	1.7	0.87
50.535	1.8046	1.8091	0.240	74	23	2.6	2.76
51.005	1.7891	1.7935	0.160	34	23	1.2	1.07
52.550	1.7401	1.7444	0.120	76	23	2.7	1.96
54.040	1.6956	1.6997	0.320	17	23	0.6	0.89
54.530	1.6815	1.6856	0.120	59	23	2.1	1.90
55.230	1.6618	1.6659	0.320	108	23	3.9	4.55
56.615	1.6244	1.6284	0.080	234	23	8.4	5.70
57.470	1.6023	1.6062	0.160	180	23	6.4	2.22
58.455	1.5776	1.5815	0.160	137	23	4.9	1.03
59.325	1.5565	1.5603	0.120	48	23	1.7	1.14
60.345	1.5326	1.5364	0.240	86	23	3.1	1.12
60.825	1.5217	1.5254	0.240	83	23	3.0	1.26
62.100	1.4934	1.4971	0.080	128	23	4.6	2.42
63.800	1.4577	1.4613	0.120	72	23	2.6	0.87
64.245	1.4487	1.4522	0.120	46	23	1.7	1.03
65.280	1.4282	1.4317	0.320	25	23	0.9	0.91
66.545	1.4041	1.4075	0.240	27	23	1.0	2.09
67.035	1.3950	1.3984	0.200	37	23	1.3	1.21
67.400	1.3883	1.3917	0.120	146	23	5.2	1.31
68.145	1.3749	1.3783	0.120	55	23	2.0	1.62
69.200	1.3565	1.3599	0.320	38	23	1.4	1.04

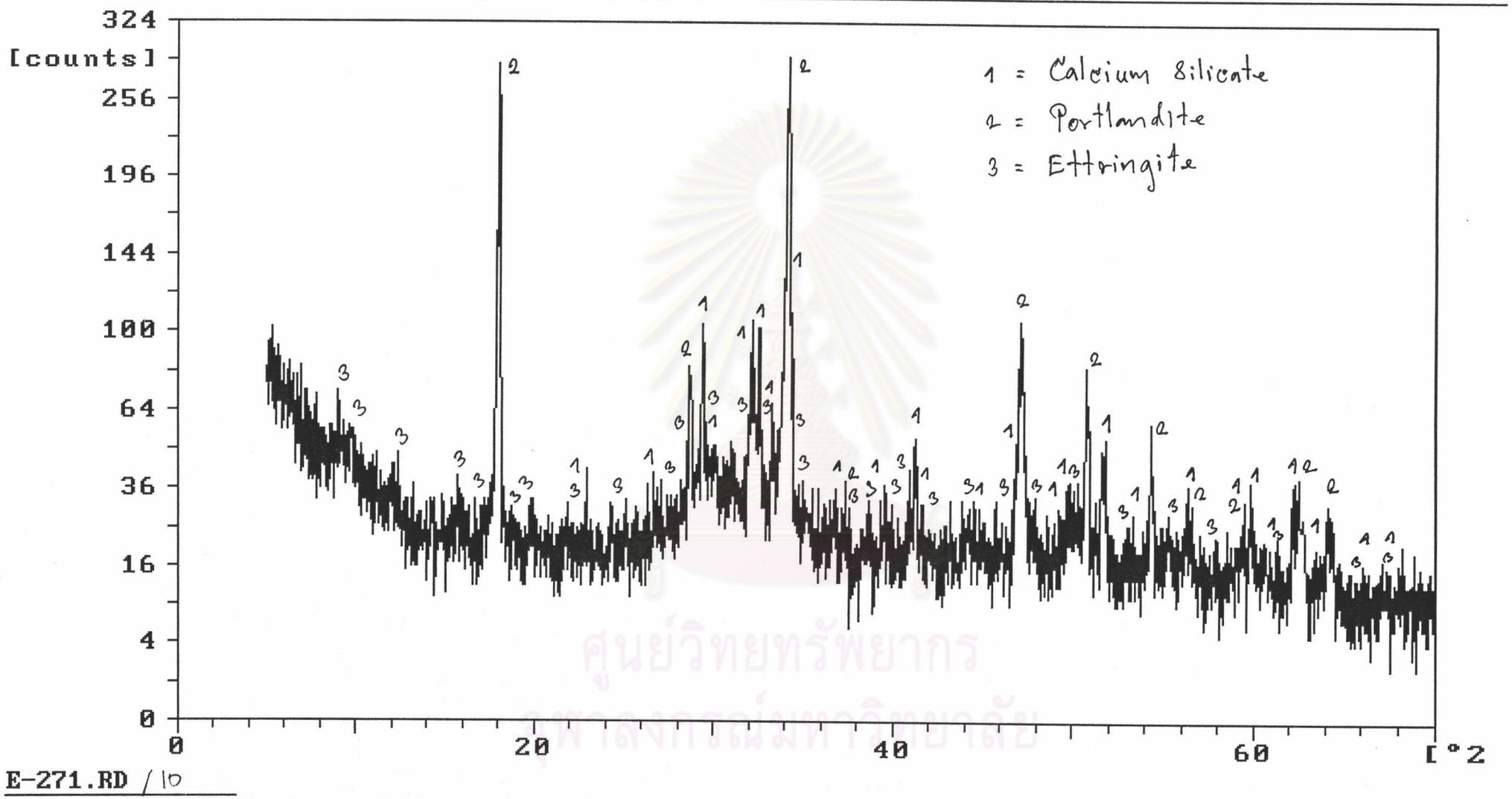


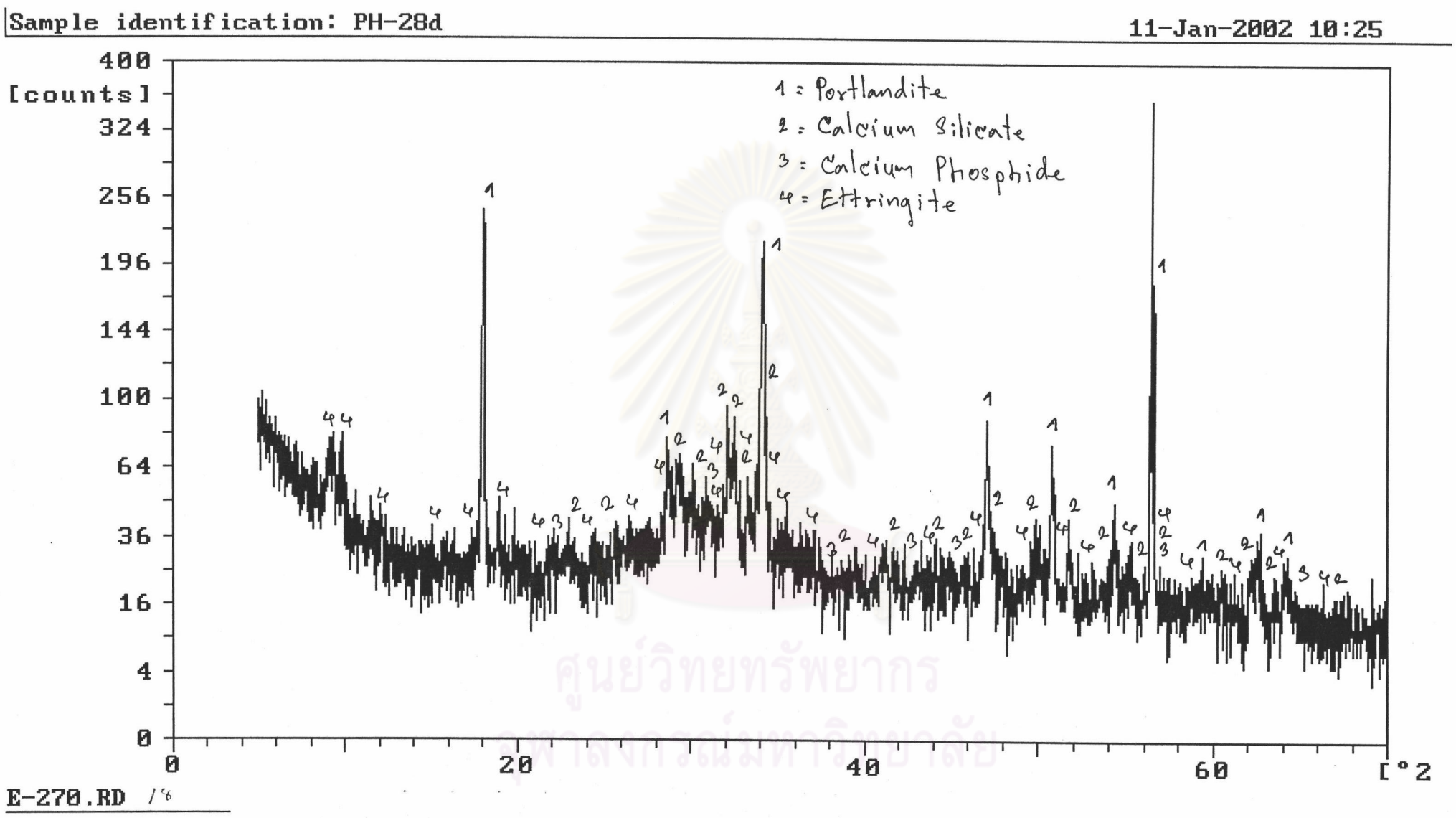


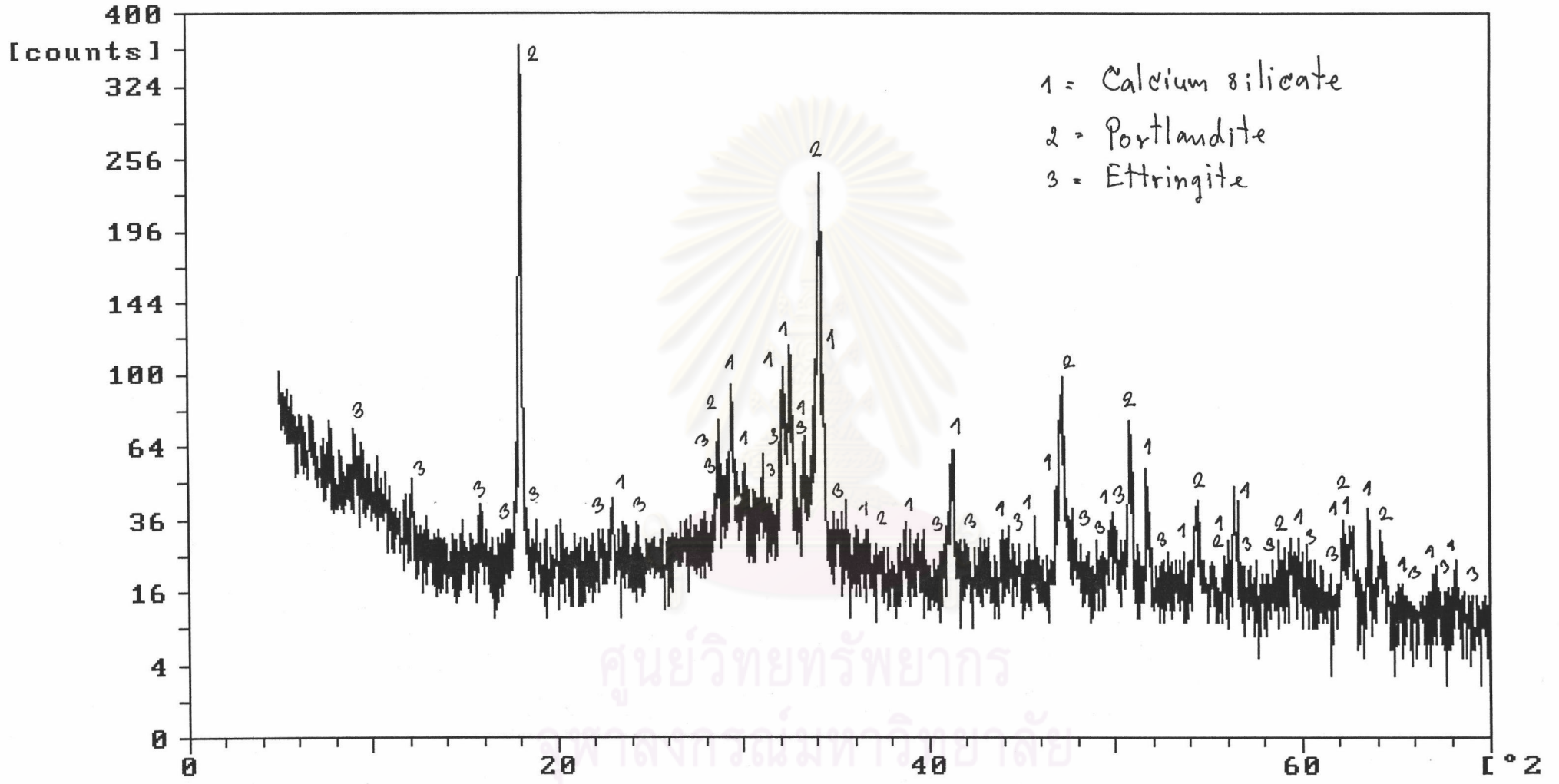


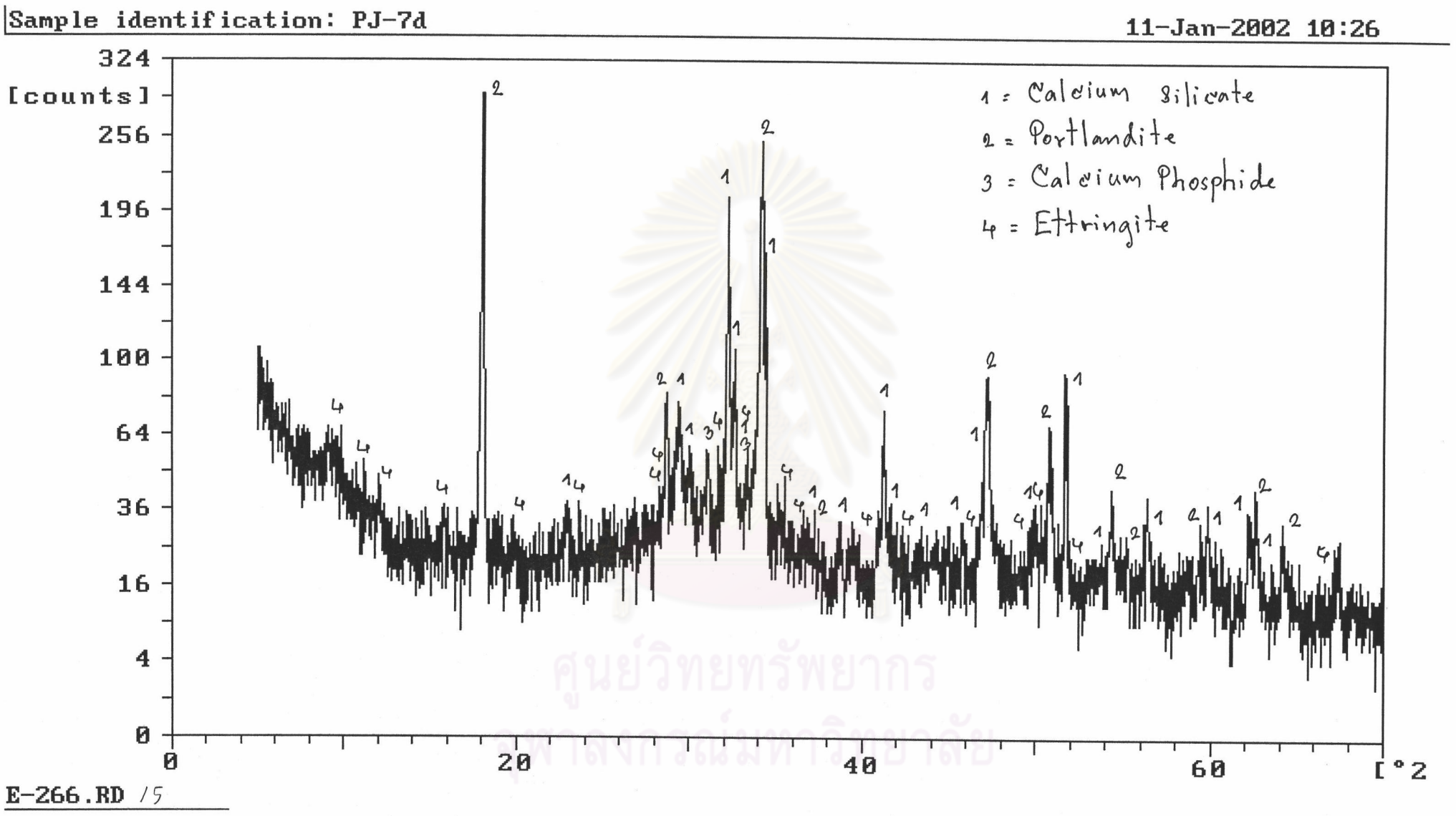


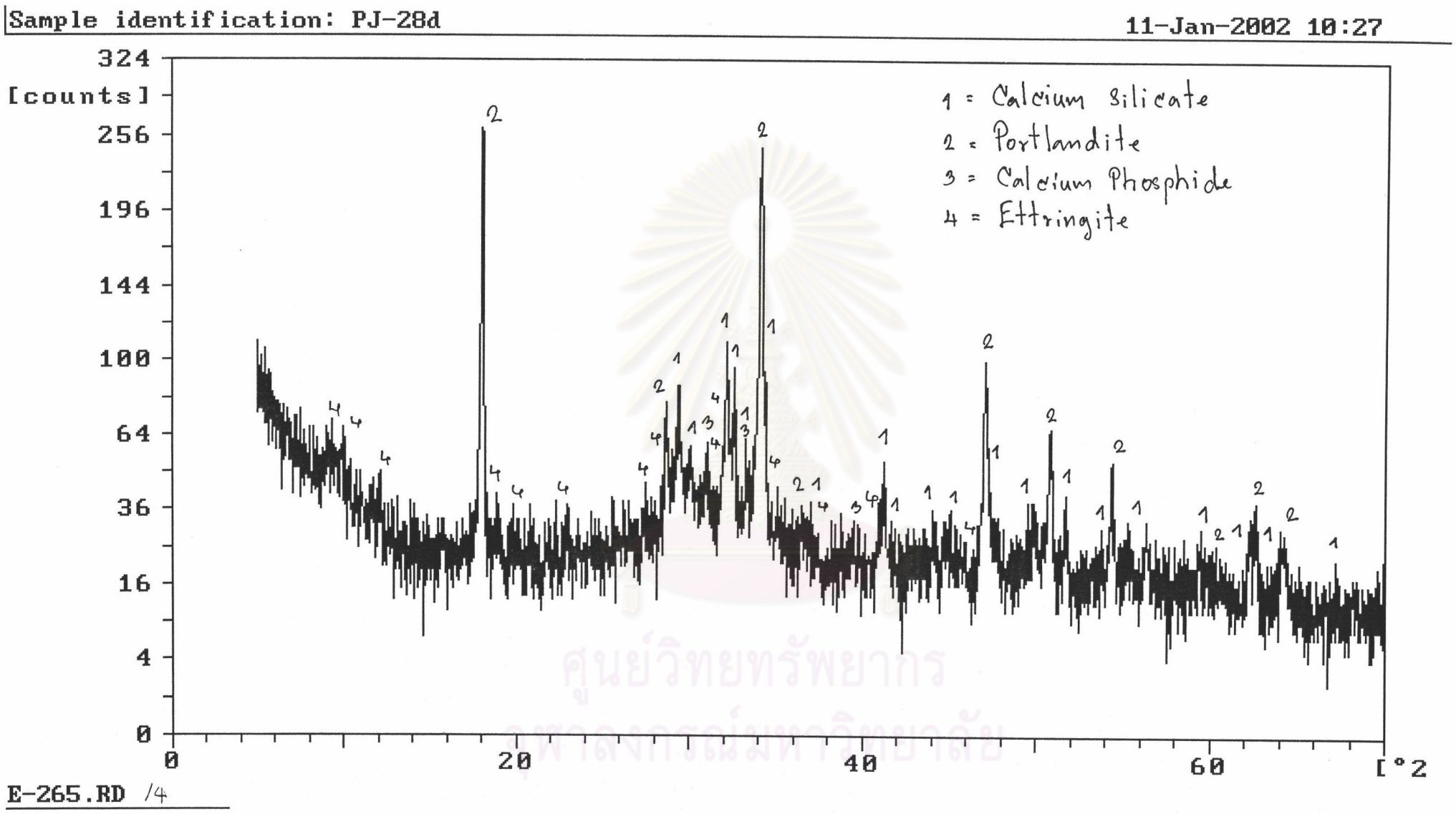


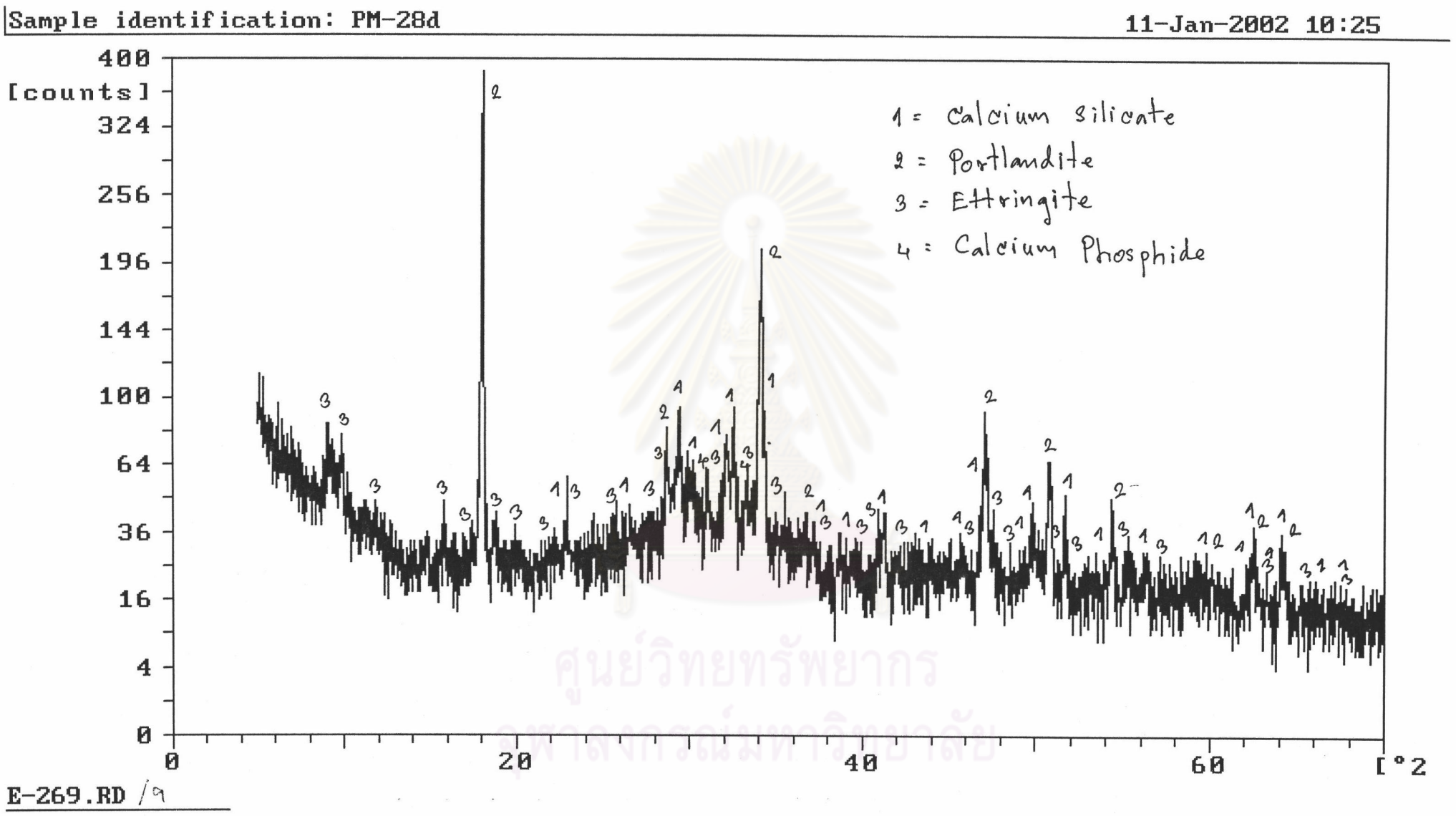


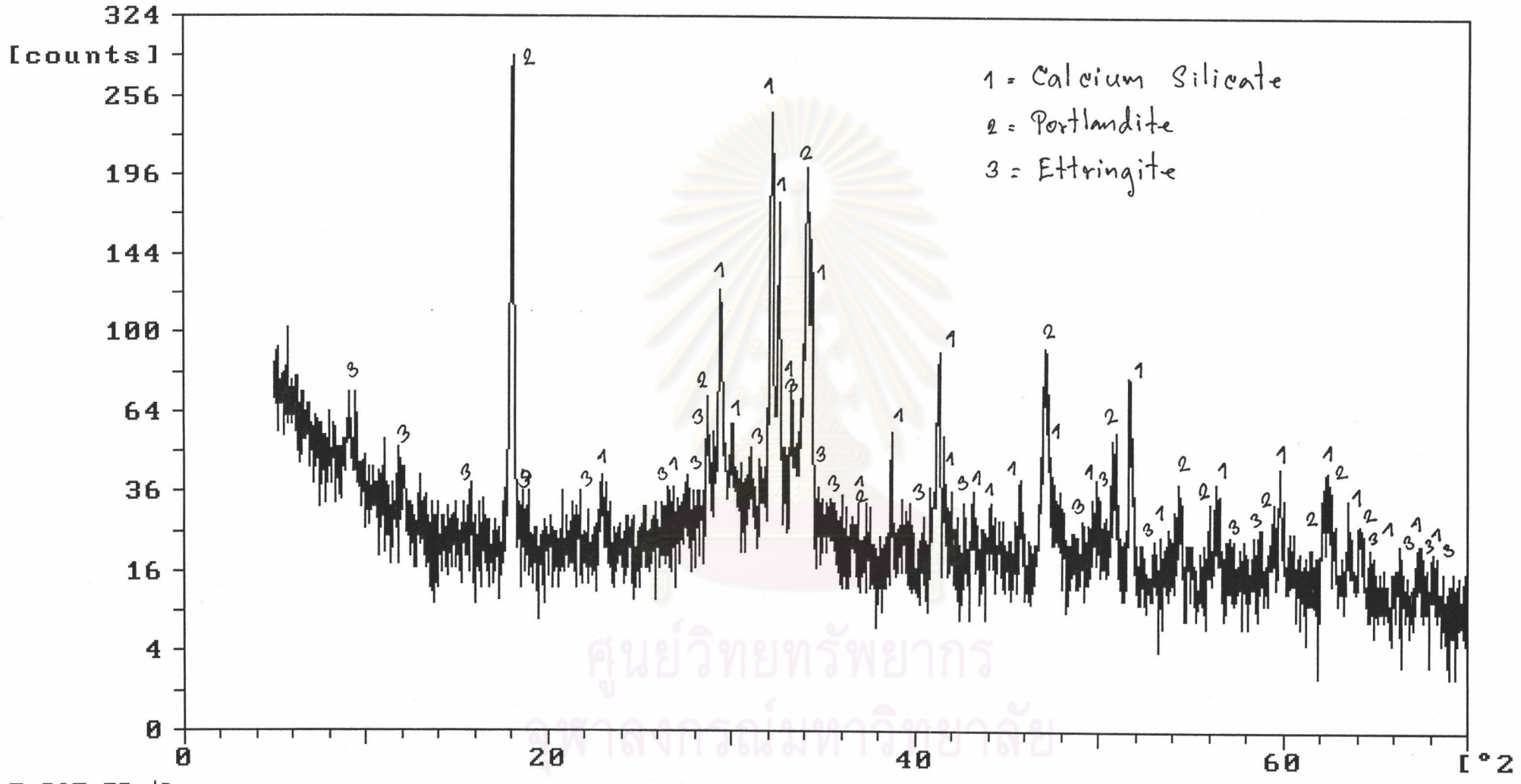












APPENDIX D

GLOSSARY

A

absorption – the ability of substance that can absorb other substance or particle into its body.

adsorption – in chemistry, the ability of substance that can absorb other substance or particle into its surface.

$Al(OH)_3$ – Aluminium Hydroxide.

Alite – C_3S, tricalcium silicate.

atomic mass - the quantity of matter contained in an atom of an element, expressed as a multiple of one-twelfth the mass of the carbon-12 atom, 1.9924×10^{-23} g, which is assigned an atomic mass of 12 units. In this scale, 1 atomic mass unit (amu.) corresponds to 1.6603×10^{-24} g.

atomic weight - ratio of the average mass of a chemical element's atoms to some standard. Since 1961 the standard unit of atomic mass has been $^1/_{12}$ the mass of an atom of the isotope carbon-12 (an isotope is one of two or more species of atoms of the same chemical element that have different atomic masses). The atomic weight of carbon is 12.011, the average that reflects the typical ratio of natural abundance of its isotopes.

B

Belite - C_2S, dicalcium silicate.

Bogue - Early cement chemist who empirically equated oxide analysis and phase compositions of OPC.

C

$C_{12}A_7$ - Mayernite, a highly reactive phase found in cements.

C_2S – Belite.

C_3A - Tricalcium aluminate, a reactive phase found in cements. C_3AH_6 - HAC hydration product after conversion from CAH_{10}, the cause of reduction in physical performance and dimensional stability in HAC concrete.

C_4AF - Brownmillerite, a reactive phase found in cements.

CA – Mono calcium aluminate, a reactive phase found in cements.

CAH – Calcium aluminate hydrate, Secondary amorphous hydration product of OPC.

CAH_{10} – Initial structural hydration product of HAC.

C_4A_3 – Ye'elimite.

Calcareous – Material containing $CaCO_3$ used in cement manufacture.

CH – Calcium Hydroxide, also used to indicate the early amorphous calcium hydroxide hydration product of OPC.

Chemical compound – any substance composed of identical molecules consisting of atoms of two or more elements.

chemical element – also called ELEMENT, any substance that cannot be decomposed into simpler substances by ordinary chemical processes. Elements are the fundamental materials of which all matter is composed.

Clinker – The fused calcination products of cement formation.

CSA – Calcium sulpho aluminate, a novel cement, mainly C_4A_3.

CSH – Calcium silicate hydrate, final amorphous hydration product of OPC.

E

equivalent weight – the quantity of a substance that exactly reacts with, or is equal to the combining value of, an arbitrarily fixed quantity of another substance in a particular reaction. Substances react with each other in stoichiometric, or chemically equivalent, proportions, and a common standard has been adopted.

Ettringite ($3CaO.Al_2O_3.3CaSO_4.32H_2O$) – the phase formed during the hydration of expansive cement which is the source of the expansive force. It is comparable to the natural mineral of the same name. It is a naturally occurring mineral, which forms hexagonal crystal structures.

Expansive cement – a cement which when mixed with water forms a paste that, during and after setting and hardening, increases significantly in volume.

Expansive cement concrete – concrete made with Type K, M and S expansive cement.

Expansive cement, Type M – a mixture of portland cement, calcium aluminate cement and calcium sulfate or an interground product made with portland cement clinker, calcium aluminate clinker and calcium sulfate.

Expansive cement, Type K – a mixture of portland cement compounds, anhydrous calcium sulfoaluminate ($4CaO.3Al_2O_3.SO_3$), calcium sulfate ($CaSO_4$) and lime (CaO). The anhydrous calcium sulfoaluminate is a component of a separately burned clinker that is interground with portland clinker or blended with portland

cement or, alternately, it may be formed simultaneously with the portland clinker compounds during the burning process.

Expansive cement, Type S – a portland cement containing a large C_3A content and modified by an excess of calcium sulfate above usual amount found in other portland cements.

Expansive component – the material interground with portland cement clinker to obtain type K expansive cement clinker to obtain type K expansive cement. It is made up of the anhydrous calcium sulfoaluminate ($4CaO.3Al_2O_3.SO_3$), calcium sulfate ($CaSO_4$), and free lime (CaO) as well as other known portland cement compounds.

F

Final set – A stage of hydration at which cementitious mixtures retain their un supported shape. The final set can not be broken using mechanical means without a large effect on the final physical characteristics of the cured mixture.

Free Lime – Calcium oxide which remains uncombined within the clinker.

G

Gel – A stage of hydration at which cementitious mixtures retain their un supported shape. The gel can be broken using mechanical means without a large effect on the final physical characteristics of the cured mixture.

Grout – A cementitious fluid mortar which may not contain sand or fine aggregate.

H

HAC – High alumina cement.

Hydration – The reaction with water of anhydrous materials.

HPC – High performance concrete.

I

Isotope – one of two or more species of atoms of a chemical element with the same atomic number and position in the periodic table and nearly identical chemical behavior but with different atomic masses and physical properties. Every chemical element has one or more isotopes.

M

Mortar – Mixtures contain cement, sand and water.

O

OPC – Ordinary Portland cement, named after the visual similarity between the set material and Portland stone.

R

Raw meal – Total ground raw materials of cement production prior to calcination.

Retarders – A compound which can delay the onset of a gel or final set, intregingly many retarders increase the final physical performance of the mortar or concrete.

S

Self stressing concrete – an expansive cement concrete in which expansion if restrained, induces compressive stresses of a high enough magnitude to result in a significant compression in the concrete after drying shrinkage has occurred.

Shrinkage compensating concrete – an expansive cement concrete in which expansion, if restrained, induces compressive stresses which approximately offset tensile stresses in the concrete induced by drying shrinkage.

Stoichiometry – in chemistry, the determination of the proportions in which elements or compounds react with one another. The rules followed in the determination of stoichiometric relationships are based on the laws of conservation of mass and energy and the law of combining weights or volumes.

T

Thaumasite – Ca_3 Si $(OH)_6$ SO_{42}– CO_{32}– 24 H_2O (C_3S H_{27}), a naturally occurring material easily confused by XRPD with Ettringite.

Topochemical reaction – a reaction between a solid particle and a surrounding solution in which the hydration product is formed on the surface of the particle.

V

Virtual – An unreal, visually solid display.

BIOGRAPHY

Wissawa Chakpaisarn was born on October 17, 1973 in Bangkok, Thailand. He has been interested in engineering since he was a child because his father was an engineer. He studied at Suankularb Wittayalai during his high school years. After that, he entered Kasetsart University in the faculty of engineering in 1990 and obtained his civil engineering degree in 1994. He received his master's degree in structural engineering from Chulalongkorn University in 1996 when he was 22. His advisor for master's level was Prof. Dr. Ekasit Limsuwan. The thesis title was "Effects of Fly Ash in Pozzolanic Reaction on Compressive Strength of HPC".

Wissawa began to work as a structural engineer at EEC-Industrial Engineering, Co., Ltd. in 1996. In his work as a designer, he designed many types of structure mostly factories. He began his Ph.D. studies at Chulalongkorn University in 1997 when he was 23 and continues to work on design projects part time. He received his Ph.D. in 2001 when he was 28. He is interested in all kinds of music especially jazz. His favorite musicians are Miles Davis, David Benoit and Ella Fitzgerald.