DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

Composition and Physical Properties Of Granitic Rocks from the NRDC/SAS Seismic Station Sites, Eastern Kazakh SSR

by

William Leith[1]
Eugene C. Robertson[1]
Bruce Bryant[2]
Paul Boden[3]

OPEN FILE REPORT 91-639

[1] National Center, Reston, VA 22092
[2] Denver Federal Center, Denver, CO 80225
[3] University of Colorado, Boulder, CO

List of Figures and Tables

Figures

Tables

Summary

Petrologic analyses and physical properties measurements were performed on seven granitic rock samples, taken from the sites of the three NRDC/SAS seismic station sites in Eastern Kazakhstan, which surround the Soviet nuclear testing ground near Semipalatinsk. Except for the sample from Bayanaul (a quartz syenite), the samples are medium to coarse grained, leucocratic granites. The borehole samples have porosities of about 2 percent, densities of about 2.5 g/cc, p-wave velocities of about 4 km/sec, and compressive strengths of about 150 MPa. The density and velocity values are somewhat smaller than expected, based on Soviet published values, because of the porosities. The petrography of the samples is near the published range for the granitic rocks at Degelen mountain (which are more alkaline), and their physical properties are probably similar. Comparisons are made with granites from U.S. and French nuclear test sites.

Introduction

In 1986, through a cooperative project between the Natural Resources Defense Council (NRDC) and the Soviet Academy of Sciences (SAS), borehole seismometers were installed at three locations surrounding the Soviet underground nuclear test site near Semipalatinsk, in the eastern portion of the Kazakh SSR (Berger and others, 1987; see Figure 1). At each location, the seismic instruments were placed in vertical holes drilled into granitic rock, and samples from various depths in these holes were recovered during the drilling operation. Each of the seismic station sites was located within the outcrop area of a late Paleozoic intrusion of a post-tectonic, leucocratic, alkali granite. These granitic intrusions, Karkaralinsk, Bayanaul' and Del'begetey (see Figure 1), are geologically quite similar to the granitic body at Degelen Mountain, one of the principal Soviet underground nuclear test sites (see, e.g., Leith, 1987; Vergino and Mensing, 1989). Therefore, the samples that were collected from these sites are important, both for confirming published Soviet accounts of the geology of these sites, and for the insight that they might lend into the physical properties of the rocks in which nuclear tests have been conducted at Degelen mountain.

In this report, we present the results of preliminary laboratory studies of the petrology and basic physical properties of granitic rock samples that were taken from the NRDC/SAS seismic station sites. These include four samples of drill cores that were recovered from the holes used for the emplacement of the seismometers at Karkaralinsk and Kara-su, and three surface samples from Karkaralinsk and Bayanaul'. The results of these analyses are compared with published values for these granitic intrusions from the Soviet literature and the physical properties of granitic rocks from U.S. and French Algerian underground nuclear test sites.

Samples were recovered from two depths within the boreholes at Karkaralinsk (KKL) and Kara-Su (KSU) seismic station sites, and surface samples from the vicinity of each of the three NRDC/SAS sites. Descriptions and location information for each of the seven samples are presented in Table 1 (following the classification and nomenclature of the IUGS Subcommission on the Systematics of Igneous Rocks, 1973). Samples 1(S) thru 3(S) were collected on the surface, and samples 5(B) through 8(B) are the borehole core samples. The latter were collected from depths ranging from 23 meters to 75 meters (see Table 1). Sample 4(S)KKL, a metavolcanic rock, is not reported on here.

<u>Modal Composition</u>

Point counts were made of each of the seven granitic rock samples. The results are shown in Table 2. In sample 2(S)BNL, the potassic feldspar is so finely perthitic that it was not possible to count the albite in the perthite. In samples 3(S)KKL, 5(B)KSU, 6(B)KSU and 7(B)KKL, the perthite is coarse textured, and the albite was counted as plagioclase.

The quartz-plagioclase-alkali feldspar modes of the seven granitic samples are plotted on a K-F ternary diagram in Figure 2, along with the averages for each site. Based on modal composition, the samples from both the Karkaralinsk and Kara-Su sites are classified as granites. The sample from Bayanaul' is classified as a quartz alkali-feldspar syenite. Note that the composition of the rocks, as judged by their modal compositions, would be close to the composition of minimum temperature melts in the system, quartz-albite-orthoclase.

Physical Properties Tests

Density, porosity, Young's modulus, and strength measurements were made on two cylindrical cores per sample; cores were about 5 cm long by 1.3 cm in diameter. These data are summarized in Table 3. The velocity measurements were made on three different cylindrical cores per sample, each 1 cm to 3 cm long and 1.3 cm in diameter. Optimum velocity values are shown in Table 3, not averages. The shear velocity measurements were considered to be unreliable.

The strength values are comparable to determinations of uniaxial compressive strength tests of Westerly granite, which range from 130 MPa to 210 MPa (Heard and others, 1974). The slopes of best-fitting lines to the elastic portions of the stress-strain data from the strength experiments were taken for the values of Young's modulus. There is a rough positive correlation between these two properties for the samples.

Two porosity values are presented for each rock sample in Table 3; samples of one set were measured by the amount of water absorbed, and those of the other set were calculated from the ratio of the bulk density to the grain density; grain densities were obtained from the modal composition and the mineral densities. The measured porosity is about half the calculated because many pores are filled with air or inaccessible to water.

The average values of each of the physical properties for all of the granitic rocks are given at the bottom of Table 3. For the borehole samples only, the average values are as follows: density, 2.52 g/cc; measured porosity, 1.15%; calculated porosity, 2.7 %; velocity, 3.9 km/sec; compressive strength, 147 MPa.

Sample 3(S)KKL is visibly weathered. This weathering is reflected in the physical properties of the rock: in particular, this sample has a markedly lower density, strength and modulus than any of the remaining samples. The relatively high velocity may be accounted for by wave propagation along acoustically well-coupled grain paths, not affected by the weathering.

Discussion

To check consistency, our evaluations of the petrography and physical properties of the Kara Su borehole core sample at 35 meters depth are compared in Table 4 with those made at New England Research Inc., (NER), on a core taken from 34 meters depth in the same hole (Martin and others, 1989).

In general, the two sets of mineral compositions and physical properties in Table 4 are quite similar. Our porosity value is somewhat lower, possibly because of differences in measurement techniques, or just normal variations in the rock itself. Both sets of density, velocity and strength measurements were made under low pressure and are close in value.

In Table 5, we compare our results on the granite sample data from Karkaralinsk with data from petrographically similar rocks at three nuclear test sites (localities described in the table footnotes). Our density and velocity values are somewhat lower than values given for the other test sites because of the higher porosities of our samples. The uniaxial compressive strengths are quite similar; many felsic rocks have relatively low uniaxial strengths.

Our density determinations are also compared to published Soviet determinations on rocks from the Karkaralinsk, Del'begetey and Bayanaul intrusions in Figure 3. In general, the reported averages are slightly higher than our borehole sample determinations, possibly due to deep weathering effects.

All granitic intrusions are complex when examined in detail, the three sampled here are not exceptions. In attempting to evaluate published physical properties data for these areas, we must take into account the precise location of the sample sites. For example, for the samples from Karkaralinsk, Anikeeva's (1964) mapping of the surface geology of the Karkaralinsk intrusion suggests the possibility that the borehole at the KKL station site was not actually located in the main (alaskite) portion of the Karkaralinsk intrusion. This is important, since Leith (1987) suggested that the alaskite intrusions at Karkaralinsk and Bayanaul may be analogous to that of Degelen mountain, one of the principal Soviet nuclear test sites (see location in Figure 1).

Our leucocratic granite samples have slightly less plagioclase than the alaskite granite of Degelen (Dobretsov and Mikhaylov, 1985), as shown in Figure 2. however, the petrographies are similar enough to make reasonable comparisons between them. Accounting for differences in porosity between our borehole samples and Degelen rocks, our measurements of physical properties are probably close to those of underground samples of granites from Degelen mountain.

In the current rock samples, none has a mineralogy within the rage reported for the "alaskite" granites at Degelen (Dobretsov and Mikhaylov, 1985; see Figure 2). Thus, it appears inappropriate to use the physical properties values reported here as estimates for the granites at Degelen (the Soviets have reported slightly lower densities and velocities for "alaskites" than for other varieties of granites).

Coincidentally, the granite samples from Karkaralinsk are mineralogically similar to granites from the French underground nuclear test site at the Hoggar massif in Algeria (see Table 5). However, the densities and velocities reported for those rock by Schock and others (1972) are notably higher than from the Karkaralinsk granites.[1]

Acknowledgements. We greatly appreciate the assistance provided by W. Burton, who provided the initial petrologic analysis of the rocks, R. Meister, who assisted in the physical properties determinations, and R. Martin, III, who provided us with a pre-publication manuscript of their results on the sample from the Kara Su site.

References

Anikeeva, A. N., Karkaralinskiy Intruzivniy Kompleks (The Karkaralinsk Intrusive Complex), Nauka, Moscow, 1964.

Berger, J., and others, EOS Trans. AGU, 68(8): p. 105 (1987).

Dobretsov, G. L., and N. P. Mikhaylov, Degelenskiy Magmatogeniy Uzel (The Degelen Magmatic Node), in Varistsiyskiy Granitoidiy Magmatizm Kazakhstana (The Variscan Granitoid Magmatism of Kazakhstan), Nedra, Leningrad, 1985, p. 128-135.

Heard, H. C., B. P. Bonner and R. N. Schock, Mechanical Behavior of Dry Westerly Granite at High Pressure, UCRL-51642, Lawrence Livermore National Laboratory (1974), 14 p.

Leith, W., in Proc. DARPA/AFGL Seismic Res. Symp., 15-18 June (1987).

Leith, W., 1987, Geology of NRDC Seismic Station Sites in Eastern Kazakhstan, U.S. Geological Survey Open File Report 87-597.

Maldonaldo, F. 1977, Summary of the geology and physical properties of the Climax Site, U.S.G.S. Open File Report 77-356, 25 p.

Martin, R. J., III, K. B. Coyner and R. W. Haupt, Physical property measurements on analog granites relatedto the Joint Verification Experiment, AFGL Rept. GL-TR-90-0171 (1990), 80 p.

Schock, R. N., and others, Mechanical Properties of the Taourirt Tan Afella Massif, Algeria, UCRL-51296 (1972).

The Times Atlas of the World (Bartholomew, London, 1977).

Urazaev, B. M., et al, Eds., Fizicheskie Svoystvo Gornikh Porod I Rud Vostochnovo Kazakhstana (The Physical properties of Rocks and Oresof Eastern Kazakhstan), Nauka, Alma-Ata, 1975.

Vergino, E. S. and R. Mensing, 1990, Yield estimation using regional m_{bPn}, Bull. Seis. Soc. Am. 80(3), p. 656-674.

Table 1. Sample Descriptions

sample	depth	intrusion	description
1(S)KKL	surface	Karkaralinsk	medium-to-fine grained, porphyritic biotite granite
2(S)BNL	surface	Bayanaul'	porphyritic quartz syenite
3(S)KKL	surface	Karkaralinsk	medium-grained leucocratic granite
5(B)KSU	35 m	Del'begetey	coarse-grained biotite granite
6(B)KSU	62 m	Del'begetey	coarse-grained, porphyritic leucocratic granite
7(B)KKL	75 m	Karkaralinsk	coarse-grained leucocratic granite
8(B)KKL	23 m	Karkaralinsk	coarse-grained leucocratic granite

Table 2. **Mode Counts** (in percent) ("x" indicates present, but not intersected in counting)

sample	quartz	plagioclase	k-spar	biotite
1(S)KKL	34.2	30.4 (An16)	31.1	3.9
2(S)BNL	18.1	11.0 (An6)	70.8	x
3(S)KKL	39.8	27.9 (An3)	32.1	x
5(B)KSU	23.5	28.0 (An16)	41.3	6.9
6(B)KSU	27.2	34.0 (An16)	35.9	0.9
7(B)KKL	39.6	25.8 (An4)	31.7	1.6
8(B)KKL	34.1	30.9 (An6)	33.3	0.7

Table 3. PHYSICAL PROPERTIES OF GRANITIC SAMPLES

Sample No. surf/boreh. station loc.	Depth (m)	Density (dry bulk) (g/cm3)	Porosity (as measured) (%)	Velocity (longitudinal) (km/sec)	Young's Modulus (GPa)	Compressive Strength (MPa)	Notes
1(S)KKL	0	2.46	2.6	3.9	20	65	
2(S)BNL	0	2.45	2.0	4.4	21	93	
3(S)KKL	0	2.36	3.8	4.4	12	60	weathered
Surface Average	*0*	*2.42*	*2.8*	*4.2*	*18*	*73*	
5(B)KSU	35	2.54	1.1	4.3	41	175	
6(B)KSU	62	2.52	0.8	3.8	43	180	
7(B)KKL	75	2.50	1.6	4.1	10	113	
8(B)KKL	23	2.50	1.1	3.5	29	120	
Borehole Average	*48.75*	*2.52*	*1.20*	*3.9*	*31*	*147*	

(S) surface sample; (B) borehole sample

TABLE 4. Comparison of determinations for borehole samples from the Kara-Su seismic station site.

	This report (sample depth 35 m)	NER[2] determinations (sample depth 34 m)
density (g/cc)	2.54	2.58
porosity (%)	1.1	1.9
velocity (km/sec)	4.25 (Pc = 0)	4.20 (Pc = 50 bars)
strength (MPa)	120	N/A
composition:		
quartz	23.5	25
plagioclase	28	13
perthite	41.3	46
biotite	6.9	8
other 0.3	8	

[2] *New England Research*, data courtesy of R. Martin. Note that strength vales may not be directly comparable, since NER used one-inch diameter samples for their strength tests, while we used half-inch samples.

TABLE 5. Comparison of the physical properties of the Karkaralinsk granite samples with granites from the U.S. and French nuclear test sites

	U. S. test sites		*French site*	*Karkaralinsk*
property	Climax[1]	Sand Springs[2]	Hoggar[3]	sample averages
rock type	grano- diorite	porphyritic granite	biotite granite	leucocratic granite
mineralogy				
% quartz	28	N/A	35	35-40
% alkali feldspar	16	"	37 microcline	32
% plagioclase	45	"	25	25-30
% biotite	9	"	2.1	1
density, bulk dry	2.67 g/cc	2.52 g/cc	2.63 g/cc	2.50 g/cc
porosity	0.6%	N/A	0.25%	1.35%
velocity, vp	6.25 km/s	5.4 km/s	5.5 km/s	4.0 km/s
compressive strength (unconfined)	127 MPa	110 MPa	N/A	120 MPa

[1] data are for the region of the emplacement of the U. S. nuclear test *Piledriver* (2 June 1966, 62 kt); an earlier test, *Hardhat* (15 Feb. 1962, 5.7 kt) was also detonated in the Climax stock, but in a quartz monzonite, not compared here. (see Maldonaldo, 1977).

[2] data are for the region of the emplacement of the U. S. nuclear test *Shoal* (26 Oct. 1963, 12.5 kt). See: R. F. Beers, Inc., Analysis of Shoal Data on Ground Motion and Containment (NTIS, 1964, 112 p.).

[3] site of 13 French underground nuclear tests detonated underground between 1961 and 1966 in the Taourirt tan Afella massif, Algeria. See: R. N. Schock et al, UCRL Rept. 51296 (LLNL, 1972).

[4] mineralogy is average of all four samples; physical properties are from the borehole samples.

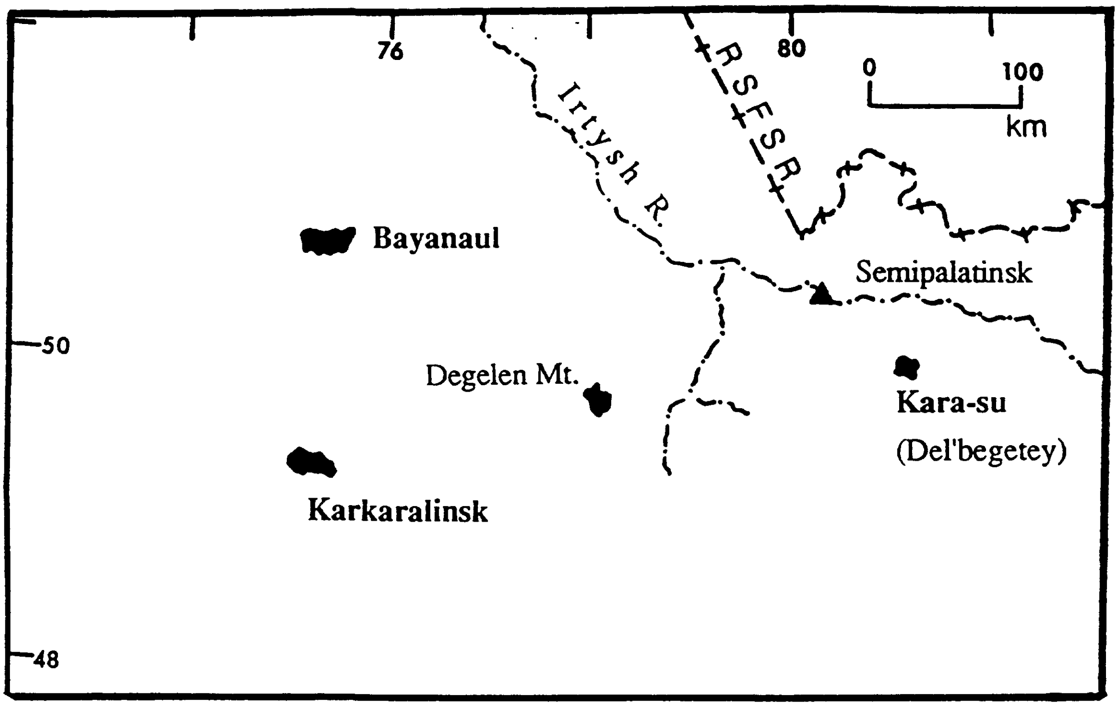

Figure 1. Location map. The NRDC/SAS seismic stations were sited on three granitic intrusions, at Karkaralinsk (station KKL), Bayanaul' (BNL) and Kara-su (KSU, Del'begetey intrusion), which surround the Soviet nuclear testing ground to the west of Semipalatinsk (Times Atlas, 1977). The location of the testing area at Degelen mountain is also shown --a similar granitic intrusion, discussed in the text.

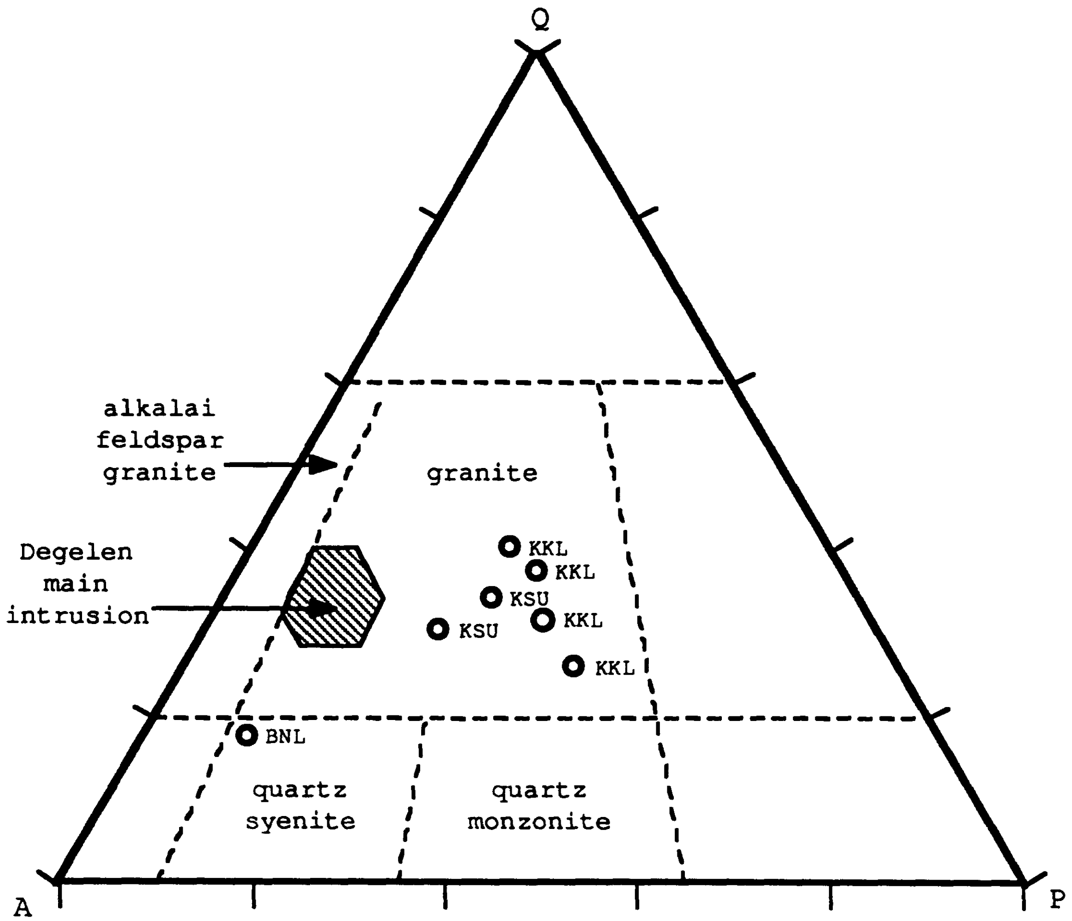

Figure 2. A ternary quartz-K-feldspar-plagioclaise diagram, with the modal composition plotted for each of the seven granitic rock samples. Also shown is the range published for the main granitic ("alaskite") intrusion at Degelen mountain, for comparison (see Dobretsov and Mikhatlov, 1985). Double circles indicate rocks where much of the perthite was too fine-grained to separate from the albite in counting.

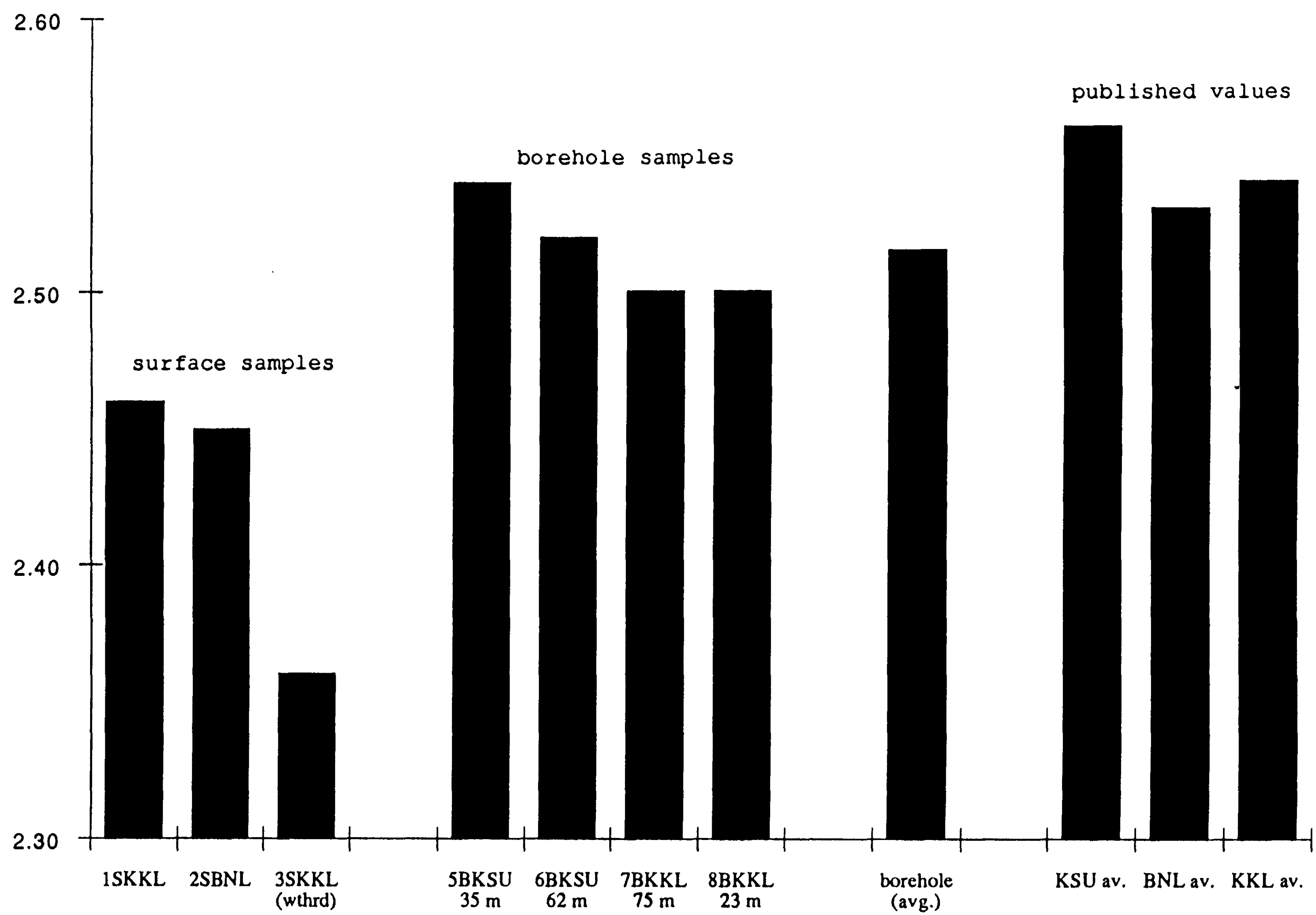

Figure 3. Density determinations for the seven samples, compared with Soviet published values. While the surface samples have lower values, the borehole samples generally have densities comparable to, but slightly less than, those reported in the literature.