GEOLOGIJA

GEOLOGICAL TRANSACTIONS AND REPORTS

RAZPRAVE IN POROČILA

Ljubljana • Letnik 1973 • 16. knjiga • Volume 16

UDK 553.7÷553.78(497.12)

Termalni in mineralni vrelci v Sloveniji

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Vsebina

1. Uvod

Termalne in mineralne vode so del našega naravnega bogastva. Ljudje so že zgodaj spoznali njihovo zdravilno vrednost. Po izkopaninah rimskih kopaliških naprav v Rimskih Toplicah sklepamo, da so se tam kopali že Rimljani. Podobno velja za Rogaško Slatino, ki je pozneje, zlasti v 17. stoletju, zaslovela po svojih mineralnih vrelcih. Radensko slatino pa so odkrili leta 1833.

Voda je bila dolgo zajeta le s plitvimi vodnjaki; večkrat so za to uporabili kletne prostore zdraviliških stavb. V takem stanju so bila zajetja naših termalnih in mineralnih vrelcev še več let po drugi svetovni vojni.

Termalni in mineralni vrelci se pojavljajo v dolinah rek in potokov, zato je prišlo v plitvih zajetjih do vpliva podtalnice. Zniževala se je temperatura tople vode in poslabšala kvaliteta mineralne vode. Upadala je količina dobre vode, ponekod stalno, drugod občasno pri visokih vodostajih.

Dotrajanost plitvih zajetij je dala povod za pričetek načrtnih raziskav primarnih vodonosnih horizontov v večji ali manjši globini zunaj vpliva površinskih tokov in podtalnice.

Po raziskavah leta 1952 so z globljim zajetjem rešili nadaljnji obstoj Rogaške Slatine. Vodil jih je J. Bać in uporabil pri raziskavah in zajetju mineralne vode strojno vrtanje. Prvo globoko zajetje termalne vode pa je vodil avtor leta 1957 v Čateških Toplicah. Nato so sledile hidrogeološke raziskave drugih pomembnih termalnih in mineralnih vrelcev v Sloveniji in trajajo še danes.

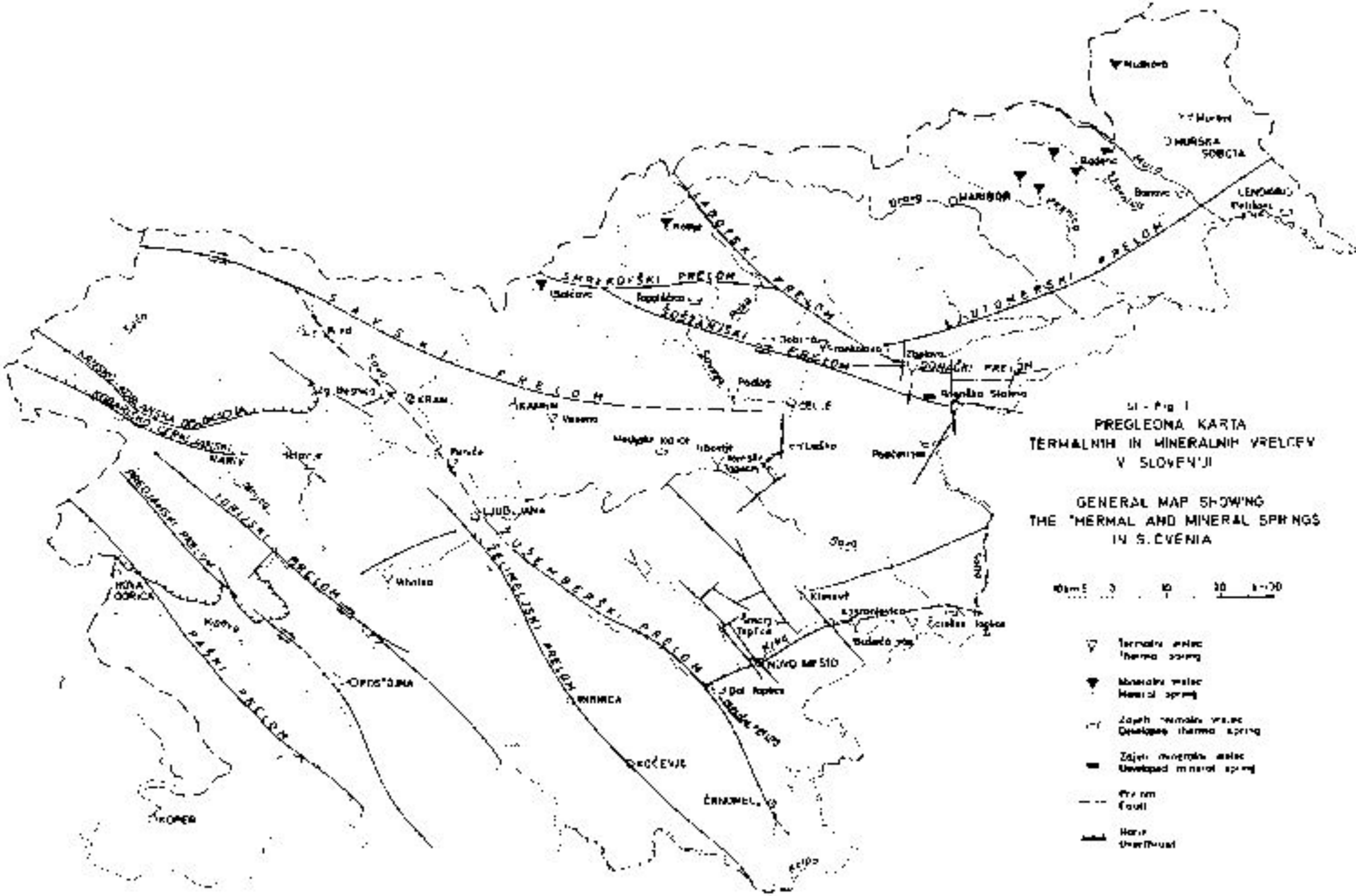
Raziskave v preteklih dveh desetletjih niso napredovale povsod do take stopnje, da bi bila vsa problematika dokončno rešena. V začetku so imele le najnujnejši obseg. Po letu 1965 je zanimanje za raziskave termalnih in mineralnih vrelcev v Sloveniji naraslo zaradi uvajanja zdravstvenega turizma in naraščanja potrošnje mineralne vode.

Osnovne hidrogeološke raziskave so bile opravljene v Dolenjskih Toplicah, Šmarjeških Toplicah, Laškem, Rimskih Toplicah, Dobrni, Topolščici, Trbovljah, pri Podčetrtku, na Bledu, pri Pirničah in v Nuskovi. Bolj detajlno so bili raziskani vrelci v Čateških Toplicah, Radencih in Rogaški Slatini (sl. 1).

Treba je poudariti vlogo Sklada Borisa Kidriča, ki je s sofinanciranjem in kreditiranjem bistveno pripomogel k raziskavam za obnovo termalnih in mineralnih vrelcev v Sloveniji.

2. Splošne karakteristike naših termalnih in mineralnih vrelcev in njihova regionalna porazdelitev

V Sloveniji imamo dva tipa termalnih vrelcev, ki se ločita po nastanku ter fizikalnih in kemičnih lastnostih. Prvega predstavljajo znani termalni izviri, ki pritekajo na površje iz dolomita in apnenca že daljšo dobo in jih imamo tako rekoč za trajne. V urejenih zajetjih sta njihova količina in temperatura konstantni. Vsebujejo do 0.5 g/l raztopljenih mineralnih snovi. Nizka vsebnost raztopljenih mineralnih snovi in nji-



SI - Fig. 1

PREGLEDNA KARTA TERMALNIH IN MINERALNIH VRELCEV V SLOVENIJI

GENERAL MAP SHOWING THE THERMAL AND MINERAL SPRINGS IN SLOVENIA hova konstantna sestava kažeta na podzemeljsko cirkulacijo vode, ki pronica v globino s površja, se zaradi geotermične energije segreva in priteka navadno po razpokah ali zdrobljenih conah ob prelomih nazaj na površje kot termalni vrelci. Pri raziskavah teh termalnih vrelcev smo ugotovili, da se izviri z višjimi temperaturami pojavljajo v bližini globokih prelomov, višina temperature pa je odvisna od razsežnosti termalnih con, litološke sestave in lege vodonosnih horizontov ter njihove izolacije proti površju. Tam kjer prihajajo vodonosne karbonatne kamenine na površje, se topla voda v plitvi coni ohlaja zaradi stika s površinskimi vodami in atmosfero. Navadno sega vpliv razhlajevanja globlje od cone letnih temperaturnih gibanj, kar je odvisno od razsežnosti poroznih con in njihove prepustnosti. Porozne cone so navadno prepojene s hladno podtalnico. Zato imamo poleg glavnih termalnih izvirov z najvišjo temperaturo stranske ali divje izvire, katerih temperatura je včasih tudi za nekaj deset °C nižja od temperature glavnega izvira.

Hladna podtalnica, s katero so prepojene porozne cone na primer v dolomitu, vzdržuje piezometrično gladino termalnim izvirom. Termalna voda priteka iz globine v najbolj prepustnih delih poroznih con. Od piezometrične gladine hladne podtalnice je odvisna izdatnost termalnih izvirov na določeni koti. Zaradi nizke povprečne vrednosti koeficienta prepustnosti v dolomitu ($k = 1 . 10^{-4}$ cm/sek) letne spremembe količin termalnih izvirov v dolomitu ne presegajo 10 %. To velja za naravni dotok termalne vode na površje. Z večjo globino zajetja termalnih voda površinski vplivi prenehajo.

Drugi tip predstavljajo termomineralne vode, ki so jih navrtali pri iskanju nafte v Moravcih, Petišovcih in Banovcih. Vsebujejo do 10 g/lit raztopljenih mineralnih snovi. Akumulirane so v poroznih peščenih plasteh mlajšega terciarja. Njihovo obnavljanje je možno le tam, kjer prihajajo porozne plasti na površje. Zato se pri tem tipu vode bolj strogo postavlja vprašanje racionalne uporabe na podlagi realno ocenjenih izkoristljivih zalog.

Mineralni vrelci se pojavljajo v obrobnih delih Prekmurja, v Slovenskih goricah in v okolici Rogaške Slatine. Mineralne vode so v bistvu površinski izviri termomineralnih voda. To dokazujejo temperature mineralne vode, zajete v globljih vrtinah. V okolici Rogaške Slatine in Radinec so bile v globini 300 m do 600 m izmerjene temperature 30° do 40 °C. Izviri mineralne vode na površju imajo navadno srednjo letno temperaturo okolice. Zaradi majhnih količin, največ nekaj 10 l/min, in počasnega toka se mineralna voda na svoji poti proti površju ohladi in prevzame srednjo letno temperaturo okolice.

Na sl. 1 vidimo, da je največ mineralnih in termalnih vrelcev v severovzhodni in centralni Sloveniji.

3. Termalni izviri v karbonatnih kameninah

Termalni vrelci v karbonatnih kameninah so v tesni zvezi s tektonsko zgradbo okolice. Glede na to jih delimo v več skupin.

3.1. *Termalni vrelci v Ljubljanski in Radovljiški kotlini*

Skupna značilnost termalnih izvirov te skupine je, da pritekajo na površje ob stranskih plitvih prelomih, navadno več kilometrov vstran od glavnih prelomov in da imajo nizko temperaturo 19° do 23 °C. Nizka temperatura je posledica nizkega geotermičnega gradienta ali pa se topla voda meša s hladno podtalnico pred dotokom na površje. Cirkulacija vode lahko sega tudi v večjo globino, vendar je temperatura vode kljub temu nizka. To so pokazale raziskave na Bledu, kjer je bila šele v globini 550,0 m izmerjena temperatura 19 °C. Torej je na Bledu geotermični gradient nižji od povprečka. Nizka temperatura izvirov kaže prej na nizek geotermični gradient in nizko primarno temperaturo izvirov te skupine kakor na vpliv hladne podtalnice.

Razen blejskih termalnih izvirov spadajo v to skupino še izviri v Zgornji Besnici, Spodnjih Pirničah pod Šmarno goro, pri Hotavljah v dolini Kopačnice in Furlanove Toplice pri Vrhniki. Glavne podatke o termalnih vrelcih te skupine kaže tabela 1.

Tabela 1.

Termalni vrelci v Ljubljanski in Radovljiški kotlini

Lokacija vrelca	Temperatura °C	Količina Q l/sek	Vodonosnik
Bled	19—22	12—14	dolomit
Zgornja Besnica	21	1,5—2	dolomit
Spodnje Pirniče	19,5—23	5—8	dolomit
Hotavlje	21	5	dolomit
Furlanove Toplice pri Vrhniki	26	15	apnenec

Osnovne raziskave so bile opravljene le na Bledu in v Spodnjih Pirničah.

3.2. *Termalni izviri v vzhodnem podaljšku Karavank*

Termalni izviri druge skupine pritekajo na površje ob stranskih prelomih med šoštanjskim in smrekovškim prelomom. Imajo v povprečju višjo temperaturo od vrelcev prve skupine (tabela 2).

Zahodna dva izvira, Topolščica in Dobrna imata višjo temperaturo, ker se pojavljata na kontaktu neprepustnih terciarnih kamenin s triad-

Tabela 2.

Termalni vrelci v vzhodnem podaljšku Karavank

Lokacija vrelca	Temperatura °C	Količina Q l/sek	Vodonosnik
Topolščica	29—31	28	apnenec
Dobrna	35,5—36	6,5—8	apnenec
Stranice	21	20	dolomit
Zbelovo	18,5	4,5	dolomit

Osnovne raziskave so bile izvršene v Topolščici in Dobrni.

nim apnencem in dolomitiziranim apnencem. Izvira pri Stranicah in Zbelovo pri Poljčanah sta po svojih karakteristikah podobna termalnim vrelcem prve skupine.

3.3. *Termalni vrelci v Posavskih gubah*

Tretjo skupino predstavljajo termalni vrelci v Posavskih gubah. V severni mejni coni med Posavskimi gubami in predgorjem Kamniških Alp sta termalna izvira Vaseno pri Selah v Tuhinjski dolini in Podlog pri Šentpetru v Savinjski dolini. Vsi ostali in obenem glavni termalni vrelci pa se pojavljajo vzdolž laškega sinklinorija. Od zahoda proti vzhodu si sledijo: Medijske Toplice, Trbovlje, Rimske Toplice, Laško in Podčetrtek (tabela 3).

Tabela 3.

Termalni vrelci v Posavskih gubah

Lokacija vrelca	Temperatura °C	Količina Q l/sek	Vodonosnik
Vaseno	21—28	1,5	dolomit
Podlog	18—21	5—16	apnenec/dolomit
Medijske Toplice	21—23	6	dolomit
Trbovlje	32	12	dolomit
Rimske Toplice	38—41	6	dolomit
Laško	34,3—39,5	18	dolomit
Podčetrtek	34—37	25	dolomit

Osnovne hidrogeološke raziskave so bile opravljene v Trbovljah, Rimskih Toplicah, Laškem in Podčetrtku.

3.4. *Termalni vrelci v dolini Krke*

Večina izvirov v dolini Krke priteka na površje na njenem desnem bregu v podnožju Gorjancev. To so Dolenjske Toplice, Topličnik pri Kostanjevici, Bušeča vas in Čateška terma. Le termalna izvira v Šmarjeških Toplicah in pri Klevevžu sta na levem bregu Krke (tabela 4).

Tabela 4.

Termalni vrelci v dolini Krke

Lokacija vrelca	Temperatura °C	Količina Q l/sek	Vodonosnik
Dolenjske Toplice	32—38,4	20—21	apnenec/dolomit
Šmarješke Toplice	28—34,5	40	dolomit
Klevevž	22	6	dolomit
Topličnik pri Kostanjevici	21—28	30	apnenec/dolomit
Bušeča vas	26—28	30	apnenec/dolomit
Čateške Toplice	57—64	110—120	dolomit

Orientacijsko so bile raziskane Dolenjske Toplice in Šmarješke Toplice ter Topličnik pri Kostanjevici, detajlno pa Čateške Toplice.

4. Pregled hidrogeoloških raziskav termalnih vrelcev v karbonatnih kameninah

4.1. *Bled*

Do leta 1958 smo na Bledu merili količino vode in temperaturo izvira v hotelu Toplice in stranskih izvirov v okolici. Meritvam je sledilo leta 1958 vrtanje 4 plitvih raziskovalnih vrtin, poskusno črpanje in termosondiranje. Leta 1967 in 1968 smo vrtali še 8 plitvih in 1 globoko vrtino, ki je segla do globine 587,60 m. Zadela je na dotoke termalne vode v globini 546,0 m do 568,0 m, kjer je bilo zajeto 7 l/sek s temperaturo 19 °C.

Okolica Bleda sestoji iz permskih, triadnih, terciarnih in kvatarnih kamenin. Globoka raziskovalna vrtina je pokazala naslednje kamenine in njihovo navidezno debelino:

do 60,00 m kvartarne jezerske in ledeniške sedimente, do 106,00 m oligocensko sivico in do 546,00 m siv dolomit. Do globine 577,60 m je sledil temno sivi apnenec, kjer je bil glavni dotok termalne vode, in nato do končne globine 587,60 m temno sivi dolomit. Zanimiva je oligocenska sivica v vrtini; v okolici Bleda sivice ni na površju, ker jo povsod prekrivajo kvartarni sedimenti.

Okolico Bleda sekajo številni prelomi s smerjo severozahod-jugovzhod. Ob enem od teh prelomov si je utrla termalna voda pot do površja. Verjetno je zadela nanj tudi globoka vrtina, na kar kaže intenzivno razpokan in zdrobljen dolomit in apnenec.

V okolici termalnega izvira v hotelu Toplice imamo dva vodonosna horizonta, v katerih se pojavlja termalna voda. Plitvi horizont so kvartarni jezerski sedimenti z manjšimi količinami termalne vode v produ. Iz teh plasti se drenira termalna voda v več izvirov manjše izdatnosti na površini okoli 15 ha. Najvišja temperatura 21,5 °C je bila v Staretovem vodnjaku.

V plitvi horizont doteka termalna voda iz triadnega dolomita, verjetno na meji z oligocensko sivico.

4.2. *Pirniče pod Šmarno goro*

Do leta 1972 so občasno merili količino in temperaturo izvira. Podatki teh meritev navajajo pretok 6 do 8 l/sek in temperaturo 18 do 23 °C.

Leta 1972 smo izvrtali 3 orientacijske vrtine, ki so pokazale, da doteka termalna voda iz globine ob kontaktu triadnega dolomita z neprepustnim terciarnim laporjem. Nosilec terme je prelom s smerjo severozahod-jugovzhod. Najvišja temperatura je bila izmerjena v vrtini V-2/72, in sicer 20,5 °C, kar je za 2,6 °C manj od izmerjene temperature izvira v izjemni suši leta 1971. Take razmere kažejo, da se termalna voda pred dotokom na površje meša s hladno v plitvi coni in da predstavljajo izviri mešano vodo. Zaradi bližine Ljubljane bi kazalo raziskave nadaljevati in ločiti z zajetjem termalno vodo od hladne.

4.3. *Topolščica*

Raziskave so se pričele leta 1970. Izdelana je bila pregledna hidrogeološka karta okolice termalnega izvira v merilu 1:10.000. Vzporedno so tekle meritve in opazovanja vseh izvirov na ozemlju, ki ga je zajelo hidrogeološko kartiranje. Tako je bila ugotovljena pretočna količina termalnega izvira, ki znaša pri srednjem vodostaju najmanj 30 l/sek s temperaturo 30,5 °C.

Raziskavam na površju je sledilo 5 vrtin, ki so dale podatke o geološki zgradbi bližnjega zaledja termalnega izvira in nakazale hidrogeološke razmere v globini do 220 m.

Naknadno smo leta 1971 barvali požiralnike ob potoku Strmina na koti okoli 500 m. Barva se je pojavila po 45 urah v bližnjem hladnem izviru, po 70 urah pa zelo razredčena tudi v termalnem izviru. Izvira sta oddaljena od požiralnika 1,1 km pri višinski razliki 130 m.

Okolica termalnega izvira v Topolščici sestoji iz sedimentov kvartarja, terciarja, triade in mlajšega paleozoika. Kvartarni pesek, prod in meljna glina zapolnjujejo doline potokov, na strmih pobočjih so melišča grušča.

Terciar zastopajo pliocenske usedline in oligocenska laporna glina (sivica) z vložki andezitnega tufa. Večjo površino zavzemajo pliocenske lignitne plasti Šaleške doline.

Triadni apnenci, dolomiti, skrilavci, apnenci z roženci in konglomerati so hidrogeološko pomembnejše kamenine. Apnenci in dolomiti predstavljajo glavni vodonosni horizont termalne in hladne vode v okolici Topolščice.

Paleozoik je razgaljen v posameznih izdankih. Permu pripada siv apnenec, ki ga spremljajo konglomerat, kremenov peščenjak in skrilavec, karbonu pa glinasti skrilavec in kremenov konglomerat.

Termalna voda v Topolščici izvira ob prelomnem kontaktu terciarnih slabo prepustnih in neprepustnih plasti s triadnim apnencem. Termalna voda priteka na površje po razpokah, ki potekajo prečno na glavni prelom.

V plitvi coni je v neposrednem zaledju termalnega izvira apnenec zakrasel. V njem je termalna voda v stiku s hladno vodo. Zaradi takih hidrogeoloških razmer niha temperatura termalnega izvira od 28 do 31 °C.

Raziskovalne vrtine so pokazale kaverne, delno zapolnjene z glino. Termalna voda se preteka iz globine le v določeni coni. Termalni izvir na površju je mešana termalna voda. Primarne termalne vode vrtine niso našle, to bo glavna naloga nadaljnjih raziskav, ki bodo morale poseči v večjo globino.

4.4. *Dobrna*

V letih 1963 do 1966 je bila izdelana hidrogeološka karta v merilu 1:5000. Nato je bilo izvrtanih 6 vrtin, globokih 120,00 m do 650,40 m. Pred pričetkom raziskav je bila s poskusnim črpanjem določena količina termalne vode v starem zajetju zdravilišča. Iz vodnjaka priteka v odvisnosti od zunanjih vplivov 5,88 l/sek do 6,64 l/sek termalne vode na prelivni koti 367,3 m s temperaturo 36 °C. Razen tega je pritekala termalna voda še v pokriti bazen, in sicer 1,5 l/sek. Raziskovalne vrtine so dale naslednje podatke: v vrtini V-1, locirani tik ob Zdraviliškem domu severozahodno od vodnjaka, je bil v globini 0,00 m do 175,00 m apnenec. Na vodonosne razpoke je zadela vrtina že v globini 2,35 m, ki so bile v neposredni zvezi s pokritim bazenom, kjer je izplaka skalila vodo.

Termalna voda je dotekala na odseku 2,50 m do 50,00 m in v globini 138,00 m. Med vrtanjem v odseku 11,00 m do 50,00 m se je termalna voda v zajetju močno kalila, obenem se je znižala temperatura, kar kaže na zvezo med vrtino V-1 in vodnjakom. Rahlo se je skalila termalna voda v zajetju tudi ko je vrtina dosegla spodnji dotok termalne vode v globini 138,00 m. S poskusnim črpanjem so bile določene količine in temperatura termalne vode v obeh vodonosnih odsekih vrtine.

Vrtina V-2 je bila locirana 30 m vzhodno od vodnjaka z namenom, da bi ugotovili debelino neprepustnega lapornega pokrova nad apnencem in morebitne dotoke termalne vode. Vrtina je zadela na apnenec v globini 26,0 m. Do končne globine 120,00 m ni bilo nobenega dotoka termalne vode v vrtino, pač pa je z globino naraščala temperatura, ki je bila pri končni globini 26,1 °C. To kaže na visok geotermični gradient (na 1 °C okoli 12 m) in na bližino termalne cone v globini. Razpoke v apnencu so bile zapolnjene z rumenkasto peščeno glino. Sledove take gline smo našli v vodonosnih razpokah v ostalih vrtinah, iz česar se da sklepati, da je rumenkasta peščena glina sediment termalne vode.

Lokacija vrtine V-3 je sledila po podatkih vrtin V-1 in V-2 17 m južno od vodnjaka na notranjem dvorišču Zdraviliškega doma. Neprepusten pokrov kvartarne meljne gline in miocenskega peščenega laporja je segal do globine 16,70 m, nakar je sledil apnenec. Prvi dotok termalne vode je bil v globini 82,00 m v kavernoznem apnencu. Prepustna razpokana in delno kavernozna cona je segala do globine okoli 95,00 m. Poskusno črpanje in termosondiranje je pokazalo najvišjo temperaturo 34 °C v globini 82,00 m.

Vrtina V-4 je bila locirana okoli 12 m severozahodno od vrtine V-1. Pod 3,00 m debelo plastjo meljne gline je zadela na apnenec, ki je segal do končne globine 120,00 m. V vrtini ni bilo dotokov termalne vode, pač pa so bili v globini 6,10 m do 21,40 m dotoki hladne vode s temperaturo 10,5 °C do 12 °C. Termosondiranje je pokazalo v globini 3,00 m temperaturo 12,5 °C. Do globine 115 m je temperatura enakomerno naraščala in dosegla na dnu vrtine 30,9 °C.

186 m jugozahodno od starega zajetja so izvrtali vrtino V-5. Čeprav je bilo njeno ustje v neposredni bližini apnenca, je do končne globine 260 m ostala v peščenem laporju.

Namen vrtine V-6 je bil, dobiti podatke o hidrogeoloških in geotermičnih razmerah v večji globini. Oddaljena je bila le 45 m od vrtine V-3, v kateri se je temperatura vode najbolj približala temperaturi vode v vodnjaku. Potekala je skoz peščenjak in peščen lapor, oligocenski apnenec in triadni apnenec z redkimi polami dolomita. Presenetljive podatke je dalo termosondiranje, in sicer je bila v globini 200 m izmerjena temperatura 45 °C. Med črpanjem 4 l/sek iz globine 150 m do 320 m je bila izmerjena temperatura 38,5 °C pri depresiji 30 m.

Okolica Dobrne sestoji iz kvartarnih, terciarnih in triadnih kamenin. Debelina kvartarne meljne gline z redkimi prodniki znaša 3,5 m do 8,5 m. Največjo debelino dosežejo kvartarni sedimenti v dolini potoka Toplice, v stranskih grapah pa so tanjši.

Terciarju pripada peščeni lapor, kremenov peščenjak s prehodom v tufit, apnenec z ostanki ostrig in andezit s tufi. Peščeni lapor tvori gričevje severno in severovzhodno od termalnih izvirov. Peščeni lapor meji na kremenov peščenjak, ki sestoji iz zrn kremena s kalcitnim vezivom; kot primes so v peščenjaku zrna sljude, klorita in vulkanskega pepela. Kremenov peščenjak obdaja z južne strani oligocenski in triadni apnenec, ki tvori vzpetino Kurjek. Triadni in oligocenski apnenec sta si zelo podobna, zato je bilo posebno v vrtinah težko določiti kontakt med njima. Ločita se le po tem, da vsebuje oligocenski apnenec lupine ostrig in ponekod oligocensko mikrofavno.

Peščeni lapor pripada v glavnem tortonu, le njegov spodnji del helvetu, kremenov peščenjak s tufskimi primesmi spodnjemu miocenu in andezit s tufom spodnjemu miocenu in verjetno še zgornjemu oligocenu. Apnenec s fosilnimi ostanki ostrig in drobnih numulitov predstavlja bazalne plasti terciarja. V podlagi terciarja je triadni apnenec.

Pri detajlnem geološkem kartiranju sta bila v okolici Dobrne ugotovljena dva preloma, ki sta važna za dotok termalne vode na površje. Starejši prelom poteka od zahoda proti vzhodu. Na površju ga označujejo krpe oligocenskega apnenca v spodnjemiocenskem peščenjaku. Starejši prelom seka drugi prelom v smeri jugovzhod-severozahod; ob njem se je pogreznilo vzhodno krilo. Prelomna ploskev je nagnjena proti severovzhodu. Poleg teh dveh prelomov je več manjših prelomov in razpok. Ena od razpok je v oligocenskem apnencu v neposredni bližini izvirov termalne vode. Oba glavna preloma sta razkosala antiklinalo, katere jedro tvori na zahodu srednjetriadni apnenec.

Termalna voda priteka na površje po razpokah, ki so ponekod razširjene v kaverne. Vodonosnik je apnenec, ki ga z vseh strani obdajajo neprepustne kamenine. Zato so izviri termalne vode nastali v neposredni bližini kontakta med apnencem in peščenim laporjem ob robu doline potoka Toplice. Vrtina V-6 je zadela na vodonosno kaverno v globini 613,95 m, ki je v zvezi s plitvim zajetjem termalne vode. Tudi ostale vrtine so nakazale zvezo z obstoječim zajetjem, vendar je imela le voda v vrtini V-6 enako temperaturo kot v zajetju. Iz tega sledi, da je zveza med kaverno v globini 613,95 m in zajetjem neposredna in se termalna voda dviga zelo hitro na površje. Najtoplejša cona je v globini 120 do 320 m; s termosondiranjem smo izmerili maksimalno temperaturo 45 °C. Ker zapira neprepustna bariera peščenjaka apnenec z južne strani in ker leži najtoplejša cona južno od izvirov, je zelo verjetno, da posreduje višjo temperaturo iz gobine prelom na južni strani termalnih izvirov. Najtoplejša cona je v apnencu tik pod peščenjakom. Kakšna je razprostranjenost najtoplejše cone in v kateri globini bi bilo najbolj smotrno zajeti termalno vodo, bodo pokazale bodoče raziskave.

Termalno vodo v apnencu obdaja s severa hladna voda, ki se drenira v apnenec v neposrednem zaledju izvirov termalne vode. To kažejo hladnejši dotoki v pokritem bazenu in temperature v vrtinah v okolici zajetja. Stabilna temperatura termalne vode v zajetju kaže, da so glavni kanali, po katerih doteka termalna voda na površje, ločeni od hladne vode v plitvi coni.

4.5. *Trbovlje*

Pri Cementarni Trbovlje je bila l. 1967 izvrtana raziskovalna vrtina, ki je v globini 45,0 m zadela v dolomitu na dotok termalne vode 12 l/sek s temperaturo 32 °C. Vrtina je bila locirana na osnovi majhnega dotoka vode s temperaturo 18 °C v bližnjih kletnih prostorih Cementarne.

Nosilec tople cone je prelom, ki poteka od severa proti jugu in loči severno od zajetja termalne vode trboveljsko premogovno kadunjo od zagorske.

4.6 *Rimske toplice*

Rimske Toplice so edine slovenske toplice, kjer izvira termalna voda nad dnom doline. Višinska razlika je okrog 40,0 m. Prvotno je bila termalna voda zajeta v dveh plitvih vodnjakih, kjer so se po letu 1956 razmere občutno poslabšale. Piezometrična gladina se je znižala, kar je imelo za posledico, da termalna voda ni mogla iz zajetij dotekati v kopališke naprave. Poslabšanje razmer je dalo povod za pričetek hidrogeoloških raziskav leta 1958. Izvrtani sta bili dve raziskovalni vrtini.

Vrtina B-1, globoka 151,70 m, je zadela na izdatne dotoke termalne vode v globini 64,65 m do 72,75 m in 76,70 m do 87,95 m. V vrtino so bile vgrajene do globine 46,24 m jeklene cevi premera 113 mm in nato slepo od 40,00 m do 95,00 m jeklene cevi premera 98 mm, ki so bile v globini obeh glavnih dotokov termalne vode perforirane. Od globine 95,00 m naprej je vrtina zarušena.

V vrtini B-2, globoki 104,30 m, so bili glavni dotoki termalne vode v globini 49,80 m do 61,80 m in 68,90 m do 72,80 m, torej nekoliko više kakor v vrtini B-1. Vanjo so vgradili jeklene cevi premera 128 mm do globine 86,20 m. Cevi so bile perforirane od 49,30 m do 86,20 m. S tem sta bila zajeta oba glavna vodonosna horizonta in vrtina pripravljena za črpanje.

Poskusno črpanje je dalo v vrtini B-1 pri depresiji 1,10 m količino 450 l/min s temperaturo 39 °C. Maksimalna temperatura v vrtini B-1 je bila 41 °C.

Iz vrtine B-2 je bilo črpano pri depresiji 2,70 m 800 l/min termalne vode s temperaturo 39 °C, na ustju vrtine se je prelivalo 160 l/min termalne vode s temperaturo 39 °C. Raziskave so se končale leta 1959 z zajetjem termalne vode v obeh vrtinah. Po ureditvi so pričeli vodo izkoriščati z direktnim črpanjem iz obeh vrtin.

Termalna voda priteka v Rimskih toplicah na površje iz dolomita, ki ga obdajajo z vseh strani neprepustne kamenine. Pomembno je zlasti, da je dolomit zaprt proti dolini Savinje z neprepustnim karbonskim in permskim skrilavcem. Zato je piezometrična gladina termalne vode, oziroma prelivna kota sorazmerno visoko nad dnom doline Savinje.

V zaledju termalnih izvirov je dolomit prepojen s hladno vodo. Od nje so odvisne hidrogeološke razmere na termalnem območju. V zadnjem desetletju se je piezometrična gladina termalne vode znižala, in sicer najprej v starih vodnjakih in nato v raziskovalno-kaptažnih vrtinah. Celotni padec piezometrične gladine od leta 1956 do danes znaša okoli 3,0 m; vzroke za to bo treba ugotoviti, če hočemo preprečiti nadaljnje zniževanje piezometrične gladine.

Zniževanje piezometrične gladine termalne vode je v tesni zvezi z zniževanjem gladine hladne vode, ki je akumulirana v dolomitu v zaledju termalnih izvirov. Verjetno je prišlo do poškodb, oziroma do znižanja neprepustne skrilave bariere, kar je povzročilo tudi znižanje piezometrične gladine hladne vode. Iz neposrednega padavinskega zaledja se drenirajo v dolomit površinske vode. Iz njih se napaja hladna podtalnica, ki izvaja na termalno vodo določen pritisk, od katerega je odvisna piezometrična gladina termalne vode in seveda tudi izdatnost termalnih izvirov na določeni koti.

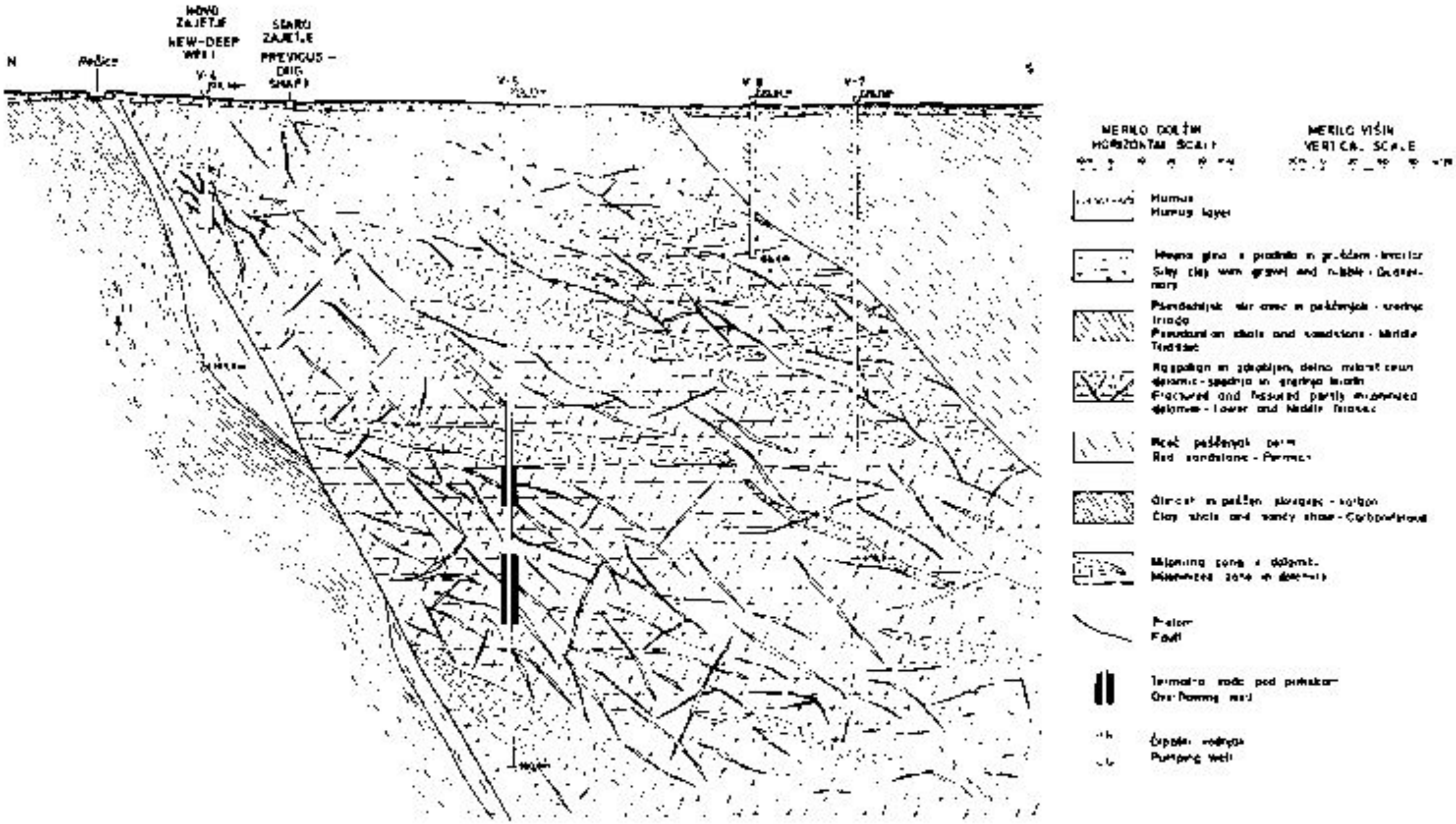
Upadanje piezometrične gladine termalne vode je morda delno povzročilo tudi dotrajano staro zajetje. Termalna voda je bila zajeta v dveh vodnjakih neposredno nad vodonosnimi razpokami v dolomitu. Pri današnji situaciji stene vodnjakov niso vodotesne in tudi njihovi temelji na dolomitni podlagi so dotrajani. Stara vodnjaka bi bilo treba zaplombirati in njuno neposredno okolico zatesniti. Na vsak način bo v bližnji bodočnosti treba poiskati vzroke upadanja piezometrične gladine, ker bo sicer prišlo do nepopravljivih poškodb termalnega sistema.

4.7. *Laško*

Termalna voda pri Laškem izvira severno od terciarne laške kadunje. Zaradi oligocenskih skladov, ki vsebujejo premog, so okolico Laškega v preteklosti pogosto geološko preučevali. Že v drugi polovici preteklega stoletja so precej podrobno raziskali premogove plasti in zaradi razlage geoloških razmer tudi mezozojske in paleozojske sklade v njihovi podlagi.

Termalno vodo so v Laškem prvič zajeli l. 1852. To zajetje je l. 1936 dotrajalo in ga je bilo treba rekonstruirati. Povprečna temperatura vseh izvirov termalne vode, zajetih leta 1936, je bila 36 °C. Vodo so zajeli z vodnjakom, globokim okoli 5,0 m; skopali so ga do dolomitne podlage. Vse izvire termalne vode, ki so imeli večjo količino, so ločeno zajeli in jih speljali v skupen vodnjak. Tudi to zajetje je dotrajalo. Zaradi neposrednega vpliva Savinje in podtalnice v kvartarnem produ je temperatura termalne vode padla od prvotnih 36 °C na 34 °C. Te okoliščine so dale leta 1965 povod za detajlne hidrogeološke raziskave. Njihov namen je bil, zajeti termalno vodo v globini in na ta način zmanjšati vpliv Savinje.

V letih 1965 do 1967 je bilo izvrtanih 7 vrtin. Prve tri plitve vrtine naj bi dale osnovne podatke o razprostranjenosti triadnih in paleozojskih plasti pod kvartarnimi naplavinami Rečice in Savinje in s tem za lokacijo globokih raziskovalnih vrtin na prostoru vodonosnega triadnega dolomita.



Sl. 2. Prečni geološki profil termalnega območja Laško
Fig. 2. Transverse geologic section across the Laško thermal area

Vrtina V-4 je bila locirana 33 m severozahodno od zajetja (sl. 2). Prevrtala je triadni dolomit, ki sega do globine 164,00 m, kjer je bil ugotovljen prelomni kontakt s permskimi sedimenti. Glavni dotok termalne vode je bil v globini 98,00 m do 115,00 m. Črpanje pri depresiji 0,17 m je dalo 6 l/sek termalne vode s temperaturo 39 °C; tako visoke temperature v Laškem do takrat niso dosegli. Vrtina je bila kasneje urejena za eksploatacijo. Pri depresiji okoli 1,50 m iz nje teče 12 l/sek s temperaturo 39,4 °C.

Vrtina V-5 je bila locirana okoli 90 m južno od vrtine V-4 in je segla do globine 660,50 m. Na tej lokaciji so bili kvartarni sedimenti debeli 8,50 m, nato pa je bil v vrtini do končne globine triadni dolomit (sl. 2) Črpalni poskusi, opazovanja temperature in meritve piezometrične gladine z naraščanjem globine so pokazali, da je odsek z maksimalno temperaturo v globini okoli 125 m do 145 m. Dalje se je z globino dvigala piezometrična gladina od kote 217,33 m, ko je vrtina zadela na prvi dotok termalne vode v globini okoli 60 m, na koto 224,57 m, ko je vrtina zadela na dotok termalne vode v globini 492,00 m. Razlika med piezometrično gladino 7,24 m je povzročila, da se je termalna voda na koti 220,78 m prelivala čez rob opažne cevi premera 98 mm. Prelivna količina je znašala 4,8 l/sek in temperatura 30,5 °C.

Z vrtino V-6, locirano okoli 80 m južno od vrtine V-5, smo imeli namen raziskati kontakt med psevdoziljskim skrilavcem in dolomitom. Geoelektrične meritve so nakazale mejo med dolomitom in skrilavcem pod kvartarnimi sedimenti. Kontakt med obema kameninama je bil ugotovljen v globini 106,80 m. Končna globina vrtine je bila 153,60 m.

V vrtini V-7, okoli 40 m jugozahodno od vrtine V-6, smo po podatkih vrtine V-5 pričakovali pod neprepustnim skrilavcem termalno vodo, ki bi iz globine prek 350 m pod lastnim pritiskom dotekala na površje. Pri naklonu kontakta med dolomitom in skrilavcem, ugotovljenem v vrtini V-6, bi morala vrtina zadeti na isti kontakt v globini 300 do 350 m. Toda zadela je na dolomit že v globini 181,79 m in do globine 450 m ni pokazala pričakovanih rezultatov. S tem so bile hidrogeološke raziskave v Laškem prekinjene.

V neposredni okolici Laškega so na površju kamenine, ki zaradi svoje litološke sestave omogočajo dotok termalne vode na površje v dolini Savinje. Pas karbonskega skrilavca in peščenjaka se vleče od zahoda proti vzhodu severno od termalnih izvirov. Lokalno nahajamo ob karbonu še krpe permskega peščenjaka in spodnjetriadne skitske plasti. Meja med permom in spodnjo triado še ni točno določena. V raziskovalni vrtini je bil v globini 164 m ugotovljen prelomni kontakt med paleozojskimi in triadnimi skladi. Triadni dolomit sega do navedene globine, pod njim pa leži rdeči permski peščenjak, ki prehaja v globini 260 m v črni karbonski skrilavec.

V okolici termalnih izvirov je na površju razgaljen srednjetriadni dolomit, ki je porozen in zato kolektor termalne vode. Dolomit se razteza od zahoda proti vzhodu v pasu, širokem do 500 m, ponekod pa se zoži na nekaj 10 m ali ga prekrijejo mlajše plasti. Ob prelomih je dolomit razpokan in zdrobljen. V glavnem je siv, so pa vmes tudi vključki temno sivega in rumenkastega dolomita. Zdrobljene cone so pogostne na površju in po podatkih vrtin tudi v globini. So nepravilno razporejene in tvorijo neprepustne leče v razpokanem dolomitu. Dolomit prekriva južno od toplic ob njegovem celotnem robu psevdoziljski skrilavec, ki vsebuje vložke peščenjaka s prehodom v tufit. Glinasti skrilavec je črn in podoben karbonskemu skrilavcu.

Psevdoziljske sklade prekinjajo leče in bloki kremenovega keratofirja in tufa. Na južno krilo antiklinale so bile odložene terciarne plasti, ki se raztezajo proti zahodu v laško premogovno kadunjo.

Območje termalnih izvirov v Laškem pripada tektonski enoti Posavskih gub. Z raziskavami neposredne okolice in strojnim vrtanjem je bila dokazana glavna dislokacija, ki poteka od zahoda proti vzhodu (sl.2). Ob njej se stikajo paleozojski sedimenti s triadnim dolomitom. Ker prekrivajo dolomit z južne strani peščenoskrilavi psevdoziljski skladi, lahko smatramo kompleks južno od preloma za antiklinalno krilo, katere jedro tvorijo severno od preloma paleozojski skladi. Podobno seka prelom tudi terciarne sedimente ob severnem robu laške sinklinale. Na ta način je ožje območje termalnih izvirov vklešČeno med dva preloma, s severne in južne strani pa obdajajo vodonosni dolomit neprepustne plasti glinastega skrilavca in peščenjaka. Tretji prelom poteka zelo verjetno vzporedno s Savinjo pod najmlajšimi naplavinami, zato na površju ni viden. Nakazuje ga nenadna zožitev dolomitnega pasu prav na ožjem vrelčnem območju. Na levem bregu Savinje je pas dolomita širok okoli 500 m, na desnem bregu, oziroma onstran ceste Celje—Laško pa se zoži na okoli 50 m.

Na tektonske smeri sever—jug in vzhod—zahod kažejo tudi številne razpoke, merjene na površju.

Z nadaljnjimi raziskavami bo potrjena ali ovržena domneva o prelomu s smerjo sever—jug. Bolj verjetno je, da ta prelom obstoji, ker se odraža tudi v morfologiji ozemlja.

Termalni izviri pritekajo na površje v dolini Savinje, ki predstavlja najnižjo koto v dolomitnem pasu. Ozemlje, kjer se pojavljajo termalni izviri z različno temperaturo, meri nekaj 1000 m^2.

Triadni dolomit zapirajo proti severu in jugu neprepustne skrilavo-peščene plasti, proti vzhodu in zahodu se obenem z neprepustno bariero na severu in jugu dolomit dviga in tvori kot bolj odporna kamenina najvišje vrhove.

Raziskovalne vrtine so pokazale, da lahko ločimo več termalnih horizontov, in sicer glede na temperaturo termalne vode v globini in na piezometrično višino.

V vrtini V-4 je bil najtoplejši horizont v globini 95,0 m do 115,0 m, obenem je bil v tej globini tudi največji dotok termalne vode 9 l/sek pri depresiji 1,5 m s temperaturo 39,4 °C. S termosondiranjem je bila sicer izmerjena v tej globini temperatura 41 °C, vendar se termalna voda na poti proti površju nekoliko ohladi.

Vrtina V-5 je prevrtala najtoplejši horizont v globini 125,0 m do 145,0 m, kjer je bila s termosondiranjem tudi izmerjena temperatura 41 °C. Temperature 36,5 do 40 °C so bile izmerjene s termosondiranjem še do globine 260,0 m, nakar je v globini pod 350,0 m temperatura padla na 33,5 °C; še danes teče iz vrtine manjša količina termalne vode s temperaturo 31,6 °C. Vrtina je ostala zacevljena s cevmi premera 113 mm do globine 238,50 m. Iz navedenega sledi, da je najtoplejši horizont v globini, kjer vpliv hladne podtalnice in Savinje že oslabi. Pod najtoplejšim horizontom pa je temperatura zopet nižja, torej se primarna termalna voda prebija proti površju skozi hladnejšo vodo, ki jo obenem ogreva. Različna globina najtoplejšega horizonta v obeh vrtinah kaže njegov naklon proti vrtini V-5. Iz katere smeri priteka termalna voda iz globine, je še problematično; tudi vrtini V-6 in V-7 nista tega pojasnili.

Po dviganju piezometrične gladine z globino je možno razdeliti dolomit kot kolektor termalne vode na tri horizonte. Zgornji horizont je pod neposrednim vplivom podtalnice v naplavinah Savinje in Rečice. Ta horizont sega po podatkih vrtine V-5 do globine okoli 110 m. Naslednji horizont je prehodni, kjer se površinski vpliv polagoma zmanjšuje in piezometrična gladina polagoma narašča. Pri tem moramo upoštevati tudi dviganje gladine zaradi vgraditve cevi v vrtino do vodonosnih plasti, oziroma prepustnejših con v dolomitu. Prehodni horizont sega nekako do globine 250 m. Od tod globje sledi tretji horizont, kjer se je piezometrična gladina naglo dvignila in pri globini vrtine 492 m dosegla najvišjo koto 224,57 m ali 4,24 m nad površjem.

Točnih meja med posameznimi horizonti ni mogoče postaviti, ker se verjetno spreminjajo vzporedno z vodnimi količinami, ki jih posreduje termalna cona prek izvirov in zajetij na površje. Dosedanje hidrogeološke raziskave še niso dale odgovora, kakšna je celotna izdatnost termalnega sistema v Laškem. Z gotovostjo moremo trditi, da je precej večja od sedanje količine. To dokazujejo izviri termalne vode v okolici zajetij. Hidrogeološke raziskave v letih 1965—1967 so nakazale, da je na termalnem območju v Laškem možno doseči dvoje: termalna voda z maksimalno temperaturo bi sama pritekala na površje, če bi bila zajeta globlje in na ustrezni lokaciji, ki jo bo treba poiskati z nadaljnjimi raziskavami. Zajetje na primerni lokaciji bi dajalo termalno vodo s konstantno temperaturo, ki bi bila višja od 38 °C.

4.8. *Podčetrtek*

Raziskave v letih 1965 do 1967 so imele namen urediti izvir termalne vode Harina Zlaka na levem bregu Sotle. Za širšo okolico izvira je bila izdelana detajlna geološka karta v merilu 1:10000, ki je dala osnovo za lokacijo raziskovalnih vrtin. Po predvidenem programu so bile izvrtane 3 raziskovalne vrtine, V-1/65, V-2/65 in V-3/65.

Vrtina V-1/65 je prevrtala kvartarne in triadne sedimente. Po 12,00 m debeli plasti peščene in meljne gline, ki jo je v spodnjem delu zamenjal grušč in slabo zaobljen prod pomešan z meljem in delno z glino, je sledil triadni dolomit z redkimi vložki skrilavca in tufita. Od globine 250 m naprej so bili vložki skrilavca bolj pogostni. V globini 274 m se je pričel temen glinasti lapor. Termalna voda se je pojavila v različnih globinah. Najvišjo temperaturo je imela na kontaktu kvartarnih in triadnih plasti, in sicer 30 °C. V triadnem dolomitu pa je imela temperaturo 23 do

23,5 °C. Izviri na površju v okolici vrtine V-1/65 imajo v regulirani strugi Sotle temperaturo do 26 °C, izviri v bližini površinskega kontakta med triado in naplavinami Sotle pa okoli 23 °C, kar ustreza temperaturi termalne vode v triadnem dolomitu v vrtini V-1/65. Vrtina je bila locirana na periferiji območja termalnih izvirov. Vanjo so bile vgrajene cevi premera 5" do globine 60,64 m in od 60,64 m do 72,00 m cevi premera 4". Cevi so bile perforirane od 25,44 m do 66,50 m, kjer so bili med vrtanjem ugotovljeni najizdatnejši dotoki termalne vode.

Vrtina V-2/65 je prevrtala kvartarne naplavine in v globini 6,00 m zadela na triadni lapor s polami peščenjaka. Od globine 27,40 m naprej je bil v vrtini razpokan sivi dolomit. V dolomitu se je pojavila voda s temperaturo 18 °C. Vrtina je bila ustavljena v globini 63,10 m. Nizka temperatura dotoka vode v dolomitu je razumljiva, saj se v neposredni bližini V-2/65 izceja iz triadnega dolomita hladna voda.

Vrtina V-3/65 na desnem bregu Sotle zahodno od izvira Harina Zlaka je zadela v globini 11,20 m pod kvartarnimi naplavinami Sotle na oligocenski lapor in pod njim po vmesni zdrobljeni coni na triadni porfiritni tuf v globini 26,40 m. V globini 45,00 m je sledil triadni dolomit do končne globine 137,00 m.

Termalna voda se je pojavila v poroznem dolomitu že na meji s porfiritnim tufom. Glavni dotok je bil v globini 45,00 m do 70,00 m in sledovi termalne vode še v globini 105,00 m do 112,00 m. Dolomit je bil od globine 70,00 m naprej zelo zdrobljen, zato je bila kasneje z vgraditvijo cevi zajeta termalna voda na odsekih 50,91 m do 84,12 m in 104,82 m do 120,49 m, kjer so bile cevi perforirane.

Leta 1966 je bila izvrtana še kaptažna vrtina K-1 do globine 80,00 m. V vrtino so bile vgrajene jeklene cevi premera 10 ¾" do globine 30,00 m, do končne globine 80,00 m pa je vrtina ostala nezacevljena, ker so bile kamenine le razpokane in kavernozne, kar velja posebej za dolomit kot vodonosni horizont.

Poskusno črpanje v kaptažni vrtini K-1 je dalo pri depresiji 1,00 m do 1,015 m 8 l/sek, pri depresiji 1,52 do 1,55 m pa 10 l/sek vode s temperaturo 35 °C.

Leta 1970 je bila 10 m zahodno od K-1 izvrtana še rezervna kaptažna vrtina K-2. S tem so bile zajete celotne količine termalne vode v plitvi coni. Litološko se vrtina K-2 popolnoma ujema z vrtino K-1, le da se porozna cona v triadnem dolomitu pričenja v globini okoli 56,00 m. Črpalni poskus opravljen v sušni dobi l. 1970 je pokazal, da je možno črpati iz plitve cone 15 do 20 l/sek termalne vode s temperaturo 33,9 do 35 °C. Leta 1971 je termalno vodo prevzelo Združeno železniško transportno podjetje Ljubljana, in sicer njegova enota za turizem in gostinstvo, ki je prevzela obveznost, da pristopi k izgradnji objektov, kjer bi se termalna voda izkoriščala v zdravstvene in turistične namene. S tem v zvezi je Geološki zavod Ljubljana izdelal program nadaljnjih hidrogeoloških raziskav, katerega del je bil realiziran leta 1972. Program hidrogeoloških raziskav je zajel globoko termalno cono z namenom, da se zajame termalno vodo z višjo temperaturo in obenem poveča njeno skupno količino.

Raziskovalna vrtina V-1/72 je bila locirana 50 m jugozahodno od vrtine K-1. V globini 9,00 m je zadela na oligocenski peščeni lapor, ki je segal do 85,60 m. Po vmesni zdrobljeni coni se v globini 88,60 m pričenja triadni dolomit z vložki porfiritnega tufa in sega do 135,20 m. Do končne globine 202,20 m je vrtina prevrtala triadni dolomit z vložki breče in temno sivega dolomita. Manjši dotok termalne vode se je pojavil v globini 90,50 do 98,00 m. V globini 111,00 m je dotok termalne vode v vrtino pričel naraščati in se je polagoma večal do 177,00 m. Vrtina V-1/72 je bila kasneje spremenjena v kaptažno vrtino s povečanjem premera in vgraditvijo jeklenih cevi.

Vrtina V-2/72 je bila locirana okoli 80 m severozahodno od vrtine K-1. Pod kvartarnimi naplavinami je v globini 11,50 m zadela na oligocenski lapor, pod njim pa 88,60 m globoko na porozen dolomit z manjšim dotokom termalne vode. V globini 91,00 m do 132,80 m je bil ugotovljen porfiritni tuf in nato do 197,30 m razpokan triadni dolomit, nakar je sledil do 222,10 m steklast porfiritni tuf ter do končne globine 224,90 m zopet dolomit.

Območje termalnih izvirov pri Podčetrtku sestoji iz triadnih, terciarnih in kvartarnih kamenin.

Kvartarni sedimenti dosežejo v dolini Mestinjščice in Sotle 12 m debeline. Sestoje iz peščene in meljne gline ter slabo zaobljenega proda. Na triadni podlagi so bazalne oligocenske plasti sivice, kremenovega peska in kremenovega peščenjaka, ki vsebuje ponekod premog.

Med oligocenom in miocenom je erozijska diskordanca, prav tako med helvetskim laporjem ter peščenjakom in tortonsko litavsko serijo sedimentov, ki se pričenja z bazalnim konglomeratom. Po mikrofavni sodeč je bil odložen le spodnji in srednji torton. V sinklinalnih krilih se priključujejo sarmatski sedimenti, in sicer prevladuje glinovec s plastmi peska, peščenjaka, konglomerata in gline. Sinklinalo pri Pristavi zapolnjujejo pliocenski sedimenti, ki jih tvori sivi in svetlo sivi glinovec s plastmi peska.

Triado zastopa dolomit z vložki tufa in tufita, glinastega skrilavca in breče. Dolomit je siv, včasih skoraj črn, vsebuje ponekod gomolje in vključke roženca in pirita. Po litološki sestavi pripada ladinski stopnji. V okolici termalnega območja se pojavlja še glinasti skrilavec in porfirit s tufi. Dalje so razgaljeni še werfenski skrilavec, lapor in dolomit. Triadne kamenine pripadajo obronkom Rudnice in segajo na površje skozi terciarne sedimente.

Okolica termalnih izvirov je razkosana po številnih prelomih, nastalih večji del v mlajših orogenetskih fazah. Prelomi so bili sicer ugotovljeni le tam, kjer prihajajo na površje triadne kamenine, vendar sklepamo po razprostranjenosti terciarnih kamenin in po morfologiji, da se nadaljujejo na ozemlje terciarnih kamenin. Predvsem kažejo na zvezo s tektoniko prečne doline, ki potekajo od severa proti jugu pravokotno na os terciarne sinklinale.

Glavna preloma s smerjo sever—jug sta vzporedna z dolino Mestinjščice in Sotle. Ob Sotli poteka prelom, ki smo ga ugotovili tudi z vrtinami na območju mineralnih vrelcev v Rogaški Slatini. Terciarni sedimenti tvorijo severno od Rudnice široko sinklinalo, ki se proti zahodu razcepi v dve sinklinali. V vmesni antiklinali prihaja na površje južno od Šmarja pri Jelšah triadna podlaga. Celotnemu ozemlju med Rudnico in Bočem so dali pečat predvsem mlajši orogenetski procesi.

Termalni izviri v okolici Podčetrtka se pojavljajo v coni, ki sega na jugu od opuščenega rudnika železa pri Olimju do sotočja Sotle in Mestinjščice na severu. Cona je široka le nekaj 100 m. Glavno območje termalnih izvirov je severno od Podčetrtka, kjer je termalna voda zajeta v treh kaptažnih vrtinah in ima najvišjo temperaturo. Vodonosni horizont je srednjetriadni dolomit, ki ga v dolini Sotle prekrivajo mlajši terciarni in kvartarni sedimenti ter delno porfiritni tuf. Širšo termalno cono so razkosali številni prelomi na več blokov. Izviri termalne vode se pojavljajo v bližini kontakta dolomita z neprepustnim pokrovom terciarnega laporja in delno skrilavca. Vodonosna je prelomna cona, in sicer ob prelomu, ki je nagnjen proti zahodu, kar so pokazale raziskovalne vrtine. Tudi debelina neprepustnih kamenin narašča v tej smeri.

Temperatura termalne vode je najvišja v severnem delu širše termalne cone, proti jugu, oziroma proti jugozahodu temperatura pada. Skrajno znano jugozahodno točko s termalno vodo predstavlja vrtina V-1/48, izvrtana v okviru raziskav železovega rudišča pri Olimju, kjer še danes priteka na površje okoli 10 l/sek vode s temperaturo 18 °C. Dotok vode v vrtino V-1/48 je v apnencu v globini 27,0 m, torej še v plitvi coni. Globlje tudi v ostalih vrtinah v dolomitu ni bilo dotokov termalne vode.

Vse dosedanje raziskave kažejo, da je glavno območje termalnih izvirov v dolini Sotle severno od Podčetrtka. Ostali pojavi s temperaturo 18 do 24 °C so stranski izviri, ki le nakazujejo nadaljevanje termalne cone proti jugozahodu.

Termalna voda je danes zajeta z vrtinami, in sicer v dveh vrtinah K-1 in K-2 plitvo v globini 46,0 m do 80,0 m in v vrtini V-1/72 v globini 120,0 do 180,0 m. Prelomna cona z najtoplejšo vodo je nagnjena proti zahodu, zato je tudi temperatura v vrtini V-1/72 37 °C, v obeh plitvih zajetjih pa 34 do 35 °C. Skupne količine, ki jih je možno pridobivati s črpanjem, znašajo okoli 30 l/sek.

4.9. *Dolenjske Toplice*

Okolica Dolenjskih Toplic je bila geološko kartirana v merilu 1:10 000 leta 1961. Do l. 1959 so raziskave obsegale le posamezne oglede termalnih izvirov in meritve količin termalne vode. O teh raziskavah obstajajo zapisniki in krajša poročila v zdraviliškem arhivu.

Hidrogeološke raziskave z vrtanjem so bile opravljene prvič l. 1960 do 1961. Izvrtane so bile štiri raziskovalne vrtine, in sicer prve tri v neposredni bližini obstoječih zajetij termalne vode in ena vrtina severno od športnega bazena ob cesti Dolenjske Toplice—Novo mesto.

Po desetih letih so bile leta 1971 izvrtane še štiri raziskovalne vrtine, ki so posegle v globino 190,0 m do 416,0 m. Rezultat teh raziskav je bilo zajetje termalne vode v globini 290,0 do 315,0 m.

Najstarejše plasti v okolici Dolenjskih Toplic pripadajo zgornji triadi. Sestoje iz sivega pasovitega dolomita s polami zrnatega dolomita in prehajajo v spodnjejurske sklade. Zavzemajo ozemlje severno od sotočja Krke z Radešco in sestavljajo okolico Soteske in Straško goro. Spodnjejurske plasti sestoje iz sivega zrnatega dolomita, temno sivega apnenca s polami skrilavega laporja in sivega apnenca z redkimi vložki drobno oolitnega apnenca. Zavzemajo ozemlje med potokoma Sušico in Radešco ter segajo čez dolino Krke na južno pobočje Straške gore. Spodnjejurskim plastem sledita srednjejurski oolitni apnenec z vložki oolitnega dolomita in zgornjejurski svetlo sivi apnenec. Nastopata strnjeno v vzpetinah Pristave in Prašičevke vzhodno in severovzhodno od Dolenjskih Toplic.

Zahodno od Radešce prihajajo na površje plasti spodnje krede, ki vpadajo proti zahodu pod Kočevski Rog. Sestoje iz temno sivega delno bituminoznega apnenca.

Kvartar zastopa kraška ilovica v dolinah Sušice, Krke in Radešce. Recentne naplavine, peščene in meljne gline ob Krki, Radešci in Sušici so prenesle površinske vode v glavnem z območja kraške ilovice.

V okolici Dolenjskih Toplic sta pomembna dva preloma. Žužemberški prelom je ena od glavnih tektonskih linij v zgradbi Slovenije in Hrvatske. Poteka od Ljubljanske kotline v gornjo krško dolino in nato ob Kočevskem Rogu vzdolž doline potoka Radešce in Črmošnjic v Belo krajino. Drugi je topliški prelom, ki poteka vzdolž potoka Sušica. Ob njem se stikata spodnjejurski zrnati dolomit in plastoviti apnenec z oolitnim apnencem spodnje jure. Med topliškim in žužemberškim prelomom se širi jurska sinklinala, ki je ob žužemberškem prelomu narinjena na spodnjo kredo. Narivna ploskev je nagnjena pod kotom 60° do 70° proti severovzhodu in jo nakazujejo tektonske drse med Meniško vasjo in Selom. Na potek večje dislokacije kaže tudi izrazita zdrobljena cona.

Termalna voda v Dolenjskih Toplicah je zajeta nad izviri v kletnih prostorih Zdraviliškega doma, kjer doteka v dva bazena. V velikem bazenu imajo dotoki temperaturo 37,1 do 38,4 °C, v jamskem bazenu pa 36,2 do 37,4 °C.

Po podatkih hidrogeoloških raziskav l. 1960/61 in 1971 priteka termalna voda na površje po sistemu razpok ob topliškem prelomu, ki so razširjene v kaverne. Torej si je termalna voda utrla v jurskem apnencu pot proti površju po razpokah in jih sčasoma razširila v kaverne. Kraški globinski sistem, po katerem se pretaka termalna voda, obdaja kraški sistem hladne vode. Na ta način je termalna voda pod vplivom hladne kraške podtalnice. Količina termalne vode se zato pri visokih vodostajih Sušice navidezno poveča, oziroma se dvigne njena piezometrična gladina. Pri nizkih vodostajih Sušice termalna voda priteka na dan v številnih izvirih v strugi potoka. Piezometrična gladina se zniža in se zato količina termalne vode v glavnih izvirih zmanjša. Črpalni poskusi, ki so trajali od 13. 12. 1960 do 20. 1. 1961, so pokazali, da se količina termalne vode s temperaturo 36,5 do 38,4 °C ne spremeni in znaša pri nizkih in visokih vodostajih potoka Sušice 12 do 13 l/sek.

Raziskovalne vrtine so pokazale, da je dotok termalne vode iz globine vezan na najbolj prepustno, zakraselo cono v jurskem apnencu in triadnem dolomitu. Jedro toka termalne vode predstavljajo izviri, zajeti v velikem bazenu z najvišjo temperaturo 38,4 °C. Jamski bazen predstavlja s svojimi izviri s temperaturo 37,4 °C že bolj periferni del najtoplejše cone.

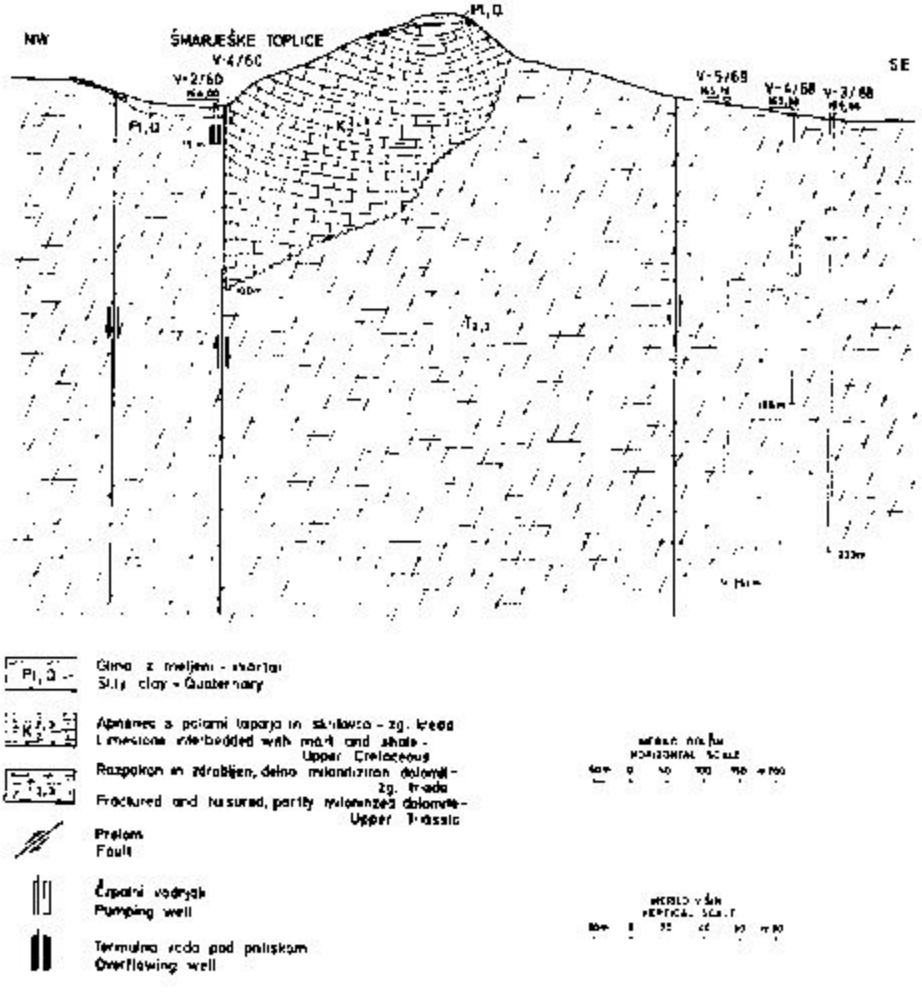
Vse raziskovalne vrtine v neposredni bližini termalnih izvirov so pokazale najprej cono z višjo temperaturo, ki je segala do globine 90,0 m do 120,0 m, nakar je temperatura padla tudi za 10 °C. Ponoven dvig temperature za 10 °C je pokazala najglobija vrtina V6/71 v globini 200,00 m in je nato zadela na termalno vodo v triadnem dolomitu v globini 299,50 m do 303,00 m, kjer je bila zajeta dodatna količina termalne vode 7 l/sek s temperaturo 32 °C. Take temperaturne razmere v globini kažejo, da je stik z globoko termalno cono pod sedanjimi izviri z najvišjo temperaturo.

Raziskovalne vrtine so pokazale tudi, da je potok Sušica južna meja plitve in verjetno tudi globoke termalne cone, kjer bi bilo možno zajeti termalno vodo v primarnem vodonosnem sloju triadnega dolomita, ki se pričenja v globini okoli 260,0 m. Dalje so pokazale, da sega sistem kavern, po katerih doteka termalna voda na površje, tudi v triadni dolomit.

Problem globokega zajetja termalne vode v Dolenjskih Toplicah bodo rešile nadaljnje raziskave z vrtanjem globokih raziskovalnih vrtin, ki bodo posegle globlje od 600,0 m.

4.10. *Šmarješke Toplice*

Šmarješke Toplice ležijo okoli 1 km severno od vasi Kronovo v dolini potoka Dolnice. O izvirih termalne vode v Šmarjeških Toplicah so do leta 1956 obstajali le posamezni komisijski zapisniki in kratka poročila F. Ž u r g e v topliškem arhivu. Prve podrobne raziskave, ki so obsegale geološko kartiranje okolice toplic v merilu 1:10 000 in meritve temperature v kvartarnih naplavinah, sta opravila D. K u š č e r in F. D r o b n e. Na podlagi teh raziskav je bilo v l. 1959 izvrtanih 19 ročnih vrtin, s katerimi sta bila ugotovljena dva centra izvirov termalne vode, oddaljena med seboj okoli 200 m. Plitvim vrtinam so sledile štiri strojne vrtine v l. 1959/60. Vrtina V-1/59 je bila locirana pri športnem bazenu, V-2/59, V-3/60 in V-4/60 pa pri pokritem bazenu. Leta 1962 je bila pri pokritem bazenu izvrtana še vrtina V-5/62. Leta 1969 smo izvrtali pri športnem bazenu štiri strojne vrtine. Okoli 0,8 km južno od Šmarjeških Toplic je še en izvir termalne vode. Ima temperaturo 16 do 18 °C in daje okoli 230 l/sek. V okolici tega izvira smo leta 1968 vrtali dve plitvi in tri globoke vrtine. S temi raziskavami smo imeli namen ugotoviti, kako bi bilo možno ločiti hladno in termalno vodo in ju ločeno izkoriščati. Dokončno tega vprašanja zaradi premajhnega obsega raziskav ni bilo mogoče rešiti, pač pa smo v dveh globokih vrtinah dobili termalno vodo, v V-3/68 s temperaturo 25 °C in v V-4/68 s temperaturo 28 °C (sl. 3). Raziskave bo potrebno nadaljevati, da bi dosegli postavljeni cilj. Vodo glavnega izvira smo kljub temu l. 1970 zajeli in bo zajetje oskrbovalo Novo mesto z okolico. Na ožjem območju termalnih izvirov v Šmarjeških Toplicah smo v letih 1959/60 in 1969 dobili podatke o plitvi coni, s kaptažnimi vrtinami pa smo podvojili količine termalne vode in obenem dobili indikacije, da je možno z nadaljnjimi raziskavami globoke termalne cone tudi zvišati temperaturo termalne vode.



Sl. 3. Pregledni geološki profil Šmarjeških Toplic
Fig. 3. General geologic section across the Šmarješke Toplice

Najstarejša in tudi najbolj razširjena kamenina v okolici Šmarjeških Toplic je svetlo sivi triadni dolomit. Natančneje starosti dolomita ni mogoče določiti; po primerjavi z razvojem dolomita drugod na Dolenjskem pripada verjetno zgornji triadi. V okolici termalnih izvirov je dolomit zdrobljen. Zdrobljena cona se vleče v smeri severoseverovzhod-jugojugozahod čez ožje območje termalnih izvirov. Široka je ponekod 100 m. V njej je v okolici zdravilišča več peskokopov. Zdrobljeno cono so prevrtale tudi raziskovalne vrtine. Na obeh straneh zdrobljene cone je dolomit bolj plastovit, vendar ga zaradi intenzivne tektonike prepletajo številne razpoke in tektonske drse.

Na dolomitu ležijo erozijski ostanki jurskega in krednega apnenca. Kredi pripada temno sivi apnenec z vložki glinastega laporja in gomolji roženca, ki zapira plitvo termalno cono proti jugu v obliki neprepustne bariere. Proti vzhodu vpadajo mezozojske plasti pod terciarni lapor, peščenjak in litavski apnenec, drugod jih delno prekriva kraška ilovica.

Doline potokov prekriva ponekod tanjša, drugod do 6 m debela plast glinastopeščenega holocena, ki vsebuje predvsem v območju termalnih izvirov organsko glino.

Zveza geološke zgradbe Šmarjeških Toplic in Krške kotline še ni raziskana. Navedbe v literaturi, da je Krška kotlina udorina, niso dokazane. Geološko kartiranje je pokazalo, da gre prej za sinklinalo, ki jo tvorijo terciarni sedimenti. Predterciarno osnovno gorstvo prekrivajo transgresivno miocenski tortonski sedimenti: peščeni lapor, apneni peščenjak in grebeni, oziroma čeri litotamnijskega apnenca. Te sedimente prekrivajo z južne in severne strani sarmatski sedimenti, na katerih leži proti vzhodu diskordantno panonski glinasti lapor.

Zdrobljeno cono v Šmarjeških Toplicah spremlja več lokalnih prelomov. Termalna voda priteka na površje severno od preloma, ob katerem se stikata triadni dolomit in kredni apnenec. Zahodno od izvirov pri športnem bazenu seka ta prelom drugi prelom s smerjo severozahod-jugovzhod, ki povezuje območje termalnih izvirov v Šmarjeških Toplicah s termalnimi izviri pri Kronovem. Ta dva preloma sta važna zato, ker doteka po razpokah ob obeh prelomih termalna voda na površje.

V prelomnih conah je dolomit silificiran, razpoke pa zapolnjujeta kalcit in drobna breča. Tudi v širši okolici Šmarjeških Toplic prevladujejo podobne tektonske razmere. Ozemlje je razkosano z lokalnimi prelomi na več blokov, ki jih posebno v dolomitu spremljajo zdrobljene cone.

Dosedanje hidrogeološke raziskave v Šmarjeških Toplicah in okolici so pokazale, da je termalna voda v zvezi s hladno podtalnico. V poroznem dolomitu je akumulirana hladna voda, na posameznih mestih pa se skozi hladno podtalnico prebija proti površju termalna voda. To dokazujejo temperature posameznih izvirov, ki so odvisne od razmerja med količinami hladne in termalne vode, oziroma oddaljenosti od termalne cone.

Vodonosna kamenina je triadni dolomit. V razpokah in zdrobljenih conah pa se termalna voda preliva na površje. Zaradi prepustnosti, ki jo karakterizira koeficient prepustnosti $k = 1,2 . 10^{-5}$ cm/sek do $4,5 . 10^{-4}$ cm/sek izračunan po podatkih črpalnih poizkusov, je dolomit prepojen s hladno vodo. Od piezometrične gladine podtalnice je odvisna količina termalne vode na današnjih kotah izvirov. Zato se v sušnih dobah količine termalne vode zmanjšajo, vendar z zakasnitvijo, ker se gladina hladne podtalnice zaradi sorazmerno slabe prepustnosti dolomita znižuje zelo počasi. Od nihanja gladine hladne podtalnice je torej direktno odvisna prelivna količina termalne vode.

V športnem bazenu je maksimalna temperatura 34,5 °C, v pokritem bazenu pa 32 °C. V obeh centrih priteka termalna voda s severa. Pri pokritem bazenu tvori južno mejo plitve termalne cone prelomni kontakt med triadnim dolomitom in krednim apnencem. Zaradi vložkov laporja in lapornega skrilavca predstavlja blok krednega apnenca neprepustno bariero, ki loči šmarješko plitvo termalno cono od okoli 800 m južno ležeče plitve termalne cone v okolici izvira »Jezero«.

Kredni apnenec v okolici Šmarjeških Toplic predstavlja erozijske ostanke, zato sega verjetno blok krednega apnenca z vložki laporja in lapornega skrilavca le v manjšo globino. V raziskovalnih vrtinah je bil ob prelomu ugotovljen kredni apnenec do globine 80 m. Take razmere kažejo, da je vir višje temperature ista termalna cona v globini za šmarješko termo in širšo okolico.

Površinski vodotoki ne vplivajo na izdatnost termalnih izvirov, ker tečejo po kvartarnih glinastih sedimentih. Na območju termalnih vrelcev v Šmarjeških Toplicah doseže debelina glinastih sedimentov 7 m. To debelino so pokazale številne ročne vrtine leta 1959.

V Šmarjeških Toplicah prevladuje na območju termalnih izvirov termalna voda, pri izviru »Jezero« pa hladna podtalnica. Mešanje hladne in termalne vode je zato bolj izrazito v plitvi coni v okolici izvira »Jezero«, saj je izmerjeni pretok izvira v suši okoli 230 l/sek. in temperatura izvira 16 do 18 °C. Problematika celotnega območja termalnih izvirov v okolici Šmarjeških Toplic še ni dokončno razčiščena. Plitva termalna cona je raziskana do globine 150 m. Termalna voda je zajeta pri športnem bazenu v globini 12 do 147 m in pri pokritem bazenu v globini 11 do 19 m. Pri izviru »Jezero« so vrtine segle do globine 257 m, tako da smo se bolj približali globoki coni. Zelo pomembna je pri izviru »Jezero« rešitev problema ločenega zajetja, in sicer hladne vode za oskrbo prebivalstva in termalne vode za rekreacijo.

Nadaljnja dela v okolici Šmarjeških Toplic bo potrebno usmeriti tako, da bi z vrtinami raziskali globoko termalno cono. S tem bi dosegli višjo temperaturo termalne vode in z globokim zajetjem preprečili vpliv hladne podtalnice, oziroma ga omejili. Istočasno bi bil rešen tudi problem zajetja hladne vode za oskrbo Novega mesta z okolico z zajetjem izvira »Jezero«. Globoke raziskovalne vrtine bodo poleg tega pokazale, kakšna je zveza med šmarješko plitvo termalno cono in plitvo cono pri izviru »Jezero«. Dosedanje raziskave so to le nakazale, niso pa dale podatkov, ali gre za enoten hidrogeološki globinski sistem ali pa sta obe območji vezani na isto termalno cono, kjer se voda ogreva in priteka na površje kot termalna voda.

4.11. *Topličnik pri Kostanjevici*

Izvir Topličnik se pojavlja ob Krki okoli 1,5 km zahodno od Kostanjevice. Voda ima temperaturo 21 do 23 °C in priteka na površje v kotanji, ki ima obliko nekakega okna podtalnice.

Po pregledu okolice je bilo ugotovljeno, da se razteza cona, kjer se pojavlja termalna voda ob desnem bregu Krke, na približno 400 m dolgem odseku. Njegovo vzhodno mejo tvorijo izviri Topličnika.

Najprej smo termalno območje orientacijsko geoelektrično izmerili. Meritve so nakazale litološko sestavo pod kvartarnimi naplavinami Krke. Nato sta bili jeseni leta 1971 izvrtani dve raziskovalni vrtini, in sicer V-1/71 južno od Topličnika ter V-2/71 med Topličnikom in Krko. Obe vrtini sta pod kvartarjem zadeli na kredni apnenec, ki je bil v razpokanih odsekih vodonosen, vendar je bila višja temperatura 25,5 °C ugotovljena le v vrtini V-2/71.

Leta 1972 so sledile obširnejše hidrogeološke raziskave celotnega prostora, kjer se pojavljajo termalni izviri ob desnem bregu Krke. Po detajlnih geoelektričnih meritvah, ki so razen litološke sestave nakazale tudi potek prelomov, je bilo izvrtanih šest raziskovalnih vrtin, in sicer V-3/72, V-4/72 in V-5/72 na levem bregu ter V-6/72, V-7/72 in V-8/72 na desnem bregu Krke.

Vse raziskovalne vrtine so zadele na dotok termalne vode, vendar na levem bregu Krke z nižjo temperaturo 21 do 24 °C, na desnem bregu pa so imeli dotoki temperaturo 24 do 27 °C, razen v vrtini V-8/72, kjer je bila izmerjena temperatura 13 °C. Vrtina V-8/72 je bila locirana tik pod cesto Šentjernej—Kostanjevica, torej že na meji območja termalnih izvirov.

Rezultati kažejo, da prihaja termalna voda iz globine z južne strani in da doteka na površje ob Krki razhlajena in pomešana s hladno podtalnico.

Vse raziskovalne vrtine so posegle le v manjšo globino, ker je bil njihov namen ugotoviti hidrogeološke razmere v plitvi coni in nato raziskave nadaljevati na osnovi dobljenih rezultatov.

Raziskovalne vrtine so pokazale, da je v plitvi coni vodonosni horizont razpokan kredni apnenec, ki ga severno od Krke prekrivajo miocenski lapor, peščen lapor in litotamnijski apnenec. Okolico termalnih izvirov so številni prelomi razkosali v posamezne bloke. Temperatura dotokov termalne vode je bila nižja tam, kjer prekriva kredni apnenec debelejša plast terciarnega laporja. To dejstvo je ovrglo prvotno domnevo, da priteka termalna voda s severa ob kontaktu neprepustnega terciarnega laporja z litotamnijskim, oziroma krednim apnencem.

4.12. *Čateške Toplice*

Do leta 1957 je bila termalna voda v Čateških Toplicah zajeta v kvartarnem produ. Na plitvo zajetje je vplivala hladna podtalnica, zato je temperatura vode nihala. Leta 1957 in 1958 smo izvrtali 15 plitvih vrtin, ki so pokazale, kje priteka termalna voda iz podlage v kvartarni prod. Z meritvami temperature in nihanja gladine v plitvih vrtinah je bila določena lokacija raziskovalne vrtine, ki je segla do globine 82,00 m. Ta vrtina je v globini 51,70 m do 52,70 m zadela na kaverno, ki je del plitvega kraškega sistema v miocenskem apnenem peščenjaku, po katerem se pretaka termalna voda proti površju. Termalno vodo smo zajeli z vgraditvijo kaptažnih cevi. Zaradi neposrednega stika s podtalnico v produ je nihala statična gladina termalne vode v zajetju. Zato se je spreminjala tudi količina termalne vode od 15 l/sek. do 30 l/sek. Čim je bila črpana večja količina pri določenem vodostaju hladne podtalnice, se je temperatura vode znižala. Pri gladini termalne vode 2,0 m pod površjem je bilo možno črpati le okoli 15 l/sek. termalne vode z maksimalno temperaturo 57,2 °C. Pri črpanju večje količine je temperatura pričela padati.

Zajetje termalne vode v globini 51,70 m je ostalo neizkoriščeno do l. 1962, ko je KZ Brežice pričela uporabljati termalno vodo za ogrevanje zimskih toplih gred. Istega leta je KZ Brežice financirala vrtanje kaptažne vrtine premera 12" do globine 60,0 m in uredila črpalnico, ki še danes obratuje.

Hidrogeološke raziskave so se nadaljevale l. 1964. Sofinanciral jih je Sklad za geološke raziskave. Te raziskave so dale odločilne rezultate za nadaljnji razvoj Čateških Toplic. Od izvrtanih štirih raziskovalnih vrtin je vrtina V-4/64 v globini 283,0 m zadela na primarni horizont termalne vode, to je triadni dolomit. Iz te vrtine še danes priteka na površje 10,6 l/sek. termalne vode s temperaturo 57,2 °C. S tem je bila odkrita globoka termalna cona, iz katere doteka termalna voda pod pritiskom 1,6 kp/cm².

Leta 1969 so se na Čateškem polju pričele sistematične hidrogeološke raziskave, ki so se končale leta 1972. Izvedbo raziskav je omogočil Sklad Borisa Kidriča, ki jih je sokreditiral in delno sofinanciral.

Leta 1969 so bile izvrtane vrtine V-1/69, V-2/69, V-3/69 in dve kaptažni vrtini širokega premera K-1/69 in K-2/69. Vse te vrtine so bile locirane v površinskem centru plitve termalne cone in 180 m jugozahodno od njega. Dale so izredne rezultate, in sicer je bilo v dveh kaptažnih vrtinah zajeto 83 l/sek. termalne vode s temperaturo 57 do 59 °C.

Leta 1970 smo z geoelektričnimi in mikroseizmičnimi meritvami raziskali debelino kvartarnega proda in litološko sestavo pod kvartarnimi naplavinami. Vrtine V-4/71, V-5/71, V-6/71, V-7/71, V-8/71 in V-9/71 so nato leta 1971 preverile podatke geofizikalnih raziskav, ki so dale solidno osnovo za lociranje nadaljnjih raziskovalnih vrtin. Po programu raziskav sta bili izvrtani raziskovalni vrtini V-10/71 in V-11/71. Za ožjo okolico je bila izdelana detajlna geološka karta v merilu 1 : 5 000 in hidrogeološka karta v merilu 1 : 25 000.

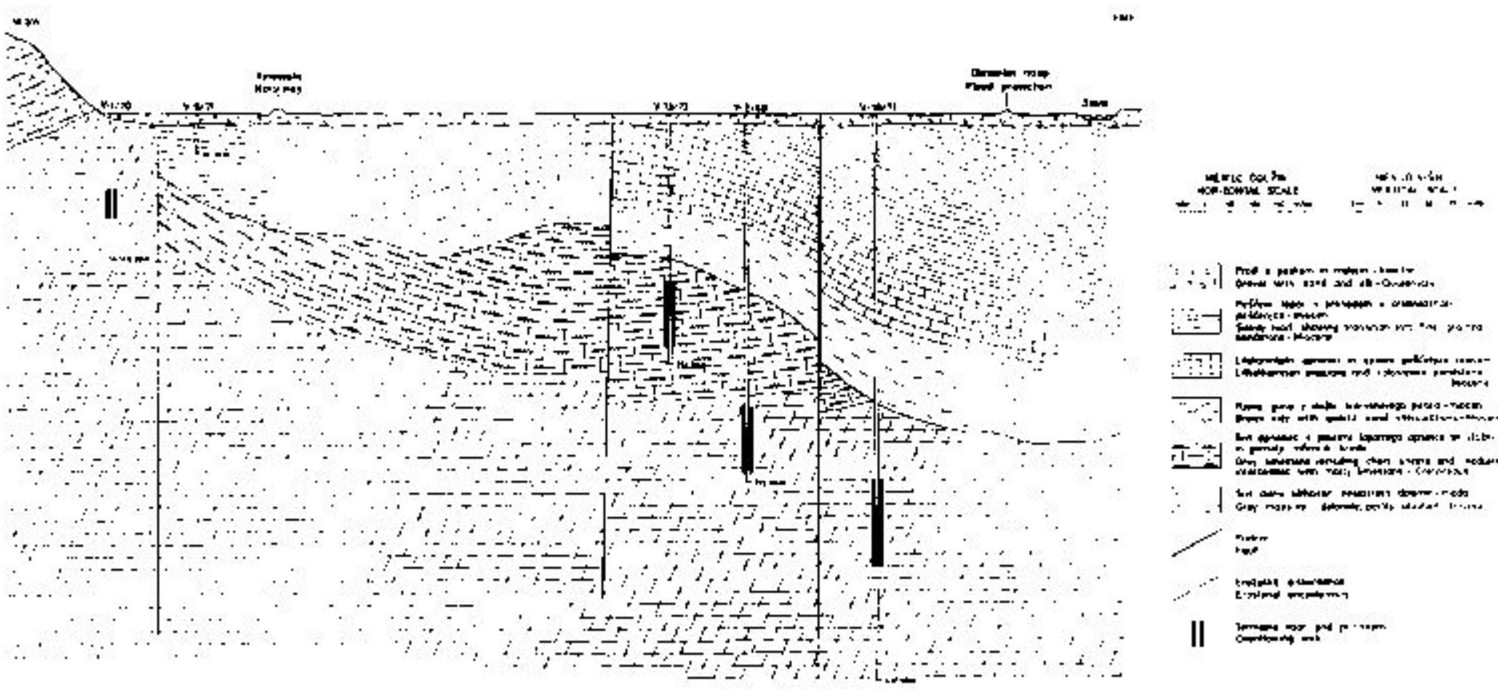
Leta 1972 so bile izvrtane še raziskovalne vrtine V-12/72, V-13/72 in V-14/72. Raziskave so bile končane s črpalnim poizkusom, ki je potrdil že prej predvideno skupno količino termalne vode okoli 120 l/sek.

Čateške Toplice ležijo na prodnati ravnini kakih 200 m južno od Save, ob robu Krške kotline. Čateško polje omejuje s severa Sava, z juga pa obrobje Gorjancev (sl. 4).

Starejša mezozojska in kenozojska podlaga prihaja na površje na obrobju Gorjancev, samo Čateško polje pa je prekrito s 7 m do 12 m debelo plastjo kvartarnega proda. Vrtine so pokazale, da slede kvartarnemu produ tortonski sedimenti do različne globine. V centralnem in zahodnem delu sega tortonski peščeni lapor, apneni peščenjak z litotamnijami in litotamnijski apnenec do globine okoli 125,0 m, južno in vzhodno pa do globine 186,0 m. Med terciarnimi plastmi in njihovo mezozojsko podlago leže bazalne plasti, ki sestoje iz plastične gline z vložki, oziroma plastmi kremenovega peska. V bazalnih plasteh se pojavljajo sledovi premoga. Debelina glinasto peščenih plasti je različna in dosеže 24,0 m do 75,0 m.

Zgornji del mezozojske podlage sestoji iz plastovitega krednega apnenca s polami lapornatega apnenca ter polami in gomolji roženca. Apnenec prehaja včasih v drobnozrnato brečo. Debelina krednih plasti ni enakomerna in se giblje v mejah 50,0 m do 197,0 m. Kreda leži na triadnem dolomitu, ki predstavlja glavni vodonosni horizont.

Vse kamenine, ki so jih prevrtale raziskovalne in kaptažne vrtine, se pojavljajo tudi na obrobju Gorjancev v podobni litološki sestavi. Debelina



Sl. 4. Geološki profil Čateškega polja
Fig. 4. Geological section across the Čatež field

terciarja in krede se tudi tukaj menjava. Kredni apnenec je na Gorjancih ohranjen le v obliki erozijskih ostankov na triadnem dolomitu. Tudi terciarne bazalne plasti se pojavljajo le na posameznih mestih.

Po podatkih raziskovalnih vrtin pripada Čateško polje obrobju Gorjancev in je območje termalne cone neposredni podaljšek Gorjancev tudi glede na litološko sestavo in stratigrafsko zaporedje.

Glavni in najvažnejši prelom, ki sega v večjo globino, poteka severno od Gorjancev in pri Čatežu v loku zavije proti severovzhodu ter prečka severno od Čateških Toplic Savo. Ta prelom so ugotovile geofizikalne regionalne raziskave. Njegov potek na Čateškem polju pa so potrdile tudi detajlne geoelektrične in mikroseizmične meritve l. 1970. Spremljajo ga široka zdrobljena cona in številni stranski prelomi ter razpoke. Mlajši prelomi sekajo glavno dislokacijo in so razkosali obrobje Gorjancev in Čateško polje na bloke. Tudi ožja termalna cona sestoji iz blokov, kar dokazuje različna debelina terciarja in krede.

Pred pričetkom prve faze hidrogeoloških raziskav na Čateškem polju je bilo znano samo to, da je s termalno vodo prepojen kvartarni prod v okolici toplic. Že prve raziskave l. 1957 so pokazale, da imamo na Čateškem polju več horizontov s termalno vodo.

Plitev horizont predstavlja kvartarni prod, v katerega se preliva termalna voda iz terciarja. Naslednji vodonosni horizont je v sistemu kavern v terciarnem litotamnijskem apnencu, kjer je bila termalna voda zajeta l. 1958. Oba vodonosna horizonta sta pod direktnim vplivom hladne podtalnice v kvartarnem produ. Gladina termalne vode v produ in v sistemu kavern v terciarnem apnencu niha z vodostajem podtalnice. Razlika je le v tem, da je statična gladina termalne vode 0,50 m do 0,90 m višja od gladine hladne podtalnice, ki z vseh strani obdaja termalno vodo. Hidrogeološke raziskave so leta 1964 odkrile globoko termalno cono, kjer je termalna voda pod pritiskom 1,2 do 1,8 kp/cm². Pritisk 1,8 kp/cm² je bil izmerjen v vrtinah, ki so prve zadele na termalno vodo v dolomitu. Zmanjšani pritisk v kasnejših raziskovalnih vrtinah je rezultat odvzema termalne vode v kaptažnih vrtinah, s čimer je nastal depresijski lijak, ki je zajel okolico kaptažnih vrtin.

Globoki termalni horizont v triadnem dolomitu je prekrit z neprepustnim pokrovom, ki sestoji iz terciarnega laporja, predvsem pa iz glinasto peščenih terciarnih bazalnih plasti in krednega plastovitega apnenca s polami laporja in roženca. Zato je na zahodu termalnega območja temperatura termalne vode 57 °C, na vzhodu pa, kjer je debelina tega pokrova večja, je temperatura termalne vode 64 °C. Na višino temperature vpliva razen tega verjetno še večja ali manjša oddaljenost od toplotnega vira. Temperatura termalne vode narašča torej od jugozahoda proti severovzhodu. Pri vasi Čatež je izvir termalne vode s temperaturo 31,5 °C. Oddaljen je od Čateških Toplic približno 1 km. Termalna voda priteka na površje direktno iz triadnega dolomita v neposredni bližini glavne dislokacije, ki je posrednik temperature tudi v centru termalne cone v Čateških Toplicah. Najbližja raziskovalna vrtina V-13/72 je oddaljena od centra termalnega območja okoli 300 m proti izviru pri Čatežu (sl. 5). V tej vrtini je bila izmerjena temperatura 42 do 45 °C. Tudi ta vrtina je bila locirana

Sl. 5. Iztok termalne vode iz vrtine V 13/72 v Čateških Toplicah
Fig. 5. The overflowing borehole V-13/72 at Čateške Toplice

v široki zdrobljeni in razpokani coni ob glavni dislokaciji. Nasprotno je bila v vrtini V-12/72, ki je oddaljena od centra termalnega območja okoli 120 m proti severu, ugotovljena temperatura 64 °C. Lociranje raziskovalnih vrtin severno, oziroma severovzhodno od vrtine V-12/72 preprečuje Sava. Ker v tej smeri poteka glavna dislokacija in narašča obenem temperatura termalne vode, je možno sklepati, da v čateški termalni coni še nismo dosegli najvišje temperature. Od izvira Perišče pri Čatežu do vrtine V-13/72 naraste temperatura za 10 °C pri medsebojni razdalji okoli 700 m. Veliko večji je porast temperature med vrtino V-13/72 in V-12/72, kjer je pri razdalji okoli 350 m temperaturna razlika 20 °C. Opisane temperaturne razmere nakazujejo možnost, da se cona z višjo temperaturo nadaljuje v triadnem dolomitu kot globokem vodonosnem horizontu ob glavnem prelomu proti severovzhodu na levi breg Save, kjer obenem naraste tudi debelina neprepustnega pokrova.

Količine termalne vode s temperaturo 57 do 64 °C so bile preverjene s črpalnim poizkusom, ki je trajal 12 dni. Pokazal je, da je možno neprekinjeno izkoriščati 120 l/sek. termalne vode s povprečno temperaturo 60 °C. Stabilizirani pritiski v opazovalnih piezometrih niso padli na 0,0 kp/cm², kar kaže še na določene rezervne količine termalne vode, ki bi se jih dalo občasno izkoristiti. Predvsem velja to za termalno vodo z nižjo temperaturo, ki bi jo bilo nujno treba izkoriščati v zdravstvene namene, ker je danes termalno vodo zaradi visoke temperature treba pred uporabo hladiti.

Uspešnost hidrogeoloških raziskav termalnega območja na Čateškem polju je očitna. Ugotovljene količine termalne vode 120 l/sek. s temperaturo 60 °C predstavljajo solidno podlago za nadaljnji razvoj zdravstvenega turizma. Posebna prednost visoke temperature termalne vode pa je v tem, da jo je možno dvakrat izkoristiti, in sicer za ogrevanje z odvzemom toplotne energije ter razhlajeno uporabiti v rekreacijskih bazenih, ki lahko obratujejo tudi pozimi brez dodatnega ogrevanja.

5. Pregled hidrogeoloških raziskav mineralnih vrelcev

5.1. *Rogaška Slatina*

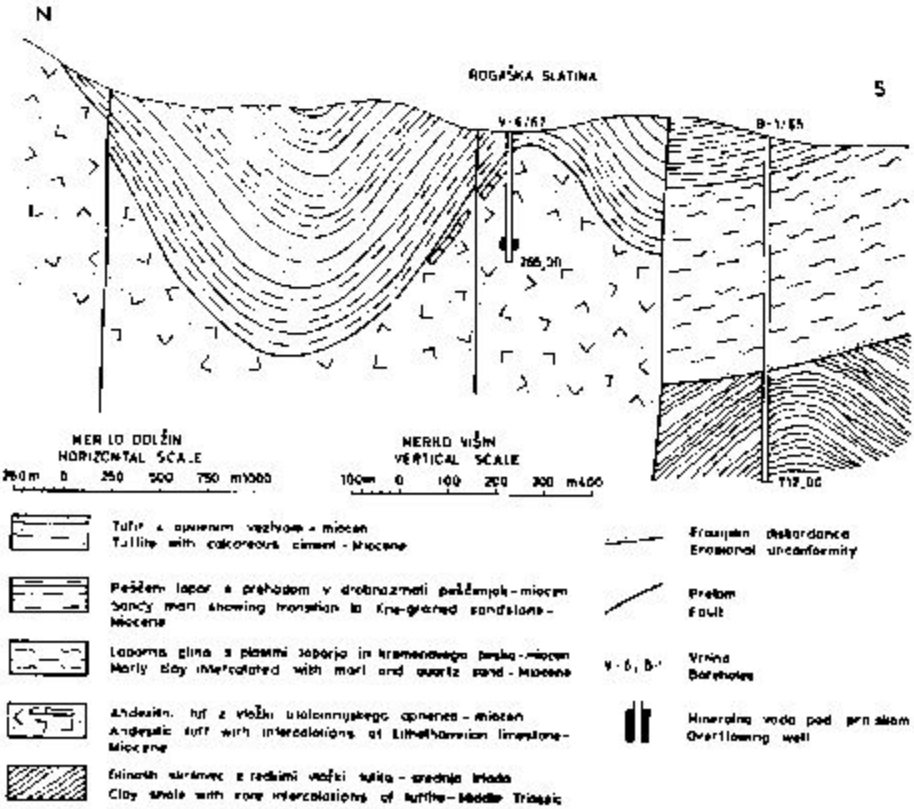
Mineralni vrelci v Rogaški Slatini so bili že pogosto predmet raziskav. V preteklosti so bile vse raziskave usmerjene na sorazmerno majhno površino vrelčnega centra. Za prva zajetja je značilno, da so bili številni vrelci zajeti s plitvimi vodnjaki, ki so jih izkopali na krajih, kjer je mineralna voda pritekala na površje. Seveda so na ta način zajeli le manjše količine mineralne vode. Taka zajetja so omogočala kratkotrajno izkoriščanje majhnih količin mineralne vode; zato je bilo l. 1888 znanih kar 11 vrelcev (A. Režek, 1973). Mineralna voda v teh plitvih zajetjih je vsebovala malo raztopljenih mineralnih snovi, kar je še danes karakteristično za izvire, ki se pojavljajo na površju v ožji in širši okolici Rogaške Slatine. Postopno so na ožjem vrelčnem območju zajeli tri tipe mineralne vode z različno količino raztopljenih mineralnih snovi, in sicer Tempel, Styria in Donat. Mineralna voda tipa Tempel in Styria je bila znana že pred letom

1908, medtem ko so tip Donat z najvišjo vsebnostjo raztopljenih mineralnih snovi zajeli l. 1908.

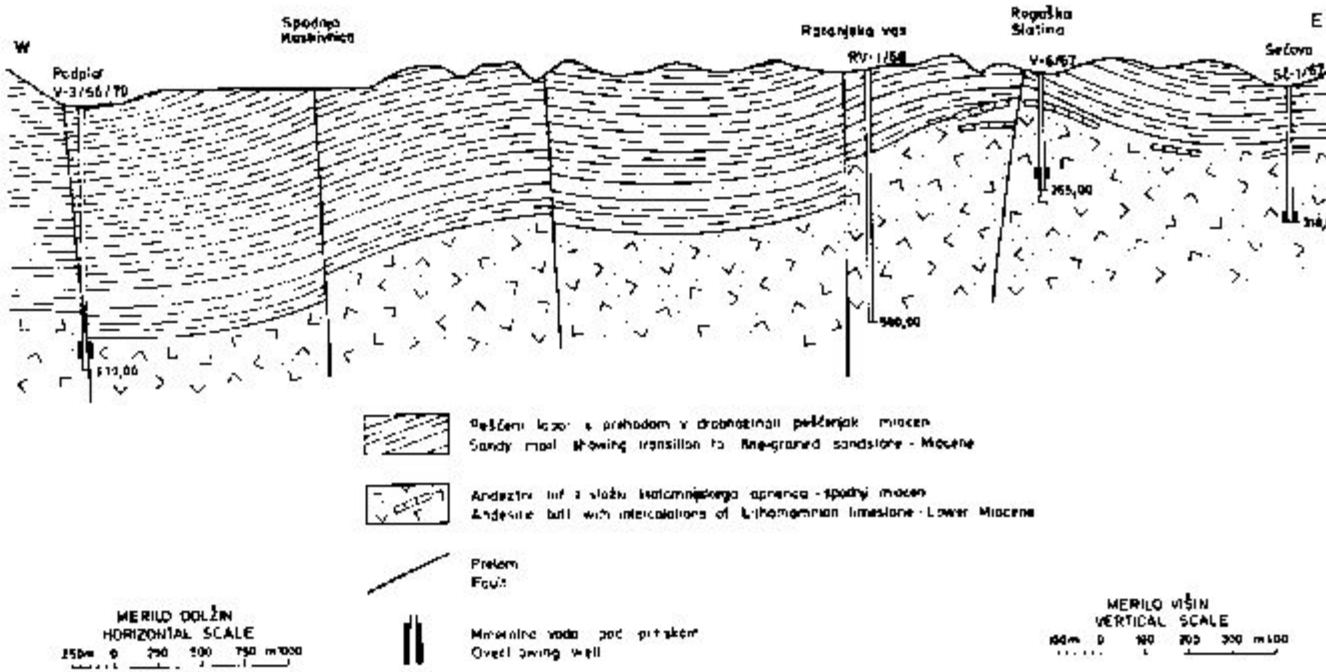
Z razvojem zdravilišča so že v preteklem stoletju poglabljali obstoječe vodnjake in kopali nove, da bi povečali količine mineralne vode. Vsako novo zajetje je poseglo nekoliko globlje; zadnja kaptažna zgradba te vrste je bila globoka 10 m. To zajetje je leta 1907 programiral in nadzoroval njegovo izvedbo J. K n e t t. Dela so bila končana leta 1908.

J. K n e t t je postavil teorijo o mešanju primarne mineralne vode s podtalnico v plitvi coni. Po letu 1952 so to potrdile raziskovalne vrtine; v globini so zadele le na visoko mineralizirano vodo, ki po količini raztopljenih mineralnih snovi presega vodo tipa Donat.

Že pred drugo svetovno vojno je v zajetju iz leta 1908 pričelo primanjkovati mineralne vode. A. R e ž e k (1964, str. 255) navaja izdatnost vseh vrelcev v času 29. do 31. 5. 1942, in sicer 17,4 l/min. Pozneje so se razmere še poslabšale in je pomanjkanje mineralne vode že pričelo ogrožati nadaljnji obstoj zdravilišča.



Sl. 6. Prečni geološki profil Rogaške Slatine
Fig. 6. Transverse geological section across the Rogaška Slatina



Sl. 7. Pregledni vzdolžni geološki profil čez območje Rogaške Slatne
Fig. 7. General longitudinal geologic section across the Rogaška Slatina area

Leta 1952 so pod vodstvom J. B a ć a izvrtali 22 vrtin in zajeli vodo v globini 30,0 m do 60,0 m. Geološko je vrtanje spremljal A. N o s a n. Leta 1953 je bilo izvrtanih še nadaljnjih 18 vrtin in je bilo tako vprašanje količine mineralne vode začasno rešeno.

Do leta 1965 so na ožjem vrelčnem območju injicirali in delno poglobili nekatere kaptažne vrtine in uredili plitvo zajetje mineralne vode tipa Tempel. K n e t t o v o zajetje iz leta 1908 pa so opustili.

Od ostalih lokacij, kjer se pojavlja mineralna voda na površju, je bila raziskana okolica izvira v Zg. Gaberniku z dvema vrtinama in izvrtana raziskovalna vrtina pri izviru v Kostrivnici ter vrtina poleg nekdanjega zajetja pri vili Rozalija južno od Zg. Gabernika. V Zg. Gaberniku sta obe vrtini zadeli na mineralno vodo, na ostalih dveh lokacijah pa sta bili vrtini prezgodaj ustavljeni.

Prve raziskave zunaj območja površinskih pojavov mineralne vode so se pričele z vrtino B-1/65 v bližini železniške postaje Rogaška Slatina (sl. 6). Naslednje vrtine so se zopet približale ožjemu vrelčnemu območju. To so bile vrtine B-2, B-3 in B-4. Vse tri vrtine so bile locirane na prostoru med hotelom Slovenski dom in športnim kopališčem, in sicer dve vrtini južno od ceste Rogaška Slatina—Celje (B-2 in B-3), ena pa severno od ceste (B-4).

L. 1966 je sledilo vrtanje vrtine G-3/66 v Zg. Gaberniku in vrtine V-3/66 severno od Podplata, ki je bila locirana po podatkih regionalnih geofizikalnih raziskav (sl. 7). V vrtini G-3/66 pri Zg. Gaberniku je bila zajeta mineralna voda, ki jo še danes izkoriščajo.

Po regionalnih geomagnetnih meritvah in večletnem preučevanju geološke zgradbe je A. N o s a n leta 1966/67 lociral dve vrtini. Prvo pri Podplatu in drugo pri Sečovem. Vrtina V-3/66 pri Podplatu je v globini 553 m zadela na dotok manjših količin mineralne vode in večjih količin CO_2.

Vrtina Sč-1/67 pri Sečovem je v globini 318 m prevrtala zdrobljeno cono v andezitnem tufu z dotokom 35 l/min. mineralne vode in večjimi količinami CO_2.

Obe vrtini dajeta sedaj glavne količine mineralne vode in CO_2 za uporabo. Pomen obeh vrtin je v oddaljenosti od ožjega vrelčnega območja; V-3/66 je oddaljena 5 km, Sč-1/67 pa 1 km in zato ne moreta povzročiti zmanjšanja količin v starem vrelčnem centru.

Na predlog J. B a ć a pa so leta 1967 izvrtali V-5/67 in V-6/67 na ožjem vrelčnem območju. V-5/67 je globoka 142 m in ne daje vode niti plina. V-6/67, globoka 265 m, je v globini 260 m zadela na dotok 50 l/min. mineralne vode in večje količine CO_2 (sl. 6 in 7). Medsebojna razdalja teh dveh vrtin je 90 m, V-6/67 pa je od eksploatacijskih plitvih vrtin oddaljena 210 m in je povzročila, da so plitva zajetja presahnila.

L. 1968 je bila po predhodnih geoelektričnih meritvah locirana vrtina Sč-2/68 okoli 800,0 m severno od vrtine Sč-1/67. Druga raziskovalna vrtina RV-1/68 je bila locirana v Ratanjski vasi, okoli 1 km zahodno od vrelčnega območja v Rogaški Slatini. Na željo Zdravilišča Rogaška Slatina je bila izvrtana še vrtina Tr-1/68 pri Tržišču. Lokacijo te vrtine je predlagal J. B a ć. Iz programa za l. 1968/69 je bila izvrtana tudi raziskovalna vrtina Sč-3/69, ki je imela namen razjasniti razmere v okolici površinskega pojava nizko mineralizirane vode v bližnjem vodnjaku. Raziskovalne vrtine izvrtane v letih 1968—69 so dale koristne podatke o geološki zgradbi okolice Rogaške Slatine, vrtini RV-1/68 in Sč-3/69 pa sta razen tega zadeli na CO_2.

Leta 1970 je Zdravilišče izbralo za svojega zunanjega sodelavca Geologisches Büro Dr. Pickel-Kassel, ki je najprej izmeril koncentracijo CO_2 v tleh, in sicer v okolici vrtine V-3/66 pri Podplatu ter v okolici novo projektiranega nalivalnega objekta. Na sestanku predstavnikov Geološkega biroja Dr. Pickel in Geološkega zavoda Ljubljana je bil določen program hidrogeoloških raziskav za l. 1970, ki je zajel že večkrat predlagano poglobitev vrtine V-3/66, vrtanje vrtine G-4/70 in po predlogu S. Jentscha predstavnika Biroja Dr. Pickel še vrtino Tr-2/70. Zadnja vrtina je bila locirana na osnovi predhodnih meritev CO_2 v tleh, vendar se je pokazalo, da je anomalno vrednost CO_2 povzročila bližnja glavna kanalizacija, ki odvaja odpadno vodo iz zdravilišča. V letih 1968 do 1970 so bile opravljene tudi v manjšem obsegu geomagnetne raziskave in izdelana detajlna geološka karta okolice Rogaška Slatina v merilu 1 : 5000.

Vrtina V-3/66/70 (sl. 8) je pri poglabljanju zadela v globini 578 m na kavernozno vodonosno cono z dotokom mineralne vode in CO_2. Iz vrtine je iztekalo pri optimalnem pritisku 4,2 do 4,4 kp/cm² 183,6 l/min. visokomineralizirane vode. Vrtina G-4/70 je prevrtala donačko prelomnico in je zadela v triadnem dolomitu na dotok vode okoli 180 l/min. Vrtina Tr-2/70 je prevrtala premogove plasti, dotoka mineralne vode in CO_2, ki so ga nakazale meritve na površju, v vrtini ni bilo niti v sledovih.

Leta 1971 sta bili izvrtani dve raziskovalni vrtini, in sicer K-1/71 v Zgornji Kostrivnici v neposredni bližini izvira mineralne vode v bližnjem potoku in vrtina Sč-4/71 90,0 m severno od vrtine Sč-1/67. V neposredni bližini vodnjaka z mineralno vodo je bila izvrtana še plitva vrtina Sč-5/71, s katero smo preverili dotok mineralne vode v bližnji vodnjak.

Rezultati hidrogeoloških raziskav po l. 1952 v Rogaški Slatini in okolici niso bili še sistematično obdelani. Njihova obdelava in delna dopolnitev raziskav bo nujna, da bi tako dobili popolno predstavo o rogaških mineralnih vodah.

Geološke razmere. Okolica Rogaške Slatine sestoji iz paleozojskih, triadnih, terciarnih in kvartarnih sedimentov. Prevladujejo terciarni sedimenti, ki so za nastanek mineralne vode najpomembnejši. Kvartarne meljne gline z redkimi prodniki zapolnjujejo doline potokov. Delno so ohranjene še prodne terase na robovih položnih vzpetin severno od Rogaške Slatine.

Najmlajši terciar so erozijski ostanki sarmatskih sedimentov na tortonskem litotamnijskem apnencu. Sarmatski sedimenti tvorijo jedro sinklinale, ki se razteza od Grobelnega prek Šmarja pri Jelšah do Mestinja in se nato pri Pristavi združi z južno sinklinalo s pliocenskim jedrom. V severni sinklinali in v erozijskih ostankih na litotamnijskem apnencu sestoji sarmat iz glinovca in laporja, v južni sinklinali pa prevladujejo peski in peščenjaki s plastmi slabo cementiranega konglomerata.

Podlago sarmatu tvorijo tortonski sedimenti. Na bazalnem konglomeratu leže apneni peščenjak, litotamnijski apnenec in peščeni lapor. Torionski sedimenti se raztezajo v več vzporednih pasovih od vzhoda proti zahodu. Starejši miocen še stratigrafsko ni razčlenjen. Poseben problem predstavlja temno sivi peščeni lapor, ki prehaja v drobnozrnati tufitski peščenjak severno od šoštanjskega preloma in sega proti severu in severovzhodu v Haloze. Temno sivi peščeni lapor leži na andezitnem tufu in na triadni oziroma paleozojski podlagi. Prekriva ga kremenov peščenjak, ki tvori na vzhodu Maceljsko pogorje, kjer sega od Sotle do Žetal. Od tod proti zahodu se razteza v obliki klina do Rogaške Slatine. Drugod se pojavlja še v Plešivcu in na Donački gori. V okolici Rogaške Slatine tvori kremenov peščenjak grič Janino, Tržaški in Ivanov hrib. Peščenjak sestoji iz kremenovih zrn, apnenega veziva, sljude in klorita. Nekaj ima tudi tufskih primesi, med katerimi so zrna plagioklaza. Čeprav sega peščenjak prav do ožjega centra mineralnih vrelcev v Rogaški Slatini, ga v raziskovalnih vrtinah ni. Južno od šoštanjskega preloma temno sivega peščenega laporja ni več in ga zamenjajo premogonosne plasti, ki sestoje v glavnem iz leč peska, vloženih med glinasti lapor. Sestava se na manjše razdalje menja. Tako je bil v vrtini B-1/65 nasproti železniške postaje Rogaška Slatina do globine okoli 115,0 m siv peščen lapor, pod njim pa do globine 485 m siva laporna glina. V vrtini Tr-2/70 300,0 m jugovzhodno od vrtine B-1/65 pa je do globine 95,0 m prevladoval zbit pesek z vmesnimi polami glinastega laporja.

Pomembni kamenini na območju Rogaške Slatine sta andezit in njegov tuf, ki ju povečini prekrivajo kamenine spodnjega miocena. Največjo razprostranjenost imata na južnem pobočju Boča in Plešivca. Z globokimi vrtinami smo našli andezitni tuf v globini 120 do 160 m med Sečovim in Podplatom.

Mezozojske in paleozojske kamenine prihajajo na površje na Boču, in sicer so to dolomit, apnenec, glinasti skrilavec, laporovec in v manjši meri peščenjak. Boč pripada Karavankam, medtem ko sta Resevna na zahodu in Rudnica na jugu del Posavskih gub, zato imajo njune mezozojske plasti drugačno sestavo. Omembe vredno je, da sta vrtini B-1/65 in Tr-1/68 v globini okoli 500,0 m zadeli na psevdoziljski skrilavec, ki kaže na nadaljevanje Posavskih gub južno od sotelskega preloma.

Poleg litološke sestave kamenin je za nastanek mineralnih vrelcev posebno važna tektonska zgradba. Zdrobljene cone vzdolž nekaterih prelomov omogočajo dotok mineralne vode na površje.

V zgradbi širše okolice sta dva glavna preloma. Na severu poteka ob južnem pobočju Boča donački prelom, ob katerem se stikajo vzhodni podaljški Karavank s Posavskimi gubami. Drugi, šoštanjski prelom poteka 3 do 4 km južno od donačkega. Oba preloma sta iste starosti in je donački verjetno veja šoštanjskega. Ob donačkem prelomu je prišlo do velikih vertikalnih premikov in verjetno v manjši meri do bočnih premikov, nasprotno pa je ob šoštanjskem prelomu moralo priti do večjih bočnih premikov. Na to kažejo očitne razlike v litološki sestavi in stratigrafski pripadnosti kamenin na obeh straneh preloma. Severno od šoštanjskega preloma imamo andezitni tuf in laporno peščeni razvoj spodnjega miocena, južno od preloma pa premogonosne plasti in v njihovi podlagi psevdoziljski skrilavec.

Prečno na oba glavna preloma poteka več stranskih prelomov, od katerih so raziskovalne vrtine potrdile že tri. Prvi je bil ugotovljen rogaški prelom že l. 1952, drugi pri Podplatu l. 1966 in tretji pri Sečovem l. 1967. Sklepamo, da so v glavnem vse strmo vrezane doline potokov s smerjo sever-jug nastale ob takih prelomih. Vzdolž teh prelomov priteka po zdrobljenih conah mineralna voda na površje.

Raziskovalne vrtine za pitno vodo, ki so prevrtale donački prelom severno od Zgornjega Gabernika, so pokazale, da je triada Boča in Konjiške gore narinjena na mladopaleozojske sedimente. Ob donačkem prelomu je bilo nato južno krilo dvignjeno, tako da se danes stika terciar s triadnimi in mladopaleozojskimi sedimenti.

Hidrogeološke razmere. Rogaški mineralni vrelci se pojavljajo na ozemlju, ki zavzema okoli 50 km^2. Naravni dotoki na površje so bili nekoč v Rogaški Slatini, v Spodnji Kostrivnici in Zgornjem Gaberniku. Danes izvira mineralna voda še južno od donačkega preloma nad Zgornjo Kostrivnico in v grapi Črna šola, okoli 0,5 km zahodno od Zgornje Kostrivnice. Od treh tipov mineralne vode se je primarni mineralni vodi najbolj približeval Donat z okoli 8 g/l raztopljenih mineralnih snovi, Styria s 6 do 7 g/l in Tempel s 3—4 g/l pa sta bila produkt bolj intenzivnega mešanja s podtalnico.

Rogaška mineralna voda je prvotno pritekala na površje v naravnih izvirih. Raziskovalne vrtine so pokazale, da je vodonosni horizont andezitni tuf, oziroma zdrobljene in intenzivno razpokane cone ob stranskih prelomih, ki potekajo prečno na donački in šoštanjski prelom.

Vodonosni andezitni tuf prekriva krovna plast neprepustnih kamenin, katerih debelina se povečuje proti severu do sredine terciarne sinklinale, kjer doseže največjo debelino. Prečni prelomi so razkosali to cono v številne bloke, obenem so zdrobljene cone ob teh prelomih v andezitnem tufu vodonosne. Čeprav sekajo prečni prelomi donačko dislokacijo na severu in šoštanjski prelom na jugu, ter segajo proti severu v prepustne karbonatne kamenine Boča, pronica le malo vode v globino. Prav zato je izdatnost mineralnih vrelcev v Rogaški Slatini in okolici majhna. Največje količine mineralne vode so bile doslej zajete v vrtini V-3/66 severno od Podplata, ki je že blizu zahodne meje širšega območja mineralnih vrelcev. Vsa ostala zajetja imajo veliko manjšo izdatnost. Vrtina G-3/66 v Zgornjem Gaberniku daje 13 l/min., V-6/67 v Rogaški Slatini okoli 60 l/min., Sč-3/67 pri Sečovem pa okoli 25 l/min. Verjetno je za večjo izdatnost vrtine V-3/66 vzrok v tem, ker je locirana ob prečnem prelomu, ki ima na severu stik s karbonatnimi kameninami zahodnih podaljškov Boča. Vzdolž tega preloma se pojavljajo izviri mineralne vode v Zgornjem Gaberniku in pri vili Rozalija.

V globokih vrtinah zajeta mineralna voda ima višjo temperaturo. Najvišja temperatura 30 °C je v vrtini V-3/66, kjer je zajeta mineralna voda v globini 578,0 m. Zaradi velikih količin CO_2, prostorninsko razmerje med mineralno vodo in CO_2 je 1 : 20, znaša npr. v vrtini V-3/66 pritisk 21,5 kp/cm^2. Temperatura 30 °C je bila izmerjena na ustju vrtine že po ekspanziji plina v vrtini, kar kaže, da je v globini še za nekaj stopinj C višja temperatura. Mineralna voda nastaja v andezitnem tufu, zato ima tako pestro sestavo raztopljenih mineralnih snovi. Plin CO_2 nastaja po rezultatih raziskav Inštituta Jožef Stefan v karbonatnih kameninah pri temperaturi 50 do 90 °C. Dotok vode s površja je možen le od severa, to je z Boča, ki sestoji v glavnem iz karbonatnih kamenin. Z južne strani se pojavljajo prve karbonatne kamenine šele na Rudnici, ki je oddaljena okoli 8 km, vmes pa jih prekrivajo več kot 1000 m debele terciarne neprepustne plasti. Razen tega sestoji triadna podlaga južno od šoštanjskega preloma iz psevdoziljskega skrilavca, ki proti zahodu pride na površje južno od Šmarja pri Jelšah. Ta skrilavec tvori skupaj s terciarnim pokrovom neprepustno bariero, ki zapira vrelčno območje z južne strani do globine, ki je večja od 700 m, kar je dokazala vrtina B-1/65 v Rogaški Slatini. Skrilavec se prične v globini 495,0 m. Če predpostavljamo, da je njegova možna debelina do 500 m, kar je bilo ugotovljeno drugod v Sloveniji, potem lahko sega do globine okoli 900 m. V vrtini B-1/65 so plasti skrilavca nagnjene. Zaradi takih razmer je možno, da sega neprepustna bariera vsaj do globine 900 m, čeprav je bil skrilavec pred odložitvijo terciarja delno erodiran.

Z nadaljnjimi raziskavami bo treba določiti lokacije za nova zajetja, ki pa bodo morala biti med seboj ločena, da ne bi bilo medsebojnih škodljivih vplivov, kot je to primer na ožjem območju mineralnih vrelcev v Rogaški Slatini. Če tudi dodatna zajetja ne bodo zadoščala, bo treba na posameznih lokacijah omogočiti bogatenje podtalnice v vodonosnih conah, kar dovoljuje zelo visoka vsebnost raztopljenih mineralnih snovi.

5.2. *Radenska Slatina (povzeto po L. Žlebniku, 1972)*

Območje Boračeve, Radinec in Petanjec je geološko in hidrološko že dokaj raziskano. Vodo so pričeli zajemati s plitvimi vrtinami konec 19. stoletja. Do druge svetovne vojne so izvrtali okoli 30 vrtin do globine 20 do 36 m, le vrtina na Radenskem vrhu je globoka 100 m.

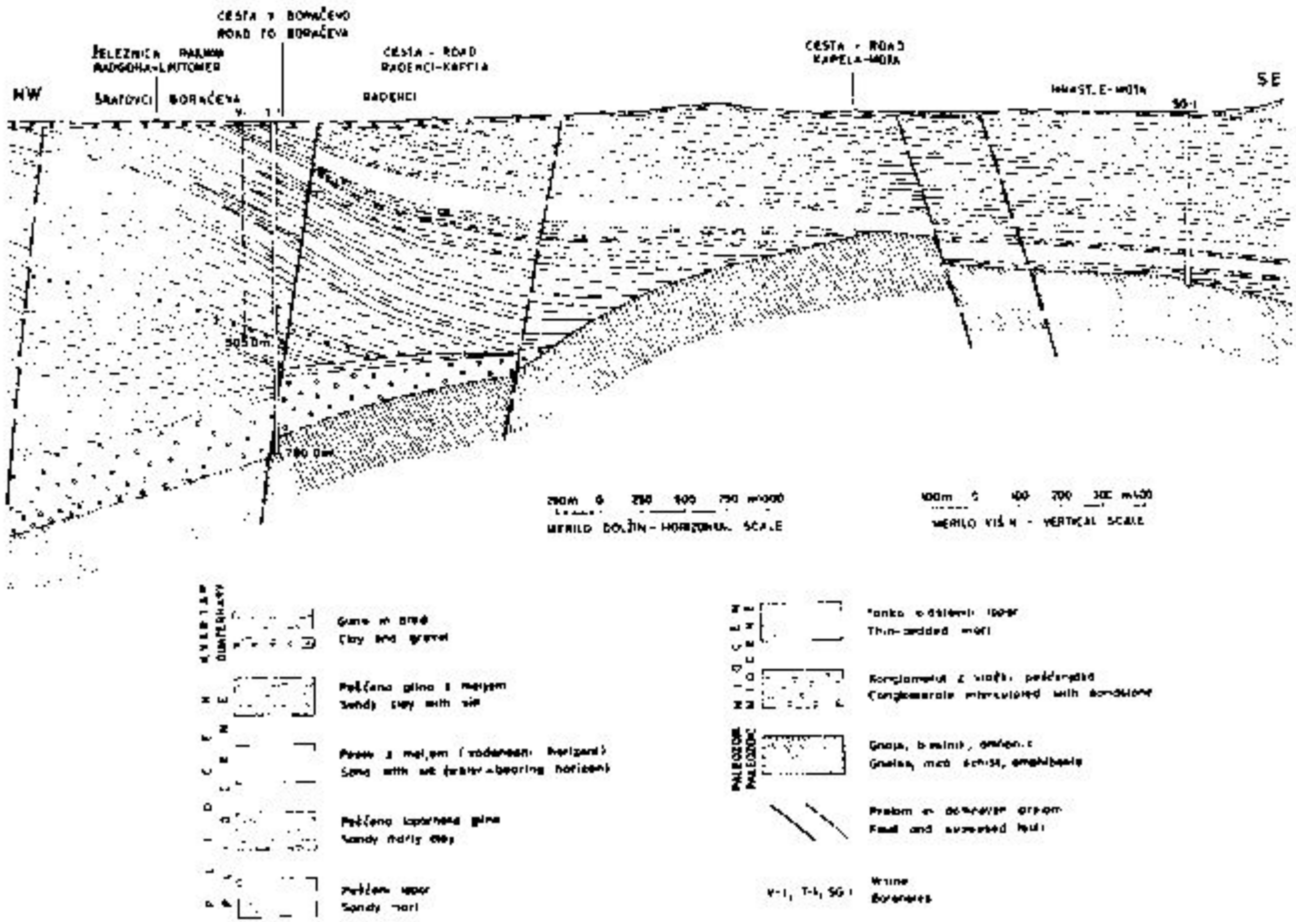
Leta 1965 so se pričele nove raziskave, s katerimi naj bi ugotovili, koliko horizontov mineralne vode je na območju Slatine Radenci, v katerih globinah so, njihovo izdatnost, razsežnost v prostoru, piezometrično gladino, kemično sestavo raztopljenih snovi in temperaturo vode.

V letih 1965 do 1972 je bilo izvrtanih prek 30 raziskovalnih vrtin, od katerih je vrtina T-1, locirana v bližini Boračeve, globoka 780 m, in 6 eksploatacijskih vodnjakov, ki dajejo skupaj okoli 40 m^3/h mineralne vode. Vrtine kažejo, da leže pod 6 do 10 m debelimi mlajšimi kvartarnimi naplavinami terciarne plasti gline, peska in redkeje peščenega proda. V peščenih plasteh so bili ugotovljeni horizonti mineralne vode in so bili tudi zajeti.

Geološki pregled. Najstarejše plasti so bile v Radencih ugotovljene v vrtini T-1, in sicer paleozojski metamorfni skrilavci v globini 737,50 m. Sestoje iz biotitnega blestnika, gnajsa in amfibolovca. Direktno na paleozojskih metamorfnih skrilavcih leže tortonske plasti. Tudi te plasti je prevrtala vrtina T-1 v globini 626,0 do 737,50 m. Sestoje iz tenko plastovitega peščenega laporja, kremenovega konglomerata in peščenjaka. Na površje prihajajo okoli 20 km zahodno od Radinec ob robu Apaške kotline pri Vratji vasi.

Na tortonskih leže sarmatski in spodnjepliocenski sedimenti. V spodnjem sarmatu prevladuje lapor in peščeni lapor s tankimi vložki pešče-

Sl. 8. Močan curek mineralne vode, speljan iz vrtine V-3/66/70 v Rogaški Slatini
Fig. 8. Strong mineral water jet led away from the borehole V-3/66/70 at Rogaška Slatina



Sl. 9. Vzdolžni geološki presek čez Radence
Fig. 9. Longitudinal geological section across Radenci

njaka, konglomerata in peska. V zgornjem sarmatu ter spodnjem pliocenu nastopajo lapor, pesek, peščeni lapor in peščenjak. Plasti peska so debele do 50 m. Na površju se pojavljajo te plasti v gričevju med Podgorjem in Črešnjevci pri Gornji Radgoni.

Najmlajše terciarne plasti pripadajo srednjemu in zgornjemu pliocenu. Sestoje iz gline, peščene gline, peska in peščenega proda. Debele so 5 do 35 m. V Boračevi in Šratovcih segajo 100 do 180 m globoko, v Radencih pa celo do 288 m. Glina vsebuje vložke organske gline in 0,5 do 1,5 m debele plasti lignita. V peščeni glini so pogostne apnene konkrecije.

Terciarne plasti prekrivajo kvartarni sedimenti, in sicer je bil v njihovem spodnjem delu odložen murski prod s peskom in meljem, zgornji del kvartarja pa sestoji iz peščene gline, peska in peščenega melja.

Radenci leže na tektonski enoti soboške grude, ki sestoji iz paleozojskih plasti, prekritih s terciarnimi sedimenti debeline največ 1000 m. Razprostira se v smeri jugozahod–severovzhod od Maribora proti Murski Soboti. Severozahodno od te grude poteka vzporedno podolgovata ozka radgonska depresija, zapolnjena s 1000 do 2000 m debelimi terciarnimi plastmi. Proti jugovzhodu prehaja soboška gruda v prostrano ljutomersko sinklinalo, kjer so terciarne plasti debele 3000 do 4000 m.

Zgradba terciarnih plasti je dokaj zapletena. Seizmične in gravimetrične raziskave ter novejše raziskovalne vrtine kažejo, da so pliocenske in sarmatske plasti položno nagnjene proti jugovzhodu, tortonski konglomerat in peščeni lapor, ki ležita na paleozojskih skladih, pa v nasprotni smeri (sl. 9).

Terciarne in paleozojske plasti sekajo po podatkih geološkega kartiranja, seizmike in vrtin prelomi, ob katerih so skladi premaknjeni za več 10 m. Ti prelomi potekajo vzporedno z mejami posameznih grud in so strmo nagnjeni ali navpični. Predterciarna soboška gruda se dviga skupaj s terciarnim pokrovom ob vzporednih prelomih proti Kapeli, kjer je teme grude, nato se ob prelomih spušča stopničasto proti osi ljutomerske sinklinale. Prelomov ni mogoče zanesljivo ugotoviti, čeprav so jih nakazale geofizikalne raziskave, ker prekrivajo terciarne plasti v gričevju debele plasti preperine, v ravnini ob Muri pa kvartarni sedimenti. Doslej izvrtane raziskovalne vrtine so z gotovostjo nakazale prelom, ki poteka od naselja Ptujska cesta v Slovenskih goricah prek Boračeve in Petanjec. Ob tem prelomu so plasti premaknjene za 25 do 50 m.

Starejše miocenske plasti nahajamo na krilih soboške grude, na temenu pa manjkajo. Možno je, da sploh niso bile odložene, ali pa jih je odstranila erozija. Na temenu so zastopani le panonski in mlajši miocenski sedimenti, kar dokazujejo raziskovalne vrtine.

Hidrogeološke razmere. Številne raziskovalne vrtine, izvrtane v letih 1965 do 1972, kažejo skupno s podatki detajlnega geološkega kartiranja, da je v okolici Radinec več vodonosnih horizontov z mineralno vodo. Kvartarni prod je prepojen s podtalnico, izjemoma pa vsebuje tudi mineralno vodo tam, kjer prihaja v stik s terciarnimi peščenimi plastmi, ki vsebujejo mineralno vodo. Do leta 1965 so izkoriščali v Radencih, Boračevi in Petanjcih mineralno vodo v plitvih zajetjih v kvartarnem produ in delno v pliocenskem pesku. Že prve raziskovalne vrtine v Boračevi so pokazale v pliocenskih in miocenskih plasteh deset tanjših in debelejših peščenih plasti z mineralno vodo do globine 313 m. Kasneje je vrtina T-1 šla skozi porozne plasti tudi globlje, vendar je dala v plasteh peščenjaka in konglomerata v glavnem CO_2, medtem ko je mineralne vode malo.

Leta 1970 in 1971 so raziskovalne vrtine pokazale, da se vodonosne plasti nadaljujejo od Boračeve proti Šratovcem in na nasprotni strani jugovzhodno proti Rihtarovcem. Vodonosne plasti, ki so pri Šratovcih v globini 75 do 140 m, so v Rihtarovcih že v globini 178 do 280 m. Ob prelomu so vodonosne plasti med Boračevo in Šratovci spuščene za 50 m. Vodonosne peščene plasti so nagnjene proti jugovzhodu. Po podatkih vrtin padajo plasti med Šratovci in Radenci pod kotom 4— 5°. Njihova izdatnost je odvisna od njihove poroznosti in debeline ter od količine raztopljenega plina (CO_2). Po podatkih raziskav narašča z globino temperatura in pritisk v horizontih mineralne vode. Z globino narašča tudi količina raztopljenih mineralnih snovi.

Terciarne plasti, ki vsebujejo mineralno vodo, se dvigajo proti Šratovcem in Orehovcem, torej proti severozahodu. V isti smeri pada tudi količina mineralnih snovi v vodi posameznih vodonosnih horizontov, medtem ko narašča z naraščajočo globino vodonosnih horizontov proti jugovzhodu. Iz tega sledi, da se vodonosni peščeni horizonti napajajo iz vrhnje prodne plasti na območju Šratovci-Mele.

V starih plitvih zajetjih se zaradi prevelikega izkoriščanja mineralne vode znižuje koncentracija mineralnih snovi, ker se poruši naravno ravnotežje med količino mineralne vode, ki prihaja iz primarnih vodonosnih plasti v kvartarni prod, in podtalnico v okolici. V globokih zajetjih, ki nimajo direktne zveze s podtalnico, bi prišlo do negativnih vplivov le v primeru, če bi eksploatacija daljšo dobo presegala naravni dotok iz območja napajanja. Zato je naloga nadaljnjih hidrogeoloških raziskav, da dajo odgovor na problematiko radenskih mineralnih vrelcev v zvezi z ohranitvijo ravnotežja med nastajanjem in kvaliteto mineralne vode na eni strani ter uporabo na drugi strani.

5.3. *Nuskova na Goričkem*

Leta 1967 je v Nuskovi INA-Nafta Lendava zajela mineralno vodo z dvema plitvima vrtinama v neposredni bližini starega zajetja. Iz ene od obeh vrtin je leta 1968 iztekala manjša količina mineralne vode, ki jo je uporabljalo okoliško prebivalstvo.

Leta 1968 in 1969 je izvrtal Geološki zavod Ljubljana 5 vrtin na levem in 2 vrtini na desnem bregu Ledave.

Raziskave so pokazale, da vsebuje mineralno vodo miocenski apnenčev peščenjak, debel 2 do 15 m. Vodonosna plast pada položno pod kotom 5—10° od severozahoda proti jugovzhodu. Izdatnost vodonosnega horizonta se od vrtine do vrtine menja. Odvisna je od prepustnosti in debeline vodonosne plasti ter niha med 8 l/min. do 180 l/min. V 4 vrtine so bile vgrajene plastične cevi. Od leta 1969 se je izdatnost stabilizirala in so kontrolne meritve v sušni dobi pokazale, da bi bilo možno izkoriščati najmanj 11 m^3/h mineralne vode.

Raziskovalne vrtine so zajele površino okoli 0,5 km². Širše vrelčno območje ni bilo raziskano, zato bo treba z nadaljnjimi raziskavami določiti njegov obseg, zaloge mineralne vode in količino, ki jo bo možno izkoriščati.

6. Termomineralni vrelci v Prekmurju in Slovenskih goricah

Termalno vodo v Prekmurju so odkrili pri vrtanju, ko so iskali nafto. Najprej je pritekla iz vrtine Mt-1 v Moravcih pri Murski Soboti pri nastreljevanju miocenskega peščenjaka. Sledile so raziskave termalne vode še v drugih vrtinah v okolici Murske Sobote, Lendave in Ljutomera. Po podatkih raziskovalnih vrtin za nafto se terciarne prepustne plasti proti jugu nadaljujejo na Ptujsko polje, na severu pa na Goričko, kjer prihajajo na površje.

Termomineralna voda je akumulirana v mlajših terciarnih plasteh kot reliktna voda. Njene zaloge niso neizčrpne in jo bo treba prav zato racionalno izkoriščati. Napajanje poroznih peščenih plasti je možno le z Goričkega.

Termomineralno vodo izkoriščajo v Moravcih pri Murski Soboti, Petišovcih pri Lendavi in Banovcih pri Ljutomeru.

6.1. *Moravci pri Murski Soboti*

Poleg vrtine Mt-1 v Moravcih imajo še vrtino MS-3 v Mlajtincih in rezervno vrtino Mt-2 pri Rimski Čardi. V vrtino Mt-1 priteka termomineralna voda po nastrelitvi iz globine 1115 m do 1234 m. Skupno je na tem odseku perforirano 30 m v slabo vezanem peščenjaku. Voda vsebuje nad 5 g/l CO_2 in ima temperaturo 72 do 75 °C.

V vrtini MS-3 v Mlajtincih je voda zajeta na odseku 1221 m do 1241 m v enakem peščenjaku kot v vrtini Mt-1. Skupno je bilo perforirano 7 m. Voda vsebuje CO_2 in ima temperaturo 62 do 64 °C.

Rezervna vrtina Mt-2 pri Rimski Čardi je bila perforirana v globini 881 m do 883 m v enaki plasti kot vrtina Mt-1 v Moravcih in v globini 1247 m do 1251 m. Voda vsebuje CO_2, njena temperatura pa je nižja kot v ostalih dveh vrtinah in znaša 55 °C.

Skupna izdatnost vseh treh vrtin ni bila točno ugotovljena. Po približni oceni doseže okoli 50 m³/h. Z nastrelitvijo celotnega zgornjega vodonosnega horizonta bi bilo možno izdatnost povečati, vendar je treba vzporedno ugotoviti optimalno količino, da bi akumulirane rezerve trajale čim dlje. V poletni sezoni porabijo dnevno okoli 500 m³ vode, medtem ko se pozimi poraba zmanjša.

6.2. *Petišovci pri Lendavi*

Termalna voda s temperaturo 55 °C teče iz naftne vrtine Pt-20, nastreljene v globini 817 m do 822 m. Je nizko mineralizirana in vsebuje CO_2 le v sledovih; zato se preliva iz vrtine na koti terena le 2,4 m³/h. Ta količina je premajhna in jo za potrebe rekreacijskega bazena povečujejo s črpanjem. Vodonosni horizont so pliocenske rhomboidea plasti. V bližini vrtine Pt-20 je perforirana v istem vodonosnem horizontu še vrtina Pt-18.

6.3. *Banovci pri Ljutomeru*

V Banovcih nastaja tretji center ob zajetju termalne vode v vrtini Ve-1 v globini 1358—1363 m ter v vrtini Ve-2 v globinah 1175—1188 m, 1530 do 1542 m, 1565—1570 m in 1649—1651 m. Vodonosni horizont so peščene rhomboidea plasti. Temperatura termalne vode je 55 °C in ne vsebuje CO_2. Pod pritiskom se preliva na koti terena okoli 5 m^3/h. Za potrebe rekreacijskega bazena je termalno vodo treba črpati. Zaloge vode niso bile ocenjene.

V bodoče bo treba zbrati in obdelati vse podatke naftnih vrtin in drugih geoloških ter geofizikalnih raziskav, da bi mogli označiti območja, kjer je pričakovati horizonte termalne vode. Oceniti bo treba zaloge termalne vode in šele na tej podlagi določiti njeno smotrno uporabo. Sedaj vrtajo globoko vrtino pri Ptuju in raziskujejo vrtino Ko-1 7 km severno od Ormoža.

Thermal and Mineral Springs of Slovenia

Anton Nosan

Contents

Abstract

Thermal and mineral waters of Slovenia occur mainly in its northeastern and central part. The paper deals with 22 thermal, 3 thermomineral, and 9 mineral water occurrences. Most of these occurrences have more than one spring in each occurrence, only a few have just one spring.

According to temperature the thermal springs can be grouped under three categories. The springs of the first group have temperatures ranging from 18 to 25 °C (ten occurrences), those of the second group 25—35 °C (six occurrences) and of the third group 35—64 °C (six occurrences). Their main particularities are the constant temperatures and discharge rates, and a dissolved solids content of up to 0,5 grams per litre of water, originating mainly from Triassic dolomite. The source of water supply is meteoric water; the hot springs are associated with secondary faults running at right angles to the main faults.

The thermomineral waters, having temperatures 55 to 75 °C, are accumulated in Tertiary beds as connate waters. They have been found during exploration for oil in depths ranging from 800 to 2000 metres.

Mineral waters rise to the surface from Tertiary sediments. Their discharge rates are essentially lower than those of the thermal springs. The mineral waters are recharged from meteoric water. Their high CO_2 content is considered to be released from carbonate rocks. The higher dissolved solids content, amounting up to 10 grams per litre of water, indicates a slow underground water flow.

According to the preliminary results of the hydrogeological studies shallow wells having been affected by ground water were abolished and deeper discharging wells were completed in the past two decades. In this way larger outputs of thermal and mineral waters were gained and the influence of ground water was eliminated. At present there are nine well developed thermal springs in Slovenia. Remarkable results were obtained at Čateške Toplice, where the wells yield up to 120 litres per second of water at 60 °C, and at Radenci and Rogaška Slatina, where the water is used on a large scale for medical, bathing, and drinking purposes. In 1972 the sale of bottled mineral waters from these springs amounted to three hundred million litres.

The investigations have to be continued; up to now they gave new data about the origin of the thermal and mineral springs, and are a reliable basis for programming and execution of the necessary further works.

1. Introduction

Slovene thermal and minerals springs are regarded as important natural resources. Their healing power has been recognized long ago; archeological findings at Rimske Toplice prove that a spa existed there in Roman times. Historians suggest the same for the Rogaška Slatina mineral springs, while the Radenci springs have been found hundred forty years ago.

The water supply existed until recent times of shallow wells only. As the thermal and mineral waters appear in the valley beds of rivers and rivulets, the shallow wells were influenced more and more by the ground water. Therefore the temperature of the thermal water dropped and the mineral water properties did not correspond to the increasing demand.

The deteriorated state of the shallow wells was the reason for starting systematical investigations of the primary water-bearing beds in greater or lesser depths beyond the zones influenced by the ground water and surface water flows.

Basic hydrogeological exploration was completed in Dolenjske Toplice, Šmarješke Toplice, Laško, Rimske Toplice, Dobrna, Topolščica, Trbovlje, Podčetrtek, Bled, Pirniče and Nuskova. In more detail were investigated the water-bearing strata of Čateške Toplice, Radenci and Rogaška Slatina (Fig. 1). Chemical analyses of the mineral and thermal waters were carried out too and will be published later in the papers dealing with particular spring areas.

It is specially necessary to acknowledge the activity of the Boris Kidrič Foundation, whose support by cofinancing and loans was of essential impact in resuming the exploration of thermal and mineral waters of Slovenia.

2. General characteristics of thermal and mineral waters of Slovenia, and their regional distribution

In Slovenia there are two types of thermal waters, that differ in origin and in physical and chemical properties as well. The first type represent the well-known thermal springs with water rising to the surface from dolomites and limestones for longer times already, and being generally considered as permanent water sources. In properly constructed supply borehole installations their yield and water temperature are constant. Their water contains up to 0.5 grams per litre of dissolved solids. This low content of dissolved mineral matter, as well as its constant composition, indicate an underground circulation of waters, which permeate from the surface to the underground, are heated by geothermic energy, and rise to the surface usually through fissured zones associated with faults. During exploitation of such thermal sources it was found that springs of higher temperatures appear in the vicinity of deep faults and their temperature depends on the extension of the thermal zones, the lithological composition and position of the water-bearing beds, and on their insulation against the earth surface. Wherever water-bearing carbonate rocks are outcropping, the thermal water is cooled in the shallow subsurface due to contact with ground water and air. Usually the influence of the cooling factors extends deeper than the zone of annual temperature variations, depending on the extension of the pervious zones and their permeabilities. The pervious rocks are usually saturated with cold ground water. Therefore besides the main thermal springs with highest temperatures, secondary springs are found as well. Their temperatures may be sometimes for some tens of degrees lower than those of the main springs.

The cold ground water that fills the porous zones in dolomites maintains the piezometric level of the thermal springs. The thermal water rises from the underground through the most permeable parts of the water-bearing zones. The yield of the thermal springs depends on the piezometric level of the cold ground water at a given elevation. Due to the low average permeability coefficient of the dolomite ($k = 1 . 10^{-4}$ cm/sec) the annual variations in the discharge rate of thermal springs in dolomites do not vary for more than 10 percent. This holds for the natural flow of thermal water to the surface. The common characteristic of this first type of Slovenian thermal water sources is that their main aquifer is dolomite; only Dobrna might be an exception.

The second type of Slovenian thermal waters is recorded as thermo-mineral water, found during exploratory drilling for oil in Moravci, Petišovci and Banovci (Fig. 1). They contain ten grams of dissolved solids per litre of water, and are accumulated in sandy Younger Tertiary beds. Due to the considerable depth of water-bearing beds a natural recharge is possible only from limited catchment areas. Therefore in this types of waters the question of their rational use, based on a true assessment of exploitable reserves, is of highest importance.

Mineral water springs occur in Prekmurje, in the Slovenske Gorice hills, and in the surroundings of Rogaška Slatina (Fig. 1). The mineral waters are essentially springs of thermo-mineral waters, cooled while rising towards the earth's surface. This can be proven by the higher temperature of the same waters when measured in bore holes. In the surroundings of Rogaška Slatina and Radenci, in depths of 300—600 metres, temperatures of 30—40 °C have been measured while the springs at the surface were of average annual temperature of the surroundings.

3. Thermal water sources from carbonate rocks

Thermal springs from carbonate rocks are closely related to the tectonic structure of their surroundings; accordingly they can be divided into more groups.

3.1. *Thermal springs in the Ljubljana and Radovljica Basins*

The common characteristics of the thermal springs of this group are their appearence at the surface near shallow secondary faults, usually in distances of a few kilometres from the main faults; and secondly their low temperature between 19 and 28 °C. It is considered that the normal geothermal gradient is the only source of heat for most of our low-temperature springs. For example, during drilling in Bled the water temperature was measured 19 °C at a depth of 550 metres. Therefore in Bled the geothermal gradient is lower than average. The low temperature of the springs indicates a low geothermal gradient and low primary temperatures rather than an influence of cold ground water.

To this group of thermal springs belong besides those of Bled also the springs in Zgornja Besnica, Spodnje Pirniče below Šmarna Gora, Hotavlje in the Kopačnica Valley, and Furlanove Toplice near Vrhnika. The main data about these springs are given in Table 1.

Table 1.

Thermal springs in the Ljubljana and Radovljica Basins

Site	Temperature °C	Discharge rate litres per second	Aquifer
Bled	**19—22**	**12—14**	dolomite
Zgornja Besnica	**21**	1,5—2	dolomite
Spodnje Pirniče	**19,5—23**	**5—8**	**dolomite**
Hotavlje	**21**	**5**	**dolomite**
Furlanove Toplice	**21**	15	**limestone**

Basic exploration was carried out in Bled and Spodnje Pirniče only.

3.2. Thermal springs in the eastern extension of the Karavanke Mountain Range

The thermal springs of this second group rise to the surface along secondary faults occurring between the Šoštanj and Smrekovec main faults. Their temperatures are in average higher than those of the first group (Table 2). The temperatures of the two springs in the west, Topolščica and Dobrna, are higher, because the springs are situated at the contact of impervious Tertiary rocks and Triassic limestone and dolomitized limestone. The characteristics of the springs in Stranice and Zbelovo near Poljčane are similar to those of the thermal springs of the first group.

Table 2.

Thermal springs in the Eastern Extension of the Karavanke Mountain Range

Site	Temperature °C	Discharge rate litres per second	Aquifer
Topolščica	29—31	20	limestone
Dobrna	33,5—36	6,5—8	limestone
Stranice	**21**	20	dolomite
Zbelovo	18,5	4,5	dolomite

Basic exploration was carried out in Topolščica and Dobrna only.

3.3. Thermal springs in the Sava Folds

The thermal springs of the third group appear in the Sava Folds region. In the boundary zone between the Sava Folds and the foothills of the Kamnik Alps are the thermal springs Vaseno in the Tuhinj Valley, and at Podlog near Šentpeter in the Savinja Valley. All other thermal springs of this group, being also of higher importance, are situated along the Laško Synclinorium. From west to east follow Izlake, Trbovlje, Rimske Toplice, Laško, and Podčetrtek (Table 3).

Table 3.

Thermal springs in the Sava Folds

Site	Temperature °C	Discharge rate litres per second	Aquifer
Vaseno	21—28	20	dolomite
Podlog	19—21	5—16	limestone/dolomite
Medijske Toplice	21—23	6	dolomite
Trbovlje	32	12	dolomite
Rimske Toplice	36—41	6	dolomite
Laško	34,3—39,5	18	dolomite
Podčetrtek	34—37	25	dolomite

Basic hydrogeological exploration was carried out in Trbovlje, Rimske Toplice, Laško and Podčetrtek.

3.4. *Thermal springs in the Krka Valley*

The greater part of the thermal springs in the Krka Valley occurs on the right bank of the river, below the slopes of the Gorjanci hills: Dolenjske Toplice, Topličnik near Kostanjevica, Bušeča Vas, and Čateške Toplice. Only Šmarješke Toplice and Klevevž are situated on the left bank of the Krka river (Table 4).

Table 4.

Thermal springs in the Krka Valley

Site	Temperature °C	Discharge rate litres per second	Aquifer
Dolenjske Toplice	32—38,4	20—21	limestone/dolomite
Šmarješke Toplice	28—34,5	40	limestone/dolomite
Klevevž	22	6	dolomite
Topličnik near Kostanjevica	21—28	30	limestone/dolomite
Bušeča Vas	26—28	30	limestone/dolomite
Čateške Toplice	57—64	110—120	dolomite

Basic and informative exploration was carried out in Dolenjske Toplice, Šmarješke Toplice and Topličnik; Čateške Toplice were studied in detail.

4. Summary description of hydrogeological exploration of thermal springs in carbonate rocks

4.1. *Bled*

Till the year 1958 only the temperatures and discharge rates were measured of the spring in Hotel Toplice and of the secondary springs in its surroundings. These measurements were followed by drilling of 4 shallow bores, pumping tests, and thermologging of the bores in 1958. During 1967 and 1968 eight additional shallow bores and one deep well were drilled. The latter struck inflows of thermal water in the depth interval between 546.0 m to 568.0 m, with a yield of 7 litres per second of water of a temperature 19 °C.

The surroundings of Bled consist of Permian, Triassic, Tertiary, and Quaternary rocks. The deep well indicated the following rocks and their apparent thicknesses: from the surface to 60.0 m Quaternary lacustrine and glacial sediments, to 108.0 m Oligocene marine clay, and to 546.0 m grey dolomite. To 577,6 followed dark grey limestone representing the main aquifer, and finally dark grey dolomite to the bottom of the well at 587.6 m. Of interest is the Oligocene marine clay in the well, as it is not encountered in the surroundings of Bled, being everywhere covered by overlying Quaternary sediments.

In the surroundings of Bled there are many faults of NW-SE direction. Along one of these faults the thermal water found its way to the surface. It is probable that the well penetrated this fault as well, as is indicated by the intensively fissurated and broken dolomite and limestone.

In the surroundings of the thermal springs in the Hotel Toplice there are two aquifers bearing thermal water. The shallow one is represented by the Quaternary lacustrine sediments, with small quantities of thermal water in the gravel. From these beds the thermal water percolates into a few springs of low yield over an area of about 15 hectares. The highest temperature amounting to 21 °C was found in a dug well at Stare's. Into this shallow aquifer the thermal water flows from the Triassic dolomite, probably along its contact with the Oligocene marine clay.

4.2. *Pirniče below Šmarna Gora*

Till the year 1972 the discharge rate and temperature of the spring was measured periodically. Data from these measurements vary in discharge rate from 6 to 8 litres per second, and in temperatures from 18 to 23 °C. In 1972 three reconnaissance bores were drilled, which indicated that the thermal water rises from the depth along the contact of Triassic dolomite and impervious Tertiary marl. The carrier of the thermal water is a fault in NW-SE direction. The highest temperature was measured in the bore V-2/72 amounting to 20.5 °C. This temperature is for 2.6 °C lower than the temperature of the spring during the extremely arid summer of 1971. Therefore it can be assumed that the thermal water is mixed with cold ground water in the shallow zone before rising to the surface. As the spring is situated near the town Ljubljana, it would be worthwhile to continue exploring, and to separate the thermal water from the ground water.

4.3. *Topolščica*

The exploration started in 1970. The surroundings of the thermal spring were hydrogeologically mapped in scale 1 : 10 000. Simultaneously observations and measurements were carried out on all springs encountered in the mapped area. In this way it was found that the discharge rate of the thermal spring, at average ground water level, amounts to 30 litres per second at a temperature of 31 °C.

Surveys of the surface were followed by drilling of 5 bores, that furnished data about the geological structure of the thermal springs' hinterland, as well as indications about hydrogeological relations down to the depth of 220 metres.

Subsequently, in 1972, water was coloured at the swallow holes near the rivulet Strmina, at an altitude of about 500 m. The tracer colour reappeared after 45 hours in a cold spring near the thermal spring, and after 70 hours, very diluted, in the thermal spring itself. The distances from both the thermal and cold spring to the swallow hole amounts to 1.1 km, the difference in altitude being 130 metres. The surroundings of the thermal spring Topolšiča consist of sediments of Quaternary, Tertiary, Triassic, and Younger Paleozoic age. Quaternary sand, gravel, and silty clay fill the valleys of the rivulets; the mountain slopes are mantled by scree. Tertiary is represented by Pliocene sediments and Oligocene marine clay with andesite tuff intercalations. In the Šaleška Dolina Pliocene lignite beds are spread over a wide area. Triassic limestone, dolomite, shale, limestone with chert, and conglomerate are hydrogeologically the most important rocks. Limestone and dolomite represent the main aquifer of thermal and drinking water in Topolšica. The Paleozoic beds consist of the Permian grey limestone, accompagnied by conglomerate, quartz sandstone, and shale, and of the Carboniferous shale and quartz conglomerate.

The thermal spring Topolščica is closely related to the fault, where impervious or nearly impervious Tertiary strata are in contact with Triassic limestone. The thermal water rises to the surface through fissures of transverse direction to the fault. In the immediate hinterland of the thermal spring the limestone is karstified. In it the thermal water is in connection with cold water. Due to such hydrogeological conditions the temperature of the water varies between 28 and 30.6 °C. The bores penetrated caverns, that were partly filled by clay. The thermal water rises from the underground in a particular zone only. The primary water flow could not be found by drilling. This will be the main task of the following exploration, that has to reach greater depths.

4.4. *Dobrna*

In the years 1963—1966 a hydrogeological survey was carried out in the scale 1 : 5000. Subsequently 6 bores were drilled to depths ranging from 120.0 to 650.4 m. The discharge rate in the old supply well was determined by pumping tests before drilling started. Depending on extraneous influences it varied from 5.86 to 6.64 litres per second of thermal water with a temperature of 36 °C, at an efflux altitude 367.3 metres. Simultaneously a quantity of 1.5 l/sec was flowing directly into the covered basin. The results of the exploratory bores were as follow: In bore V-1, situated immediately at the bathing establishment in the northwest of the well, in the depth interval from 0.0 to 175.0 m there was limestone. The bore penetrated water-bearing fissures already in the depth of 2.35 m. They were in direct connection with the covered bathing basin, as drilling fluid was observed entering the thermal water in the basin.

Inflow of thermal water was observed in the complete interval from 2.5 to 50.0 metres, and in the depth 138.0 m as well. During drilling the interval from 11.0 to 50.0 m the drilling mud penetrated strongly into the thermal water well, and the water temperature decreased simultaneously, which indicates an interconnection between bore V-1 and the thermal well. When the bore reached the second thermal water inflow at 138.0 m, the water in the supply well became slightly muddy again. Pumping tests determined output and temperature of the thermal water in both water-bearing intervals of this well.

The bore V-2 was situated 30 metres in the east of the old supply well, with the intention to determine the thickness of the impervious marl overlying the limestone, and to try finding thermal water. The bore struck limestone at the depth of 26.0 m. Down to the final depth of 120.0 m no thermal water was found, but the temperature in the bore increased with depth up to 26.1 °C at the bottom of the bore. This indicated a geothermal gradient of about 1 °C per 12 metres, and suggested the adjacent thermal zone. The fissures in the limestone were filled by yellowish sandy clay. Traces of such clay have been found in water-bearing fissures in other bores as well, therefore it is allowed to assume that this yellowish sandy clay is a sediment of the thermal water.

The site of the bore V-3 was chosen according to the results of bores V-1 and V-2. It is 17 metres south of the old supply well in the inner courtyard of the bathing establishment. The impervious cover of Quaternary silty clay and Miocene marl reached a thickness of 16.7 metres, below it was limestone. The first inflow of thermal water occurred in the depth of 82.0 m in cavernous limestone. The pervious, fissurated and partly cavernous zone continued to a depth of about 95 m. Pumping tests and thermologging indicated the highest temperature of the water 34 °C in the depth of 82.0 m.

The fourth bore V-4 was located about 12 metres northwest of V-1. Below a 3.0 m thick stratum of silty clay there was limestone up to the final depth of 120.0 m. There were no inflows of thermal water, but cold water was struck in the interval from 6.1 to 21.4 m depth, with temperatures 10.5 to 12.0 °C. By thermologging the temperature of the bore was measured, amounting to 12.5 °C at 3.0 m depth, and increasing steadily to 30.9 °C in 115 metres depth.

In a distance of 186 m southwest of the supply well the bore V-5 was drilled. Although situated in the immediate vicinity of outcropping limestone, it went from top to bottom at 260 m through sandy marl only.

The main purpose of drilling bore V-6 was to obtain data on hydrogeological and geothermal conditions in greater depths. The bore was situated only 45 metres from V-3, whose temperature was the nearest to the temperature of the old supply well. The bore penetrated sandstone and sandy marl, Oligocene limestone, and Triassic limestone with a few dolomite layers. Surprising were the results of thermologging, which indicated a temperature of 45 °C in the depth of 200 m. During the pumping test at an output of 4 litres per second from the depth interval between 150 to 320 metres, at a drawdown of 30 metres, the temperature of 38.5 °C was measured.

The surroundings of Dobrna consist of Quaternary, Tertiary and Triassic rocks. The thickness of the Quaternary silty clay with rare gravel inclusion is between 3.5 and 8.5 metres. The Quaternary sediments are of greatest thickness in the Toplica river valley, in secondary rivulets they are thinner. Tertiary is represented by sandy marl, quartz sandstone passing into tuffite, limestone containing oyster remnants, and andesite with tuffs. The hills in the north and northeast of the thermal springs are built from sandy marl. This sandy marl is contiguous to quartz sandstone, that consists of quartz grains cemented by calcite; admixtured in the sandstone are grains of mica, chlorite, and volcanic ash. The quartz sandstone is bordered on its southern side by Oligocene and Triassic limestones, which form the hill Kurjek. Triassic and Oligocene limestones are very similar, therefore it is rather difficult to define their boundary, especially in bores. Oligocene limestone differs from the other by containing oyster shells, and in some places Oligocene microfauna. Sandy marl belongs mainly to Tortonian, only its lower part to Helvetian; the quartz sandstone with tuff admixtures belongs to Lower Miocene, and probably to Upper Oligocene as well. The limestone with fossil remnants of oysters and tiny nummulites represents the basal beds od Tertiary underlain by Triassic limestone.

Detailed geological surveying ascertained in the vicinity of Dobrna two faults, important for the flow of thermal water to the surface. The older fault, of W—E direction, is distinguished at the surface by patches of Oligocene limestone in Lower Miocene sandstone. This older fault has been cut by the second fault of a SE—NW direction; along this fault the eastern flank sunk down. The fault plane is inclined towards northeast. Besides these two faults there are some smaller faults and fissures. One of these fissures is in Oligocene limestone in the immediate vicinity of the thermal springs. Both main faults have dissected an anticline, whose core in the west consists of Middle Triassic limestone.

The thermal water rises to the surface along fissures, that are in some places widened into caverns. The aquifer is limestone, enclosed by impervious rocks from all sides. Therefore the thermal springs originated in the immediate vicinity of the contact betweeen limestone and sandy marl at the brink of the Toplica river valley. The bore V-6 struck a water-bearing cavern at the depth of 613.95 metres, which is connected with the shallow dug supply well for thermal water. The other bores indicate connections with the existing thermal water installations as well, but only the water in V-6 had the same temperature as that in the dug well. Therefore a direct connection between the cavern in the depth of 613.95 m and the well can be assumed, with a very high rising velocity of the thermal water. The warmest zone is in the depth of 120 to 320 metres, where the temperature of 45 °C was measured. As the impervious sandstone barrier encloses the limestone from the south, and as the warmest zone was detected in the south of the springs, it is very probable that the fault in the south of the thermal springs transmits the higher temperature from the depth. The warmest zone is in the limestone immediately below the sandstone.

The thermal zone is bordered in the north by cold water that drains into the limestone in the immediate hinterland of the thermal springs. This is indicated by the cooler water in the covered basin and by the lower temperatures inside the bores in the vicinity of the supply well. The stable temperature of the thermal water in the supply well indicates that the main channels carrying thermal water to the surface are insulated from the cold water in the shallow zone.

4.5. *Trbovlje*

Near the Cement Factory Trbovlje an exploratory bore was drilled in 1967. In the depth of 45.0 metres thermal water appeared from dolomite. The discharge rate was 12 litres per second at a temperature of 32 °C. The drilling site was chosen on the basis of an inflow of thermal water of negligible quantities, but of a temperature of 18 °C into the basement rooms of the Cement Factory. The carrier of the warm zone is a fault, striking from north to south, and dividing in the north of the bore the Trbovlje Coal Basin from the Zagorje Coal Basin.

4.6. *Rimske Toplice*

Rimske Toplice are the only Slovenian thermae where the thermal water emerges above the bottom of a valley. The difference in altitude is about 40 metres. There existed two shallow dug wells, which deteriorated considerably after 1956. The piezometric level dropped, and the thermal water stopped to flow to the bathing establishment. This was the reason for starting hydrogeological studies in 1958. Two bores were drilled.

Aboundant thermal water was found in the depth intervals 64.65 to 72.75 m, and 76.70 to 87.95 metres of the bore B-1. Steel pipes of 113 mm diameter were installed to the depth 46.24 m, and steel pipes of 98 mm diameter from 40.0 to 95.0 m. The latter were subsequently perforated in the depth of both main thermal water aquifers. From 95.0 to 151.7 m the bore collapsed.

The bore B-2, 104.3 m deep, penetrated the main thermal aquifers in the depth intervals 49.8—61.8 metres and 68.9—72.8 metres, somewhat higher than the bore B-1. Steel pipes of a diameter 128 mm were installed from top to the depth 86.2 m, and perforated from 49.3 to 86.2 metres. Both bores were developed for exploitation. Pumping tests in bore B-1 yielded at a drawdown of 1.10 metres 450 litres per minute of water with a temperature 39 °C, whereas the highest temperature measured in the bore itself was 41 °C. Bore B-2 discharged 160 litres per minute of overflowing water at a temperature of 39 °C; by pumping at a drawdown of 2.70 m the bore yielded 800 litres per minute of water having a temperature of 39 °C.

The thermal water at Rimske Toplice is pumped from water-bearing dolomite which is enclosed from all sides by impervious rocks. It is of special importance that the dolomite is insulated against the valley of the Savinja river by impervious Carboniferous and Permian shales. Therefore the piezometric level of the thermal water, or the altitude of the water overflow respectively, are situated rather highly above the bottom of the Savinja river.

In the hinterland of the thermal springs the dolomite is saturated with cold water. From this water depend the hydrogeological conditions of the Rimske Toplice thermal region. In the last decade the piezometric level of the thermal water sunk first in the dug wells, and later in the supply boreholes. The total drop of the piezometric level since 1956 amounts to 3.0 metres. The thermal water level depends upon the pressure exerted by cold ground water accumulated in the dolomite in the hinterland of the thermal springs. It is supposed that either a damage occured to the impervious shaly barrier, or that this barrier was lowered, which caused a drop of the piezometric level of the cold water. Consequently the piezometric level of the thermal water sunk as well, and reduced the discharge rate of the springs.

The decrease of the piezometric level of the thermae might have been caused partly by the deterioration of the old dug wells as well. Today the walls of these wells are not tight, and their bottoms, based on the dolomite, are in bad repair as well. Therefore it is necessary to seal up both old wells, as well as their immediate surroundings. In any case the causes for the decrease of the piezometric level should be found, so as to avoid irreparable damages to the thermal system.

4.7. *Laško*

The thermal springs of Laško are situated in the north of the Tertiary Laško basin. Due to the Oligocene coal beds, the vicinity of Laško has been in the past frequently geologically surveyed. Already in the second half of the former century the coal-bearing beds have been studied rather thoroughly, and for the interpretation of the geological conditions the Mesozoic and Paleozoic strata underlaying the coal beds as well.

The Laško thermal water was for the first time made available for use in 1852. In 1936 the installations were so badly deteriorated, that repair was necessary. The average temperature of all thermal springs in 1936 amounted to 36 °C. All thermal springs with significant discharge rates were tapped separately and conducted to the main well dug down to dolomite. Due to the influence of both the Savinja river and the ground water in Quaternary gravel, the temperature of the thermal water decreased later from the original 36 to 34 °C. It was therefore decided in 1965 to perform hydrogeological studies, with the aim of tapping the thermal water in greater depths and to eliminate the influence of the Savinja river.

During the years 1965—1967 seven bores were drilled. The first three should give basic information about the extent of Triassic and Paleozoic strata below the Quaternary alluvial deposits of the Rečica and Savinja rivers, and should indicate the most favourable drilling sites for deep wells in the area of water-bearing dolomite.

The bore V-4 was situated 33 metres NW from the old dug shaft (Fig. 2). It went through dolomite and penetrated a fault plane between dolomite and Permian sediments in the depth of 164 metres. The main inflow of thermal water was in the depth interval 98.0—115.0 metres. Pumping at a drawdown of 0.17 metres yielded 6 litres per second of thermal water at 39 °C; such a temperature had not been reached in Laško up to then. This bore was later reconstructed for exploitation. At a drawdown of about 1.5 metres its discharge rate is 12 litres per second at a temperature of 39.4 °C.

The bore V-5 was drilled about 90 m in the south of the bore V-4, and was 660.5 metres deep. Here the Quaternary sediments were 8.5 m thick, and down to the bottom of the bore followed Triassic dolomite (Fig. 2). Pumping tests, thermologging, and observation of piezometric levels conducted during drilling indicated the interval of highest temperature between 125 m and 145 metres. The piezometric level increased from the altitude 217.33 as the bore struck the first thermal aquifer in 60 metres depth to the altitude of 224.57 metres, as the bore struck thermal water in the depth of 492 metres. As the altitude of the outlet of the well casing is 220.78 m, the difference in piezometric levels caused overflow of 4.8 litres per second of thermal water having a temperature of 30.5 °C.

By drilling the bore V-6, about 80 m in the south of V-5, it was intended to study the contact between pseudozilian shale and dolomite. Geoelectrical measurements indicated the boundary between dolomite and shale below the Quaternary sediments. The contact was found in the depth of 106.8 m. The final depth of the bore was 153.6 m.

In the bore V-7, situated about 40 m SW of the bore V-6, it was expected according to the data from bore V-5, to find below the impervious shale thermal water, which would overflow from a depth of about 350 m. According to the dip of the shale-dolomite contact as found in the bore V-6, the same contact should be encountered in a depth between 300 and 350 metres. However, dolomite was found already at 161.7 metres depth. After drilling to the depth of 450 m without obtaining thermal water, the hydrogeological explorations in Laško were discontinued.

In the immediate surroundings of Laško the geological structure is favourable for free outflow of thermal water into the Savinja Valley. A belt of Carboniferous shale and sandstone spreads from west to east in the north of the thermal springs. Along the Carboniferous, some patches of Permian sandstone and Lower Triassic Scithian beds are found locally. The boundary between Permian and Lower Triassic has not yet been defined. In the bore V-4 a tectonic contact between Paleozoic and Triassic rocks has been found in the depth of 164 metres. The Triassic dolomite reaches to this depth. It is underlain by red Permian sandstone, passing into black Carboniferous shale in the depth of 260 m.

In the surroundings of the thermal springs Middle Triassic dolomite spreads over a wide area from west to east. The dolomite belt is up to 500 metres wide, but in some places its width amounts to only some tens of metres, somewhere it is even covered by younger strata. Due to its porosity it is a collector of thermal water. Along the faults the dolomite is broken and fissurated. It is mainly of grey colour, somewhere also inclusions of dark grey or yellowish dolomite are found. Broken zones are numerous on the surface, and according to data obtained by drilling, in the underground as well. Their distribution is irregular, and they represent impervious lenses in the fissured dolomite. The dolomite is covered along its whole border in the south of the thermal springs by pseudozilian shale with intercalations of sandstone passing into tuffite. The shale is black and resembles the Carboniferous shale. The pseudozilian beds are disconnected by lenses and blocks of quartz keratophyre and tuff. On the southern flank of the anticline Tertiary beds were deposited, which extend westwards into the Laško coal basin.

The area of the Laško thermal springs belongs to the tectonic unit of the Sava folds. By surveying the immediate vicinity a significant fault trending W—E was defined (Fig. 2). Along it the Paleozoic beds have been brought in contact with Triassic dolomite. As the dolomite is covered in the southern part by pseudozilian sandy shale, the whole southern side can be considered to be a flank of an anticline. Its core form the Paleozoic beds in the northern fault side. Similarly a fault cuts the Tertiary sediments along the northern border of the Laško syncline. In this way the narrower locality of the Laško thermal springs is a dolomite block enclosed from the south and from the north by impervious shale and sandstone. The third fault, being transversal, extends very probably parallel to the Savinja river below the younger sediments, therefore concealed. It is however indicated by an unexpected narrowing of the dolomite belt just in the vicinity of the thermal springs area. On the left bank of the Savinja the dolomite belt is 500 m wide, but on the right bank, beyond the road Celje—Laško, only 50 metres. Its existence is reflected in morphological features of the area as well.

The thermal springs rise to the surface in the Savinja Valley, which is of lowest altitude in the dolomite belt. The total area where thermal springs of different temperature appear, covers some 1000 square meters.

In the bore V-4 the warmest zone was found in the depth interval 95 to 115 metres; simultaneously in this interval also the discharge rate was the largest, i.e. 9 litres per second at a drawdown of 1.5 m and at a temperature of 39.4 °C. By thermologging at this depth a temperature of 41 °C was measured.

The bore V-5 drilled through the warmest zone from 125 to 145 m, where the same temperature of 41 °C was measured. Temperatures 36,5 to 40 °C were measured down to the depth of 260 m, but below 350 m it amounted to 33.5 °C only. Even today smaller quantities of water with a temperature of 31.6 °C flow from this bore. The bore has been cased with 113 mm diameter steel pipes to the depth of 238.5 metres.

The investigations have shown that the warmest zone lies in a depth where the influence of the cold ground water and of the Savinja river is week. Below this warmest zone the water temperature decreases, which shows that there the primary thermal water penetrates trough cooler water, warming it partly up. The differing depths of the warmest water level in bores V-4 and V-5 show its dip towards bore V-5. The direction of flow of the thermal water from the underground is still not known; the bores V-6 and V-7 could not give any indications about this question.

According to the increase of the piezometric level with deepening of the bores, the dolomite can be divided into three zones. The uppermost zone is under direct influence of the ground water of the Savinja and Rečica alluviums. According to data from V-5 this influence persists down to the depth of about 110 metres. The next is an intermediate zone, where the influence of the ground water diminishes, and the piezometric level slowly increases. Here also the rise of the piezometric level due to installation of casing must be considered. This intermediate zone reaches down to the depth of about 250 metres. From there downwards follows the third zone, where the piezometric level rises quickly, to reach at a depth of 492 m the highest altitude of 224.57 m, i.e. 4.24 metres above the surface.

The boundaries between the different zones probably change accordingly to the quantities of thermal water exploited. The hydrogeological explorations carried out up to now could not determine the total yield of the Laško thermal system, but it is definitely higher than the output used today. This prove also the secondary thermal springs in the area surrounding the actual supply wells.

4.8. *Podčetrtek*

In 1965—1967 investigations were carried out for development of the so called Harina Zlaka thermal spring on the left bank of the Sotla river near Podčetrtek. Hydrogeological mapping in the scale 1:10 000 gave the basis for locating three exploratory bores V-1/65, V-2/65 and V-3/65.

The bore V-1/65 penetrated a twelve metres thick overburden of sandy and silty clay. The lower portion of this Quaternary deposit contains angular and subangular fragments of dolomite and porphyrite. The following strata consist of Triassic dolomite with rare shale and tuffite intercalations. Below 250 m the shale intercalations become more frequent. In 274 m depth a dark clayey marl appeared.

Thermal water was found in different depths. The water of the highest temperature 30 °C was found at the contact of Quaternary and Triassic beds. In the Triassic dolomite the water temperature varied from 23 to 23.5 °C. The springs at the surface in the vicinity of the bore V-1/65 show a temperature of 26 °C in the ameliorated bed of the Sotla river, and the springs near the denuded contact between the Triassic beds and the Sotla alluvium about 23 °C, which corresponds to the temperature in the Triassic dolomite in the bore V-1/65. The bore site lies at the periphery of the thermal springs area. Steel 5" casing was installed down to the depth of

60.64 m, and 4" casing from 60.64 to 72.00 m. The casing was perforated throughhout the depth interval from 25.44 m to 66.50 m, where maximum inflow of thermal water was detected during drilling.

The bore V-2/65 penetrated Quaternary sediments of a thickness of 6.0 m, and below them Triassic marl with sandstone intercalations. At 27.4 m grey, fissurated dolomite was encountered. The water in the dolomite had a temperature of 18 °C. Drilling was stopped at the depth of 63.1 m.

The bore V-3/65, situated on the right bank of the Sotla river drilled through Quaternary deposits and penetrated into Oligocene marl at a depth of 11.2 m. After a broken zone Triassic porphyry tuff occurred at 26.4 metres. In the depth of 45.0 m followed Triassic dolomite up to the final depth of 137.0 metres.

Thermal water appeared in the porous dolomite already at the contact with the porphyry tuff. The main inflow was in the depth interval between 45.0 and 70.0 metres; and small quantities appeared between 105.0 and 112.0 m. The dolomite was from 70.0 m downwards highly broken, therefore the subsequently installed casing was perforated in the intervals from 50.91 to 84.12 m, and from 104.82 to 120.49 metres for collection of thermal water.

In 1966 a discharge well K-1 was drilled to the depth of 80,0 metres. Steel casing of 10 1/2" diameter was installed to the depth of 30.0 m; from there to the final depth 80.0 m the bore was left uncased, as the rock was only fissurated and cavernous, but firm, especially in the water bearing dolomite. The pumping tests of the well yielded at a drawdown of 1.000 to 1.015 m 8 litres per second, and at a drawdown between 1.52 and 1.55 metres 10 litres per second of thermal water, both at a constant temperature of 35 °C.

In 1970 ten metres in the west of K-1 a stand-by discharging well K-2 was drilled. In this way the total quantity of available thermal water in the shallow zone has been taken hold of. The well K-2 resembles lithologically the well K-1, only here the Triassic dolomite starts at the depth of about 56.0 m. Pumping tests during the dry season in the year 1970 have shown that the shallow zone yields 15—20 litres per second of thermal water with temperatures from 33.9 to 35.0 °C.

In 1971 the thermae were taken over by the Section for Tourism of the Railways Association Ljubljana (ZŽTP Ljubljana), which took over the responsibility of building a balneological and recreation establishment. For this reason the Geological Survey Ljubljana prepared a programme for additional hydrogeological exploration, part of which was carried out in 1972. It is intended to explore thermal water in the deeper zones, so as to ascertain a large quantity of thermal water of higher temperature.

The site of the exploratory bore V-1/72 is 50 m southwest of the bore K-1. Oligocene sandy marl was drilled from the depth 9.0 m to 85.6 m. After an intermediate broken zone Triassic dolomite starts in the depth 88.6 m, intercalated with porphyry tuff, and reaches to the depth of 135.2 m. Down to the final depth 202.2 metres there is Triassic dolomite interbedded with breccia and dark grey dolomite. A smaller inflow of thermal water occurred in the interval from 90.5 to 98.0 metres. From the depth of 111.0 m to 177.0 m the inflow of thermal water increased steadily. The exploratory bore V-1/72 was later reconstructed to a discharge well of larger diameter, and steel casing was installed.

The bore V-2/72 was drilled about 80 m northwest of the well K-1. Below the Quaternary overburden it struck at the depth of 11.5 m Oligocene marl, and at 88.6 m porous dolomite bearing smaller amounts of thermal water. Between 91.0 and 132.8 m there was porphyry tuff, then down to 197.3 m fissured Triassic dolomite, deeper up to 222.1 m vitreous porphyry tuff, and finally again dolomite up to the bottom of the bore at 224.9 m.

The environments of the thermal springs near Podčetrtek consist of Triassic, Tertiary and Quaternary rocks. Quaternary rocks reach in the valleys of the rivers Mestinjščica and Sotla thicknesses up to 12 metres. They are composed of sandy and silty clays, and subangular gravel. On the Triassic rest basal Oligocene beds of marine clay, quartz sand, and quartz sandstone; in some places they contain coal.

Between Oligocene and Miocene beds there is an erosional unconformity, as well as between the Helvetian marl and sandstone, and the Tortonian Lithothamnion series of sediments which starts with basal conglomerate. According to the microfauna, only the Lower and Middle Tortonian were deposited. In the synclinal flanks they are overlain by Sarmatian claystone intercalated with sand, sandstone, conglomerate and clay. The syncline at Pristava is filled by Pleistocene sediments, consisting of claystone with sandy strata.

The Triassic beds belong to the Ladinian stage, and consist of dolomite with intercalations of tuff and tuffite, clayey shale and breccia. The dolomite is grey, somewhere nearly black in colour, and includes sometimes chert nodules and pyrite. In the environment of the thermal springs area shale, and porphyrite with tuff occur as well. Somewhere also Werfenian shalle, marl and dolomite are lain bare. The Triassic rocks on the slopes of the Rudnica mountain crop out penetrating Tertiary sediments.

The environment of the thermal springs is cut by numerous faults that originated mainly in younger orogenetic phases. Although the faults were ascertained only in localities where the Triassic beds crop out, it can be concluded by the extent of the Tertiary rocks as well as by morphological features, that faults continue into the area of Tertiary rocks. Transverse valleys in north-south direction indicate strongly the tectonic relations. The main faults of north-south direction are parallel to the Mestinjščica and Sotla valleys. The fault along the Sotla river was proven also by drilling in Rogaška Slatina. The Tertiary sediments form in the north of the Rudnica mountain a wide syncline, that splits in the west into two synclines. In the intermediate anticline the Triassic beds crop out in the south of Šmarje pri Jelšah.

The thermal springs at Podčetrtek appear in a zone extending from the abandoned iron mine near Olimje in the south, to the confluence of the Sotla and Mestinjščica rivers in the north. The width of the zone is a few hundred metres only. The main springs area is in the north of Podčetrtek. The aquifer is Middle Triassic dolomite, which is in the Sotla valley covered by younger Tertiary and Quaternary sediments, and partly by porphyrite tuff. The thermal zone is cut by faults into blocks. The thermal springs appear near the contact of dolomite with impervious Tertiary beds. Water-bearing is the fault zone, namely the fault that dips westwards, as proven by exploratory drilling. The thickness of the impervious beds also increases in western direction.

The temperature of the thermal water is the highest in the northern part of the thermal zone; in southern or south-western direction it decreases. The farthest known locality containing thermal water is the bore V-1/48, drilled 1948 at Olimje, where even now 14 litres per second of water at 18 °C are overflowing.

The thermal water is at present collected by three wells. Two of them, K-1 and K-2, collect the water from the depth between 46.0 and 80.0 metres; the third well, V-1/72, from the depths between 120 and 180 metres. The fault zone with the warmest water is inclined westwards, therefore the temperature of the water is the highest in V-1/72 37 °C, and in both shallower wells it amounts to 34—35 °C. The total output obtainable by pumping amounts to 30 litres per second.

4.9. *Dolenjske Toplice*

In the year 1960 the Dolenjske Toplice area has been mapped in scale 1 : 10 000. Up to 1959 the thermal springs have been only occasionally inspected and their discharge rates measured. The respective short reports and records exist in the archives of the balneological establishment.

Hydrogeological survey connected with drilling was started in 1960–61. Four bores were drilled, three of them in the immediate vicinity of the existing baths, and the fourth in the norht of the open swimming pool along the road Dolenjske Toplice—Novo mesto. Ten years later, in 1971, four additional bores were drilled, which reached depths from 190 to 416 metres. They resulted in tapping thermal water in depths of 290 to 315 metres.

The oldest formation in the surroundings of Dolenjske Toplice belongs to Upper Triassic laminated dolomite, including sheets of granular dolomite. It covers the areas in the north of the confluence of the Krka and Radešca rivers, the Straška Gora mountain, as well as the surroundings of Soteska. The Lower Jurassic beds consist of grey granular dolomite, dark grey limestone with sheets of shaly marl, and of grey limestone with intercalations of oölitic limestone. They cover the area between the rivers Sušica and Radešca, and reach the Krka valley below the southern slope of the Straška Gora mountain. The Lower Jurassic beds are followed by Middle Jurassic oölitic dolomite, and Upper Jurassic light grey limestone. They jointly form the hillocks Pristava and Prašićevka in the east and northeast of Dolenjske Toplice.

In the west of the Radešca river Lower Cretaceous beds occur, dipping westwards below the Kočevski Rog. They consist of grey, partly bituminous limestone.

Quaternary is represented by karstic loam in the valleys of the rivers Sušica, Krka and Radešca. Recent deposits, sandy and silty clay along the Krka, Radešca and Sušica, have been transported mainly from the area of karstic loam.

In the surroundings of Dolenjske Toplice two faults are important. The Žužemberk fault is one of the main tectonic lines in the structure of Slovenia and Croatia. It runs from the Ljubljana basin along the Upper Krka valley and then at the Kočevski Rog along the valley of the Radešca river and Črmošnjice to Bela Krajina. The second is the Toplice fault along the Sušica river. At the Toplice fault meet the Lower Jurassic granular dolomite and laminated limestone with the Lower Jurassic oölitic limestone. Between both the Toplice and Žužemberk faults spreads a Jurassic syncline, that is at the Žužemberk fault overthrusted on Lower Cretaceous strata. The thrust plane dips 60°—70° towards northeast, and is indicated by slickensides between Meniška Vas and Selo. A very distinctive broken zone indicates a rather large dislocation.

The thermal water of Dolenjske Toplice fills two basins excavated in the basement of the bathing establishment. In the larger basin the spring temperature varies from 37.1 to 38.4 °C, in the smaller one from 36.2 to 37.4 °C.

According to the hydrogeological studies during 1960/61 and in 1971, the thermal water flows to the surface through a system of fissures along the Toplice fault, enlarged with time into caverns. The thermae are under influence of the cold karstic ground water system. During high water level of the Sušica, the piezometric level of the thermal water increases; at low levels of the Sušica the thermal water issues in numerous springs into the river bed, and therefore the piezometric level drops. Consequently the discharge rate in both basins decreases. Pumping tests in wells, performed from 13. 12. 1960 till 20. 1. 1961, however, proved that the total discharge rate of the thermal water with temperatures from 36.5 to 38.4 °C does not change, and amounts at high or low water levels of the Sušica river to between 12 and 13 litres per second. To prevent the lowering of the piezometric surface of the thermal water, the aquifer has to be tapped in a proper depth.

The thermal water flow is associated with the karstified zone in the Jurassic limestone and Triassic dolomite. The main current of the thermal water is represented by the springs of the larger basin, with the highest temperature of 38.4 °C. The springs of the smaller basin with the temperature 37.4 °C are already peripheral parts of the warmest zone.

All exploratory bores in the vicinity of the thermae indicated a warmer zone between depths of 90 to 120 metres; deeper down the temperature decreased even for 10 °C. The deepest bore V-6/71 showed an increase of temperature again for 10 °C in the depth of 200 m, yielding 7 litres/sec thermal water of 32 °C from Triassic dolomite in the depth interval from 299.5 to 303.0 metres. Such temperature conditions show, that the deep thermal zone lies directly below the warmest surface springs. The exploratory bores have also shown that the Sušica river represents the southern boundary of the shallow zone and most probably of the deep thermal zone as well, where it could be possible to capture warm water in the primary water-bearing bed of Triassic dolomite, that appears in a depth of about 260 metres. Further it was proven that the system of caverns extends into the Triassic dolomite.

4.10. *Šmarješke Toplice*

The thermal bath Šmarješke Toplice lies about one kilometre in the north of the village Kronovo, in the valley of the river Dolnice.

Up to 1956 there existed only a few observation records about the Smarješke Toplice thermal springs, and short reports given by J. Žurga, which are kept in the archives of the spa. The first detailed geological mapping in the scale 1:10 000, and temperature measurements in Quaternary sediments were conducted by D. Kuščer and F. Drobne. On the basis of these surveys in 1959 there were 19 shallow bores drilled by hand, which discovered two thermal centres in a mutual distance of about 200 metres. The shallow bores were followed by four machine drilled bores in 1959/60. The bore V-1/59 was drilled near the open swimming pool, V-2/59, V-3/60 and V-4/60 near the covered basin. In 1962 a fifth bore V-5/62 was drilled near the covered basin, and in 1969 four bores near the open swimming pool. About 0.6 km in the south of Šmarješke Toplice there is another thermal spring with a discharge rate of 230 litres per second at temperatures of 16—18 °C. Near this spring two shallow and three deep bores were drilled in 1968, with the intent to find out if and how it would be possible to separate the thermal from the cold water, and also to utilize them separately. A final answer to this question has not been obtained, due to the rather restricted extent of the explorations.

In two deep bores thermal water was obtained, with temperatures of 25 °C in V-3/68 and 28 °C in V-4/68 (Fig. 3). The exploration should be continued for a definitive answer to the outlined problem. However, the main spring was developed in 1970, and will furnish drinking water for the town Novo Mesto and its surroundings.

The oldest and also most widespread rock in the surroundings of Šmarješke Toplice is light grey Triassic dolomite. A more exact age of the dolomite cannot be defined; by comparing it with other dolomites of Lower Carniola it probably could belong to Upper Triassic. In the vicinity of the thermal springs the dolomite is broken. The broken zone extends in the direction NNE SSW within the limits of the thermal springs zone. Its width is in places up to 100 metres. In this zone there are a few sand quarries near the spa. Some of the exploratory bores have penetrated the broken zone. On both sides of this zone the dolomite is rather bedded, showing many fissures and slickensides.

On the dolomite lie erosional remnants of Jurassic and Cretaceous limestones. To Cretaceous belongs dark grey limestone with intercalations of clayey marl and chert nodules, that closes up the thermal zone in its southern part, forming an impervious barrier. Eastwards the Mezozoic beds dip below Tertiary marl, sandstone and Lithothamnion limestone, otherwhere they are covered by karstic loam.

The valleys of the rivers are covered in places by thin, otherwhere up to 6 metres thick beds of clayey-sandy Holocene, which contains, specially within the limits of the thermal springs, organic clay.

The connection between the geological structure of Šmarješke Toplice and the Krško basin has not yet been explored. The Krško basin has been considered to be a fault basin, but present geological surveys indicate a syncline, built by Tertiary sediments. The pre-Tertiary basement is covered by Tortonian sediments: sandy marl, calcareous sandstones, and Lithothamnion limestone. These beds are overlapped in their southern and northern parts by Sarmatian sediments followed eastwards by Pannonian clayey marl.

The broken zones in Šmarješke Toplice are connected by intersecting local faults. In the west of the thermae the fault having brought in contact Triassic and Cretaceous limestones is cut by another fault of NW—SE direction, that connects the thermal springs of Šmarješke Toplice with those of Kronovo. Both faults are important, because through fissures along them thermal water rises to the surface. In the fault zones the dolomite is silicified, the fissures are filled by calcite and fine breccia. In the wider surroundings of Šmarješke Toplice similar tectonic conditions prevail as well. The area is cut up by local faults into numerous blocks, which are accompagnied, especially in dolomite, by broken zones.

Hydrogeological studies in Šmarješke Toplice have shown the connection of thermal water and ground water. The aquifer is dolomite. Its permeability coefficient, calculated from pumping tests data, varies from $k = 1.2 \cdot 10^{-4}$ cm/sec to $k = 4.5 \cdot 10^{-4}$ cm/sec. The discharge rate of thermal water depends on the piezometric level of the ground water. Therefore in dry seasons the discharge rates of the thermal water decrease, but with some retardation. The quantity of the overflowing thermal water is therefore directly proportional to the oscillations of the ground water table.

In the open swimming pool the maximum temperature is 34.5 °C, and in the covered basin 32 °C. To both spring centres the thermal water flows from the north. At the covered basin the fault between the Triassic dolomite and the Cretaceous limestone forms the southern boundary of the shallow thermal zone. The block of Cretaceous limestone forms an impervious barrier due to its intercalations of marl and clay, and separates the shallow thermal zone of Šmarješke Toplice from the other shallow thermal zone Jezero, in about 800 metres distance. The block of Cretaceous limestone with intercalations of marl and marly shale at Šmarješke Toplice reaches probably only shallow depths, as it is an erosional remnant. In exploratory bores along the fault this limestone reached a depth of 80 metres.

The surface streams flow in clayey Quaternary sediments, and therefore have no influence on the output of the thermal springs. In the area of Šmarješke Toplice the thickness of the clayey sediments reaches up to 7 metres, as proven by numerous hand drilled bores in the year 1959.

The hydrogeological problems in the wider surroundings have not yet been solved. The shallow thermal zone was explored up to the depth of

150 metres. Thermal water was captured at the swimming pool in the depths from 12 to 147 metres, and at the covered basin from 11 to 19 metres. Near the spring Jezero the bores reached the depth of 257 m. There the discharge rate amounts to 230 litres per second with temperatures from 16 to 18 °C. At Jezero the fractional exploitation would be of extreme importance, as it would allow to deliver cold drinking water for population, and thermal water for recreation purposes as well.

The further work in Smarješke Toplice should be directed to explore the deep thermal zone by drilling. This would result in higher water temperatures, deep well installation would reduce or even eliminate the influence of the cold water. Recent explorations gave only general features of the relationship between both shallow thermal zones at Šmarješke Toplice and at Jezero. Deep bores, however, would clarify whether there is a uniform hydrogeological system, or two different systems occur related to the same source of heat supply.

4.11. *Topličnik*

The thermal zone along the right bank of the river Krka is about 400 metres long. The easternmost spring named Topličnik issues from an opening in the ground surface. In autumn 1971 two exploratory bores were drilled: V-1/71 in the south of Topličnik and V-2/71 between Topličnik and the Krka river. Both bores struck Cretaceous limestone below the Quaternary overburden. The limestone was in its fissured parts water-bearing, but only in V-2/71 the temperature rised to 25.5 °C.

After detailed geoelectrical resistivity surveys in 1972 six exploratory bores were drilled, on the left bank of the river the bores V-3/72, V-4/72, and V-5/72, and on the right bank of the river the bores V-6/72, V-7/72 and V-8/72.

All exploratory bores struck thermal water, having lower temperatures betweeen 21 °C and 24 °C on the left bank, and somewhat higher temperatures of 24—28 °C at the right bank, with exception of V-8/72, whose temperature was 13 °C only. This bore is situated immediately at the road Šentjernej—Kostanjevica, that is at the boundary of the thermal zone.

The results indicate that the thermal water flows from the south, and emerges to the surface near the Krka river mixed with cold ground water.

All exploratory bores were shallow, as their aim was only to explore hidrogeological conditions in the shallow zone, and to give indications for the best site where to explore in greater depths.

By drilling the aquifer of the shallow zone has been proved to be the fissurated Cretaceous limestone, which is in the north of the Krka covered by Miocene marl, sandy marl, and Lithothamnion limestone. The surrounding of the thermal springs is cut into different blocks by numerous faults. The temperature of the thermal water was lower in places where the Cretaceous limestone is covered by thicker beds of Tertiary marl. This fact disproved the former supposition, that the thermal water flows from the north along the contact between impervious Tertiary marl and Lithothamnion limestone, or Cretaceous limestone respectively.

4.12. *Čateške Toplice*

Until the year 1957 the shallow discharging wells of Čateške Toplice were dug in Quaternary gravel. The influence of the cold ground water was evident in temperature variations of the thermae. In 1957/58 fifteen shallow bores were drilled, which indicated the flow of thermal water from the underlying beds into the Quaternary overburden. According to results of the temperature and water level measurements in the shallow bores, the drilling site for an exploratory bore was chosen. The bore was 82.0 m deep, and struck a cavern between 51.7 and 52.7 metres in karstified Miocene calcareous sandstone, through which thermal water flows to the surface. The static water level in the bore oscillated due to the contact with ground water in the gravel, and the discharge rate varied from 15 to 30 litres per second. If larger quantities of water were pumped, its temperature decreased. At a level of 2.0 m below surface only about 15 litres per second of water at 57.2 °C could be obtained; when pumping greater quantities, the temperature dropped.

In 1962 the Cooperative Society Brežice started using the thermal water for heating hot-houses. In the same year they financed the drilling of a well of 12" diameter to the depth of 60 metres, and built a pumping installation, that works continuously till now.

Hydrogeological surveys were continued in 1964, financed by the Federal Fund for Geological Exploration. The results of these surveys enabled the furter development of Čateške Toplice. Four exploratory bores were drilled; V-4/64 struck the primary aquifer of the thermal water i. e. Triassic dolomite, in the depth of 283.0 metres. From this bore flow up to now continuously 10.6 litres per second of thermal water of a temperature 57.2 °C, with a pressure of 1.6 kp/cm^2 at the outflow on the surface.

In 1969 systematic hydrogeological surveys were started on the whole Čateško Polje, and were concluded in 1972. The surveys were made possible by the financial support of the Boris Kidrič Foundation.

In 1969 exploratory bores V-1/69, V-2/69, V-3/69, and discharging wells of large diameter K-1/69 and K-2/69 were drilled. These wells were located over the centre of the shallow thermal zone, and 180 metres SW of it as well. Their results were very satisfactory, as both discharging wells yield a total of 83 litres per second of thermal water having temperatures of 57—59 °C.

In 1970 we surveyed the Čatež area by geoelectrical and microseismical methods, to determine the thickness of the Quaternary gravel and the lithological composition of the underlying rocks. Shallow bores V-4/71, V-5/71, V-6/71, V-7/71, V-8/71 and V-9/71 checked in 1971 the results of the geophysical surveys, and found good correlation, as well as a reliable basis for deciding on further drilling sites. According to the exploration programme, two bores, V-10/71 and V-11/71, were drilled. A detailed geological map in the scale 1 : 5 000 was drawn, and a hydrogeological map in scale 1 : 25 000 as well.

Exploratory driling was resumed in 1972, by bores V-12/72, V-13/72 and V-14/72. The exploration was concluded by pumping tests, which confirmed the discharge rates of Čateške Toplice at about 120 litres per second of thermal water.

Čateške Toplice are situated on a gravelly plain, about 200 metres in the south of the river Sava, along the border of the Krško basin. Its northern boundary is the Sava, the southern boundary the foothills of the Gorjanci mountains (Fig. 4).

The Mezozoic beds crop out only in the foothills of the Gorjanci mountains; the Čateško Polje itself is covered by a 7 to 12 metres thick bed of Quaternary gravel. Drilling has shown, that the gravel is underlain by Tortonian sediments of different thicknesses. In the central and western part the Tortonian sandy marl, calcareous sandstone and Lithothamnion limestone extend down to about 125 m, in the south and east to about 186 metres. Between the Tertiary and Mezozoic beds occur basal beds of plastic clays with intercalations of quartz sand and coal smits. The thickness of the clayey sandy beds varies from 24 to 75 metres.

The upper part of the Mesozoic beds is composed by layered Cretaceous limestone with intercalations of marly limestone and chert. The limestone somewhere passes over into breccia. The thickness of the Cretaceous beds is not regular, but varies from 50 to 197 metres. The Cretaceous limestone is underlain by Triassic dolomite, which is the main aquifer.

All rocks which have been penetrated by drilling, appear in the foothills of the Gorjanci mountains as well. The thickness of Tertiary and Cretaceous beds varies here as well. The Cretaceous limestone is in the Gorjanci preserved only in the shape of erosional remnants on Triassic dolomite. Also the Tertiary basal beds are encountered only in few places.

According to the data obtained by drilling the Čateško Polje belongs to the Gorjanci foothills. Therefore the area of the thermal zone represents an extension of the Gorjanci mountains, as proved by the lithological composition and stratigraphic sequence of the beds.

The most important fault that extends into greater depths, originates in the north of the Gorjanci mountains, curves near Čatež village towards northeast, and crosses the river Sava in the north of Čateške Toplice. This fault has been determined by regional geophysical surveys. Its course on the Čateško Polje has been proved by detailed geoelectrical and microseismic surveys in 1970. It is accompagnied by a wide broken zone and numerous secondary faults and fissures. Younger faults crossing the main dislocation have cut the Gorjanci foothills and the Čateško Polje into blocks. The thermal zone itself consists of blocks, as proved by the different thicknesses in Tertiary and Cretaceous beds.

Until the Čateško Polje was hydrogeologically surveyed, it was known only that the Quaternary gravel near the thermal springs is saturated with warm water. Already the first exploration in 1957 has shown that there are more different thermal water levels.

The shallow water level is in the Quaternary gravel, the warm water flows into it from the underlying Tertiary beds. The next water-bearing level is in the system of caverns in the Tertiary Lithothamnion limestone, where thermal water was tapped in 1958. Both water-bearing levels are influenced by the cold ground water in Quaternary gravel. The level of the thermal water in the gravel, and in the system of caverns in the Tertiary limestone as well, varies according to the ground water table.

The only difference is in the static level of the thermal water, which is 0.50 to 0.90 m higher than the level of the cold ground water, which surrounds the thermal water from all sides. The hydrogeological studies in 1964 have discovered the deep thermal zone, with thermal water under pressures from 1.02 to 1.8 kp/cm². The pressure 1.8 kp/cm² has been measured in the first bores that struck thermal water in dolomite. The decrease in pressure in the following exploratory bores is due to the exploitation of thermal water by deep wells, consequently causing the forming of a depression cone.

The deep thermal level in Triassic dolomite is covered by an impervious bed of Tertiary marl, and chiefly of clayey sandy Tertiary basal beds as well as Cretaceous layered limestone with marl and chert intercalations. Therefore the temperature in the west of the thermal zone amounts to 57 °C, and in the east, where the impervious cover is thicker, to 64 °C. The temperature may as well depend on the distance from the centre of origin of the thermal water. As mentioned, the temperature of the water increases from SW towards NE. Near the village Čatež there is a thermal spring Perišče of a temperature 31.5 °C, in a distance of about 1 km from Čateške Toplice. The thermal water flows to the surface directly from Triassic dolomite near to the main fault, that transfers the heat flow in the thermal centre of Čateške Toplice as well. The next exploratory bore V-13/72 lies in a distance of 300 m from the thermal centre towards the spring Perišče at Čatež village. The water temperatures measured were between 42 and 45 °C. Also this bore is located in the wide, broken and fissured zone along the main fault. In the bore V-12/72, located in a distance of about 120 m in the north of the centre of the thermal zone, water temperatures of 64 °C were measured. Due to the river Sava it is impossible to drill further exploratory bores northwards or in NE of the bore V-12/72. As in this direction extends the main fault, and also temperatures of the thermal water increase, it can be assumed that up to now the highest temperatures in the Čatež thermal zone have not yet been reached. From the spring Perišče to the bore V-13/72 the temperature increases for 10 °C at a distance of about 700 m. Much higher, 20 °C, is the temperature increase between V-13/72 and V-12/72, at a distance of about 350 m. This indicates that the zone of higher temperatures continues in the deep aquifer of Triassic dolomite, along the main fault towards northeast on the left bank of the Sava river, where the thickness of the impervious cover increases as well.

The quantities of thermal water with temperatures from 57 to 64 °C were measured by a 12 day pumping test. It was shown that a continuous exploitation of 120 litres per second of thermal water with an average temperature of 60 °C is possible. As the stabilized pressures in observation wells did not decrease to 0.0 kp/cm², there exist still additional thermal water sources, that could be pumped intermittently, in case of need. This especially holds for water with lower temperatures that should be used for balneological purposes, as today this thermal water has to be cooled before use.

The success of the hydrogeological studies in Čateško Polje is evident. The discharge rate of thermal water 120 l/sec at 60 °C is a good base for further development of balneological and recreative tourist establishments. The high temperature allows the water to be used twice: first for heating, and then, when cooled off, in open basins, which work in winter as well without any additional heating.

5. Hydrogeological Investigations for Mineral Waters

5.1. *Rogaška Slatina*

In the past the studies of the Rogaška Slatina springs were directed to the immediate vicinity of the shallow wells, where the water rised to the surface. Due to the short well life and limited amounts of mineral water more and more springs had to be developed. In 1888 eleven springs were known (A. Režek, 1937). Owing to the increase in the demand for mineral water in 1908 the operating wells were deepened at most to ten metres. The construction of the discharging establishment was designed by J. Knett (1908).

Even before the Second World War the available water quantities were not sufficient. A. Režek (1964, p. 255) states the total discharge rate of all wells measured from 29.—31. 5. 1942 as 17.4 litres per minute. Later even this discharge rate decreased, and the want for mineral water was heavy.

In 1952 there were 22 wells drilled under the general supervision of J. Bać, and geological surveillance by the author. Mineral water was tapped in depths ranging from 30 to 60 m, and the mineral water supply problem was temporarily solved.

Until the year 1957 maintenance and protecting of the main springs was carried out and a new spring water with low mineral content was reconditioned, and Knetts' well from 1908 was abandoned.

In the wider surroundings of Rogaška Slatina the Zgornji Gabernik spring was investigated in 1957/58 by two exploratory bores, the Kostrivnica spring by one bore, and an old well at Spodnji Gabernik by one bore. Both exploratory bores at Zgornji Gabernik and Kostrivnica struck mineral water; the borehole at Spodnji Gabernik was stopped too soon.

The first exploratory bores away from the immediate surroundings of mineral water occurrences at the surface started in 1965 by drilling the bore B-1/65 near the railway station Rogaška Slatina (Fig. 6). The next bores B-2, B-3, and B-4 neared again the springs centre. All of them were between the Hotel Slovenski Dom and the swimming establishment; B-2 and B-3 in the south, B-4 in the north of the road Celje—Rogaška Slatina.

In 1966 te well G-3/66 was drilled at Zgornji Gabernik; it is in exploitation still now. According to data obtained by regional geophysical surveying the drilling of bore V-3/66 in the north of Podplat was started (Fig. 7). The drilling site was determined by A. Nosan, after studying the geological structure of the whole area, and considering geomagnetic anomalies in this region. Another drilling site was chosen at Sečovo.

The bore at Sečovo Sč-1/67 penetrated in the depth of 318 m a broken zone of andesite tuff, with a mineral water discharge rate of 35 litres per minute and considerable quantites of CO_2. The bore at Podplat V-3/66 struck in the depth of 553 m small quantities of mineral water, and large quantities of CO_2.

Both bores V-3/66 and Sč-1/67 are now the main sources for mineral water supply of Rogaška Slatina, as well as for production of CO_2. Their distances from the Rogaška Slatina springs centre (V-3/66 5 km westwards, Sč-1/67 1 km eastwards) is of special significance, as their exploitation cannot influence the water discharge rate of the Rogaška Slatina springs centre. According to the suggestion of J. Bač in 1967 two bores, V-5/67 and V-6/67 were drilled, near the springs centre. V-5/67 is 142 m deep, without water or gas. V-6/67 is 265 m deep, struck mineral water (50 l/min) and considerable quantities of CO_2 in the depth of 260 m (Figs. 6 and 7).

The distance between both bores is 90 m, and from V-6/67 to the shallow wells 210 m. Its exploitation caused the shallow wells to run dry.

In 1968, subsequently to geoelectrical resistivity sounding, a bore Sč-2/68 about 800 north of Sč-1/67 was drilled. Another bore RV-1/68 was drilled in Ratanjska Vas (Fig. 7), about 1 km west of the Rogaška Slatina springs. According to the request of the Rogaška Slatina Authorities bore Tr-1/68 was drilled near Tržišče, its location being given by J. Bač. According to the 1968/69 exploration programme Sč-3/69 was drilled to obtain better information about low grade mineral water, appearing in a well for domestic drinking water supply. Bores RV-1/68 and Sč-3/69 discharge CO_2. Between 1968 and 1970 some geomagnetic surveys were carried out in small scale, as well as detailed geological mapping of the Rogaška Slatina area in 1 : 5 000. The exploration programme for 1970 included the already mentioned and often proposed deepening of bore V-3/66, drilling of the bore G-4/70, and on suggestion of S. Jentsch, representing the Geologisches Büro Dr. Pickel the drilling of the bore Tr-2/70. The bore V-3/66/70 penetrated in the depth of 578 m cavernous andesite tuff yielding mineral water and CO_2 at a pressure of 21.5 kp/cm². After regulation nozzles were installed, at the optimum pressure of 4.2 to 4.4 kp/cm² the bore produced 183.6 litres per minute of highly mineralized water (Fig. 7). The bore G-4/70 cut the Donat fault, and discharged 180 litres per minute of drinking water rising from Triassic dolomite. Bore Tr-2/70 penetrated coal beds, but found neither water nor CO_2. The drilling site of this bore was chosen according to CO_2 measurements carried out by Geologisches Büro Dr. Pickel-Kassel. Later it was found, that the mesured CO_2 anomalies originated from the main sewer carrying off polluted water and waste water from the health resort

In 1971 two bores were drilled, K-1/71 at Zgornja Kostrivnica in the immediate vicinity of a mineral water spring inside a brook, and Sč-4/71 about 90 m north of the well Sč-1/67. In the immediate vicinity of the domestic water well with mineralized water a shallow well was drilled, to check the inflow of the mineralized water.

The results of the various hydrogeological investigations after 1952 in the Rogaška Slatina district have not yet been systematically evaluated. Their evaluation, together with some additional surveys, is necessary for a full understanding of the mineral water sources of Rogaška Slatina.

Geological conditions. The surroundings of Rogaška Slatina consist of Paleozoic, Triassic, Tertiary, and Quaternary sediments. Tertiary sediments prevail, being also most important for the origin of mineral water. Quaternary silty clays with some interspersed gravel, fill the riverbeds. Some gravel terraces are still partly preserved along the foothills north of Rogaška Slatina. The youngest Tertiary is represented by erosional remnants of Sarmatian sand and sandstone overlying Tortonian Lithothamnion limestone. The Sarmatian sediments form the core of a syncline, that extends from Grobelno over Šmarje pri Jelšah to Mestinje, and joins near Pristava the southern syncline with a core of Pliocene sediments. In the northern syncline the Sarmatian consists of claystone and marl, in the southern syncline prevail sand and sandstone with intercalations of weakly cemented conglomerate.

The Sarmatian is underlain by Tortonian sediments consisting of basal conglomerate, calcareous sandstone, Lithothamnion limestone and sandy marl. The Tortonian sediments extend in a few parallel east-west belts. The older Miocene has not yet been stratigraphically defined. A special problem is the dark grey sandy marl, that grades into fine-grained tuffite sandstone in the north of the Šoštanj fault, and extends north and northeast into the Haloze hills. The tuffite sandstone is underlain by andesite tuff or by the Triassic and Paleozoic basement. The dark grey sandy marl is overlain by quartz sandstone, that forms the Macelj mountains. From there westwards the sandstone reaches Rogaška Slatina in a wedgelike shape, and is also found on the mountains Plešivec and Donačka Gora. The sandstone consists of quartz grains, calcareous cement, mica, and chlorite. It contains also some tuff components, such as plagioclase grains. Although the sandstone extends on the surface up to the springs centre in Rogaška Slatina, it has not been found in the bore holes. In the south of the Šoštanj fault the dark grey sandy marl does not appear, but is replaced by coal-bearing beds, that consist mainly of clayey marl with intercalated lenses of sand. The composition of these beds changes in short distances. In the bore B-1/65 opposite the railway station Rogaška Slatina there was grey sandy clay to the depth of about 115 m, and below it to 485 m grey marly clay. In the bore Tr-2/70 that is 200 m southeast from B-1/65, there was densely compacted sand with intercalations of sandy marl found prevailing down to the depth of 95 metres.

Important rocks of the Rogaška Slatina district are andesite and its tuff, overlain for the most part by Lower Miocene rocks. They spread at the widest on the southern slopes of the Boč and Plešivec mountains. By drilling andesite tuff has been found in the area between Podplat and Sečovo as well.

The Mesozoic and Paleozoic rocks are outcropping on the Boč mountain; they are mainly dolomite, limestone, shale, and marlstone, in a lesser degree sandstone. This rock sequence reflects the geologic structure of the Karavanke mountains. On the other hand in Resevna in the west from Rogaška Slatina and Rudnica in the south, pseudozilian shale occurs, that is a common rock of the Sava folds.

It is worth to mention that bores B-1/65 and Tr-1/68 struck in depths of about 500 metres pseudozilian shale, that indicates an extension of the Sava folds. It became evident that the Donat fault marks the boundary between the eastern extensions of the Karavanke mountains and the Sava folds. The Donat fault is considered to be a branch of the Šoštanj fault. Along the Donat fault it came to large vertical movements, and to longitudinal movements in a lesser degree; along the Šoštanj fault, however, the longitudinal movements were of greater extent. This is indicated by evident differences in lithologycal composition and stratigraphic relations of rocks. In the north of the Šoštanj fault there are andesite tuff and marly and sandy Lower Miocene strata, but south of the fault there occur coal beds underlain by the pseudozilian shale. Transverse to the main faults run younger faults, three of them already confirmed by drilling. The first was the Rogaška Slatina fault, penetrated by drilling in 1952, the second at Podplat in 1966, and the third at Sečovo in 1967. It is assumed that all steeply cut river beds of north-south direction originated along such secondary faults.

Between both the Šoštanj and the Donat fault the Tertiary beds form a rather steep syncline, which eastwards passes over into the Macelj syncline; in the west it is cut off by the Šošstanj fault, along which the Lower Miocene beds are brought against the wide Tortonian syncline between Ponikva and Šentjur.

Exploratory bores for drinking water that penetrated the Donat fault in the north of Zgornji Gabernik, have shown that the Triassic beds of the Boč and Konjiška gora mountains form an overthrust covering the Younger Paleozoic sediments. Later along the Donat fault the southern flank was lifted, so that today Tertiary is adjoining Triassic and Younger Paleozoic sediments.

Hydrogeological conditions. The Rogaška Slatina mineral water springs appear in an area of about 50 km². Formerly natural springs were known only in Rogaška Slatina, Spodnja Kostrivnica and Zgornji Gabernik; recently they have been found in the south of the Donat fault northwards of Zgornja Kostrivnica and in the ravine Črna Sola, about 0.5 km westwards of Zgornja Kostrivnica as well. Since 1908 three types of Rogaška Slatina mineral water are distinguished: Tempel, Styria, and Donat. The nearest to the primary water is the Donat type with about 8 grams of dissolved solids per litre of water, whereas Styria contains 6—7 g/l, and Tempel 3—4 g/l. The different types of mineral water resulted from the mixing of mineral water with ground water in shallow sections as already found by J. Knett (1908). Exploratory drilling has shown that the aquifer is andesite tuff, chiefly its rent and fissured zones associated with secondary faults, running transverse to both the Donat and Šoštanj faults. The andesite tuff aquifer appears on the surface in a limited area of the springs centre at Rogaška Slatina, otherwhere it has been found by drilling in depths ranging from 120 to 650 metres, overlain by Tertiary sandy marl and fine-grained sandstone, and in the north of the Donat fault on the southern slopes of the Boč and Plešivec mountains.

The region supplying water to the andesite tuff is the Boč area, consisting of carbonate rocks and andesite tuff. From this natural recharge area the water percolates downwards, flows through rent and fissured andesite zones, and rises to the springs in Rogaška Slatina, where the andesite tuff appears at the surface. Otherwhere the tuff is overlain by thick impermeable strata, that have to be penetrated by drilling to obtain mineral water. Moving through the tuff the water becomes mineralized. It is interesting to note, that the mineral content is lower near the Boč area, and increases in greater distances. The discharge rate of the Rogaška Slatina springs is small, due to the low natural recharge. The largest outputs 183.6 l/min were obtained in the well V-3/66/70 in the north of Podplat, which is already near to the western boundary of the wider mineral springs area. All other wells are of smaller capacities; G-3/66 in Zgornji Gabernik yields 13 litres per minute, V-6/67 in Rogaška Slatina about 60 l/min, Sč-3/67 near Sečovo about 25 l/min. The higher output of the well V-3/66/70 might be due to its location at the transverse fault that reaches in the north the carbonate rocks of the western extension of the Boč mountain. Along this fault appear the mineral water springs of Zgornji Gabernik and at Spodnji Gabernik as well.

Mineral water from deep wells is of higher temperature. The highest temperature of 30 °C was measured at the outlet of the well V-3/66/70 where mineral water rises from the depth of 578 m. Due to the high CO_2 content, the volume ratio between water and CO_2 amounting to 1 : 20, the pressure of the water is 21,5 kp/cm^2. The temperature of 30 °C at the outlet of the well has been measured after the expansion of the gas in the well, which indicates an even higher temperature in the aquifer.

The mineral water originates in andesite tuff, therefore its chemical composition of mineral matter is so variegated. The gaseous CO_2 originates in carbonate rocks, according to experiments conducted at the Institute Jožef Stefan, Ljubljana, at temperatures between 50 and 80 °C. The recharge from the surface is possible only from the north, i. e. from the Boč mountain, which is composed mainly of carbonate rocks. In the south carbonate rocks occur at the Rudnica mountain only, which is from the Šoštanj fault 8 km distant; the intermediate area is, however, covered by confining Tertiary beds of more than 1000 m thickness. Moreover the Tertiary beds in the south of the Šoštanj fault are underlain by pseudo-zilian shale, which is outcropping in the south of Šmarje. This shale builds together with the Tertiary cover an impervious barrier that closes up the springs area on its south to a depth greater than 700 m, as confirmed by bore B-1/65 in Rogaška Slatina, where the shale occurred in a depth of 495 m. As the thickness of this shale in other areas in Slovenia can amount to about 500 m, the shale might extend to a depth of 900 m. In the bore B-1/65 the shale was found in inclined position. Therefore a thickness of the impervious barrier of 900 m could be assumed even taking into account a partly erosion of the shale before the sedimentation of the Tertiary rocks.

The hydrogeological conditions of the wider mineral springs region do not allow for a natural recharge of the andesite tuff aquifer. Therefore the existing output of the wells will not be sufficient for further development of the health resort.

Further investigations will be necessary to find new locations for wells, separated from each other so as to avoid harmful mutual interference, as is observed now in the inner springs area in Rogaška Slatina.

Would even these additional wells not be sufficient, an artificial recharge of the ground water in the water-bearing zones should be considered, as the very high content of dissolved mineral matter would allow such a solution.

5.2. *Radenska Slatina (summary according to L. Žlebnik, 1972)*

The area of the villages Boračeva, Radenci, and Petanjci has been geologically and hydrogeologically surveyed formerly to a certain degree. Till the Second World War about 30 wells were drilled to depths of 20—36 m, only the well in Radenski Vrh reached 100 m. In 1965 new investigations were started, with the aim to determine the number of aquifers in the Radenska Slatina area, to establish their respective depths, outputs, size, piezometric levels, chemical composition and temperature of the water.

During 1965 and 1972 more than 30 exploratory bores were drilled, one of them (T-1, near Boračeva) to a depth of 780 metres, as well as 6 exploration wells with a total discharge rate of 40 cubic metres of mineral water per hour.

The oldest formations in Radenci were found in the bore T-1. This are metamorphic rocks belonging to Paleozoicum, found in the depth of 737.5 m. They consist of biotite schist, gneiss and amphibolite. The Paleozoic metamorphic rocks are overlain by Tortonian beds penetrated by the bore T-1 in depths from 626.0 to 737.5 m. They consist of thinly layered sandy marl, quartz conglomerate, and sandstone. These rocks crop out about 20 km in the west of Radenci near Vratja Vas on the border of the Apače basin.

The Tortonian beds are overlain by Sarmatian and Pliocene sediments. In Lower Sarmatian prevail marl and sandy marl with thin intercalations of sandstone, conglomerate and sand.

In Upper Sarmatian and Lower Pliocene appear marl, sand, sandy marl, and sandstone. The sandy beds are up to 50 metres thick. At the surface these beds occur in the hills between Podgorje and Črešnjevci near Gornja Radgona.

The youngest Tertiary beds belong to the Middle and Upper Pliocene. They consist of clay, sandy clay, and sandy gravel. Single layers are of thicknesses between 5 and 35 m. In Boračeva and Sratovci they reach to the depth of 100 to 190 m, in Radenci even to 288 m. The clay contains intercalations of organic clay and 0.5 to 1.5 m thick lignite lenses. In the sandy clay calcareous concretions are frequently found.

The Tertiary beds are overlain by Quaternary sediments; in their lower part Mura gravel with sand and silt prevails and the upper part consists of sandy clay, sand, and sandy silt.

The wider surroundings of Radenci belong to the Sobota horst tectonic unit consisting of paleozoic beds covered by Tertiary sediments up to 1000 m thick. It extends from Maribor in the southwest to Murska Sobota in the northeast. Northwest of this horst runs parallel to it the narrow Radgona graben, filled by 1000 to 2000 m thick Tertiary sediments. Along the southeastern border of the Sobota horst extends the wide Ljutomer syncline, where the Tertiary reaches depths of 3000 to 4000 metres.

The tectonic structure of the Tertiary beds is rather complicated. Seismic and gravimetric measurements, as well as recent exploratory bores show that the Pliocene and Sarmatian beds are slightly inclined towards southeast, whereas the Tortonian conglomerate and sandy marl that overlie the Paleozoic strata, dip in the opposite direction.

The Tertiary and Paleozoic strata are cut by faults, along which the respective beds sunk for some tens of metres. These faults run parallel to the borders of the individual blocks, and are vertical or subvertical. The pre-Tertiary Sobota horst rises continuously together with its Tertiary cover along parallel faults towards its vertex at Kapela, and from there drops in step faults towards the Ljutomer syncline. The faults cannot be exactly located, although they are confirmed by geophysical surveys, as the Tertiary beds are covered in hills by thick weathered beds, and in the flat along the Mura river by Quaternary sediments. One fault was ascertained by several exploratory bores, and runs from the village Ptujska Cesta in Slovenske Gorice over Boračeva and Petanjci. The amount of downthrow of this fault is 25—50 metres.

Miocene beds can be found at the flanks of the Sobota horst only, they are missing on its top. It is possible, that they have not been deposited at all, or that they have been removed by erosion. On top of the horst rest only Pannonian sediments, as proven by exploratory drilling.

The hydrological conditions have been investigated by drilling during the years 1965—1972. Numerous aquifers, bearing mineral water, have been found. The Quaternary gravel is saturated with ground water; exceptionally the ground water is mineralized in places, where it is in contact with Tertiary sandy beds bearing mineral water. Up to 1965 in Radenci, Boračeva and Petanjci mineral water was exploited by shallow wells in Quaternary gravel and partly from Pliocene sands. The first exploratory bores in Boračeva have shown up to the depth of 313 m ten mineral water aquifers of various thicknesses in Pliocene and Miocene beds. Later the bore T-1 found porous beds in greater depths as well, but the sandstones and conglomerates contained mainly CO_2, and mineral water only in negligible quantities.

In 1970 and 1971 the exploratory bores indicated an extension of the aquifers from Boračeva towards Šratovci, as well as towards Rihtarovci in the opposite direction. The aquifers, encountered in Sratovci in depths between 75 and 140 m, are found in Rihtarovci in depths of 178 to 280 m. Along the fault between Boračeva and Šratovci the aquifers are lowered for 50 m. The sandy aquifers are inclined towards northeast for 4—5°, as indicated by the bores between Šratovci and Radenci. Their output depends on the thickness of the beds, as well as on the quantity of dissolved CO_2. The surveys show an increase of temperature and pressure with increasing depth, as well as an increase of dissolved solids. The Tertiary beds, containing mineral water, rise towards Šratovci and Orehovci, i. e. towards NW. In the same direction also decreases the mineral content, and increases in the opposite SE direction with increasing depth of the water-bearing beds. It can be therefore concluded that the sandy aquifers are recharged by water from the upper gravelly bed in the Šratovci—Mele area.

Overproduction of mineral water from the shallow wells causes a decrease of dissolved solids content in the water, due to disturbance of the natural equilibrium between the quantity of mineral water flowing from the primary aquifers into Quaternary gravel, and the ground water in its vicinity. In deep wells that have no direct contact with ground water, negative influences are expected only in cases, when exploitation will for a longer time exceed the natural recharge. Therefore further hydrogeological investigations are necessary, with the aim to define the conservation of the equilibrium between the forming of mineral water and its rational exploitation.

5.3. *Nuskova*

In 1967 investigations were carried out by drilling two shallow bores in the immediate vicinity of an old hand-dug well. From one of the bores a small quantity of mineral water was flowing, and was used by the population for drinking water.

In 1968 and 1969 two bores were drilled along the right bank of the Ledava river, and 5 along its left bank. The aquifer of the mineral water is Miocene calcareous sandstone of a thickness 2 m to 15 m. The aquifer dips 5—10° towards SE. The yield of the individual bores varies between 8 and 180 litres per minute, depending on the thickness of the aquifer. Four of the bores have been developed, and plastic tubing was installed. Since 1969 the discharge rate of the wells became constant. Measurements during the dry season in 1969 indicated a possible safe yield of at least 11 cubic metres per hour of mineral water.

The exploratory bores covered an area of about 0,5 km^2. The wider surroundings have not been studied. Therefore further investigations are necessary to determine the total area of mineral water resources, and its total safe yield as well.

6. Thermomineral water in Prekmurje and Slovenske Gorice

Thermomineral water in Prekmurje was discovered during exploratory drilling for oil at Moravci near Murska Sobota, and subsequently at Petišovci and Banovci.

This thermomineral water is accumulated in Younger Tertiary beds as connate water. The total water reserves are limited as a natural recharge is possible only in limited extent from Goričko, where the Tertiary water-bearing beds crop out.

6.1. *Moravci near Murska Sobota*

Besides the bore Mt-1 at Moravci there are productive bores MS-3 at Mlajtinci and the stand-by bore Mt-2 near Rimska Čarda. Into bore Mt-1 thermomineral water flows from the depth 1115—1234 m. In this interval a total of 30 m of water-bearing loosely cemented sandstone was perforated. The water contains 5 grams per litre of CO_2 having a temperature of 72—75 °C.

In the bore MS-3 in Mlajtinci water is produced from the interval 1221 to 1241 m in identical sandstone as in Mt-1. A total of 7 m of casing has been perforated. The water contains CO_2, and has a temperature of 62—64 °C.

The stand-by bore Mt-2 near Rimska Čarda was perforated in the depth 881—882 m. in identical sandstone as Mt-1, as well as in the depth 1247—1251 m. The water contains CO_2, and has a temperature amounting to 55 °C.

The total discharge of the three bores has not been measured, but roughly assessed at 50 m³/h. It could be increased by perforation of the upper aquifer, however simultaneously the optimum safe yield should be determined, to assure a longer life of the accumulated reserves.

The health and touristical resort Moravci works through the whole year. The water consumption during the summer months amounts to 500 m³ of water per day, in winter it is less.

The three bores and a subsequent perforation of casing in all water-bearing beds can guarantee the supply of thermomineral water for some time. The water production is rather cheap, as water flows to the surface due to the expansion of CO_2.

6.2. *Petišovci near Lendava*

The thermal water has a temperature of 55 °C and was obtained by perforation of the abandoned oil well Pt-20 in a depth of 817 to 822 m. It is lowly mineralized and contains CO_2 only in traces; therefore its overflow discharge rate amounts to 2.4 m³/h only. This quantity is not sufficient, therefore a pump has been installed for water supply. The aquifer consists of the Pliocene rhomboidea beds. Near to the well Pt-20 there is also Pt-16 perforated in the identical aquifer. Near the recreation centre in Petišovci that is still under construction, there are still more abandoned oil wells which could be used for water supply.

6.3. *Banovci near Ljutomer*

In Banovci there is the third recreation centre in development. Its thermal water supply is delivered by exploratory bores Ve-1 from the depth 1358—1363 metres, and Ve-2 from the depth intervals 1175—1188 m.

1524—1530 m, 1565—1570 m, and 1649—1651 metres. The aquifers are rhomboidea beds. The temperature of the thermal water is 55 °C; the water contains no CO_2. Only 5 m^3/h of water rises freely to the surface, therefore additional quantities have to be pumped. The water reserves were not assessed.

To obtain additional quantities of thermal water in Prekmurje and Slovenske Gorice with their southwestern foothills, further investigations are necessary. Now a deep exploratory bore near Ptuj is drilled, and bore Ko-1 at Koračice village in the north of Ormož is under observation.

It is necessary to collect and evaluate all obtainable data about exploratory bores for oil, as well as respective geological and geophysical data, and to outline areas, where thermal water aquifers might be struck. The water reserves have to be calculated, and subsequently a rational regime of their exploitation determined.

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